
Spatial orientation and exploration behavior of free-ranging domestic dogs

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Beautiful creatures

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Zusammenfassung

In dieser Studie wird das Bewegungsmuster und Raumnutzungsverhalten freilaufender Haushunde (n=30) analysiert, während sie mit Ihren Besitzern in bekanntem und unbekanntem Gelände spazieren gingen (n=120). Die Hunde durften während der Spaziergänge nicht abgerufen werden. Ziel war herauszufinden auf welche Distanz und wie lange sie sich vom Besitzer entfernen, um Daten für Freilaufauswertungen zu sammeln. Die Bewegungsmuster der Hunde wurden per GPS aufgezeichnet, um die unterschiedlichen Laufverhalten darzustellen. Individuelle Läufe wurden ab einem Radius von >20 m vom Besitzer gemessen (n= 3145 Läufe), und für diese Läufe wurden sieben verschiedene Explorationsmuster erstellt und evaluiert. 1. Der Hund läuft vor und wartet oder folgt seinem Besitzer auf dem Weg; 2. Sternmuster; 3. Loop; 4. Loop + Sternmuster; 5. Gemischte Formen: Läuft vor und macht einen Loop; 6. Läuft vor und läuft ein Sternmuster; 7. Läuft parallel vom Besitzer.

Im ersten Kapitel präsentiere ich die Analyse der Bewegungsmuster mit Fokus auf die Besitzer-Hund Beziehung. Im zweiten Kapitel stelle ich Daten bezogen auf die einzelnen Hunde sowie die Hunde Dyaden und Triaden vor. Im Teil drei gehe ich auf Beziehungsaspekt des Besitzers ein, basierend auf Resultaten des Lexington Attachment to Pets Scale (LAPS) Tests.

In dieser Studie fanden alle Hunde, unabhängig von Laufdistanz, Laufzeit oder Umgebung ihren Besitzer wieder. Die Lauflänge > 20 m variierte stark zwischen den einzelnen Hunden, wie auch die gezeigten Laufmuster. Aufgrund dieser Variationen wurden die Hunde in drei Gruppen unterteilt: Gruppe 1 Hunde blieben auf allen Läufen > 20 m innerhalb eines Radius von 150 m vom Besitzer; Gruppe 2 Hunde blieben auf allen Läufen > 20 m innerhalb eines Radius von > 150 m und < 350 m vom Besitzer; Gruppe 3 Hunde entfernten sich auf mindestens einem Lauf > 20 m über 350 m vom Besitzer. Fast die Hälfte der Hunde (43 %) blieben auf allen Läufen > 20 m innerhalb des 150 m Radius. Ungefähr ein Drittel (27 %) blieben im Radius < 150 m und >350 m vom Besitzer. Ein Drittel (30 %) der Hunde hatten mindestens einen Lauf über 350 m vom Besitzer entfernt. Zudem zeigten 62 % der Hunde das Laufmuster 1, d.h. sie liefen vor oder folgten ihrem Besitzer auf dem Weg. Es kann also gezeigt werden, dass die Mehrheit der Hunde in Besitzernähe und auf dem Weg bleiben.

Alle Hunde liefen signifikant längere Distanzen (Wilcoxon Test $p < 0.001$) und signifikant schneller (Wilcoxon Test $p < 0.001$) als ihre Besitzer, ein Hinweis auf die Bedeutung des Freilaufs. Tendenziell zeigten die Hunde größere Laufdistanzen und längere Laufzeiten in bekannten als in unbekanntem Gebieten, die Unterschiede waren allerdings nicht signifikant.

Signifikante Korrelationen in Bezug auf das Laufverhalten der Hunde eines Besitzers (Teams) konnten für Distanz- und Zeitparameter (Läufe $> 20\text{m}$) gezeigt werden (Spearman Korrelation $p < 0.001$), ein wichtiger Indikator für den Einfluss des Besitzers auf das Laufverhalten seiner Hunde im Vergleich zu Rasse oder Alter der Hunde.

In Teil zwei wird das Laufverhalten der einzelnen Hunde sowie der Dyaden/Triaden (ein Besitzer nahm mit zwei oder drei Hunden teil) betrachtet. Es zeigte sich, dass Dyaden/Triaden ähnliche Bewegungsmuster vorwiesen und es meist einen Hund gab der initiierte oder führte. In manchen Teams blieb ein Hund die gesamte Zeit beim Besitzer und lief nicht mit den Artgenossen. Erkennbar waren egozentrische, allozentrische/geomagnetische Komponenten der Laufmuster. Zudem gab es signifikante Unterschiede ($p < 0.001$, Wilcoxon Test; $p < 0.001$, Kruskal-Wallis Test für Gruppe 1, 2 und 3) zwischen der Zeit outbound (vom Besitzer weg) und inbound (zum Besitzer zurück) und dem Tempo der Hunde ($p < 0.001$, Wilcoxon Test): der Rückweg zum Besitzer war signifikant kürzer und schneller. In Bezug auf das Geschlecht der Hunde konnte im Einklang mit erwarteten sozio-ökologischen Aspekten gezeigt werden, dass männliche Hunde signifikant weiter laufen als weibliche ($p = 0.003$; Mann-Whitney-U Test). In Bezug auf Reproduktionsstatus wurden keine signifikanten Unterschiede festgestellt. Signifikante lineare Korrelationen waren nachweisbar für das Explorationsverhalten, die Laufdistanz und Laufzeit für mehrere Hunde eines Besitzers, ein weiterer Indikator für den Einfluss des Besitzers auf das Laufverhalten seiner/s Hunde(s).

Der dritte Teil beschäftigt sich mit dem Bindungsverhalten des Besitzers zu seinem/n Hund(en). Die Besitzer füllten im Vorfeld einen Fragebogen bezüglich Ihres/r Hunde(s) aus. Die Antworten wurden dann mit Teilen eines zweiten Fragenkatalogs, dem Lexington Attachment to Pets Scale (LAPS) korreliert. Der LAPS evaluiert das Bindungsverhalten des Besitzers zu seinem Hund. Die Bindungswerte in dieser Studie zwischen Besitzer und Hund waren hoch bis exzellent. Signifikante Korrelationen bestanden zwischen Länge der Läufe und der Subskala Tierwohlfahrt (Spearman Korrelation $p = 0.001$; $p^* = >0.024$) sowie LAPS total (Spearman Korrelation $p = <0.001$ $p^* = >0.024$). Hohe Einschätzungen des Jagdverhaltens korrelierten negativ mit der Subskala allge-

meine Bindung ($p < 0.001$; $p^* = < 0.012$) sowie LAPS total ($p = < 0.001$; $p^* = < 0.012$). Besitzer von Rüden hatten einen höheren Bindungswert ($p = 0.010$; $p^* = 0.040$) als Besitzer von Hündinnen; Besitzer von intakten Hunden hatten signifikant geringere Bindungswerte ($p = 0.009$; $p^* = 0.036$) und Tierschutzwerte ($p = < 0.001$; $p^* = 0.004$) als Besitzer von kastrierten Hunden. Zudem hatten Besitzer von Mischlingshunden höhere Werte in der Subskala Tierschutz ($p = 0.001$; $p^* = 0.004$) und LAPS total ($p = 0.015$) als Besitzer von reinrassigen Hunden. Interessanterweise hatten die Besitzer der weitläufigsten Hunde (Gruppe 3) signifikant höhere Bindungswerte ($p = 0.001$), als die Besitzer der beiden anderen Gruppen.

In dieser Studie kann gezeigt werden, dass 70 % der Hunde in einem Radius von weniger als 350 m vom Besitzer laufen, auch wenn sie nicht abgerufen werden. Zudem zeigen die meisten Hunde ein Laufmuster das wenig vom Weg des Besitzers abweicht. Alle Hunde haben ein höheres Lauftempo und laufen eine größere Distanz als ihr Besitzer, unabhängig von Rasse, Größe oder Alter. Das sind wichtige Hinweise darauf, dass Hunde Freilauf benötigen, um ihr physiologisches und psychologisches Lauftempo selbst zu bestimmen. Hunde eines Besitzers zeigen vergleichbare Laufmuster, ein Indikator dafür, dass der Besitzer einen größeren Einfluss hat als beispielsweise die Rasse des Hundes. Als Fazit kann gesagt werden, dass die meisten Hunde in der Nähe ihres Besitzers bleiben und somit Restriktion in Bezug auf Freilauf dringend überdacht werden sollten.

Summary

In this thesis, I studied the behavior of free-ranging (off-leash) exploring domestic pet dogs (n=30) whilst walking with their owner in new and familiar areas (n=120) and not being signalled or called to. Aim of this study was to collect data to assess distance and time dogs spent away from the owner to determine movement patterns and whether dogs should be allowed off leash in more areas. The roaming behavior of the dogs was measured via GPS during four consecutive walks whilst off the leash at all times. Individual runs were assessed if the dog travelled in excess of 20 m away from their owner in any direction (n= 3145 runs) and of those runs seven different exploration patterns were evaluated: 1. Dog runs ahead and waits/follows; 2. Star pattern; 3. loop; 4. Loop + star pattern; 5. Mix forms: runs ahead & loop; 6. Mix forms: runs ahead & star; 7. Runs parallel then meets owner.

The first chapter looks at the owner-dog dyad/triad movement patterns during the walks. Part 2 analyzes data of the individual dogs as well as dog-dog interactions (dyads and triads). Part 3 looks at owner attachment to their dog(s) as assessed by the Lexington Attachment to Pets Scale (LAPS) and correlated to an owner questionnaire.

All dogs in this study returned to their owner, independent of exploration distance, time or area. Length of trials (runs > 20 m) varied greatly, so did the movement patterns. Due to the variation dogs were placed into three groups: Group 1 dogs stayed within a radius of 150 m of the owners at all runs > 20 m; Group 2 dogs stayed within a radius of >150 m and <350 m of the owner for all runs >20 m; and Group 3 dogs went beyond the radius of 350 m of the owner for runs >20 m at least once. Almost half of the dogs showed a difference of less than 150 m away from the owner (43 %); about 1/3 of the dogs never explored beyond the 350 m radius (27 %); and 30 % of the dogs explored at least once beyond the 350 m radius. Out of all runs >20 m (n= 3145) the dogs utilized primarily (62 %) the travelling pattern of running ahead of the owner on the path and waiting or following.

All dogs travelled significantly longer distances (Wilcoxon test $p < 0.001$) than their owners and at significantly higher speed (Wilcoxon test $p < 0.001$), indicating the importance of being off-leash to determine their own pace. The dogs explored further and longer in known than unknown areas, the difference was not significant however.

Significant correlations regarding time and distance of runs > 20 m (Spearman Correlation $p < 0.001$) could be demonstrated for dogs of one owner (teams) indicating that their exploration behavior is mainly influenced by their owner and to a lesser extent the dog's age, breed or sex.

Looking at the individual dogs and dyads/triads of dog teams (dogs of one owner) in Part 2 it could be demonstrated that most dog teams tend to travel together displaying similar exploration patterns with one initiating or leading dog. In some teams, one dog stayed with the owner and did not explore with its conspecific. Significant difference could be shown between their way outbound (away from owner) as compared to inbound (back to owner) regarding time ($p < 0.001$, Wilcoxon Test; $p < 0.001$, Kruskal-Wallis Test, Group 1, 2 und 3) and speed ($p < 0.001$, Wilcoxon test): dogs on their way away from the owner were slow and more circuitous whereas inbound they were direct and fast. Results herein are in accordance with expected socioecological differences, in that male dogs explored further than female dogs ($p = 0.003$; Mann-Whitney-U Test), possibly because of a relevant function in reproduction. With respect to reproductive status no differences were found. Significant linear correlations for distance and time measures as well as exploration patterns could be demonstrated between two/three dogs of one owner, indicating the influence of the owner on their behaviour.

Part three focuses on the owner attachment to his/her dog(s). Dog owners had to fill out two questionnaires which were then analyzed and partly correlated: First, an owner questionnaire pertaining to their dog and secondly the Lexington Attachment to Pets Scale (LAPS) to measure owner attachment values. Attachment scores in this study were found to have high to excellent values.

Significant correlations were found between distance measures and the subscale animal welfare (Spearman Correlation $p = 0.001$; $p^* = >0.024$) as well as LAPS total scores (Spearman correlation $p = <0.001$ $p^* = >0.024$). High expected hunting scores as assessed by the owner questionnaire were negatively correlated with the subscale general attachment ($p < 0.001$; $p^* = < 0.012$) and LAPS total ($p = <0.001$; $p^* = < 0.012$). Owners of male dogs' displayed higher attachment values ($p = 0.010$; $p^* = 0.040$) than owners of female dogs. Owners of intact dogs had significantly lower general attachment values ($p = 0.009$; $p^* = 0.036$) and subscale animal rights values ($p = <0.001$; $p^* = 0.004$) than owners of castrated dogs and owners of mixed breed dogs had significantly higher values in the animal rights subscale ($p = 0.001$; $p^* = 0.004$) and the overall LAPS score ($p = 0.015$) than owners of purebred dogs. Interestingly owners of far ranging (Group 3)

dogs had significantly higher LAPS total scores ($p = 0.001$) than owners of the other two groups.

In this study it could be demonstrated that 70 % of dogs stayed within a radius of <350 m to their owner, despite external stimuli and whilst not being called. Furthermore, most dogs employed an exploration pattern of running ahead or following their owner on the path. All dogs, however, walked significantly longer distances and at higher speed than their owner, independent of breed, age or size. These are important indications that dogs need to walk off leash to determine their physiological walking pace. Dogs of one owner displayed similar exploration patterns indicating the importance of owner influence rather than breed or age. In conclusion, most dogs stay close to their owner and off leash restrictions should be reconsidered.

General introduction

The majority of domestic dogs (*Canis familiaris*) (approximately 80 % of the global dog population) are considered feral or free roaming and live in a human-dominated niche (Hughes & Macdonald, 2013; Lord et al., 2013). Pet dogs therefore represent only a fractional part of the entire dog population. In Germany and most industrialized countries, the days of free roaming dogs that may wander around unrestrained during the day (or night) are long gone. Due to legal restrictions and densely populated areas with appurtenant dangers like cars, poison or mistreatment by humans, the days of Lassie and friends are bygone. The total number of dogs reported in Europe 2017 is estimated at 85 million, Germany ranked highest with a dog population of approximately 9.2 million in 2017, followed by the United Kingdom (UK) with 8.7 million (www.statista.com 2018). In the main, these dogs live either in enclosed properties or their exercise takes place in form of a daily round of walks with their owner, often on a leash (Christian et al., 2013). In particular in the cities, the options of running free are frequently limited to park areas and many owners do not make the time to actually leave the city for a walk or are uncertain of their dogs' behavior. A survey conducted in the UK found that the average dog spends 17 minutes off leash per walk, maximum half the time of the walk and one in four owners never let the dog off the leash because they feel it's too dangerous (<https://www.harringtonspetfood.com/dogventures> 2017). This certainly may raise health and welfare concerns (cf. Döring et al., 2008; Feddersen-Petersen, 1997; Hallgren, 1997; Wallis et al., 2018). In contrast, a German survey of 300 dog owners found that more than 90 % of the owners take their dogs on daily walks (40 % more than two hours; 40 % between one and two hours and 17 % less than one hour), about half of them mostly off the leash (Olsen 2008). Olsen (2008) further found a correlation between walking length/frequency and unrestricted walks in that the longer or more frequent the daily walks, the less restricted the dogs and the more often they were off the leash.

To my knowledge, however, no research has actually been done to ascertain how domestic pet dogs in fact do behave whilst off the leash unrestricted in an unenclosed area: How far do they travel? Do they return to their owner? Do they get lost? Will they chase potential prey?

In this study the exploration behavior of 30 dogs was measured via GPS during four consecutive walks with their owner, twice in known and twice in unknown areas to collect data on their roaming behavior whilst off the leash at all times and not being (acoustically) communicated to by their owner (no calling, whistling, signalling etc.). Individual runs were assessed if the dog travelled in excess of 20 m away from their owner in any direction ($n = 3145$ runs) and of those runs different travelling patterns were evaluated. 51 factors were recorded for each run.

Part 1 looked at the owner-dog dyad/triad and the interaction of different data during the walks. Part 2 analyzed data of the individual dogs as well as dog-dog interactions. Part 3 looked at owner issues and attachment as assessed by the Lexington Attachment to Pets Scale (LAPS) by Johnson et al., (1992). The owner additionally had to fill out a questionnaire prior to the walks regarding the behavior of their dog(s) with 33 items and 24 questions.

The omnipresence of the domestic dog inspired many scientific endeavors, but research on pet dog walks mainly focused on applicable aspects of health effects of the owner (Dall et al., 2017; Taniguchi et al., 2018), epidemiology (Smith et al., 2015), or has been conducted in enclosed areas or laboratory settings (Duranton et al., 2019; Duranton et al., 2017; Scandurra et al., 2018; Fugazza et al., 2017). One study was done of six dogs of one breed from one household while unleashed on an unenclosed field regarding leadership characteristics of the dogs in a multiple dog setting (Akos et al., 2014). Therefore, despite of its general popularity and its proverbial being “men’s best friend”, it is astonishing how little we actually know about the sensory biology and behavior of the pet dog during a field trial.

Hypothesis

In this thesis I studied the behavior of free-ranging, exploring domestic pet dogs whilst walking with their owner in new and familiar areas and not being signalled or called to.

In numerous studies the close bonding, reliance, dependency, attachment and resulting specific behavior of domestic dogs with respect to their human owner has been demonstrated (cf. Duranton et al., 2019; Gácsi et al., 2013; Horn et al., 2013; Miklósi, 2007; Topál et al., 2005). Dogs distinguish between their owner and other humans (Cimarelli et al., 2019; Kerepesi et al., 2014) and therefore I hypothesized that dogs have high motivation based on this strong bonding to return to their owner, regardless of

breed, area or external stimuli thus, that free ranging, off leash pet dogs in known or unknown areas, even if not called or signalled to, return to their owner.

Further, I hypothesized that the time and the speed on their return path (inbound) to their owner differs from the time on their outbound route (runs >20 m) and that the distance travelled by the dogs outbound vs. inbound (runs >20 m) differs.

I hypothesized that the length and speed of and on the walks differs between owner and dog based on physiological and biomechanical factors (Denny, 2008; Minetti 2000) as well as being influenced by motivational factors, i.e. the dogs' interest to explore.

The majority of current literature proposes that domestic dogs, primarily due to domestication, have lost or only have a reduced ability of spatial orientation compared to wolves (Frank & Frank, 1982; Lea & Osthaus, 2018; Osthaus et al., 2005). I hypothesized, however, that domestic free-ranging pet dogs will find back to a specified, varying non-stationary locality (i.e. their owner) in different environments even subsequent to having travelled a certain distance i.e. out of range of visibility or/and olfaction based on their ability to establish cognitive maps and the use of spatial reference systems (Fugazza et al., 2017; Scandurra et al., 2018; Wang, 2016).

I hypothesized that the area (known or unknown) will make a significant difference with respect to the dog's exploration behavior and that the distance travelled (runs >20 m) by the dogs varies in known areas compared to new areas. The exploratory behavior may be constrained in unknown areas to decrease exposure to danger (e.g. getting lost), and neophobic behavior might be amplified resulting in shorter distances away from the owner (Moretti et al., 2015). I further hypothesized that the time travelled (runs >20 m) by the dogs varies in known areas compared to new areas, as they may show a reduced latency to approach objects and thus spend less time exploring objects (Moretti et al., 2015).

It has been postulated that sex differences exist in regard to spatial orientation (Hawley et al., 2012; Mongillo et al., 2017; Scandurra et al., 2018; Shah et al., 2013) as well as differences in spatial navigation performance between intact and spayed/neutered dogs (Scandurra et al., 2018).

I hypothesized therefore, that the distance and time travelled between male and female dogs (runs >20 m) differs and that the distance and time travelled between neutered and intact dogs (runs >20 m) varies.

Exploratory behavior is considered as an aspect of sensory processing involved in investigating novel stimuli rather than an instinctive behavior (Kelley et al., 1989) and partially depends on motor and spatial capabilities and on the motivation to explore (Caston et al., 1998). Studies have also demonstrated a linkage between learning, memory, exploratory behaviors and genetics (Puurunen et al., 2018; Shin et al., 2016), and breed differences have been proposed (Sarviaho et al., 2019; Turcsán et al., 2018).

I therefore hypothesized, that dogs, depending on their individual traits, character, learning experience, breed, socialization and age may utilize contrasting travelling patterns whilst exploring.

I hypothesized further, however, that most dogs will not explore extensively on runs >20 m away from the owner, as has also been noted by Seguinot et al. (1998) and Akos et al., (2014), neither with respect to distance nor time. Extensive travelling is defined herein as maximum distance on runs >20 m of >2000 m or longer than 20 minutes away from the owner.

It has been postulated that the presence of a familiar conspecific has been shown to be more effective for social buffering (Kiyokawa et al., 2014). Therefore, in potentially stressful situations, as when confronted with a novel object or area, the presence of a conspecific might be a valuable resource for reducing potential stress, which would lead to the expectation that familiar dogs would explore together, Therefore I hypothesized that dogs of one owner (dyads or triads) display similar exploration patterns.

Importance of this study

The aim of this study was to garner data about the factual exploratory behavior of pet dogs, in particular as it pertains to the strict regulations and prejudices currently existing and their implications for domestic pet dogs' physical and psychological welfare besides the impact on cognitive abilities and functions (Head et al., 2001; Olsen, 2008; Wallis et al., 2018). Ethology is the biological analysis of animal behavior based on observations in nature (cf. Tinbergen, 1963; Lorenz, 1981; Miklósi, 2016) but this concept has seldom been applied to pet dogs and most studies cited herein have been conducted in laboratory settings, which may have limited relevance to natural behavior.

Depending on the country (e.g. Great Britain; Australia, USA) and thus the cultural differences of dog ownership many dog owners do not walk their dog at all (Christian et al., 2013) or solely on a leash (<https://www.harringtonspetfood.com/dogventures>), even though it has been shown that off leash activity benefits dogs so they may become

older and keep healthier (Wallis et al., 2018). No statistics exist regarding German dog owners and their walking behavior. One study based on an ownership questionnaire (n=300) found that 90 % of the German dog owners took their dogs on daily walks about half of them mostly off the leash (Olsen, 2008).

Taking into account legal restrictions e.g. the Landeshundegesetz in the State of North Rhine Westphalia (LHundG NRW § 2 allgemeine Pflichten; § 5 Pflichten) in Germany and preconceptions often voiced i.e. by the hunting community that pet dogs will chase prey and taking into consideration the appurtenant fears of the owner of being fined or worse, it is important to ascertain how far and fast the dogs actually travel whilst off the leash.

These results might be useful in establishing areas where off leash dog walking is allowed, help dog-trainers to get more information about exploration behavior of pet dogs and may help in designing walking areas, as dog walking is a popular method for increasing human physical activity (Westgarth et al., 2016). Furthermore it has been voiced that data is needed about if and how the behavior of off-leash dogs differs from the behavior of on-leash dogs (Bekoff, 2016) as differences in behavior certainly exist (Olsen, 2008). Another aspect raised is the owner perspective: Do owners actually have an indication/knowledge/good realistic judgment of where their dog goes, how far he or she explores, and how they find back? Is the displayed travelling behavior consistent with the owner assessment? If not, what implications may be raised?

This thesis has a tripartite structure: Part 1: the owner- dog dyad; Part 2: the individual dogs, including behavior of two or three dogs belonging to one owner exploring together; Part 3: the owner perspective regarding the exploration behavior of their dog(s) as assessed through the owner questionnaire and the Lexington Attachment to Pets Scale (LAPS) to determine correlations between owner attachment and dog exploration behavior.

To my knowledge there has been, thus far, no published study, showing the behavior and navigational abilities of free-ranging pet dogs in a field study using GPS collars, thereby monitoring their exact movement.

1 The Owner - Dog dyad

1.1 Introduction

For this thesis, certain essentials had to be assumed: To elicit the behavioral sequence of exploration, behavior to gather information about the environment that may directly or indirectly influence survival and reproduction (Moretti et al., 2015), i.e. to travel from and back to the owner, the dogs had to have an interest to cooperate and communicate with their owner. This is arguably established through the processes both of domestication and socialization and therefore a motivation to return even despite potentially strong external stimuli based on attachment behavior. Further, the dogs had to have the ability of spatial orientation and an understanding of a moving target i.e. object permanence. They further had to have the cognitive abilities to find their owner and nonetheless display an interest to explore and thus leave the owner which requires behavioral variation through behavioral stability; i.e. by persisting with a particular behavioral response like a travelling pattern and nonetheless consistently returning to their owner.

1.1.1 Domestication

The symbiotic relationship between dogs and humans is proposed to date back at least 18.000 years and it is being debated that the domestication process occurred independently twice. Genomic and archaeological evidence suggest a dual geographic and temporal origin of domestic dogs (Thalmann et al., 2013): A domestication process in East Asia beginning approximately 15.000 years ago (Savolainen et al., 2002), and recent findings suggesting that the domestication of dogs may have occurred even earlier, during the late Pleistocene in modern day Belgium, the Czech Republic (Germonpré et al., 2012) and southwestern Siberia dating to >30.000 years ago (Ovodov et al., 2011; Thalmann et al., 2013). Therefore, the exact timing and location of dog domestication is still unclear (Perri, 2016). However, most modern breeds, as we define them today by kennel standards, are less than 200 years old and of European ancestry (Parker et al., 2017).

It has been postulated that in the past a hunting partnership existed between humans and dogs which was the basis for dog domestication (Clutton-Brock, 1984), its value being to assist with large game hunting or to act as guards (cf., Clutton-Brock, 1995; Cohn, 1997). However, wolf puppies were first commensals in a human communi-

ty exhibiting reduction of size in the early stages of domestication, followed by transitional morphological stages e.g. change of coat color and reduction of teeth size (Clutton-Brock, 2016). Price (1984) described domestication as a two-stage process of first genetic adaptation to the human environment and second socialization of individuals in each generation (see also, Lord et al., 2016).

Several hypotheses regarding the domestication process of the dog and the particular behavioral traits that had a selection advantage have been put forward, suggesting human selection for specific qualities, for instance, increased attention to humans (Marshall-Pescini et al., 2017; Miklósi et al., 2003; Nagasawa et al., 2015), acceptance of humans as social partners (Catala et al., 2017; Gácsi et al., 2009), reduced fear and aggression (Hare & Tomasello, 2005; Range et al., 2019), a tamer temperament (Hare et al., 2012; Range et al., 2019) and human-directed social competence (Albuquerque et al., 2016; Miklósi & Topál, 2013). Range et al. (2019) postulate in their Deferential Behavior Hypothesis that during domestication, after an initial reduction in fear of humans, dogs were selected for increased submissive inclinations. The reason being to minimize conflicts over resources, to ensure safe co-habitation and co-working in a way that humans lead and dogs followed and that domestication led to changes enhancing cooperation specifically with humans. These factors are proposed to have led to increased cooperativeness and associated cognitive skills in dogs.

It has been reasoned that these behavioral and cognitive skills were based on direct selection by humans for specific traits which Larson & Fuller (2014) called 'human-oriented' or human-selected hypotheses as opposed to the 'self-domestication' hypothesis (Coppinger & Coppinger, 2016; Larson & Fuller, 2014). The latter is a two-stage process in which during the first stage ancestral dogs' exploited new feeding niches provided by humans, thereby reducing reliance on conspecific group hunting and increasing dependence on human generated food. During the second stage humans began a selection process favoring dogs with the preferred characteristics (cf. Marshall-Pescini et al., 2017). The 'human-oriented' hypothesis emphasizes genetic predispositions that may have facilitated dogs to develop communicative skills adjusted to humans (Hare, 2017), whereas the 'self-domestication' hypothesis focuses on ontogenetic aspects (Udell & Wynne, 2010; Wynne et al., 2008), denoting that dogs may have learned from humans during their ontogenesis, thus shaping their behavioral responses (D'Aniello et al., 2015; Scandurra et al., 2015) and improving their social communicative skills (D'Aniello & Scandurra, 2016).

These two theories were first merged into the “synergistic hypothesis,” which suggests that sensitivity to human gestural cues may have developed at both the evolutionary and ontogenetic levels and which was postulated by Gácsi et al. (2009). The switch from natural (and sexual) selection to artificial selection by humans may have diminished the selective pressure in dogs for essential survival traits (Price, 2002) for instance spatial orientation and navigation skills.

The selection process focused on the ability to recognize human signals and to cooperate (Duranton & Gaunet 2018; Reid, 2009), in establishing eye contact with humans and adapting their behavior to human attitudes (Gácsi et al., 2013, but see Marshall-Pescini et al., 2017) as well as in demonstrating social referencing, adjusting their behavior according to human emotional signals (Colbert-White et al., 2018; Merola et al., 2014; Merola et al., 2012b).

Dogs have proven successful in several tasks that are thought to require high attention toward conspecifics as well as humans, such as social learning (Bradshaw & Rooney 2016; Mersmann et al., 2011; Topál et al., 2006) communication skills (D’Aniello et al., 2016; Kaminski et al., 2012; Schwab & Huber, 2006; Virányi et al., 2004), “fast mapping” of words (Kaminski et al., 2004) and the capacity for discriminative processing of some aspects of human language (Prichard et al., 2018) promoting social learning in the dog–human dyad. It has been postulated that through positive evolutionary and ontogenetic feedback processes, dogs have developed increased social attentiveness and thus, can achieve more complex forms of dog-human communication and cooperation than for instance wolves (Miklósi et al., 2003; Range et al., 2019; Virányi et al., 2008). Despite the overall high sociability in dogs, there are indications that females may be more likely to interact with humans, (D’Aniello et al., 2015; Persson et al., 2015, but see Asp et al., 2015: male dogs were more interested in human-directed play; and Strandberg et al., 2005: males scored higher in social play than females) which may lead to the expectation that female dogs stay closer to the owner.

Studies moreover suggest that dogs have become socially more tolerant and attentive during domestication (compared to wolves), and that these characteristics were essential for cooperation, enabling dogs to successfully live and work with humans (Range et al., 2019; Range & Virányi, 2015). Miklósi et al. (2004, 2016) proposed that dogs and humans went through a convergent evolution based on the idea that dogs were selected by humans to cooperate and communicate and thus evolved genetic predispositions allowing them to develop skills shared with humans (see also, Miklósi & Topál,

2013; Topál et al., 2009). Accordingly, domestication has equipped dogs with two abilities necessary for cooperative problem solving—namely, social tolerance and social attentiveness, enabling them to adjust their behavior to that of their human partners (Range et al., 2019; Ostojić & Clayton, 2014).

One of those social cooperative behaviors is walking with their owners. Studies on dog-owner walks have thus far focused on the owners (Dall et al., 2017; Taniguchi et al., 2018) or have been conducted in an enclosed area (Duranton & Gaunet, 2018; Howse et al., 2018). It is important to recognize the features of the natural environment of the dogs under study so they can be observed in tasks that correspond to challenges in a more routine setting.

Communication takes place between members of the same species (here the dog dyad), as well as between interspecific individuals (dog-owner), based on the cohabitation process and inter-dependent relationship present in domestic dogs and humans. Communication “...a stylized signal or display by one individual modifying the response of another” (Barnard 2006, in Bradshaw & Rooney, 2016 p.139) may further encompass passive transmission of information like identity or reproductive status (Bradshaw & Rooney, 2016). Dogs engage in a multitude of communicative patterns: visual communication by modifying different parts of their body; tactile communication; and in auditory and olfactory communication, with vocalizations and body odors, respectively.

D’Aniello et al. (2016) found that Labrador and Golden Retriever females relied more on visual signals, such as human gestural commands, compared to males. Similarly Duranton et al. (2016) stated that females of shepherds and molossoids dogs displayed more referential gazing behavior toward the owners than males and Mongillo et al. (2016) proposed that females of different pure and mixed breeds displayed more gazing behavior toward the owners than males. Female dogs seemed to rely more on visual signals than males in their behavioral regulation. Based on the findings of these studies it could be expected that females would stay closer to their owner to establish visual communication.

Moreover, it has recently been demonstrated that dogs are able to perceive human emotions via chemosignals, suggesting a type of olfactory communication (D’Aniello et al., 2018; Siniscalchi et al., 2016). Dogs herein could thus have been influenced by the emittance of chemosignals by their owners.

1.1.2 Dog-owner attachment

An attachment bond is a close, emotional relationship between two individuals (Bowlby, 1958). The dog-owner dyad is believed to have attachment bonds comparable to those that characterize human caregiver-infant relationships (Payne et al., 2015; Topál et al., 1998). Attachment is the highest within the dog-owner dyad and another familiar person is not in the position to take over the owner's social role (Cimarelli et al., 2019; Sundman et al., 2018; Topál & Gácsi, 2012). Dogs form bonds with specific humans and make decisions by attending preferentially to social signals from familiar humans (Cimarelli et al., 2019; Cook & Jacobs, 2014; Sundman et al., 2018). In addition to using humans as a social reference point (Rehn et al., 2017; Topál et al., 1998), dogs have been shown to develop attachment bonds allowing them to interact securely with their environment in the presence of the owner (Gácsi et al., 2013; Horn et al., 2013; Rehn et al., 2017). Thus, in this study solely the dog-owner dyad was used to collect data on the exploration behavior of the dogs based on this special attachment bond.

Dogs have displayed behaviors indicative of an attachment relationship, for instance proximity seeking, where the dog will seek out the attachment figure as a means of coping with stress (Rehn et al., 2017; Schoeberl et al., 2012, 2016). The presence of a human may attenuate the effect of a stressful event, thereby constituting the so-called "safe haven effect" of attachment theory (Gácsi et al., 2013). Further, dogs have also demonstrated the so-called secure base effect, where the presence of an attachment figure i.e. the owner enables them to more freely to investigate novel objects (Horn et al., 2013). These effects would also influence the exploration behavior of the freely moving dogs, either in that they would stay close to their owner – displaying the safe haven effect – or by exploring further, arguably based on the secure base effect. How the dogs would seek support from their owner in a challenging situation, i.e. how far they would explore is also influenced by the owner's prior caregiving strategy and the dogs experience from their previous interaction history.

What remains unclear are the exact factors influencing the nature of attachment bonds dogs develop with their owners (and vice versa). Numerous factors are likely to influence dogs' affective states and thereby effect their behavioral output, for instance, the use of positive as opposed to invasive training methods (Deldalle et al., 2014), affiliative interactions (Horváth et al., 2008), learning experiences and quality time spent with the dog contributing to a positive emotional bond. For this reason only dogs which were trained without negative or invasive training methods were used, which herein is defined

according to e.g. Progressive Reinforcement Training Emily Larlham <https://dogmantics.com/progressive-reinforcement-training-manifesto/english-manifesto/> and ethical training methods as proposed by Pet Trainers of Europe <https://www.pdte.eu/code-of-ethics>.

Furthermore, the influence of owner psychological characteristics, such as personality and attitudes, cannot be discounted in the dog-owner dyad. The physiological and emotional benefits that ensue from a positive dog-human relationship extend to both members of the dyad, having similar qualities as interpersonal relationships in that both parties can be significant attachment figures for one another (Rynearson, 1978). Although it has been postulated in the past that the tendency for dogs to form close relationships with humans may be attributed to social dominance, with dogs seeing owners as surrogate pack leaders (Landsberg et al., 2003), it is more likely that social and associative learning are highly relevant to dog-human interactions (Bradshaw et al., 2009; Kubinyi et al., 2009), and, given that relational factors can affect dog performance (Lefebvre et al., 2007) it is probable that dog-owner relationships are bidirectional in their value (Kaminski et al., 2014). Furthermore, the concept of dominance has been viewed critically due to a wide variety of definitions (cf. O'Heare, 2008) and has to be distinguished from leadership concepts (Akos et al., 2014).

For dogs, their owner may be a social partner providing emotional fulfilment and attachment (Rehn et al., 2017; Topál et al., 1998). Therefore, it is reasonable to postulate that dogs view humans as peers who often provide salient information about the surrounding environment, but are distinct from conspecifics (Cimarelli et al., 2019; Payne, 2016). This bidirectional relationship also applies to a shared walk of the owner-dog dyad and for this study a strong human-dog bond was imperative to ascertain that the dog(s) would return to their owner even without leash, signals and calling and despite potential strong external stimuli like game or other dogs.

Furthermore, during the dog-owner walk behavioral synchronization, an evolutionary adaptive mechanism fostering social cohesion may be displayed. It has been proposed that synchronization of behavior between humans and dogs can only emerge if there is attachment between the individuals, and that this synchrony relies on dogs 'sensitivity to humans' behavioral cues through previous learning experiences (Naderi et al., 2001). In humans, affiliation between partners is associated with a high level of behavioral synchronization and Duranton et al. (2019) postulated that dogs show a greater affiliation with humans who mimic their walking behavior (stopping, turning, gazing in the same direction) and that behavioral synchronization between owner and dog acts to

facilitate attachment. Duranton et al. (2019) explored whether, when allowed to move freely in a familiar but fenced outdoor space, dogs synchronize their behavior with their owners' movements and found that dogs synchronized both their location (staying in close proximity) and their activity (moving when their owner moved, and at the same pace, and standing still when their owner stood still) with those of their owners. Herein familiar and unfamiliar areas were explored and no distance restriction was imposed.

Studies indicate that dogs sense the attentional state of their owners by judging observable behavioral cues such as eye contact and eye, head, and body orientation (Kaminski et al., 2013; Schwab & Huber, 2006; Range et al., 2019). This has also been called joint-attention. Dogs also have perceptions of emotional expressions of humans (Albuquerque et al., 2016; Ben-Aderet et al., 2017), are able to discriminate human facial expressions and emotional sounds (Andics et al., 2014; Ben-Aderet et al., 2017; Nagasawa et al., 2011; Racca et al., 2012) and demonstrate perspective taking (Catala et al., 2017). The importance of eye contact in human-dog communication, and, to a lesser extent, the calling of the dog's name has been shown (Huber et al., 2017; Kaminski et al., 2012), thus during the walks the dogs could of course still garner information through eye contact, posture, body orientation etc. from the owner, despite being not signalled or called to.

1.1.3 Spatial cognition and orientation

Spatial cognition and orientation, for instance the ability of path integration and homing, is essential for survival and successful reproduction of free roaming animals, as it enables them to locate food, den, mates, and other resources (cf. Macpherson & Roberts, 2010; Etienne & Jeffrey, 2004).

Spatial navigation necessitates cognitive processes that assist animals to know where they are and to find a way back to a specific point of interest e.g. their shelter, food caches or in this case their owner, by using multiple information sources, such as path integration, magnetic cues and different landmarks (Brodbeck & Tanninen, 2012).

Anecdotes credit dogs with often amazing orientation abilities. Most scientific studies postulate, however, that dogs do not possess any specific path finding/spatial navigation or homing abilities (Macpherson & Roberts 2010) e.g., Frank & Frank 1982: "*Working spatial memory in dogs was found to be surprisingly low*" (p. 96); Miklósi (2007) argued that there is no good scientific evidence for homing abilities in dogs and that "*most lost dogs never find their homes*" (p. 153). Numerous studies suggest the possibility

that the spatial memory capacity of dogs might be reduced relative to species that did not undergo intense domestication (e.g. Frank & Frank 1982; Lea & Osthaus, 2018; Osthaus et al. 2005).

Homing abilities in dogs were first reported by Richardson with messenger dogs in World War I (Richardson, 1921). Further studies were done by Cathy (1956), who suggested that dogs were able to use allocentric cues (e.g. roads, trees, etc.) to navigate in a familiar environment, but did not provide any cues about the nature of the spatial information encoded by the dogs. Homing tests were also conducted by Bernhard Müller between 1953 and 1962 with 75 different dogs (Müller, 1965) and the author postulated a “polarized sense of direction” which enabled the dogs’ orientation also to remote places.

Spatial orientation is either maintained allocentrically by memorizing specific landmarks, positions and locations in known locations (cf. Etienne & Jeffrey, 2004; Fugazza et al., 2017; Macpherson & Roberts, 2010), or egocentrically by integrating signals or cues which indicate the extent of self-motion along their locomotion trajectory (Scandurra et al., 2018; Wehner & Srinivasan, 1981; Wittlinger et al., 2007). Furthermore the geomagnetic field of the earth may be used to establish a sense of compass direction, not only of the path traversed but also to return to a location (Hart et al., 2016; Wiltschko & Wiltschko, 2005).

The term Path integration, a fundamental constituent of spatial navigation ability in many species (Etienne & Jeffrey, 2004) was introduced by Mittelstaedt & Mittelstaedt (1982) to reflect the continuous updating process of direction and distance during movement from a starting point. According to Müller & Wehner, (1988, p. 288) “*Path integration means that the animal is able to continuously compute its present location from its past trajectory and, as a consequence, being able to return to a starting point by choosing the direct route rather than retracing its outbound trajectory*”. Cattet & Etienne (2004) demonstrated that dogs use path integration. Path integration has primarily been studied through homing, in which an animal returns for instance to its den or nest after foraging for food. Herein path integration may be applied to some of the travelling pattern displayed by the dogs (e.g. “star”) during which they return to the starting point of their exploration.

Dogs are capable of integrating spatial signals during locomotion, continuously updating the information about the distance and direction from an object (Cattet & Etienne, 2004) and developing novel paths based on knowledge of paths already used before (Séguinot et al., 1998). In a landmark-based search paradigm, dogs proved to be

able to encode spatial information related to local and global allocentric cues (Fiset & Malenfant, 2013; Fiset 2009, 2007). Recently it has been shown that dogs in a social learning paradigm preferentially relied on allocentric information in matching the location of the owner's demonstration (Fugazza et al., 2017), however, dogs were able to switch to an egocentric strategy when allocentric cues were made unreliable (Scandurra et al., 2018).

It has further been postulated that dogs use both egocentric and allocentric cues and mechanisms for spatial cognition in a hierarchical fashion (Fiset & Malenfant, 2013; Fiset et al., 2006; Macpherson & Roberts, 2010). Fiset et al. (2007) proposed that when a dog searches for a hidden object, the preferred strategy is to use egocentric cues to find it, for instance a linear path or dead reckoning, in which the animal keeps track of their displacements in space by encoding egocentric information such as direction, distance and speed. If these cues are unavailable, however, the dogs then utilize allocentric cues, such as the position of a target (i.e. the owner) relative to landmarks and global cues. Allocentric cues therefore may only be used by the dogs on walks in known environments, as they have to establish and know familiar landmarks to orient (for discussion, see Part 2).

It could therefore be expected that the dogs herein display different strategies depending on the area, known or unknown, and accordingly different exploration patterns if out of range of visibility, acoustic cues and olfaction of the owner.

1.1.4 Object permanence

The dogs moreover have to have an understanding of the concept of object permanence i.e. they must understand that the owner, even if not visible, is still in the vicinity, thus that an object that has disappeared from view (or from the range of other senses) continues to exist. Otherwise the dog could also have returned to the car or their home, more stationary objects (which apparently some dogs do, but none in this study).

The theory is based on Piaget's cognitive concept of object permanence. He demonstrated that infants understand that objects exist even when they cannot be directly perceived (Piaget, 1954). The dogs have to have an understanding of object permanence by finding the owner in a novel place (because the owner continued the walk) on each consecutive run provided the dog travelled far enough to be out of range of visibility/olfactory and acoustic cues.

Prior research established that dogs will search for an invisibly displaced object (cf. Doré et al., 1996; Lea & Osthaus, 2019; Miller et al., 2009; Zentall & Pattison, 2016).

Doré et al. (1996) postulated that dogs were unable to succeed in switch transpositions and to predict the new position of the hidden object by inferring its movement. Dogs are furthermore able to retain the memory of a displaced object for some time, cf. Fiset et al. (2003; up to 240 seconds). Miller et al. (2009), however, proposed that dogs can search accurately for a delayed visible displacement but not for an invisibly displaced object following a short delay (no time given). Müller et al. (2014) found that only two dogs of 16 tested passed both sham-baiting conditions of the visible displacements, despite experiencing more than 40 trials of simpler visible displacements, and neither of them passed the invisible displacement conditions. They also found no evidence for a better performance of females compared to males in the object permanence tasks (Müller et al., 2014). Results however can be strongly affected by details of the procedure, especially the social interactions (Topál et al., 2009). Some studies postulate that the basis for solution of invisible displacement tasks lies in associative learning rather than in a mental representation of the vanished object (Collier-Baker et al., 2004; Fiset & LeBlanc, 2007). Thus, the prior learning experiences of the dogs herein would impact on the understanding of object permanence.

I presupposed that the dogs possessed the cognitive capacity to repeatedly, i.e. on each new trial, search for the invisible displaced object, the owner. Furthermore, that they possessed the associative ability that latter was for each consecutive trial in a varying, previously unknown, location. It has been recognized that, albeit unlikely, even one-trial learning in search tasks can be based on associative processes (see, Gagnon & Doré, 1992). This applies only if the spatial or temporal contiguity between a highly preferred object, here the owner, and a particular location was a cue that was powerful enough to induce a bias toward searching in its vicinity. Studies thus far discounted this possibility (Fiset et al., 2003). In this research the dogs arguably had to reset their spatial working memory at each consecutive trial which studies postulate they are not able to do (Gagnon & Doré, 1993; Pattison et al., 2013).

1.1.5 GPS devices/Tracking technologies

The use of tracking technology has been rapidly extending to pet dogs (Haraway, 2008) and dog owners are able to purchase a wide variety of GPS devices (Mancini et al., 2012), however, in Germany the use of GPS tracking of pet dogs is not common, in comparison to, for instance, the USA. Existing studies regarding GPS devices for dogs have focused on the human side, either by exploring experiences with and expectations of the technology

while hunting (Paldanius et al., 2011) or by observing the interactions of the human-dog dyad during a hunt (Weilenmann & Juhlin, 2011). Because owners are legally responsible for their dogs' welfare and behavior, tracking their movement may be helpful and reassuring. Indeed, not being able to keep track of one's dog may have serious repercussions (cf. Landeshundegesetz NRW, Germany).

1.2 Materials and Methods

1.2.1 Animals and Parameters

During a four year period from 2014 to 2018, I collected GPS data on trials ($n = 3145$) of free ranging, freely exploring domestic pet dogs ($n=30$) of different breeds, size, reproductive status, sex and age (see, **Tables M1.2.1 and M.1.2.2**) while walking with their owners on four consecutive walks in two known and two unknown areas in North Rhine Westphalia, Germany ($n=120$), see also Section 1.2.3 and Video material (**Appendix CD**). For coordinates of each walk, see **Appendix CD**. For all parameters recorded see **Table M1.2.5** and data recorded see **Table M1.2.3**. A dog had to travel a minimum distance of 20m away from the owner to be recorded as a run, see **Fig. M1.2.1**, and seven different travelling patterns were distinguished, see **Fig. M1.2.2; Fig. M1.2.3**, pictograms. Length of the walks depended on age and physical ability of the dog, the average length was mean 1:17:17h per walk; (median 1:12h) mean 5:24:53h (median 5:38h) over all walks, for details see **Table M1.2.4**.

Data were collected on a total of 30 different dog-owner dyads. For each dyad data of four different walks (two in known and two in unknown areas) were collected (total time 177:36:20h, see **Table M1.2.4** for walking times; **Table M1.2.1** for dog-owner dyad details; **Table M1.2.5** for parameters recorded. A total $n=120$ measurements with an $n=3145$ total runs >20 m resulted, see Appendix for all details. There were 18 different owners, 15 female (83 %) and three male (17 %), see **Table M1.2.1**. 83 % of the owners had more than one dog, 17 % owned one dog, see **Table M1.2.1**. Out of the 30 dogs eight belonged to a single dog household owner, 22 to a two or more dog owner – in this group ten owners accounted for 22 dogs, see **Table M1.2.1; Table M2.2.2, Table R1.0**. The median age of the dogs was 63, 5 months, see **Table M2.2.1**. 40 % of the dogs were male ($n=12$), of which 75 % of were neutered and 60 % were female ($n=18$), of which 72 % were spayed; of all dogs 30 % were intact and 70 % neutered/spayed, see **Table M2.2.2**. 33 % ($n=10$) of the dogs were mixed breeds and 67 % ($n=20$) of the dogs were pure breeds, see **Table M1.2.2**. Of the pure breeds nine were sighthounds, two herding dogs; four hunting dogs, three working dogs and two toy dogs, ranging in size from > 60 cm to <40 cm shoulder height, see **Table M1.2.1**.

Table M1.2.1: *All dogs and their owners; dog breed, reproductive status, sex and birthdate of dog. Owner-dog dyads(s) with gender of owner and dogs belonging to one owner and whether they were adopted or with the owner since puppyhood.*

No	Name	Owner	Breed	Neutered/ intact	Sex	birth
1	Amanda	H.M.	Collie	Intact	Female	19.06.2017
2	Amy	S.S.	Labrador Retriever	Neutered	Female	23.04.2014
3	Arthur	V.B	Standard Poodle	Intact	Male	28.04.2017
4	Balin	H.M.	Great Dane Mix	Neutered	Male	22.02.2014
5	Balou RR	C.C.	Rhodesian Ridgeback	Neutered	Male	24.06.2007
6	Balou	C.B.	Husky Shepard Mix	Intact	Male	11.11.2012
7	Bill	S.L.	LabradorMix	Neutered	Male	18.02.2011
8	Dr.Pepper	S.M.	Silken Windsprite	Intact	Male	01.05.2017
9	Emma Lea	E.M.	Miniature Pinscher	Intact	Female	28.05.2015
10	Emma	A.S.	Perro de Aqua espanol Mix	Neutered	Female	01.10.2009
11	Freya	N.P.	Pug	Neutered	Female	23.07.2016
12	Honey	D.S.	Whippet	Neutered	Female	15.06.2011
13	Kaito	S.L.	Mastiff Mix	Neutered	Male	18.02.2011
14	Kimi	M.K.	Whippet	Neutered	Female	19.02.2012
15	Lili	C.B.	Pastor Mallorcin Mix	Neutered	Female	01.01.2011
16	Lou	S.L.	Collie-Shepherd Mix	Neutered	Male	05.10.2007
17	Luna	C.C	Rhodesian Ridgeback	Neutered	Female	29.11.2010
18	Mal(oc)a	A.S.	Perro de Aqua Espanol	Neutered	Female	01.07.2007
19	Manja	A.U.	Italian Greyhound	Intact	Female	21.04.2009
20	Marley	G.B.	Labrador Mix	Neutered	Male	14.03.2015
21	Molly	N.B.	Pug	Neutered	Female	18.04.2016
22	Nele	S.S	Labrador Retriever	Neutered	Female	09.12.2007
23	Nina	M.K.	Greyhound Mix	Neutered	Female	08.09.2012
24	Odin	A.W.	Whippet	Neutered	Male	25.06.2009
25	Raffaele	A.U.	Italien Greyhound	Neutered	Male	23.01.2014
26	Raiya	S.M.	Borzoi	Intact	Female	14.02.2017
27	Tamina	G.B.	Terrier/Chinese Crested Mix	Neutered	Female	01.01.2014
28	Thorin	S.W.	Borzoi	Neutered	Male	27.06.2013
29	Wantje	H.M.	Collie	Intact	Female	30.03.2014
30	Zlata	A.S	Borzoi	Neutered	Female	22.06.2011

Number owner	Owner	Dog(s)	breed	Gender owner	Adopted (a)/ since puppy (p)
1	H.M	Amanda	Collie	Female	P
		Wantje	Collie		p
2	S.S	Amy	Labrador	Male	p
		Nele	Labrador		p
3	V.B	Arthur	Standard Poodle	Female	P
4	H.N	Balin	Great Dane Mix	Female	A
5	C.C.	Balou RR	Rhodesian Ridgeback	Female	A
		Luna	Rhodesian Ridgeback		A
6	C.B.	Balou_Mix	Husky Shepherd Mix	Female	a
		Lily	Pastor Mallorcin Mix		A
7	S.L	Bill	Labrador Mix	Female	A
		Kaito	Mastiff Mix		A
		Lou	Shepherd Mix		A
8	S.M	Dr.Pepper	Silken Windsprite	Female	P
		Raiya	Borzoi		A
9	E.M	Emma Lea	Miniature Pinscher	Female	A
10	A.S.	Emma	Perro de Aqua espanol Mix	Female	A
		Maloca	Perro de Aqua espanol		A
		Zlata	Borzoi		A
11	N.P.	Freya	Pug	Female	P
12	D.S.	Honey	Whippet	Female	A
13	M.K.	Kimi	Whippet	Male	a
		Nina			A
14	A.U.	Manja	Italien Greyhound	Female	A
		Raffaele	Italien Greyhound		A
15	G.B.	Marley	Labrador Mix	Female	p
		Tamina	Terrier/Chinese crested Mix		p
16	N.B	Molly	Pug	Male	p
17	A.W.	Odin	Whippet	Female	p
18	S.W.	Thorin	Borzoi	Female	a
				15/18=83 % ; 3/18=17 %	11 p/19 a

Table M1.2.2: All dogs, breed and size (shoulder height).

Pure breeds n=20	>60cm	<60cm	<40cm
Size	Large	Medium	Small
Sighthounds n=9	Borzoi n=3 (# 26,28,30)	Whippets n=3 (# 11,24,13) Silken Windsprite n=1 (# 8)	Italian Greyhound n=2 (# 19,25)
Herding dogs n=2	Collies n=2 (# 1,29)		
Hunting/sPORTing dogs n=4	Standard Poodle n=1 (# 3)	Labrador Retriever n=2 (# 2,22)	Miniature Pinscher n=1 (# 14)
Toy breed n=2			Pugs n=2 (# 10,21)
Working group n=3	Rhodesian Ridgeback n=2 (#6,17)	Perro de Aqua Espanol n=1 (# 18)	
Mixed breeds n=10	>60cm	<60cm	<40cm
	Great Dane Mix (#4)	Husky Shepard Mix (# 5)	Terrier/Chinese Crested Mix (# 27)
	Mastiff Mix (# 12)	Labrador Mix (# 7)	
	Greyhound Mix (# 23)	Perro de Aqua Espanol Mix (# 9)	
		Pastor Mallorcin Mix (# 15)	
		Collie-Shepherd Mix (# 16)	
		Labrador Mix (# 20)	

The dogs were off the leash during the entire walk and were not to be called or signalled to. Owner-dog dyads were acquired through personal acquaintance and different face-book sites, see Appendix CD.

1.2.2 Global positioning devices

The GPS used were a Garmin Astro® 320 and the dog collars DC™ 50, and T5 Mini, Garmin International Inc., Kansas, USA. The data were then analyzed using the software Garmin BaseCamp™ 4.5.2.1 which depicts the route visually and records the following information:

Table M1.2.3: Data recorded. Example of data collected by the handheld GPS device Garmin Astro® 320 and depicted by Garmin BaseCamp™4.5.2.1.

Vgo 001									
Übersicht		Zeit		Geschwindigkeit		Höhe		Trittfrequenz	
Punkte:	92	Verstrichene Zeit:	0:10:20	Durchschnitt:	10.6 km/h	Min.: 348 m	Anstieg: 90 m	Durchschnitt:	196 1/min
Distanz:	1.8 km	Zeit in Fahrt:	0:10:15	Durchschnitt in Fahrt:	10.7 km/h	Max.: 420 m	Abstieg: 83 m	Min.:	196 1/min
Fläche:	92032 qm	Pausenzeit:	0:00:05	Min.:	0 km/h	Neigung:	0.4 %	Max.:	196 1/min
Max.:				Max.:	33 km/h				

Ind...	Höhe	Teilstrecke	Fahrzeit	Geschw./T...	Richtung/...	Zeit	Position	Trittfrequenz
1	401 m	28 m	0:00:05	20 km/h	78.8° wahr	04.09.2015 19:35:46	N50° 02' 854" E14° 07' 854"	196
2	403 m	31 m	0:00:05	22 km/h	88.9° wahr	04.09.2015 19:35:51	N50° 02' 857" E14° 07' 877"	196
3	406 m	16 m	0:00:05	12 km/h	57.0° wahr	04.09.2015 19:35:56	N50° 02' 857" E14° 07' 903"	196
4	408 m	18 m	0:00:10	7 km/h	60.9° wahr	04.09.2015 19:36:01	N50° 02' 862" E14° 07' 915"	196
5	410 m	62 m	0:00:20	11 km/h	130.1° wahr	04.09.2015 19:36:11	N50° 02' 867" E14° 07' 928"	196
6	412 m	16 m	0:00:10	6 km/h	9.8° wahr	04.09.2015 19:36:31	N50° 02' 845" E14° 07' 968"	196

The dogs were monitored through a GPS collar (Garmin T5 and DC™ 50) and the owner carried a hand held GPS device (Garmin Astro® 320) to determine the distance between dog and owner. All walks were monitored and accompanied by me. In cases of potential external stimuli like jogger, other dogs, horses etc. I, unannounced, quickly changed directions and the owner had instructions to follow me immediately at all times. If we encountered deer, hare or rabbit we continued on our path. If we encountered wild boar, the owner was allowed to call his/her dog(s).

Accuracy of GPS: The margin of error for the Astro® 320 is within +/- 3.65 m. Dog collar details: The DC™ 50 weighs 289g (sender; antennae and collar); the size is (B x H x T): 9 x 4.9 x 4.6 cm; distance of recording is up to 14.5km. The T5 weighs 198g (sender; antennae and collar); size (B x H x T): 8.9 x 4.4 x 4.7 cm; distance of recording up to 12km. The Video camera used was a Garmin VIRB® Elite. Size: (H x B x T): 32 mm x 53 mm x 111 mm; weight 170g. Datatype: MP4; 1080p-HD-Video: 1920 × 1080; 30 fps. Video data were also displayed on Garmin BaseCamp™4.5.2.1. The camera, however, was only used on the larger dogs as it was too heavy and difficult to attach to the small dogs. For further appliance details see

- https://static.garmincdn.com/pumac/Astro320_DC50_OM_EN.pdf;
- https://static.garmin.com/pumac/Astro_320_T5_T5_mini_EN_OM.pdf;
- <https://buy.garmin.com/de-DE/DE/p/119594#specs>

All walks took place in Germany, North Rhine Westphalia, near the city of Oberhausen, for details see coordinates of each run. Length of the walks depended on age and physical ability of the dogs.

Table M1.2.4: *Duration of walking time of owners and all dogs: mean, SD, median and sum of walks in minutes.*

	Duration of owners walking round in min.				Duration of dogs traveling round in min.			
	mean	SD	median	Sum of all walks	mean	SD	median	Sum of all walks
Amanda	82	3	82	328	77	5	75	308
Amy	71	3	72	283	69	3	69	276
Arthur	79	16	74	315	79	15	74	314
Balin	92	4	91	367	90	5	88	358
Balou_Mix	81	11	78	324	80	11	79	318
Balou_RR	95	5	94	380	95	6	93	380
Bill	95	6	95	379	93	6	93	373
Dr. Pepper	81	9	80	324	77	4	79	309
Emma	116	35	112	462	114	31	112	454
Freya	70	12	72	281	71	16	70	284
Honey	110	40	103	439	111	39	104	443
Kaito	92	8	93	368	90	10	91	358
Kimi	77	7	75	307	77	7	76	306
Lea/Emma	66	6	67	263	67	6	69	266
Lili	81	12	78	323	80	13	77	318
Lou	111	30	112	443	110	30	111	440
Luna	98	4	99	391	99	4	100	395
Mala	127	7	126	506	126	6	126	505
Manja	112	29	117	447	112	31	118	447
Marley	85	3	83	338	82	5	81	328
Molly	73	8	73	290	70	9	70	281
Nele	71	3	72	283	69	3	69	276
Nina	77	7	75	307	74	10	76	295
Odin	73	1	74	292	72	3	74	289
Raffaele	112	34	103	447	112	34	104	446
Raya	67	14	68	267	66	13	67	262
Tamina	85	3	83	338	83	5	82	333
Thorin	96	22	103	383	95	22	102	381
Wantje	82	3	82	328	77	4	76	309
Zlata	138	20	134	413	143	19	145	570
total	89	23	83	10616/354	89	24	81	10622/354

Using the recorded data it was determined how often the dog left the owner's range beyond 20 m (in all directions, see **Fig. M1.2.1**, pictogram) as well as the time and distance travelled during each run using the software Garmin BaseCamp™ 4.5.2.1. In addition, the dog collars DC and T5 also recorded the movement of the dog. The collars recorded bearing, azimuth, speed and movement every two seconds. The trail was then visualized using the software Garmin BaseCamp™ 4.5.2.1. Therein all information was directly imbedded, e.g. any mark that was made on the GPS whilst exploring (prey; disturbances; special events) is shown on the Basecamp map.

Wind speed and direction was measured with an anemometer (Technoline EA-3000) and handheld compass. Ambient temperature was also recorded therewith.

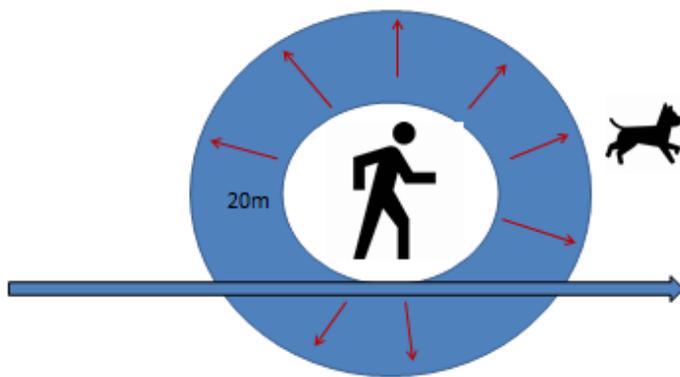


Fig. M1.2.1: Pictogram illustrating the minimum distance requirement.

51 parameters were recorded for each dog-owner dyad, for an overview see the list below, **Table M1.2.5**.

Table M1.2.5: *Parameters recorded.*

Dogs	Name	Breed	Sex	Age	No. of trials/ runs <20m	Health	Did dog get lost	Animal sighting
Time	Day/ month/ year	Total time own- er walk Total time dog walk Time moving/ Pausing time owner Time moving/ Pausing time dog	Starting time Owner walk/ dog walk/ each run End of walk owner/ dog walk/ each run	Time at owner	Time point of return	Time out- bound	Time inbound	Time dif- ference in- bound/out bound
Dis- tance	Total distance owner walk	Total distance dog walk Total distance of each run < 20m	Distance entire round	Distance out-bound	Distance in- bound	Distance between point of return and start	Distance between point of return and own- er meet	Distance difference
Envi- ron- ment	Latitude/ longitude	New/ Known area	Animal sighting tracks	Wind	Location	Temper- ature	Weather	
 Direc- tion	Travel- ling pat- terns dog	Direct/shortest way to owner	Same or new route on return Traceback own route	Azimuth point of return- start	Azimuth Point of return	Azimuth Starting point	Azimuth anticipa- tion Azimuth Point of alignment	
Speed	Owner average speed overall and each run	Dog average speed overall and each run	Mean speed total walk/each run	Dog Maxi- mum/ minimum speed to- tal/ each run	Mean Speed travelling out	Mean Speed return route	Speed differ- ences inbound/ outbound	Step fre- quency dog

1.2.3 Factors controlled for; minimum requirements

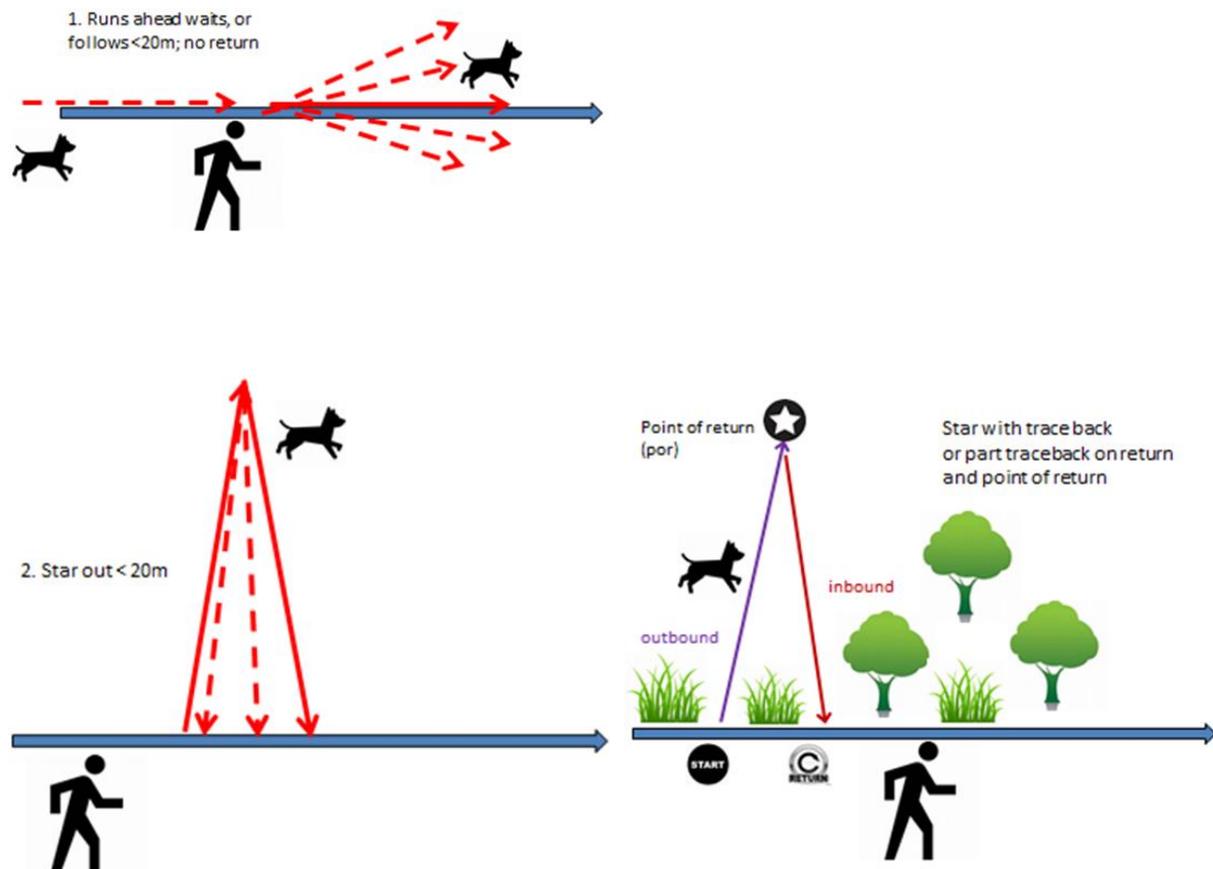
The minimum distance the dog had to travel on any given trial was > 20 m away from the owner in any direction, see **Fig. M1.2.1**. Trials were performed in wooded areas, preferably with dense underbrush to prevent visual contact. If two dogs from one owner participated in any given trial data from both dogs, as visualized on Garmin BaseCamp™, were used and compared, individually and grouped. Solely uninhabited areas, without roads or major pathways, were visited. The owner was not to whistle or call or offer any other kind of acoustic or visual signal.

1.2.4 Path set up and travelling patterns

In this study the dogs were released by their owner in known or unknown areas to explore. The dogs wore a GPS collar at all times.

Data were collected with a handheld GPS (Astro® 320 Garmin) as well as the dog collars (DC™ 50 and T5 Mini; Garmin). Then the factors of interest (**Table M1.2.5**) were recorded for each trial.

Seven travelling patterns were differentiated for each run > 20m: 1. Dog runs ahead and waits/follows; 2. star; 3. loop; 4. loop+star; 5. Mix forms: runs ahead & loop; 6. Mix forms: runs ahead & star; 7. Runs parallel then meets owner. Regarding the travelling patterns, see **Fig. M1.2.2** for pictograms.



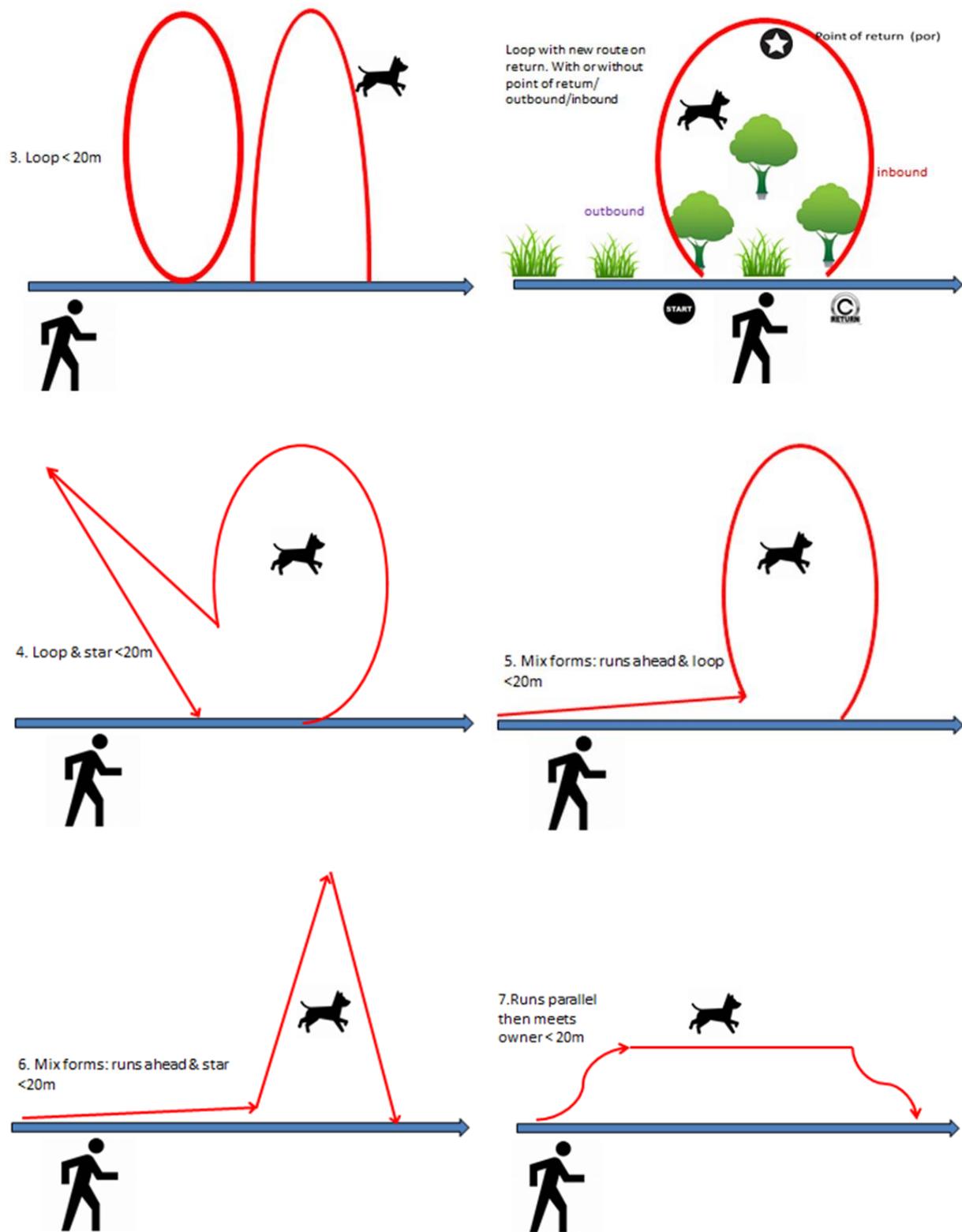


Fig. M1.2.2: Pictogram illustrating the seven recognized travelling patterns.

1. Dog runs ahead and waits/follows: the dog runs ahead on the path and waits briefly (two – four second segments) for the owner and/or establishes visual contact before continuing or the dog follows owner on the path. No return route to owner and therefore no point of return (POR) or data on outbound/inbound route.
2. Star: the dog displayed a travelling pattern similar to one arm of a star, thus the outbound route being fairly identical to the inbound route and the starting point being almost identical to the return point (therefore displaying a trace back or part trace back on return, and most of the time a point of return and accordingly an outbound and inbound route), see **Fig. M1.2.3**.
3. Loop: a circular or semicircular pattern, thus a route which a dog did not retrace to return (therefore displaying a new return route, which however, does not necessarily mean direct return route and which may also be a “route of anticipation”). A point of return was established if the data indicated a decrease in speed and consecutive change of direction within a 2 sec segment to return to owner, in which case there also was an outbound and inbound route.
4. Loop and star: the dog travelled off the path in a loop and a star pattern.
5. Mix forms runs ahead & loops: the dog runs ahead on the path and then continues in a loop before returning on the path.
6. Mix forms runs ahead & star: the dog runs ahead on the path and then continues in a star pattern before returning on the path.
7. Runs parallel then meets owner: the dog does not stay on the path but travels parallel to the owner, often out of range of visibility, before returning onto the owner’s path. No point of return, no data on outbound/inbound route.

A point of return (POR) was established if within the two second segment of the GPS data it could be clearly seen that the dog changed direction to return to the owner, which usually included a decrease in speed and consecutive change of direction on the return route with an increase in speed, see **Fig. M1.2.3** for example. If a POR was established the data was used to determine the speed/time/distance outbound (from start to POR) away from the owner and inbound (from POR back to the owner). Some travelling patterns did not have a point of return, for instance when the dog ran parallel or ahead of the owner without returning, or followed. In these cases data on inbound and outbound distance, speed and time could not be collected.

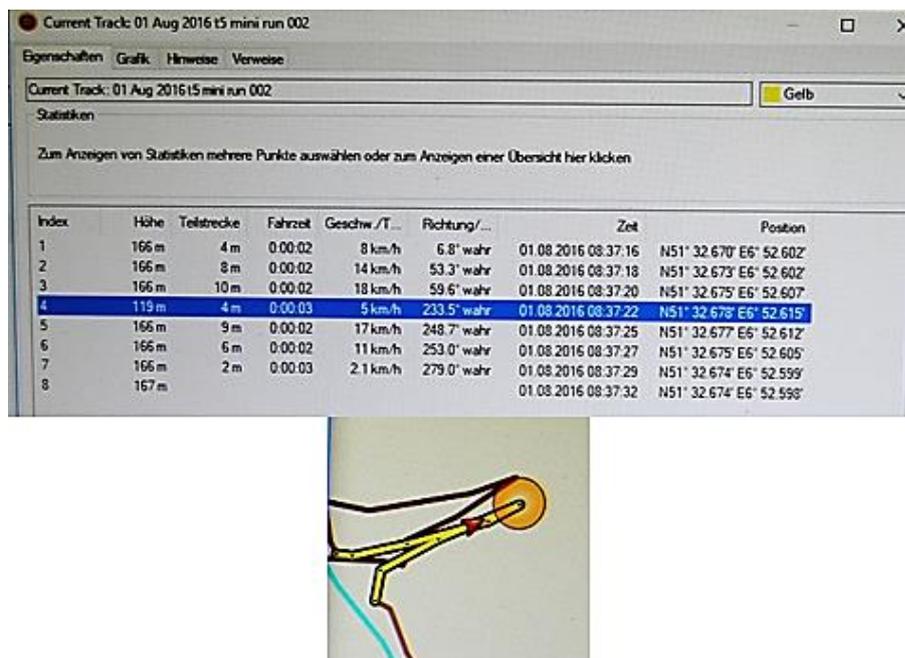


Fig. M1.2.3: Graphic representation illustrating a point of return (POR) of a star travelling pattern.

1.2.5 Statistics and correlative values

A total of 30 different dogs were analyzed. For each dog data of four different walks with its owner (two in known and two in unknown areas) were collected in resulted in a total $n=120$ measurements. For each of the 120 walks all runs >20 m were recorded in detail and resulted in $n= 3145$.

Descriptive analysis was performed calculating number of valid measurements (n), mean (m), median, quartiles and standard deviation (SD). Relationships were plotted using scatterplots, bar charts, boxplots or mean \pm 95 % confidence interval.

Boxplot charts display the distribution of data within groups or overall groups. The box represents the "middle 50 %" of the data, starting with the lower quartile and ending at the upper quartile. The length of the box represents the inter quartile range (IQR). The line in the middle of the box indicates the median. The whiskers extend from either side of the box and represent the bottom 25 % and the top 25 % of the data values. Outliers which extend $1,5 \cdot \text{IQR}$ are shown as dots, extreme values greater than three times IQR are represented by asterisks, see **Fig. M1.2.4**. (Definition of boxplots according to Tukey, 1977).

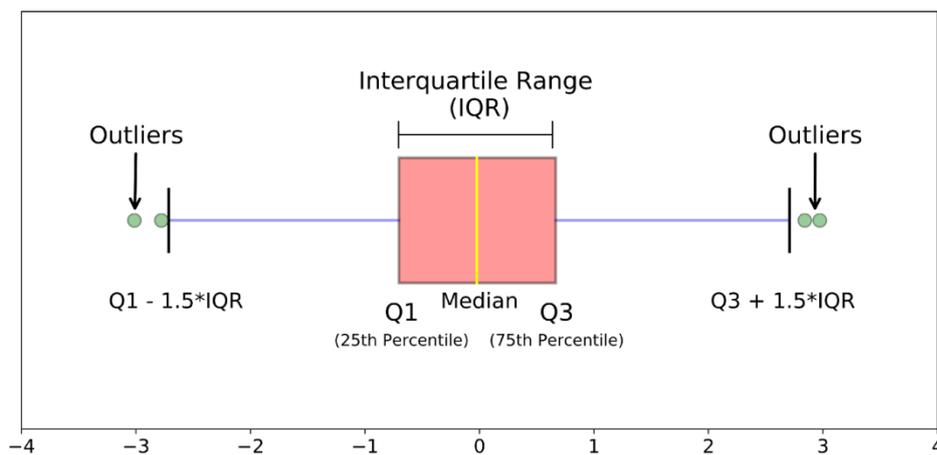


Fig. M1.2.4: Boxplot and its interpretation.

Nonparametric tests were used for inductive statistics. Mann-Whitney U Test was used to compare two independent samples, Wilcoxon test for dependent samples of ordinal data. Also randomization (or permutation) tests were applied for comparison of dependent or independent groups of interval scaled data. Randomization test is a different and always valid method of determining statistical significance without assuming any underlying distribution. The distribution of the test statistics is computed over all possible permutations of group assignments. All assignments have to be equally likely. In detail the following steps are carried out:

1. For the observed data, a suitable test statistic is computed, so that the hypothesis could be evaluated (e.g. mean difference).
2. Enumerate all possible group assignments and compute the statistic for each permutation. So you get the randomization distribution under the null hypothesis.
3. The p-value of the test statistic is obtained using the randomization distribution.

Spearman correlation coefficients were used to examine the monotone relationship of two continuous variables, whereas Pearson correlation coefficients are applied for describing linear relationships. In case of linear correlation, a linear regression model was calculated to quantify the effect of the variables.

For bivariate nominal data (yes/no) exact binomial test was applied to compare frequency of occurrence between two groups. Exact Chi-Square Test was used for testing differences in crosstabs.

Hierarchical cluster analysis was applied to find walks with similar running patterns and to find the appropriate number of clusters. Squared Euclidian distance was used as measure of distance and Ward method was used as linkage method. K-Means

clustering with three Clusters was applied to assign all walks (n=120) to the cluster. A Cluster analysis is neither parametric nor non-parametric as the algorithms are based on exploratory data mining. Cluster analysis is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters), in here the travelling patterns regarding distance of the dogs. Connectivity-based clustering, also known as hierarchical clustering, is based on the core idea of objects being more related to nearby objects than to objects farther away. These algorithms connect "objects" to form "clusters" based on their distance. A cluster can be described largely by the maximum distance needed to connect parts of the cluster. At different distances, different clusters will form, which can be represented using a dendrogram (see Appendix), which explains where the common name "hierarchical clustering" comes from: these algorithms do not provide a single partitioning of the data set, but instead provide an extensive hierarchy of clusters that merge with each other at certain distances. For the distance function the Euclidian distance was used (squared Euclidean distance) followed by the Ward's minimum variance criterion, which minimizes the total within-cluster variance. To implement this method, at each step the pair of clusters that led to minimum increase in total within-cluster variance after merging was found. This increase was weighted against the squared distance between cluster centres. At the initial step, all clusters are singletons (clusters containing a single point). To apply a recursive algorithm under this objective function, the initial distance between individual objects must be (proPORtional to) squared Euclidean distance.

To determine travelling patterns in more detail and describe difference between the dogs more specifically three Groups were applied with respect to travelling distance (runs > 20 m): **Group 1:** radius < 150 m maximum distance from owner travelled by the dogs; **Group 2:** 150 m <radius< = 350 m maximum distance from owner; **Group 3:** radius > = 350 m distance from owner.

All tests were performed two-tailed on a 5 % level of significance. Standard Bonferroni correction of p-values < 0.05 was applied in case of multiple testing. Two-tailed tests were performed unless otherwise denoted. SPSS version 25, IBM Inc. was used for analyzing the data. StatKey (<http://www.lock5stat.com/>) was used for performing randomization tests using a simulated sample of size n= 5000.

1.3 Results

The Dog – Owner Dyad

All dogs, independent of sex, age, reproductive status or breed, found and returned to their owner in different environments subsequent to having travelled at least 20 m away from their owner, see **Table R1.0** and Appendix. Out of 120 trials and n=3145 total runs >20 m of 30 free-ranging dogs in familiar and new areas in Germany no dog got lost, including the deaf dog (#13). Length of trials (runs > 20 m) varied greatly between 20 m and 2300 m; see **Table R2.1.1**; **Table R2.3.1** (Results Part 2) for details; the number of runs also varied greatly, **Table R1.0.**, **Table R2.1.1**; **Table R2.2.1**. Therefore even the dogs which were out of range of visibility, or olfaction or hearing found back to their owner despite external stimuli or unknown area.

1.1 Duration over all walks of owner and dog

Median duration of dog walks over all dogs (81 min) (mean 89 min. +/- 24 min.) and median duration of owner walk (83 min.) (mean 89 min. +/- 23 min.) was comparable, see **Table R1.1.1**, differences being due to the start/stop sequence of the respective GPS device (GPS collar dogs or GPS handheld device owner). Median and quartiles were identical between owner and dog. Values were thus comparable, **Table R1.1.1**; **Fig. R1.1.2** The Histogram depicting the difference in walking time between dog and owner, **Fig R1.1.3**, showed very congruent walking times.

1.2 Walking distance between owner and dog

The mean difference between dog and owner walking distance (n=120) ranged from 1593 +/- 1600 m, see **Table R1.2.1** 50 % of the dogs showed a median difference in walking distance to their owner of 1000 m (lower quartile 400 m; upper quartile 2300 m), see **Table R1.2.1**. Data demonstrates the dogs great intraspecific differences: A quarter of the dog-owner walks indicated a distance of less than 400 m difference between dog and owner, the travelled distance over all between dog and owner being almost identical, the dogs being close to their owner during the entire walk. Half of the walks showed a difference between dog and owner travelled distance of less than 1000 m, see **Table R1.2.1**. Only a quarter of the walks indicated a difference of more than 2300 m between dog and owner distance travelled. In these cases the dogs travelled a distance in excess of 2300 m compared to the owner walked distance which corre-

sponds to a 43 % increase compared to the walked distance of the owner, see **Table R1.2.1** and **Fig. R1.2.1**.

Dogs over all, however, always travelled longer distances than their owners (runs >20 m are included), see **Fig. R1.2.1** and **Table R1.2.1** and the distance difference travelled was significantly larger for dogs compared to owners ($p < 0.001$), see **Table R1.2.1**.

Based on the large intraspecific differences between the dogs three groups were established to illustrate the variances in more detail: Group 1 dogs stayed within a radius of 150 m of the owners at all runs > 20 m; Group 2 dogs stayed within a radius of >150 m and <350 m of the owner for all runs >20 m; and Group 3 dogs went beyond the radius of 350 m of the owner for runs >20 m. Dogs of all three groups, however, travelled longer distances than their owners, see **Table R1.2.1**.

1.3 Time and distance travelled in known and unknown areas

Looking at the over all time and distance of the total walks between known and unknown area between owner and dog no significant differences existed ($p = 0.137$ (distance owner), $p = 0.914$ (distance dog), $p = 0.925$ (time owner), $p = 0.879$ (time dog) Wilcoxon test) see **Table R1.2.2**. The over all time was comparable, differences might be resulting from GPS measurements in turning the GPS device on/off.

Differences between dog and owner over all distances travelled could clearly be seen and resulted in known areas in a 27.4 % (median)/ 29.8 % (mean) increase of distance travelled by the dogs ($n=120$; median 5300 m owner versus median 6750 m dog; mean owner 5753 +/- 1701 m versus mean dog 7467 +/- 2315 m); with the higher quartile of 9100 m showing an increase of 35 %. In unknown areas dogs displayed an difference of distance travelled of 22.9 % (median)/24.4 % (mean); owner median 5450 m versus the dog median of 6700 m; owner mean of 6035 +/- 1949 m vs. dogs mean of 7508 +/- 2315 m and the higher quartile indicated an difference of 8700 m=30 %; **Table R1.2.2**.

1.4 Speed of owner and dog

The results clearly show that the speed between owner and dog differed strongly, independent of the group the dogs belonged to or factors like age, size or exploration patterns see **Fig. R1.3.1; R1.3.2; R1.3.3**. Large intraspecific differences in speed could be observed, see **Fig. R1.3.1** and **Table R1.3.1**.

Based on these large intraspecific differences of the dogs the three groups were utilized to illustrate the variances in more detail: Speed differences could also be established between these three groups, with Group 3, the dogs with the largest radius, displaying the highest speed differences between owner and dog see **Fig. R1.3.2** (in km/h) and **Fig. R1.3.3** (in minutes). Using randomization tests for one mean difference, a significant difference between owner and dog speed during the walk could be shown, **Fig. R1.3.4**. The median speed of the owners amounted to 4,4km/h (mean 4.43 +/- 0.43 km/h) compared to 5.7 km/h (mean 6.01 +/- 1.21 km/h) of the dogs. The difference between owner and dog speed was statistically significant ($p < 0.001$; Wilcoxon Test), see **Table R1.3.1**.

1.4.1 Correlations of dogs' time travelled belonging to one owner

To determine whether dogs belonging to one owner displayed similar behaviour with respect to time and distance explored, as well as speed patterns potential correlations were determined. For the dog-owner dyads/triads see **Table M1.2.1**. Two owners walked with three dogs. Here all pairwise correlations were considered, i.e. dog 1 vs. dog 2, dog 2 vs. dog 3 and dog 1 vs. dog 3. Ten teams were established, see overview **Table R1.4.3.1**.

Significant linear correlations could be shown between the duration of the travelling round, difference in walking time (owner/dog), time inbound and time outbound. All correlations were positive for most teams, i.e. the longer one dog of an owner travelled, the longer the second dog of the owner travelled, **Table R1.4.1.1**. The correlations were visualized using Scatterplots. The x-axis showed values of dog 1, the y-axis parameters of dog 2 or 3. High values of one dog were correlated with high values of the other dog(s). In every team a leader or independent dog with a more extensive time range could be observed, see **Fig. R1.4.1.1 - R1.4.1.5**.

1.4.2 Correlations of dogs' distance travelled belonging to one owner

Correlations were also assessed with respect to total distance of the walks; total runs >20 m; maximum distance of the runs as well as the distance inbound and outbound travelled by the dogs.

Significant linear correlations for all distance measures could be found between two/three dogs of one owner. All correlations were positive, indicating that higher values of one dog were correlated with higher values of the other dog(s). Measurements of

one of the dogs was higher than that of the other dog(s), indicating an initiating or leading dog, see **Fig. R1.4.2.1 - Fig. R1.4.2.5**.

Correlations were also assessed with regard to the average speed of the owner and his/her dogs and correspondingly the ten teams were evaluated **Table R1.4.3.1**. There were four speed measures, one for each walk and each dog/owner. No tests could be performed for n=4 in each group. Not overlapping confidence intervals indicated significant differences at 5 % level of significance. Using confidence intervals standard Bonferroni correction was applied for accounting for multiple testing. The average speed of dogs was higher than the speed of the corresponding owner, **Fig. R1.4.3.1; Table R1.4.3.1**.

1.3.1 Off leash pet dogs in known or unknown areas, even if not called or signalled to, return to their owner

Despite great intraspecific differences all dogs returned on all explorations, independent of area, distance travelled, sex, reproductive status, breed or age to their owner.

Table R1.0: All dogs; number of runs; owner; breed; reproductive status; sex; birthdate.

No.	No. runs >20 m	lost	Name	Owner	Breed	Neutered/intact	Sex	birth
1	204	0	Amanda	H.M.	Collie	Intact	Female	19.06.2017
2	208	0	Amy	S.S.	Labrador Retriever	Neutered	Female	23.04.2014
3	177	0	Arthur	V.B	Standard Poodle	Intact	Male	28.04.2017
4	15	0	Balin	H.M.	Great Dane Mix	Neutered	Male	22.02.2014
5	138	0	Balou RR	C.C.	Rhodesien Ridgeback	Neutered	Male	24.06.2007
6	174	0	Balou	C.B.	Husky Shepard Mix	Intact	Male	11.11.2012
7	221	0	Bill	S.L.	LabradorMix	Neutered	Male	18.02.2011
8	44	0	Dr.Pepper	S.M.	Silken Windsprite	Intact	Male	01.05.2017
9	145	0	Emma Lea	E.M.	Miniature Pinscher	Intact	Female	28.05.2015
10	6	0	Emma	A.S.	Perro de Aqua Espanol Mix	Neutered	Female	01.10.2009
11	9	0	Freya	N.P.	Pug	Neutered	Female	23.07.2016
12	58	0	Honey	D.S.	Whippet	Neutered	Female	15.06.2011
13	148	0	Kaito	S.L.	Mastiff Mix	Neutered	Male	18.02.2011
14	96	0	Kimi	M.K.	Whippet	Neutered	Female	19.02.2012
15	74	0	Lili	C.B.	Pastor Mallorcin Mix	Neutered	Female	01.01.2011
16	182	0	Lou	S.L.	Shepherd Mix	Neutered	Male	05.10.2007
17	149	0	Luna	C.C	Rhodesian Ridgeback	Neutered	Female	29.11.2010
18	2	0	Maloca	A.S.	Perro de Aqua Espanol	Neutered	Female	01.07.2007
19	5	0	Manja	A.U.	Italian Greyhound	Intact	Female	21.04.2009
20	159	0	Marley	G.B.	Labrador Mix	Neutered	Male	14.03.2015
21	13	0	Molly	N.B.	Pug	Neutered	Female	18.04.2016
22	201	0	Nele	S.S	Labrador Retriever	Neutered	Female	09.12.2007
23	103	0	Nina	M.K.	Greyhound Mix	Neutered	Female	08.09.2012
24	58	0	Odin	A.W.	Whippet	Neutered	Male	25.06.2009
25	47	0	Raffaele	A.U.	Italian Greyhound	Neutered	Male	23.01.2014
26	106	0	Raiya	S.M.	Barsoi	Intact	Female	14.02.2017
27	147	0	Tamina	G.B.	Terrier/Chinese Crested Mix	Neutered	Female	01.01.2014
28	122	0	Thorin	S.W.	Barsoi	Neutered	Male	27.06.2013
29	123	0	Wantje	H.M.	Collie	Intact	Female	30.03.2014
30	11	0	Zlata	A.S	Barsoi	Neutered	Female	22.06.2011

Free-ranging pet dogs, independent of sex, age, reproductive status or breed, found and returned to their owner in different environments subsequent to having travelled at least 20 m away from their owner, see **Table R1.0** and Appendix. All 30 dogs returned to their owner on all runs. Great intra-individual differences can be perceived with respect to number of runs > 20 m as well as distance.

1.3.2 Duration of walk: Dog(s) and owner travelling time

To establish that the overall values are comparable the total owner and dog walking mean and median duration was assessed and no significant differences were found. Individual differences between owner-dog dyads travelling times could be shown, however, and dogs travel generally faster than their owners.

Table R1.1.1: Comparison of total time of owner and dog walks in minutes. Duration of walk: Dogs do not travel longer than their owner.

Duration of dogs walking round in min.						Duration of owners walking round in min.					
n	mean	median	Q25	Q75	SD	n	mean	median	Q25	Q75	SD
120	89	81	73	97	24	120	89	83	73	97	23

Mean duration over all dogs (1:29 h +/- 0:24 h) and mean duration of owner walks (1:29 h +/- 0:23 h) did not differ significantly over all walks. Differences were mainly due to the start/stop sequence of the respective GPS (GPS collar dogs or GPS handheld device owner). Median and quartiles are identical between owner and dogs. Values are thus comparable.

However, looking at the individual differences between owner-dog dyads travelling times dogs travel generally faster than their owners (negative values, see **Fig.R1.1.2**) including runs >20 m. For details see also **Table R1.2.1**. The Wilcoxon test for paired samples shows a significant p-value <0.001. Thus, it can be shown that the duration of the owner-dog dyads during the walks differs significantly during the walks. However, the difference lies mainly in the -1min. /+1min. segment, (59 walks, 52.7 %) thus the effect strength is small, see also **Fig. R1.1.3** histogram.

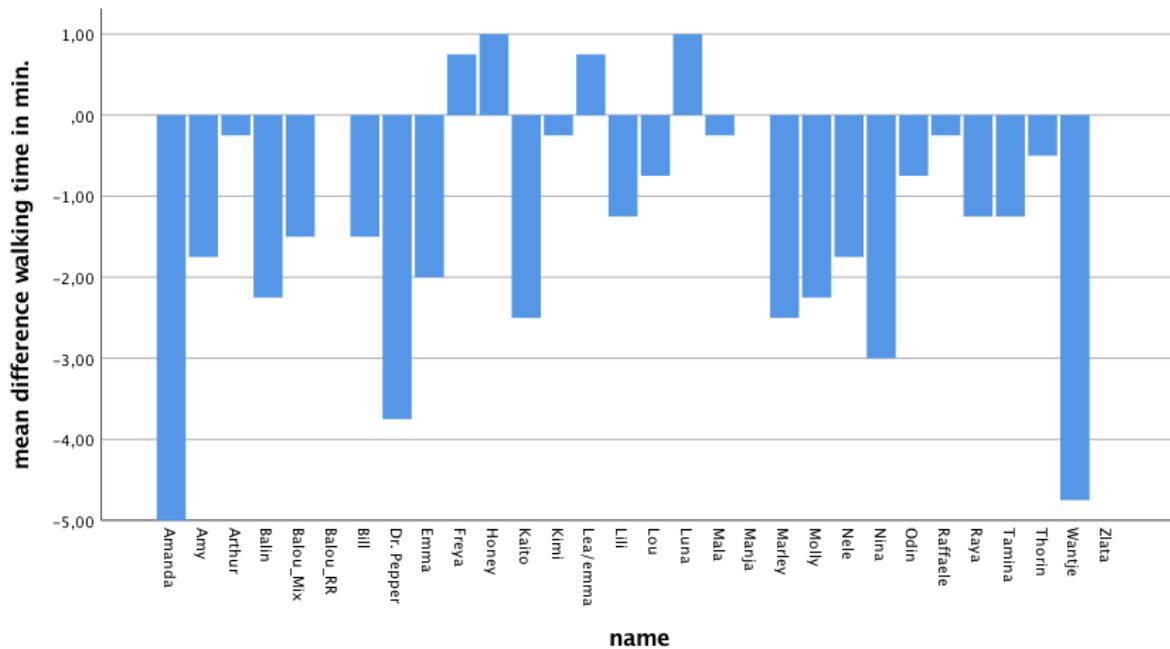


Fig. R1.1.2: Mean difference of walking time in minutes of each dog, negative values, of the dog-owner dyad.

Slight differences can be perceived looking at the different dog-owner walking times.

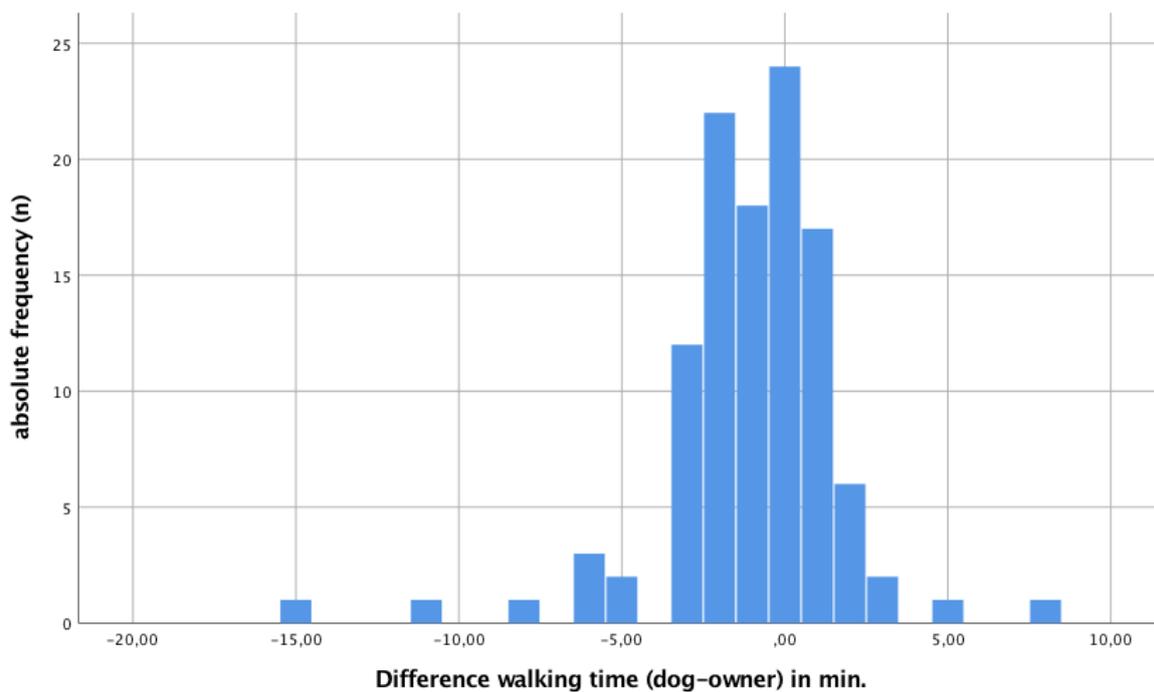


Fig. R1.1.3: Histogram depicting the difference in walking time between dog and owner in minutes.

From **Fig. R1.1.3** (Histogram) it can be seen that most walks have congruent walking times. Only three of 120 walks have a difference greater than 10 minutes, where in two of these three cases the dogs show lower total walking times, i.e. the dogs are earlier at the end of the walk (owner car) than the owner.

1.3.3 Distance of walk: Length of walks differ between owner and dog

The walking distances of the dog-owner dyads are compared (mean and median) and the data demonstrates great intraspecific differences between the dogs. The over all distance travelled is significantly larger for dogs compared to owners.

Table R1.2.1: Comparison of total distance of owner and dog walks in meter.

	n	mean	median	Q25	Q75	SD	p-value (Wilcoxon Test)
total distance owner walk in m	120	5894	5300	4900	6200	1827	
total distance dog walk in m	120	7488	6700	5850	8700	2202	
Difference_walking_distance in m (dog-owner dyad)	120	1596	1000	400	2300	1600	<0.001

The mean difference between dog and owner over all walking distance is 1596 +/- 1600 m. 50 % of the dogs show a median difference in walking distance to their owner of 1000 m, with a lower quartile of 400 m, and an upper quartile of 2300 m. The standard deviation, however, is very high. The data demonstrates that the dogs show great intraspecific differences. About 25 % of the dog-owner walks shows an over all distance of less than 400 m difference between dog and owner, the travelled distance between dog and owner being almost identical, the dogs are close to their owner during the entire walk. Half of the walks show a difference between dog and owner travelled distance of less than 1000 m. Only a quarter of the walks show a difference exceeding 2300 m between dog and owner distance travelled. In these cases the dogs travel a distance which is in excess of 2300 m compared to the owner which corresponds to a 43 % increase compared to the walked distance of the owner.

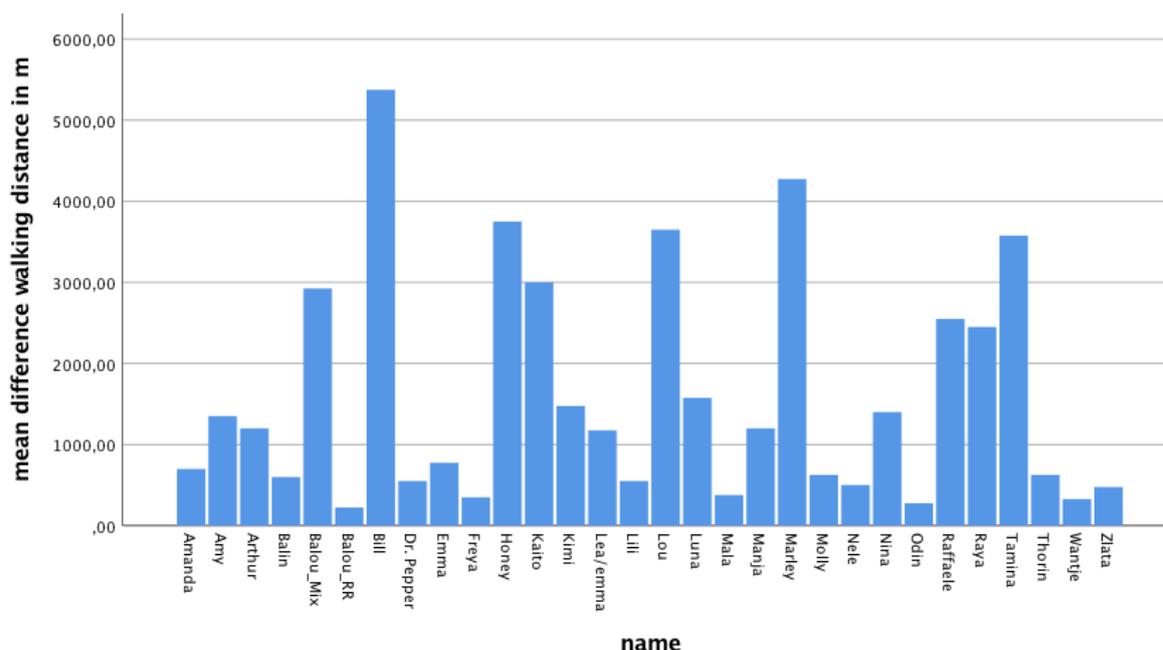


Fig. R1.2.1: Mean difference between owner and dog of walking distance in meter, all individual dogs ($n=30$).

Dogs always travel longer distances than their owners (Runs >20 m are included). The distance travelled is significantly larger for dogs compared to owners ($p<0.001$). This includes all dogs even those in Group 1 (radius <150 m distance from owner) which always stayed in close proximity to their owner. The largest differences can be seen in Group 3 (Balou Mix; Bill; Honey; Kaito; Lou; Marley; Tamina).

Table R1.2.2: Overall distance and time of total walk in known and unknown areas; owner and dog.

n=120	area									
	Known area (n=60)					Unknown area (n=60)				
	mean	median	Q25	Q75	SD	mean	median	Q25	Q75	SD
total distance walk owner total in m	5753	5300	4700	6050	1701	6035	5450	5000	6450	1949
total distance dog walk in m	7467	6750	5850	9100	2102	7508	6700	5850	8700	2315
Duration of owners walking round in min.	89	83	73	97	21	90	85	72	98	24
Duration of dogs walking round in min	87	81	73	97	21	90	83	72	98	26

There are no significant differences in time or distance of the total walks between known and unknown area between owner and dog ($p = 0.137$ (distance owner), $p = 0.914$ (distance dog), $p = 0.925$ (time owner), $p = 0.879$ (time dog) Mann Whitney U Test). The median distance of the owner in known areas is 5300 m, in unknown areas 5450 m. About 25 % of the walks in known areas are in excess of 6050 m, in unknown areas 6450 m, thus there is a slight increase in unknown areas. Median duration of 50 % of the walks in known areas is 01:23 (83 minutes), in unknown areas 01:25h (85 minutes). The upper quartile duration of owner walks in known and unknown area is identical. Dogs have a median walking duration of 01:21h (81 minutes) in known and 01:23h (83 minutes) in unknown areas, respectively. The median distance in known areas is 6750 m, in unknown 6700 m, the lower quartile being identical, whereas the upper quartile in known areas is 9100 m, in unknown 8700 m, respectively, and shows a tendency of less distance travelled in unknown areas. The difference between the distance of the owner walks versus the dogs walks can clearly be seen by a mean of the owner walks in known areas of 5753 +/- 1701 m and a mean of the dogs walks of 7467 +/- 2315 m (increase 30 %), with a median distance of owner walks of 5300 m versus median distance of dog walks of 6750 m (27 % increase). The higher quartile of 9100 m even shows an increase of 35 %. In unknown areas the owner median is 5450 m versus the dog median of 6700 m, an 23 % increase; the owner mean of 6035 +/- 1949 m vs. dogs mean of 7508 +/- 2315 m shows an 24 % increase and the higher quartile of 8700 m even a 30 % increase; displaying a slight decrease in distance travelled in unknown areas.

1.3.4 Walking speed: Owner speed differs from dog speed

One aim of this study was to assess whether the walking speed of an owner and their dog differed significantly if the dogs are allowed to run free and thus chose their own travelling speed. The speed between owner and dog differed strongly, independent of the group the dogs belonged to or factors like age, size or exploration patterns.

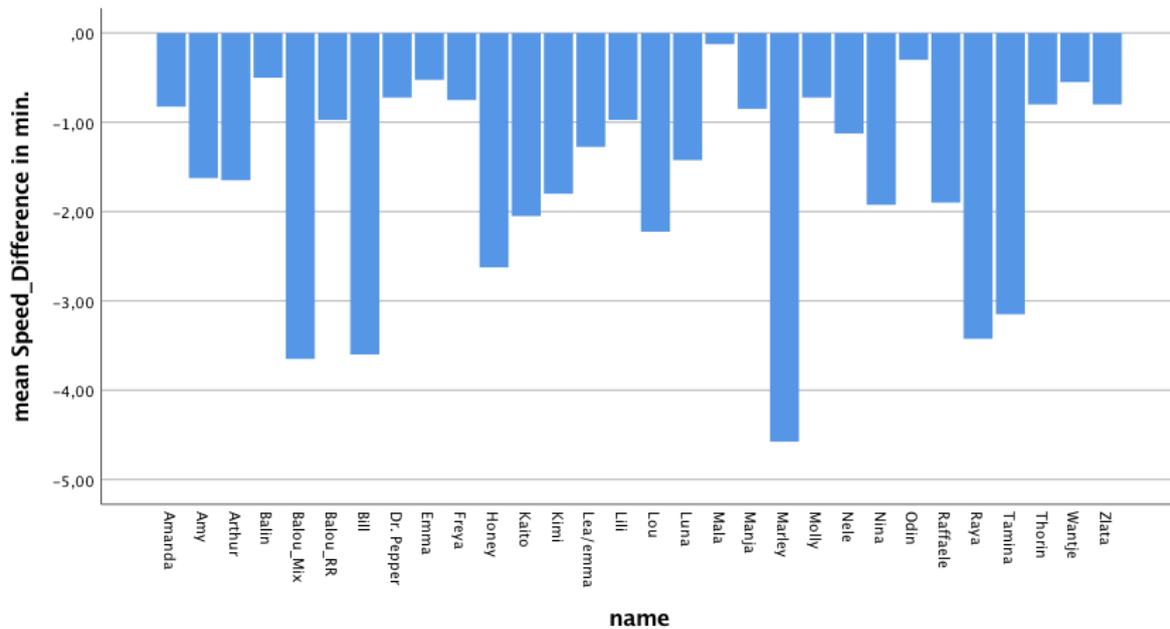


Fig. R1.3.1: Mean speed difference in minutes; owner and dog. Each dog individually.

Based on the large intraspecific differences of the dogs three groups were established to illustrate the variances in more detail: **Group 1** dogs stayed within a radius of 150 m of the owners at all runs > 20 m; **Group 2** dogs stayed within a radius of >150 m and <350 m of the owner for all runs >20 m; and **Group 3** dogs went beyond the radius of 350 m of the owner for runs >20 m. Speed differences could also be established between these three groups, with Group 3, the dogs with the largest radius, displaying the highest speed differences between owner and dog.

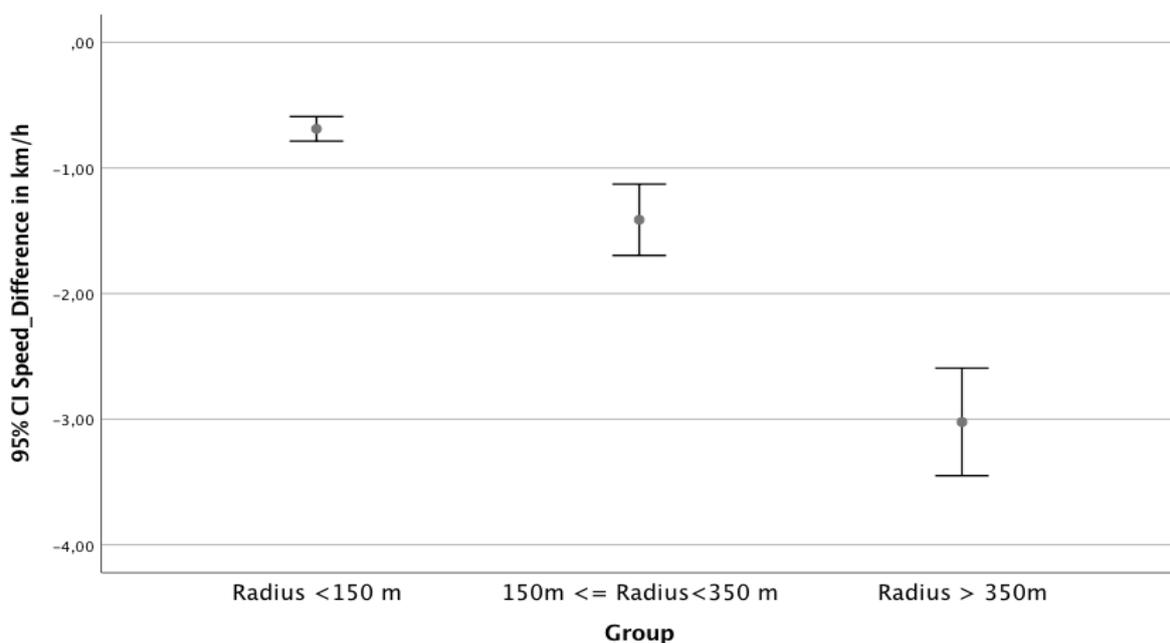


Fig. R1.3.2: Mean speed difference in km/h and Group 1, 2 and 3 of owner-dog dyad.

Large speed difference can be perceived between the dogs of the different radius groups.

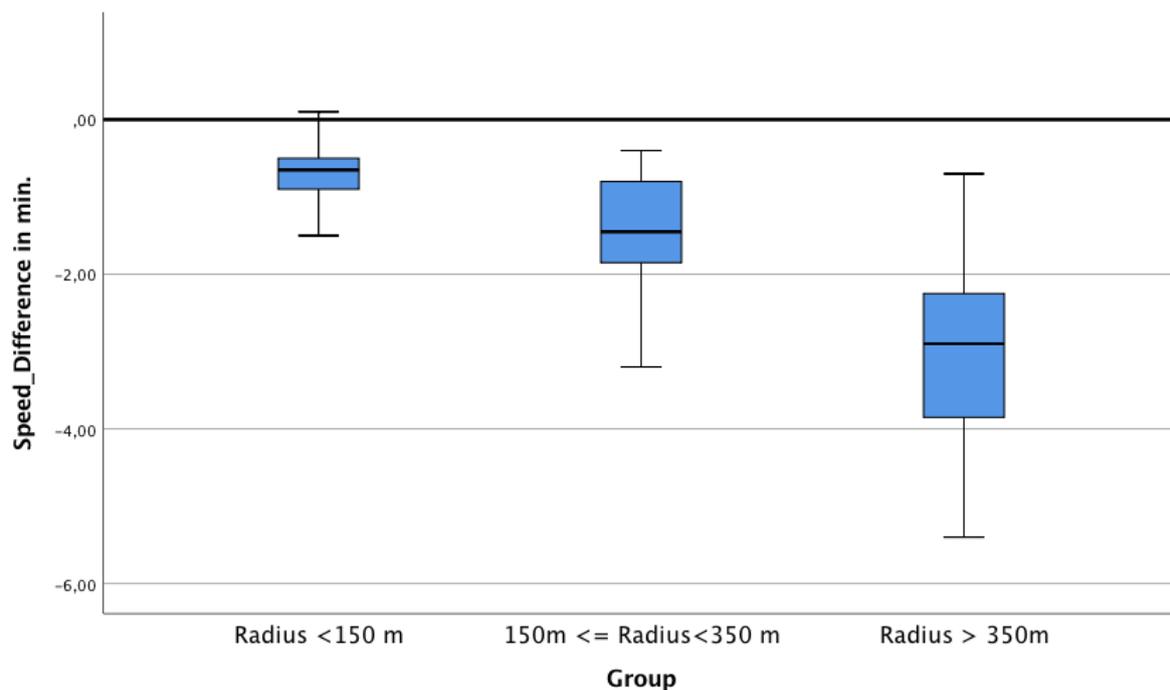


Fig. R1.3.3: *Boxplot: Speed difference in minutes, Group 1, 2 and 3, owner-dog dyad.*

Speed of owner and speed of dog differ strongly. All dogs demonstrate a higher speed than the owner. Balou_Mix (Husky Mix), Honey (Whippet), Marley (Labrador Mix), Raiya (Borzoi) and Tamina (Terrier Mix) (all dogs have a radius ≥ 350 m (Group 3)) show very high differences in speed compared to the speed of their owner, see **Table R1.3.1**. Group 1 dogs, staying closest to the owner, display the smallest speed difference in minutes or km/h.

Table R1.3.1: Average walking speed of the owner and each dog; difference in km/h; Group of each dog and over all speed.

Dog n=30	Group	owner average walking speed in km/h					dog average walking speed in km/h					Speed_Difference				
		mean	median	Q25	Q75	SD	mean	median	Q25	Q75	sd	mean	median	Q25	Q75	SD
Amanda	1	4.30	4.3	4.3	4.3	0.00	5.13	5.1	5.0	5.3	0.22	-0.83	-0.8	-1.0	-0.7	0.22
Amy	2	4.45	4.5	4.3	4.6	0.17	6.08	6.0	5.9	6.3	0.31	-1.63	-1.5	-1.9	-1.4	0.39
Arthur	2	4.55	4.6	4.5	4.7	0.13	6.20	6.2	6.1	6.4	0.24	-1.65	-1.6	-1.8	-1.5	0.24
Balin	1	4.25	4.3	4.1	4.5	0.26	4.75	4.9	4.5	5.0	0.33	-0.50	-0.5	-0.6	-0.5	0.08
Balou_Mix	3	4.10	4.2	3.8	4.4	0.36	7.75	7.6	6.8	8.7	1.18	-3.65	-3.4	-4.6	-2.8	1.21
Balou_RR	1	4.25	4.3	4.2	4.3	0.06	5.23	5.3	5.1	5.4	0.24	-0.98	-1.0	-1.2	-0.8	0.22
Bill	3	4.18	4.2	4.0	4.4	0.28	7.77	7.6	7.3	8.3	0.80	-3.60	-3.4	-4.3	-2.9	1.00
Dr. Pepper	1	4.30	4.3	4.2	4.4	0.16	5.03	5.0	4.9	5.2	0.19	-0.73	-0.7	-1.0	-0.5	0.34
Emma	1	4.60	4.6	4.3	5.0	0.44	5.13	5.0	5.0	5.3	0.32	-0.53	-0.6	-0.7	-0.4	0.25
Freya	1	5.03	5.0	4.6	5.5	0.59	5.77	5.7	5.5	6.1	0.38	-0.75	-0.7	-1.0	-0.6	0.26
Honey	3	4.23	4.1	3.7	4.8	0.74	6.85	6.8	6.4	7.4	0.82	-2.63	-2.8	-3.7	-1.6	1.50
Kaito	3	4.03	4.0	3.9	4.2	0.21	6.07	6.1	5.7	6.5	0.46	-2.05	-2.1	-2.6	-1.6	0.58
Kimi	2	4.28	4.2	3.9	4.7	0.52	6.07	6.2	5.4	6.8	0.80	-1.80	-1.8	-2.9	-0.7	1.27
Lea/Emma	2	4.65	4.8	4.5	4.9	0.31	5.93	6.0	5.6	6.3	0.51	-1.27	-1.4	-1.9	-0.7	0.68
Lili	1	4.05	4.1	3.8	4.3	0.31	5.03	5.1	4.8	5.3	0.34	-0.97	-0.9	-1.2	-0.8	0.30
Lou	3	3.95	4.0	3.9	4.1	0.13	6.18	6.3	5.7	6.7	0.74	-2.23	-2.3	-2.6	-1.9	0.62
Luna	2	4.28	4.3	4.2	4.4	0.10	5.70	5.7	5.3	6.1	0.58	-1.42	-1.5	-1.8	-1.1	0.54
Mala	1	4.83	4.9	4.7	5.0	0.25	4.95	5.0	4.8	5.1	0.21	-0.13	-0.2	-0.3	0.0	0.17
Manja	1	4.70	5.0	4.4	5.1	0.61	5.55	5.5	5.1	6.0	0.70	-0.85	-0.8	-1.2	-0.5	0.44
Marley	3	4.78	4.7	4.5	5.1	0.41	9.35	9.7	9.0	9.8	0.70	-4.58	-4.8	-5.3	-3.9	0.92
Molly	1	4.85	4.9	4.6	5.2	0.39	5.58	5.5	5.2	6.0	0.48	-0.73	-0.8	-0.9	-0.6	0.17
Nele	1	4.45	4.5	4.3	4.6	0.17	5.57	5.6	5.5	5.7	0.17	-1.13	-1.1	-1.4	-0.9	0.30
Nina	2	4.28	4.2	3.9	4.7	0.52	6.20	6.3	5.5	6.9	0.83	-1.92	-1.9	-3.1	-0.8	1.30
Odin	1	4.25	4.4	4.1	4.4	0.24	4.55	4.6	4.4	4.8	0.24	-0.30	-0.4	-0.4	-0.2	0.14
Raffaele	3	4.55	4.6	4.0	5.2	0.70	6.45	6.4	5.6	7.4	1.14	-1.90	-1.5	-2.9	-0.9	1.47
Raiya	3	3.98	4.0	4.0	4.0	0.05	7.40	7.5	6.7	8.2	1.04	-3.43	-3.5	-4.2	-2.7	1.00
Tamina	3	4.78	4.7	4.5	5.1	0.41	7.93	8.3	7.6	8.3	0.68	-3.15	-3.4	-3.9	-2.5	0.89
Thorin	2	5.05	5.1	4.9	5.2	0.25	5.85	5.8	5.6	6.2	0.37	-0.80	-0.9	-1.0	-0.7	0.27
Wantje	1	4.30	4.3	4.3	4.3	0.00	4.85	4.8	4.8	5.0	0.17	-0.55	-0.5	-0.7	-0.5	0.17
Zlata	2	4.57	4.6	4.5	4.7	0.17	5.38	5.2	5.1	5.7	0.57	-0.80	-0.6	-1.2	-0.4	0.57
total		4.43	4.4	4.2	4.7	0.43	6.01	5.7	5.2	6.6	1.21	-1.58	-1.1	-2.3	-0.7	1.29

Using randomization tests for one mean difference also a significant difference between owner and dog speed during the walk can be shown **Fig. R1.3.4**. The mean speed of owners is 4.4 +/- 0.4 km/h compared to 6.0 +/- 1.2 km/h of the dogs. The difference between owner and dog speed is statistically significant ($p < 0.001$; Wilcoxon Test). Dogs travel significantly faster than their owners.

Altogether 50 % of the owners show a walking speed of less than 4.4 km/h; 50 % of the dogs have a walking speed of less than 5.7 km/h. A quarter of the owner has a travelling speed of less than 4.2 km/h, the lower quartile of the dogs shows a speed of 5.2 km/h. The higher quartile of the owner lies at a travelling speed of 4.7 km/h; the higher quartile of the dogs travelling speed is 6.6 km/h. The total median speed difference amounts to -1.1 km/h; mean 1.6 km/h.

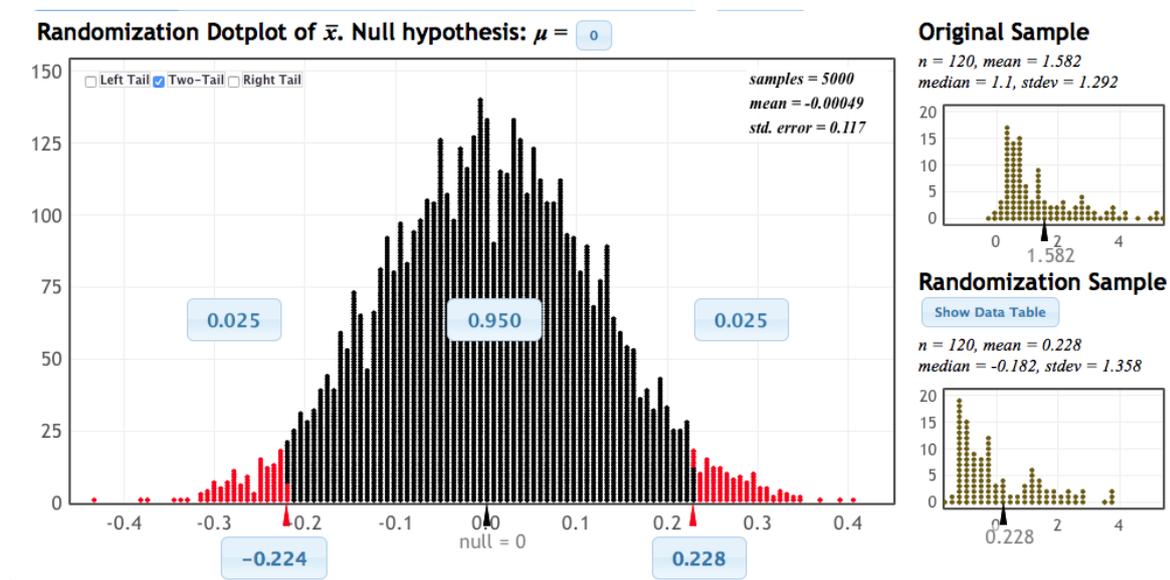


Fig. R1.3.4: Randomization test for one mean difference: dog / owner travelling speed.

For the randomization test 5000 replicate samples with a sample size of 120 are generated under the assumption that the null hypothesis (speed differences between owner and dog is zero) is true. No assumption about the distributions is made (i.e. no normal distribution is assumed). The estimate of the p-value is defined as the fraction of replicates with at least a test value as large as that of the observed data. Looking at the dog – owner travelling a speed of 1.58 km/h was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the null hypothesis of no effect are -0.224 and 0.228 km/h. The observed value is outside these limits, therefore $p > 0.05$, the null hypothesis could be rejected. A significant difference between owner and dog speed during the walk can be shown ($p < 0.001$).

1.3.5 Correlation of 2/3 dogs of the same owner: Time, distance, speed.

To determine whether dogs belonging to one owner displayed similar behaviour with respect to time and distance travelled, as well as speed patterns potential correlations were determined. For the dog-owner dyads/triads see **Table M1.2.1**. Two owners walked with 3 dogs. Here all pairwise correlations are considered, i.e. dog 1 vs. dog 2, dog 2 vs. dog 3 and dog 1 vs. dog 3. Ten Teams were established see overview **Table R1.4.3.1**.

1.3.5.1 Correlations Time: owner and dog 1, dog 2 and dog 3

Correlations are assessed reading the walking time of the owner and his/her dogs as a team. Significant linear correlations can be shown between the duration of the travelling round, difference in walking time (owner/dog), and time inbound and time outbound of the dogs of one owner.

Table R1.4.1.1 Spearman Correlation between time measures of dog 1 and dog 2 / 3 of one owner.

		Dog 1 - Dog 2	Dog 1- Dog 3	Dog 2- Dog 3
Time_20 m_away	r	0.529	0.725	0.708
	p	<0.001	0.042	0.050
	n	40	8	8
Duration of dogs traveling round in min	r	0.703	0.455	0.072
	p	<0.001	0.257	0.866
	n	40	8	8
Difference_walking_time	r	0.471	-0.568	0.087
	p	0.002	0.142	0.854
	n	39	8	7
Time_inbound	r	0.531	.	.
	p	0.002	.	.
	n	32	4	4
Time_outbound	r	0.528	-0.400	0.000
	p	0.002	0.600	1.000
	n	32	4	4

Significant linear correlations can be shown between the duration of the travelling round, difference in walking time (owner/dog), time inbound and time outbound. All correlations are positive, I.e. the longer one dog of an owner runs, the longer the second dog of the owner runs. Only mean and SD are reported to compare dogs of one owner. Median and Quartiles can be seen in **Table R1.2.2** and **Table R2.4.1**. For walking time details see **Table R1.1.1**; **Fig. R1.2.1**. For time outbound vs. inbound travelling round >20 m each dog in meter see **Table R2.6.1**. For correlations between times measures of dog 1 and 2/3 of one owner see **Table R1.4.1.1**.

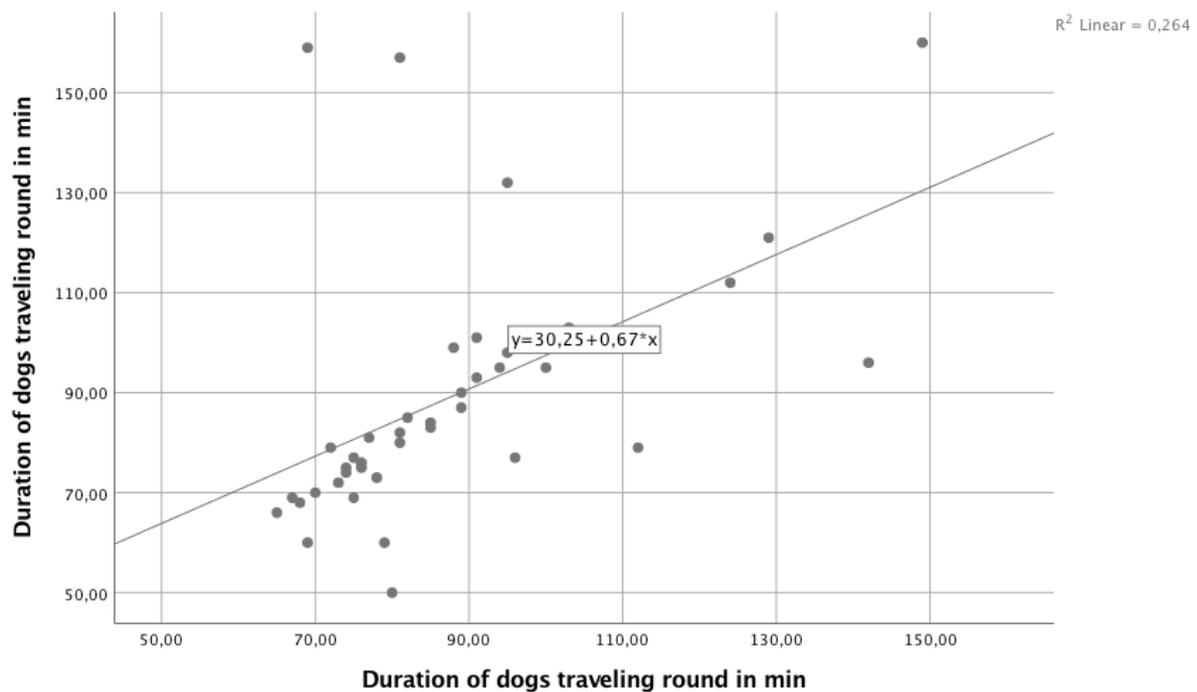


Fig. R1.4.1.1 Correlation between the duration of dogs travelling round in minutes, dog 1 and dog2/3.

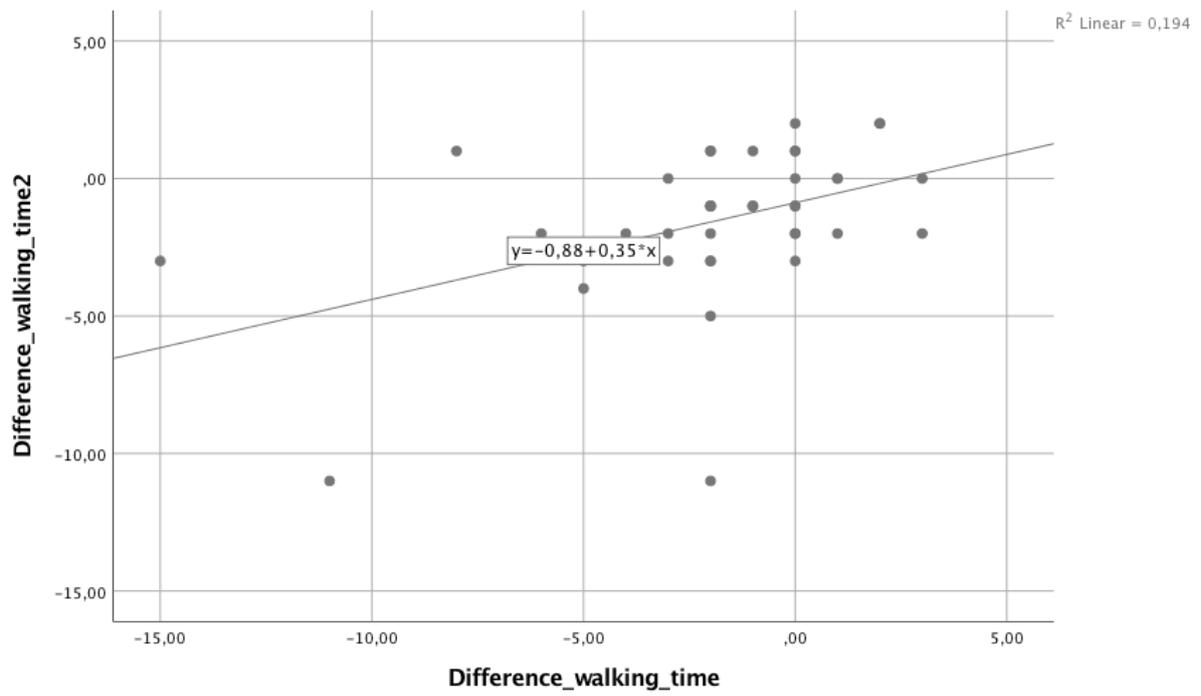


Fig. R1.4.1.2 Correlation between the differences in walking time (owner/dog)

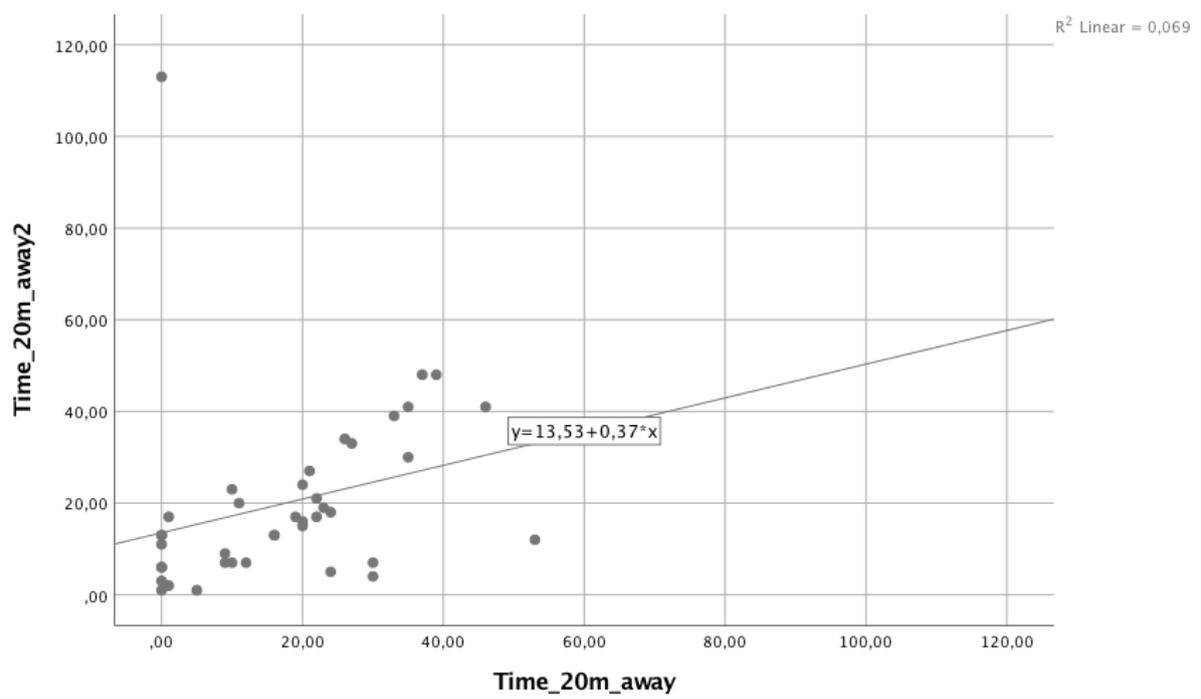


Fig. R1.4.1.3 Correlation between the time away from owner runs >20 m, dog 1 and dog 2/3.

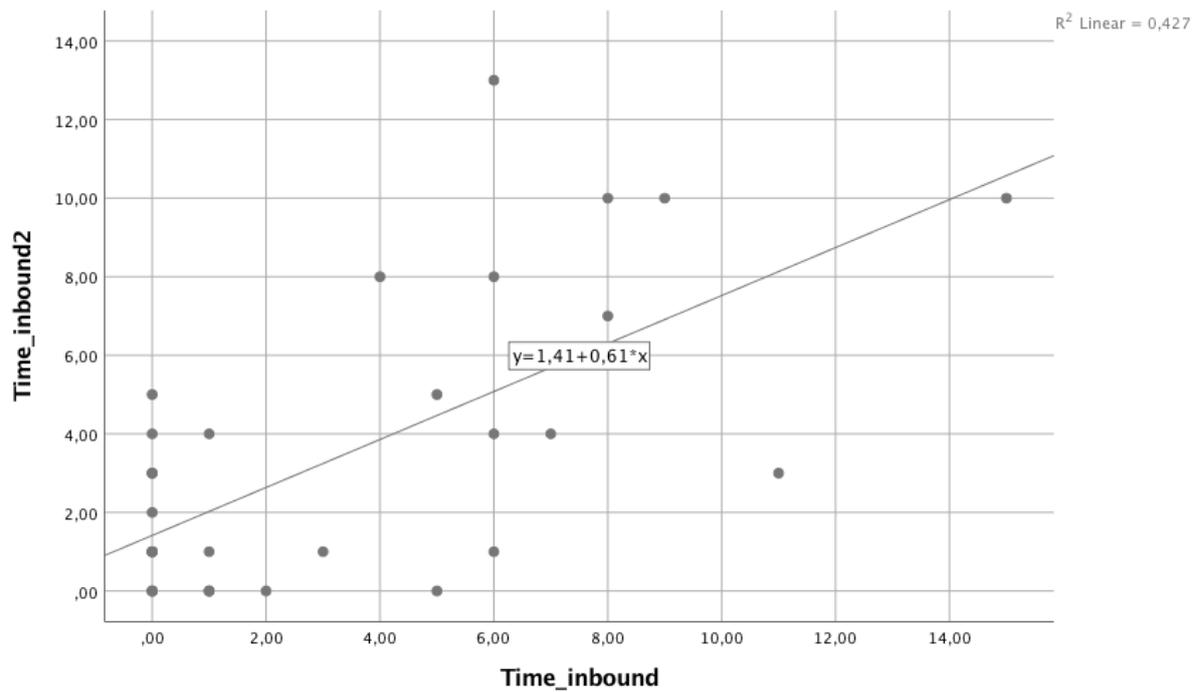


Fig. R1.4.1.4 Correlation between the time inbound to owner, runs >20 m, dog 1 and dog 2/3.

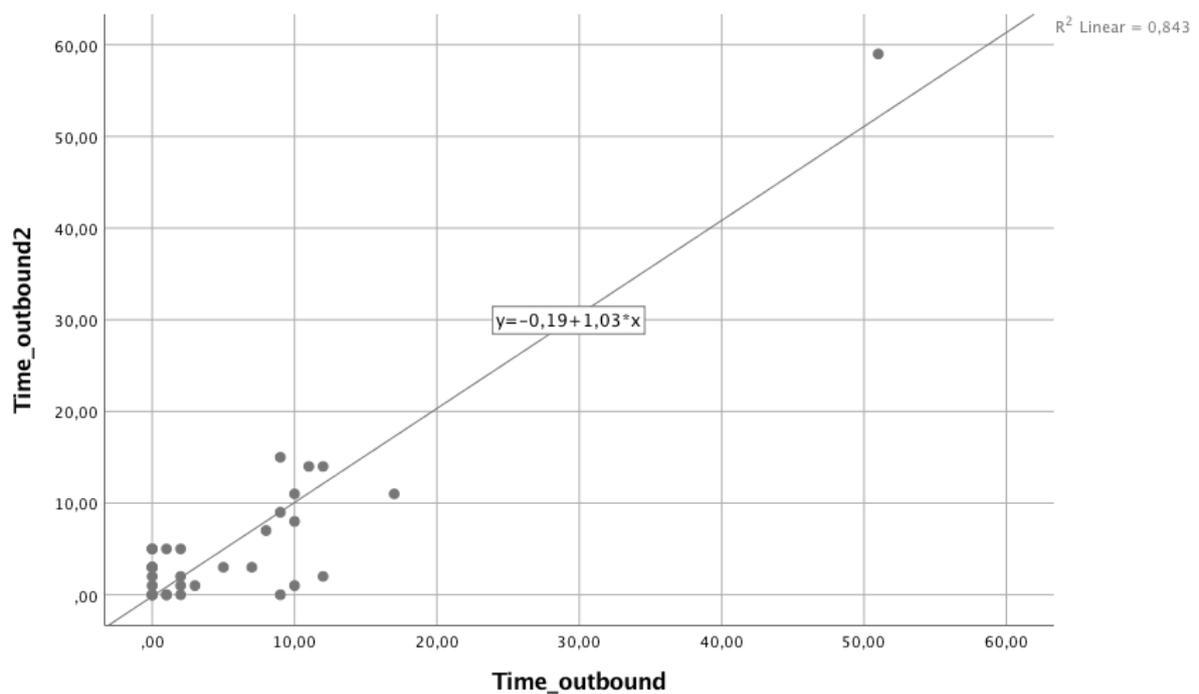


Fig. R1.4.1.5 Correlation between the time outbound from owner runs >20 m, dog 1 and dog 2/3.

The correlations are visualized using Scatterplots. The x-axis shows values of dog 1, the y-axis parameters of dog 2 or 3. High values of one dog are correlated with high values of the other dog. In every team a leader or independent dog with a more extensive time range can be observed. The regression lines drawn in the scatterplots show linear inter-

polation below the bisecting line. This can also be obtained looking at the regression coefficient beta shown in the middle of the Scatterplot (see **Fig. R1.4.1.1 - R1.4.1.5**).

1.3.5.2 Correlations Distance measures of owner and dog 1, dog 2 and dog 3

Correlations were also assessed with respect to total distance of the walks; total runs >20 m; maximum distance of the runs as well as the distance inbound and outbound travelled by the dogs. Significant linear correlations for all distance measures can be seen between two/three dogs of one owner.

Table R1.4.2.1 Spearman Correlation between distances measures of dog 1 and dog 2/3 of one owner.

		dog 1- dog2	dog 1- dog3	dog 2- dog 3
total distance dog walk in m	r	0.444	0.599	-0.214
	p	0.004	0.117	0.610
	n	40	8	8
total runs>20 m in m	r	0.544	0.543	0.657
	p	<0.001	0.266	0.156
	n	40	6	6
Max distance of run in m	r	0.277	0.695	0.419
	p	0.084	0.056	0.301
	n	40	8	8
Distance outbound in m	r	0.442	-0.800	0.000
	p	0.013	0.200	1.000
	n	31	4	4
Distance inbound in m	r	0.394	-0.800	-1.000
	p	0.028	0.200	.
	n	31	4	4

Only mean and SD are reported to compare dogs of one owner. Median and Quartiles can be seen in **Table R1.2.1** and **Table R1.2.2**; **Fig. R1.2.1**. For walking time details see **Table R1.1.1**; **Fig. R1.2.1**. For distance outbound vs. inbound travelling round >20 m each dog in meter see **Table R2.5.1**; **Fig. R2.5.1**. **Table R2.3.3** shows the maximum distance of runs>20 m; **Table R2.3.2** shows for each dog the minimum & maximum distance of runs>20 m.

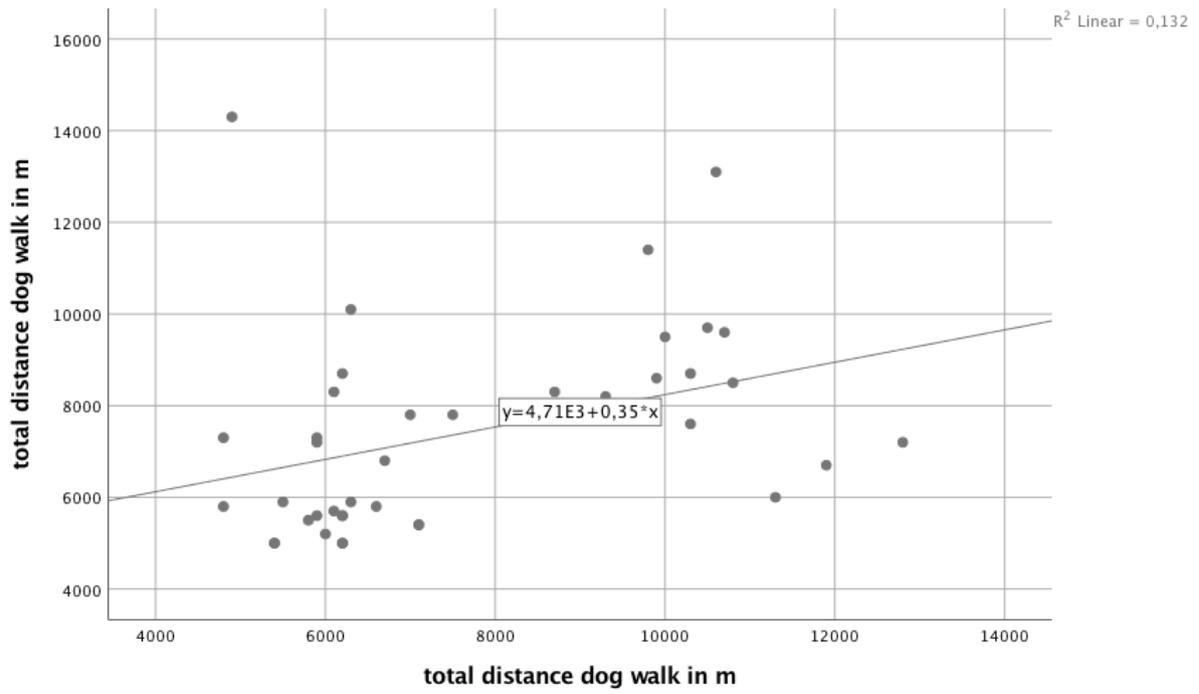


Fig. R1.4.2.1: Correlation total distance of runs >20 m dog 1 and dog 2/3 of one owner.

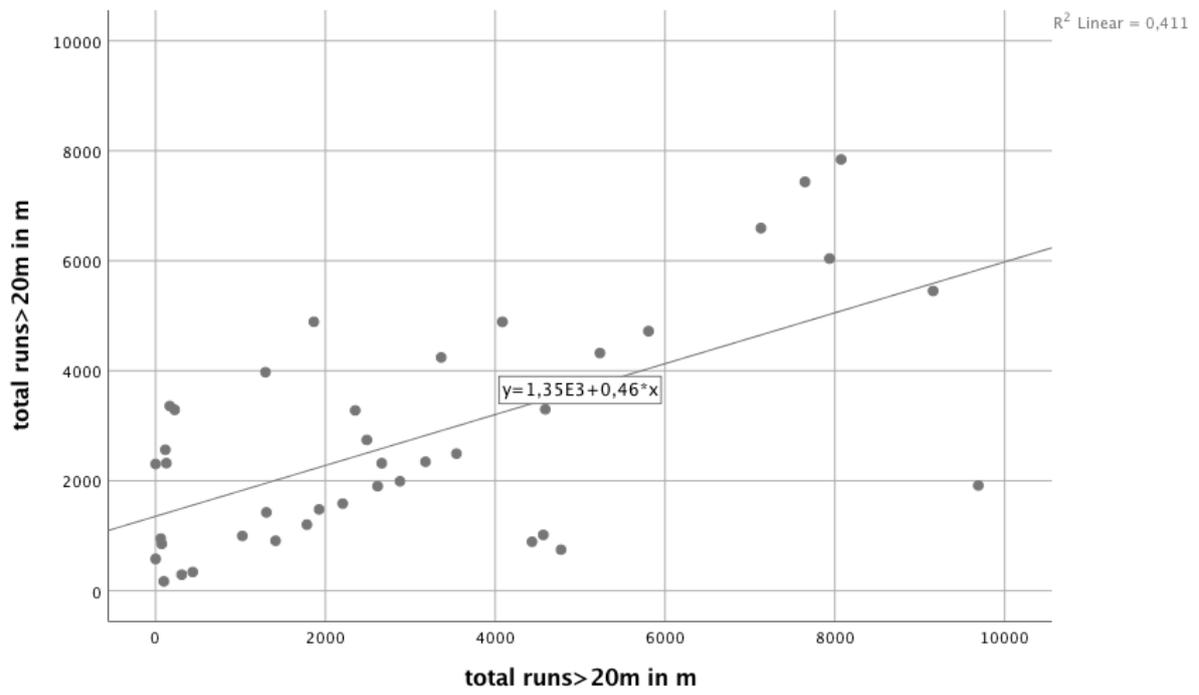


Fig. R1.4.2.2: Correlation total runs >20 m dog 1 and dog 2/3 of one owner.

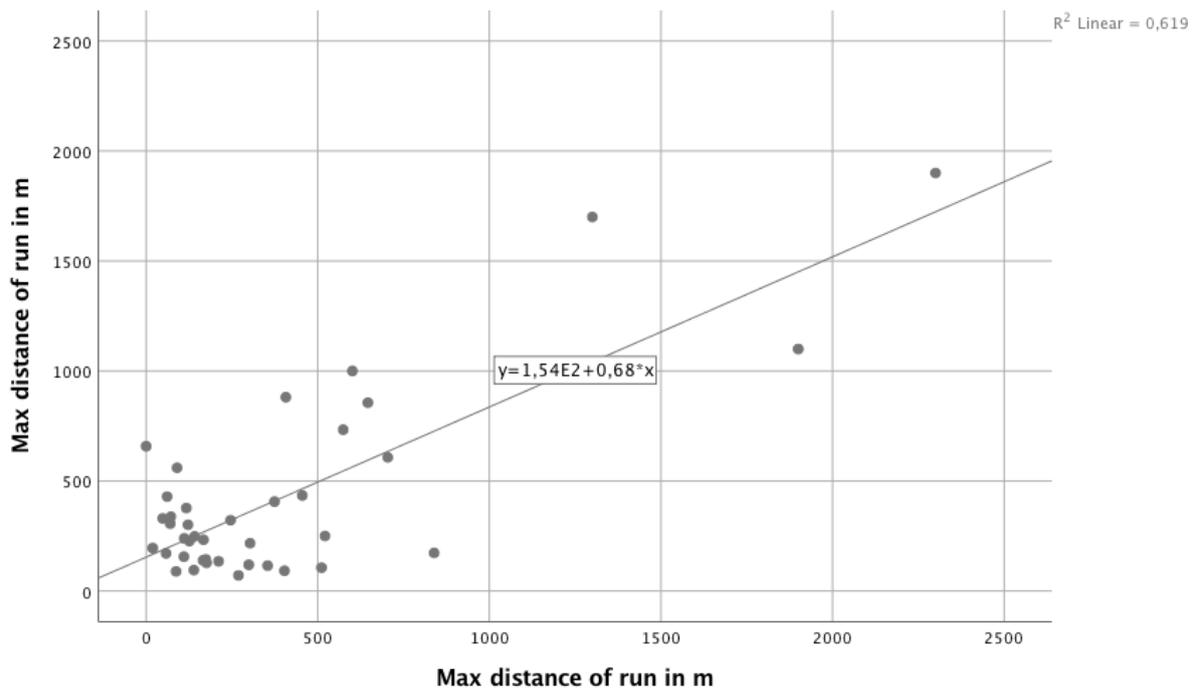


Fig. R1.4.2.3: Correlation maximum distance of runs >20 m dog 1 and dog 2/3 of one owner.

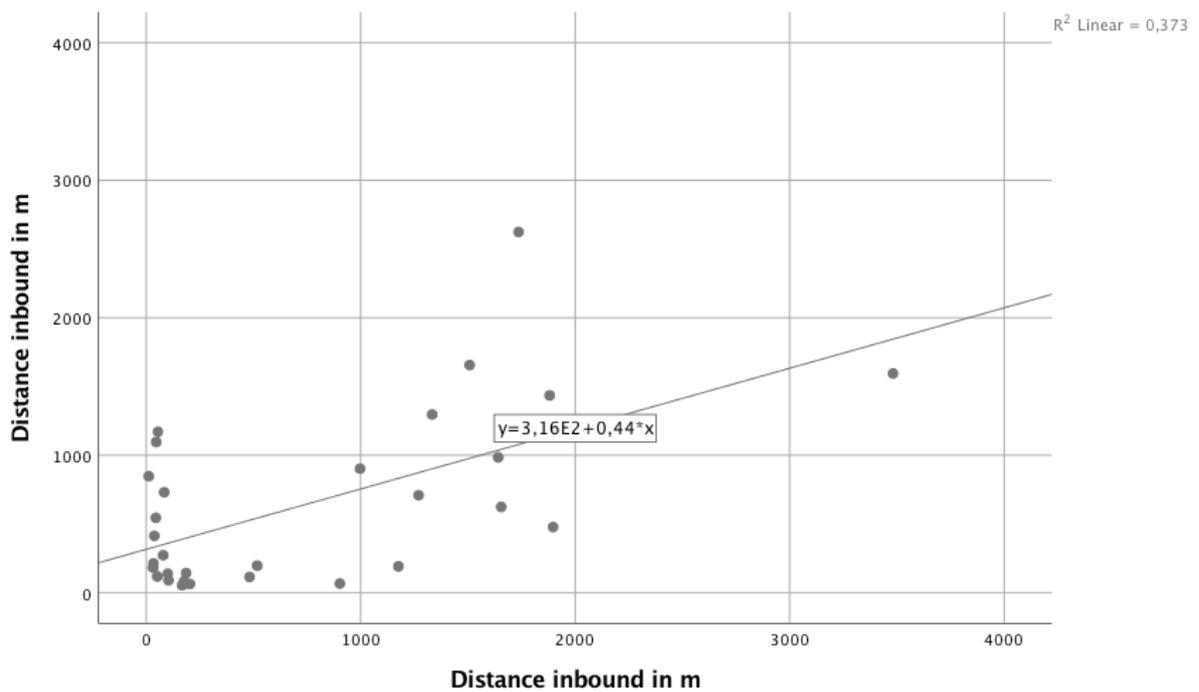


Fig. R1.4.2.4: Correlation distance inbound in meter dog 1 and dog 2/3 of one owner.

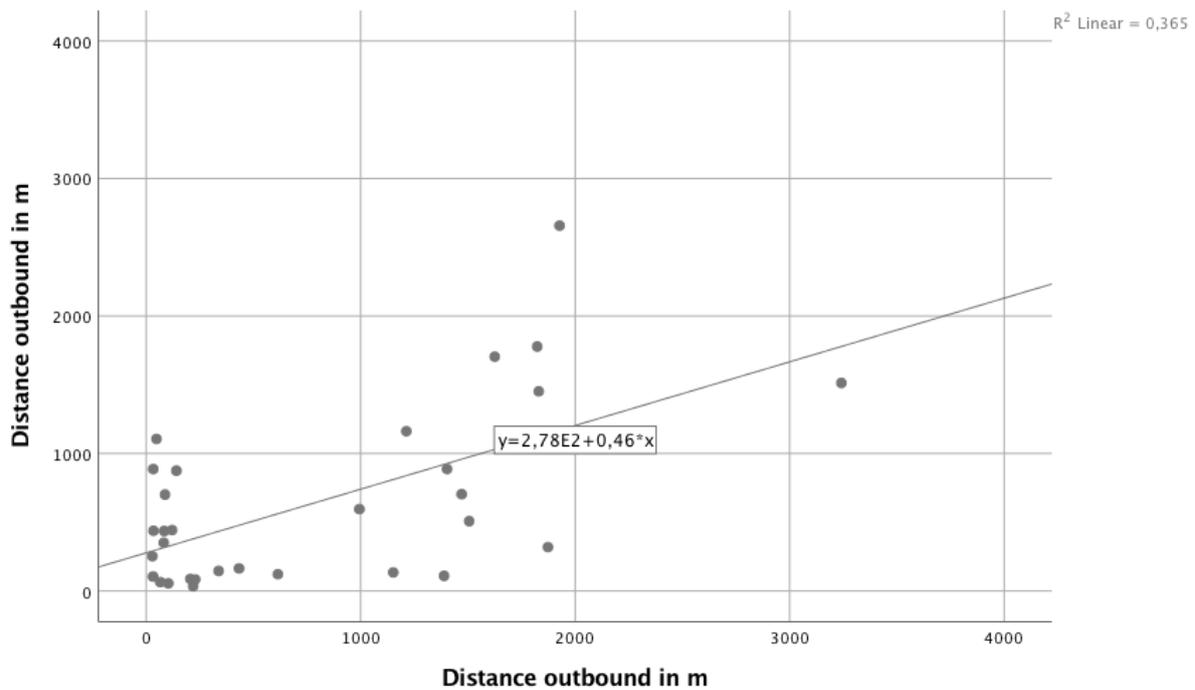


Fig. R1.4.2.5: Correlation distance outbound in meter dog 1 and dog 2/3 of one owner.

Significant linear correlations for all distance measures can be seen between two/three dogs of one owner. All correlations are positive, indicating that higher values of one dog are correlated with higher values of the other dog. Correlations are visualized using Scatterplots. Values of dog 1 are shown at the x-axis, values of dog 2/3 are shown at the y-axis. Linear interpolation line is drawn and the corresponding regression equation is shown in the middle of the diagram. The regression coefficients are below 1, so the slope is below the bisecting line. This means that the measurements of one of the dogs are higher than that of the other dog.

1.3.6 Correlation speed of dogs of one owner

Correlations are assessed with regard to the average speed of the owner and his/her dogs. Ten Teams were established.

Table R1.4.3.1 Average speed of owner and his/her dogs resulting from four walks (n=4).

Team		average speed in km/h		95 % confidence interval (Bonferroni corrected *)	
		mean	SD	Lower limit	Upper limit
1	Amanda	5.13	0.22	4.88	5.38
	Wantje	4.85	0.17	4.66	5.04
	owner	4.3	0.01	4.30	4.30
2	Balou	7.75	1.18	6.42	9.08
	Lilli	5.03	0.34	4.65	5.41
	owner	4.08	0.34	3.70	4.46
3	Balou_RR	5.23	0.24	4.96	5.50
	Luna	5.7	0.58	5.05	6.35
	owner	4.27	0.08	4.18	4.36
4	Amy	6.08	0.31	5.73	6.43
	Nele	5.57	0.17	5.38	5.76
	owner	4.45	0.17	4.26	4.64
5	Dr. Pepper	5.03	0.19	4.82	5.24
	Raiya	7.4	1.04	6.23	8.57
	owner	4.14	0.105	4.02	4.26
6	Kimi	6.07	0.80	5.17	6.97
	Nina	6.2	0.83	5.27	7.13
	owner	4.28	0.52	3.70	4.87
7	Manja	5.55	0.70	4.76	6.34
	Raffaele	6.45	1.14	5.17	7.73
	owner	4.63	0.66	3.89	5.37
8	Marley	9.35	0.70	8.56	10.14
	Tamina	7.93	0.68	7.17	8.70
	owner	4.78	0.41	4.32	5.24

Team		average speed in km/h		95 % confidence interval (Bonferroni corrected *)	
		mean	SD	Lower limit	Upper limit
9	Bill	7.77	0.80	6.87	8.67
	Kaito	6.07	0.46	5.55	6.59
	Lou	6.18	0.74	5.35	7.01
	owner	4.05	0.21	3.81	4.29
10	Emma	5.13	0.32	4.77	5.49
	Zlata	5.38	0.57	4.74	6.02
	Mala	4.95	0.21	4.71	5.19
	owner	4.67	0.29	4.34	5.00
total	dog 1 total	6.31	1.53	4.59	8.03
	dog 2 total	6.06	1.12	4.80	7.32
	dog 3 total	5.56	0.83	4.63	6.49
	owner total	4.37	0.42	3.90	4.84

There are four speed measures, one for each walk and each dog/owner. No tests could be performed for $n=4$ in each group. 95 % confidence intervals for mean speed are calculated. Not overlapping confidence intervals indicate significant differences at 5 % level of significance. Using confidence intervals Bonferroni correction was applied for accounting for multiple testing. The average speed of dogs is higher than the average speed of the corresponding owner. Only dogs of Team 10 (Emma, Zlata and Mala) and Manja (Team 7) show overlapping confidence intervals with their owner. There are teams of dogs with similar average speed (Teams 1, 3, 6 and 9) but also teams with large speed differences (Teams 2 and 5), see **Fig. R1.4.3.1**.

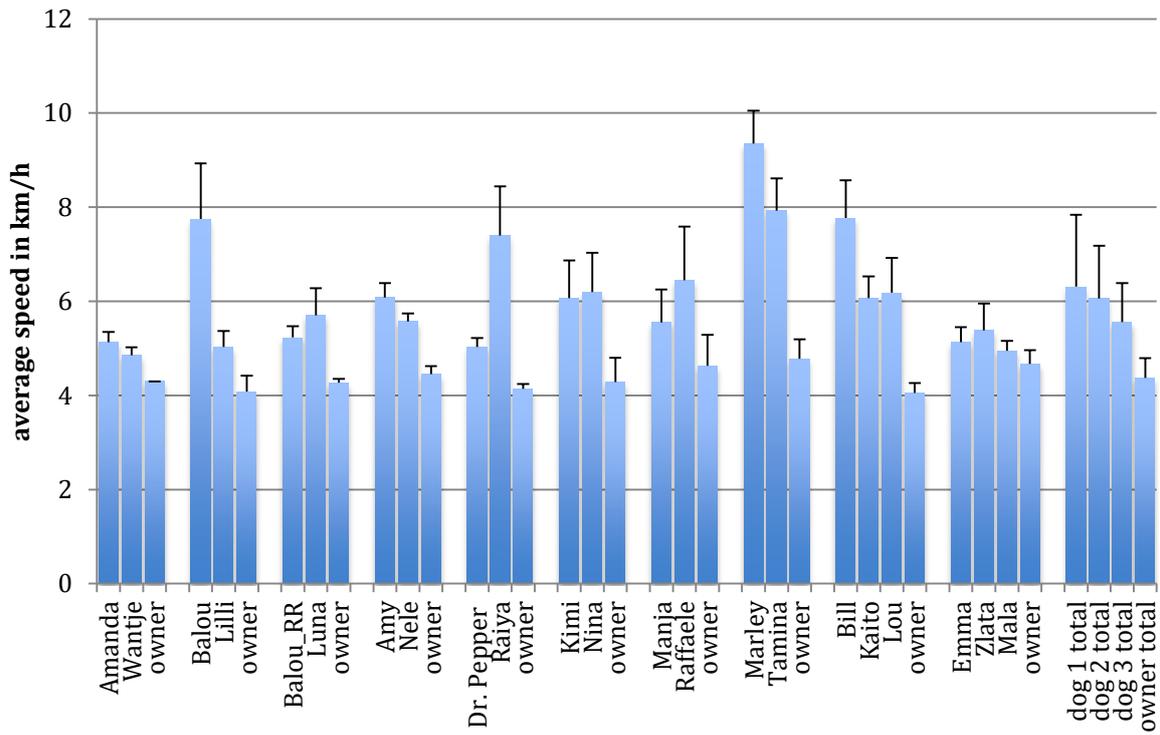


Fig. R1.4.3.1: Average speed in km/h between teams: owner and his/her dogs.

1.4 Discussion

1.4.1 Domestication, cooperation, communication

Different scenarios have been proposed for the early stages of dog domestication, for instance the human-selection and the self-domestication hypothesis. The 'human-selection' hypothesis (or 'directed pathway', Larson & Fuller, 2014) postulates that wolf pups were actively adopted and only the most docile animals were selected for reproduction (Clutton-Brock, 1999). The focus lay on specific traits such as increased attention to humans (Miklósi et al., 2003); acceptance of humans as social partners (Gácsi et al., 2009); reduced fear and aggression (Hare, 2017); a tamer temperament (Hare et al., 2012) and human-directed social competence (Miklósi & Topál, 2013), qualities believed to lead to increased cooperativeness and related cognitive skills. Circumstantial evidence for this scenario comes from archaeological and anthropological studies which indicate that adoption and taming of various Canid species by indigenous people happened prior to the arrival of domestic dogs (Stahl, 2013), proposing this may have occurred likewise with wolves.

Differently, the 'self-domestication' or 'commensal pathway' hypothesis postulates a two-stage process. In the first stage, dogs' ancestors started exploiting a new feeding niche provided by humans (e.g. waste) reducing their reliance on conspecific group hunting, and increasing their dependence on human generated food (Larson & Fuller, 2014). Selective pressures may have influenced animal's characteristics even at this stage with less fearful individuals being more likely to approach human settlements, thereby gaining an advantage in the exploitation of the new niche compared to more fearful conspecifics (Hare, 2017). Evidence that these individuals were able to attain and maintain distinct characteristics despite continued gene flow with wolves comes from studies of two wolf populations in North America (Stronen et al., 2014). At the second stage humans started a direct selection by choosing animals with the desired characteristics (Marshall-Pescini et al., 2017).

Another hypotheses, the 'emotional-reactivity hypothesis' proposes that selection on social-emotional systems could have provided an initial catalyst for an extensive social cognitive evolution in dogs (Hare, 2007; Hare & Tomasello 2005a, b) and based on their intensive socialization in the human environment (Scott & Fuller, 1965) the dogs individual experiences further amplified these evolutionary changes leading to additional adaptations to humans (Udell et al., 2009). Hare & Tomasello (2005a) postulated

that selection for a tamer temperament and reduced fear and aggression was the reason for a higher success of dogs in cooperative and communicative interactions with humans in comparison to wolves (but see Range et al., 2019). This hypothesis has been extended to suggest that during domestication dogs became less aggressive and more tolerant than wolves not just toward humans but also toward conspecifics (Hare et al., 2012), which has recently been disputed (Marshall-Pescini et al., 2017; Range et al., 2019) with divergent results.

The Canine Cooperation Hypothesis (Range & Virányi, 2015; Range et al., 2019) states that dog-human cooperation evolved on the basis of wolf-wolf cooperation and in contrast to many domestication hypotheses, it proposes that dogs did not need to be selected for a general increase in their social attentiveness and tolerance.

Today the majority of domesticated dogs live in a human-dominated niche, even if they are considered feral or free roaming dogs, which constitute approximately 80 % of the global dog population (Hughes & Macdonald, 2013; Lord et al., 2013). Pet dogs therefore represent only a fractional part of the entire dog population and the question may be raised whether e.g. adopted street dogs display altered levels of bonding/communication/behavior based on their different social ecology. Out of the 30 dogs assessed herein only 11 lived with their owners since puppyhood, 19 were adopted from organizations or shelters, of which five may have lived on the street (Emma and Mala: one owner; Kaito, Lou, Bill: one owner, see **Table M1.2.1**). To assess the social competence and potential differences would require a study of various populations of dogs with diverse social ecology conditions. Herein no differentiation was made.

Pet dogs growing up in the human environment generally have ample learning opportunities of how to interact and communicate with humans. These experiences may enhance their cognitive skills because they live in a very complex social environment, an ontogenetic process called “enculturation” (Call & Tomasello, 1996). Interspecies interaction and communication may have impacted on attentiveness toward humans, and in turn their social tasks performance with humans (see also Miklósi et al., 2016; Topál et al., 2009). Studies postulate an enhancing effect of domestication on the social skills of dogs in cooperative–communicative tasks (Hare & Tomasello, 2005a; Miklósi et al., 2016) like a social walk with their owner, impacting on exploration behavior like synchronicity (see also, discussion 1.4.2). It has been proposed that by means of positive (both evolutionary and ontogenetic) feedback processes, dogs developed increased social attentiveness compared to wolves and therefore are able to accomplish more com-

plex forms of dog-human communication and cooperation than wolves (Miklósi et al., 2016, but see Range et al., 2019). This is based on the assumption that dogs have evolved some genetic predispositions permitting them to develop skills shared with humans (Hare et al., 2002; Miklósi & Topál, 2013).

Accordingly, it has been suggested that domestication has equipped dogs with two abilities prerequisite for cooperation—namely social tolerance and social attentiveness, enabling them to adjust their behavior to that of their social partners (Ostojic & Clayton, 2014). Social attentiveness, that is, paying sufficient attention to one's partners in order to adjust behavior and thus to cooperate (Range & Virányi 2015) would form the basis of attending to their owner whilst walking, i.e. the dogs had to pay attention to movement and location (and speed) of the owner in order to find him/her again. Otherwise the dog could just have used the opportunity to explore without returning to the owner, or to walk with a different person or conspecific, or to return to a stationary location like the car, which they did not **Table R1.0**.

Dogs have proven successful in several tasks that are thought to require high attention toward conspecifics and humans, such as social learning (Range et al., 2007, 2011) social referencing (Merola et al., 2012a,b), communication (Kaminski et al., 2012) and cooperation (Ostojic & Clayton, 2014), forming the foundation for this study. High attention toward conspecifics and humans as well as social referencing can arguably be shown for the dog-owner dyads (see **Table M1.2.1**): Significant linear correlations were found between the duration of the travelling round, difference in walking time (owner/dog), time inbound and time outbound of the dogs of one owner, **Table R1.4.1.1**; **Table R1.4.3.1**. However, great intraspecific differences could be perceived with respect to time and distance travelled **Table R1.2.1**; **Table R1.2.2**; **Fig. R1.2.1**. A quarter of the dog-owner walks indicated an over all distance of less than 400 m difference between dog and owner, the dogs being close to their owner during the entire walk and adjusting their walking speed accordingly. Half of the walks showed a difference between dog and owner over all travelled distance of less than 1000 m, see **Table R1.2.1**. Only 25 % of the walks indicated a difference of more than 2300 m between dog and owner over all distance travelled, which corresponds to a 43 % increase, see **Table R1.2.1** and **Fig. R1.2.1**.

Thus the hypothesis that the length and speed of and on the walks differs significantly between owner and dog based on physiological and biomechanical factors (Denny, 2008; Minetti, 2000) as well as being influenced by motivational factors, i.e. the dogs'

interest to explore can be confirmed. Dogs travel longer distances and at higher speed on the walks than their owner.

Based on the large intraspecific differences between the dogs three groups were established to illustrate the variances in more detail: Group 1 dogs stayed within a radius of 150 m of the owners at all runs > 20 m; Group 2 dogs stayed within a radius of >150 m and <350 m of the owner for all runs >20 m; and Group 3 dogs went beyond the radius of 350 m of the owner for at least one run >20 m. Dogs of all three groups, however, despite travelling longer distances than their owners, see **Table R1.2.1**, returned reliably to their owner.

Therefore the hypothesis that free ranging, off leash pet dogs have high motivation based on their strong bonding to return to their owner, regardless of breed, area or external stimuli, whether in known or unknown areas, even if not called, can be confirmed.

The dogs did display social attentiveness and cohesion, the variability of intraspecific exploration behavior was large however.

1.4.1.1 Owner-dog Communication

One component to the success and maintenance of an interspecific interactive social system integrating social attentiveness and cohesion is a communication system capable of conveying multiple information in a variety of settings and through a variety of channels.

For example, the selection of dogs to specialize for different tasks (like herding, hunting, guarding) may affect their exploration behavior by modifying their sensory and neurological capacities (Gácsi et al., 2009b), as well as their communicative abilities (Feddersen-Petersen, 2000). It has been proposed that by relying on food provided by humans (Axelsson et al., 2013), the selective pressure to be quiet (in order not to scare away game) for instance was relaxed resulting in vocal exaggeration (Cohen & Fox, 1976). Herein different breeds and “specialists” participated; see **Table R2.12.1** for overview, which may have resulted in behavioral variances.

Communication takes place intraspecifically between the dogs, as well as interspecifically between dog and owner (Elgier et al., 2009). Dogs engage in visual, tactile, auditory, vocal and olfactory communication as well as through chemosignals. Living in close contact with humans for at least 30,000 years (Thalmann et al., 2013), dogs have developed skills enabling them to communicate with humans (Kaminski & Nitzschner, 2013). Here in particular, the co-habitation process and interspecific attachment led to

modified cross-species communicative abilities, the result of which is to perceive and understand the other species' signals and correctly respond to them (Worsley & O'Hara, 2018). This, of course, was one base on which to conduct this study as I had to rely on cooperation through communication of the dog- owner dyad.

Dogs arguably evolved into a synanthropic species via the domestication process by natural and artificial selection and co-evolution with humans thereby shaping the dog's cognitive processes accordingly and favoring behaviors aimed to optimize their adaptation to various anthropogenic, e.g. our urban, environments. Dogs are able to utilize different behavioral strategies in response to human communicative cues through different sensory channels. They are being responsive to both verbal and non-verbal vocal cues (Mills, 2005). Dogs are able to recognize up to several hundred words (Kaminski et al., 2004) with specific neural mechanisms that analyze and integrate word meaning and intonation (Andics et al., 2016). They are sensitive to different verbal and gestural signals of humans (D'Aniello et al., 2016, 2017; Scandurra et al., 2017), and are able to perceive human emotions via chemosignals (D'Aniello et al., 2018; Siniscalchi et al., 2016). Therefore, even though the owner was not to call or signal to the dog numerous alternative channels were provided during the walks for interspecies communication.

Thus, I will discuss the visual, tactile, auditory, vocal and olfactory communication channels, according to valence, in more or less detail, as pertains to findings herein.

1.4.1.2 Visual communication

Dogs have a flexible behavioral repertoire when communicating with humans, utilizing the same signals used in intraspecific interactions, which however often carry a different meaning interspecifically (e.g., eye contact, Siniscalchi et al., 2018; Topál et al., 2014). One key element thought to have been modulated during domestication is dogs' propensity and inclination to gaze at humans. This propensity has been shown to differ between breed-groups (Konno et al., 2016), sex (D'Aniello et al., 2016; Duranton et al., 2016), to have a genetic basis (Pearsson et al., 2015) and to be influenced by life experience (Lazzaroni et al., 2019).

Dogs' ability to use visual information from humans is multifaceted: dogs are predisposed to follow overt human communicative gestures to locate resources (Hare & Tomasello, 2005b; Virányi et al., 2008) and to refine this ability through experience (Udell et al., 2010). Witnessing human demonstrators influences dogs' performance in detour (Pongrácz et al., 2001) and manipulative tasks (Miller et al., 2009) and dogs can

learn to imitate some human motor patterns (Topál et al., 2006; Fugazza & Miklósi, 2014). Dogs may also determine humans' attentional states by looking at them and are able to modify their behavior accordingly: they prefer to obey and beg from attentive rather than non-attentive humans (Gácsi et al., 2004; Virányi et al., 2004) and can take advantage of inattention, for instance by eating forbidden pieces of food (Call et al., 2003; Schwab & Huber, 2006).

Furthermore, dogs will not pay equal attention to any person and studies have shown that the dogs' owner receive higher attention than an unfamiliar person during the same activity (Range et al., 2009). An increase in attention levels requires a close relationship, rather than mere familiarity (Horn et al., 2013), which is one reason why only dog-owner teams were selected to participate. The owner's capacity to elicit particularly high levels of attention by their dogs becomes evident if the dog is presented simultaneously with 2 human "targets," a condition in which dogs will look at their owner with much longer gazes than at a stranger (Mongillo et al., 2010).

Several studies investigating dogs' comprehension of human visual signals showed that dogs comprehend human visual communication (Kaminski & Nitzschner, 2013), display a high sensitivity to human-given cues in an early stage of their development (Wallis et al., 2015), and that dogs follow spontaneously human body postures, gaze direction, and pointing gestures (Miklósi & Soproni, 2006; Soproni et al., 2001). Furthermore, they prefer to rely more on human gestures than auditory cues when the information received is contradictory, suggesting that gestures are more salient for them (D'Aniello et al., 2016). Therefore herein even without the verbal cues by the owner the dyads certainly communicated or exchanged information based on alternative channels in particular through visual cues like body posture or gaze direction, which could also be observed during the walks (and on the video material).

Gazing or looking back behavior could be observed extensively during the walks. Dogs, often just within a two second segment, gazed back at their owner e.g. when they saw an external stimulus (another person, horse, bicycle) or, if they went ahead of the owner, at a T-junction. 'Looking back' at humans has been considered an expression of dogs seeking assistance or guidance (Miklósi, 2016; Topál et al., 2014). Even the far travelling dogs would often stand elevated at temporal intervals gazing at the owner (to assess his or her walking direction?) and then continue to explore (here in particular the Group 3 dogs). Data reflects this in particular in dogs alternating between very fast as well as moderate or slower runs, **Fig. R2.13.1; Fig. R1.3.1 and Table R1.3.1**. The slow

elements often reflect brief gazing behavior. The slower dog displayed gazing behavior as well, due to their over all low speed this was more difficult to assess in the two second data segments, it can be observed on the videos however.

D'Aniello et al. (2016) proposed that female dogs rely more on visual signals than males because in the absence of visual signals, females made more mistakes than males, which could arguably lead to female dogs staying closer to their owner than males to be able to perceive the signals. Their study aimed to assess the preferred communicative channel between verbal and gestural messages and underlined a preference for visual cues in dogs (D'Aniello et al., 2016), however only Labrador and Golden Retrievers were tested and breed differences may certainly exist. Herein the (spayed female) Labradors also stayed close to their owner (Group 1 and 2 with travelling patterns of running ahead or following owner) and over all female dogs explored shorter distances than male dogs, see **Fig. R2.7.1, Fig. R2.7.2; Table R2.7.1; Fig. R2.7.5 Appendix.**

Studies proposed that female dogs are more visually focused towards their owners and seem to rely more on visual signals than males in their behavioral regulation (Scandurra et al., 2018) and in social cognition (Duranton et al., 2016; Mongillo et al., 2016; D'Aniello et al., 2016) and physical cognition (Duranton et al., 2015; Müller et al., 2011) tasks. Follow-up studies however, found no differences (Duranton et al., 2018; Müller et al., 2014).

In the present study, the difference between female and male dogs with respect to the distance explored of runs >20 m was significant ($p = 0.003$; Mann-Whitney-U Test). Male dogs explored significantly longer distances than females **Fig. R2.7.1, Fig. R2.7.2; Table R2.7.1; and Fig. R2.7.5 Appendix.**

However, some of the long ranging dogs (Group 3) displaying the largest exploration radius were females and differences were possibly due to the setting (outdoor with off-leash dogs). Additionally, nothing is known about sex effect on dogs' gazing behavior towards humans during spatial tasks, as the owner was providing mainly speed and directional information. Using such information from humans may be a core ability present in all dogs, independent of the sex of the individuals.

Studies show that dogs are adroit in interpreting the communicative intent of humans by understanding the ostensive-referential nature of specific signals, such as eye contact or directed-speech (Kaminski et al., 2012; Miklósi & Topál, 2013). Ostensive cues are a characteristic element of human communicative interactions expressing the sender's intention to initiate communication (Topál et al., 2014). The dogs' ability to

recognize these signals suggests a high level of adaptation to the human social environment (Miklósi & Topál, 2013). The flexible comprehension of human gestures allows dogs to discriminate which of the numerous human social behaviors displayed are directed to them (Topál et al., 2014), evaluate the same behavior differently according to the presence of an ostensive cue that precedes or accompanies it and ignoring unintended movements (Kaminski et al., 2012). During the walks dogs could have received signals through body posture, gestures or visual cues of the owner with respect to e.g. walking direction, thereby initializing for instance a change of direction leading arguably to spatial synchronicity of some owner-dog teams **Fig. R1.4.3.1; Table R1.4.3.1** and/or temporal synchrony **Table R1.4.1.1; Table R1.4.3.1**. Among human ostensive signals, eye contact represents the most important and efficient one (Kaminski et al., 2012) and whilst walking, of course owners could not be prohibited from looking at their dog and thereby communicating. This would only apply to the dogs who stayed close i.e. could establish visual contact with the owner, however (Group 1 dogs, **Table R1.2.1; Fig. R1.2.1**).

From an early age, dogs show a spontaneous tendency to gaze at human faces and to make eye contact (Virányi et al., 2008) and during the walks the dogs initiated eye contact during a wide array of situations, some dogs e.g. gazed at the owner prior to exploring (“may I go?”), perhaps due to the fact that vocal cues were missing to an even greater extent, in particular those dogs who were normally called very frequently by their owner (see owner questionnaire Part 3). The human-directed gaze has also been interpreted as a “request of help” (Topál et al., 2014). Thus, dogs use eye contact to communicate with humans differently from conspecifics (Handelman, 2012) and in interspecific communication gazing facilitates the beginning or maintenance of human-dog interaction (Vas et al., 2005). Miklósi & Topál (2013) argued that through the domestication process, dogs have modified the functional meaning of this behavioral pattern to adapt it to a cross-species communication, acquiring a more human-like communication mode. Furthermore, it has been maintained that the human-dog mutual gaze enhances the establishment of an affiliative relationship and a social bond by the same oxytocin-mediated effect as described for the mother-infant dyad (Nagasawa et al., 2015). The owners did establish eye contact as well and were at frequent intervals looking for/at the dog (alternatively at the GPS).

Mongillo et al. (2014) found that the use of a leash also had a significant impact on dogs' attention to their owners, with free running dogs looking at their owners more

frequently and with longer gazes than dogs kept on a leash. The reason may be that the constraints of the leash could limit the space available to dogs, requiring them to pay greater attention to potential obstacles than to their owners. Alternatively, being allowed off leash may increase the odds of meeting with challenging situations as it increases potential encounters and interactions with external stimuli (other dogs, prey etc.). In this case, dogs off leash may resort to look at their owners more often and with longer gazes to regain proximity and feel more secure in a situation of need. At the same time, the simple physical perception of the leash, or other perceptual cues given by the owners' proximity, may be sufficiently informative about the owner's presence for dogs on a leash.

Although there are a few studies that focused on dogs' social interactions in natural contexts (Bekoff & Meaney, 1997; Westgarth et al., 2010; Rezá et al., 2011), these found a significant effect of leash use on dogs' attention. Mongillo et al. (2014) established that when dogs were on a leash, almost half of them were never oriented to their owners and when they did both the frequency and duration of their gazes were generally very low. Low values were also found for the total duration of dogs' orientation to owners, which remained below 1 % of the time for most dogs. All parameters: gaze length; gaze frequency; and looking time of dogs' attention were significantly higher for off-leash than on leash dogs.

Training methods also influence gazing behavior: dogs involved in positive-training programs displayed a greater propensity to visually interact (Deldalle & Gaunet 2014).

It is also possible that dogs which display high levels of attention to their owners are perceived as more reliable and therefore are more often allowed to walk off leash; in such case, higher attention levels may be the reason, rather than the consequence, of the dogs being allowed off leash (Mongillo et al., 2014). Mongillo et al. (2016) argued that the gaze patterns observed by dogs and owners in urban contexts seemed to be mainly functional to monitor each other's presence/position. The results of Mongillo et al. (2016) are in contrast to laboratory data, where dogs have been shown to look at their owners at least 20 times as much (e.g., Range et al., 2009; Mongillo et al., 2010; Horn et al., 2013), with 3 times longer (e.g., Range et al., 2009; Mongillo et al., 2010) and more frequent gazes (e.g., Range et al., 2009), which again underlines the difference and effect of laboratory versus natural setting.

The informative role of the eyes in interspecific communication has been demonstrated by the enhanced interest of dogs in investigating the eye region of humans compared with other facial features (Somppi et al., 2014). Dogs were able to assess human's attentional state during communicative interactions by evaluating human gaze direction and adapted their behavior accordingly (Schwab & Huber, 2006). This could also be observed during the walks: if the owner gazed at specific external stimuli evaluating whether to call or change direction the dogs acted accordingly by gazing at the stimuli and then gazing at the owner. Therefore, eye contact plays a crucial role in the dogs' communication with humans (Schwab & Huber, 2006). It has been shown that dogs produce persistently referential signals until they elicit a satisfactory human response (Gaunet, 2010) and are able to interrupt them when they are no longer successful (Elgier et al., 2009). Referential signals were initiated by the dogs in particular to show game (e.g. rabbits) by gazing back and forth between owner and game, or at T-junctions to receive information about the new travelling direction. Dogs, indeed, are able not only to flexibly use human gaze to regulate their behavior in specific contexts, but also to communicate with humans to direct their attention to a specific object of their interest, by performing the so-called "showing behavior" (Kaminski et al., 2011). It has been reported that dogs can use up to 19 different referential gestures during everyday interactions with humans, eliciting humans' appropriate responses (Worsley & O'Hara, 2018). They use their body position and sustained gaze as a local enhancement signal (Gaunet et al., 2011) or they alternate their gaze between the target object and humans to indicate to them the object location (Miklósi et al., 2003). These signals are displayed to communicate with humans and are modulated both by human availability to communicate with them (Savalli et al., 2016) and by human responses.

Dogs are able to regulate their behavior toward an unknown or ambiguous object by using human emotional referential expressions, especially when provided by their owner (Merola et al., 2014) which may be the reason for the behavior displayed during the walk when confronted with new stimuli. Interestingly, when the owners were inattentive, dogs actively attempted to involve them to obtain information, alternating their gaze between the object and them, demonstrating the existence of social referencing (Gaunet, 2010; Merola et al., 2014).

Facial expressions also play an important role in the dog-human visual communication. Dogs are able to assess humans' emotions (Bloom & Friedman 2013; Cuaya et al., 2016; Müller et al., 2015; Somppi et al., 2016), and respond differently according to

their valence. Albuquerque et al. (2018) demonstrated that dogs displayed mouth-licking behavior (a stress indicator) more often when presented with human negative emotional facial expressions (compared to positive ones) - dogs perceived the negative valence of the human emotion, which increased their own stress level, and responded by displaying behavior used in intraspecific communication to “appease” the sender (Handelman, 2012; Somppi et al., 2016). Herein, dogs walking close to their owner could assess the emotional facial expressions and as mentioned in **Section 1.4.6** the use of the GPS may have led to the result that owners displayed more relaxed facial expressions.

Siniscalchi et al. (2018) postulated that the emotional cues conveyed by human emotional faces are processed in an asymmetrical way by the canine brain. They used a behavioral method commonly employed to study both visual and auditory lateralization (namely the “head orienting paradigm”) to show that dogs are sensitive to human faces expressing Ekman’s six basic emotions (e.g., anger, fear, happiness, sadness, surprise, disgust, and neutral) with a specialization of the right hemisphere for the analysis of human faces expressing “anger”, “fear” and, “happiness” emotions, but an left hemisphere bias for human faces expressing “surprise” (Siniscalchi et al., 2018).

In human visual communication the face has a unique function, because it is the most reliable source of one’s emotional or mental states and intentions (Todorov et al., 2008). The ability to recognize behavioral indicators of emotions in others plays a key role in the social organization of group-living species as it might help to predict others’ subsequent behavior, and the development of such skills can be highly beneficial for domestic dogs that live in an interspecies social systems (Nagasawa et al., 2011, 2017; Racca et al., 2012). Dogs are not only able to detect and recognize the human face (Racca et al., 2010), but also to connect facial expressions with probable outcomes (Nagasawa et al., 2011; 2017). Dogs, similarly to adult humans, showed left gaze bias only towards upright positioned human faces but not towards monkey, dog faces or objects (Guo et al., 2009). They can also learn to discriminate between neutral and happy facial emotional expressions (Deputte & Doll, 2011; Nagasawa et al., 2011, 2017; Somppi et al., 2016). The effects of oxytocin on dogs’ social behavior are increasingly explored, and most of the findings support a role of the oxytocin system in dogs’ human-like social skills (for reviews, see: Buttner, 2016; Kis et al., 2017). This is an ongoing debate, as some authors think that the role of oxytocin in the co-evolution of humans and domestic animals is clear (Herbeck et al., 2016), while others have a more critical attitude towards oxytocin research in dogs (Tops et al., 2018; Rault et al., 2017).

Cimarelli et al. (2017) proposed an association between epigenetic modifications of OXTR and dog social behavior. They found higher methylation levels in females than in males at site -1383 and lower methylation level at site -727 in females than in males, which was associated with a higher likelihood to approach a threatening unfamiliar person in males and a lower likelihood to remain passive or hide behind the owner. Furthermore, at the two sites -751 and -1383, males with higher methylation levels were more likely to remain passive or to hide behind the owner than those having lower methylation levels. While females were more likely to approach an unfamiliar person in an appeasing manner if their methylation levels were higher in site -1383, in males the opposite relationship was found. This, however, could also be explained by a differential interplay between the methylation of the OXTR gene and other biological mechanisms (e.g., the expression of sex hormones) and/or reflect a sex-specific response strategy to social threat (Cimarelli et al., 2017). It has further been proposed that OXTR and OPRM1 gene variants differ in their effects not only between sexes but also between breeds and accordingly result in different breed specific social behavior (Kubinyi et al., 2017).

Although dogs react to the informative nature of human ostensive-referential cues, for instance pointing gestures, they may interpret the gestures as an order rather than understanding the communicative intent to share information (Miklósi & Topál, 2013). This hypothesis is supported by dogs' higher attitude to follow owner's signals rather than those from a stranger and to follow human gestures to locate food even if the olfactory information about its position is contradictory (Elgier et al., 2009). Furthermore, it has been reported in an eye-tracking study that dogs are able to discriminate between social and non-social interactions depicted on a picture, showing a longer gaze toward the individuals in a social context compared with a non-social one (Törnqvist et al., 2015).

Marshall-Pescini, et al, (2009) proposed that dogs engaged in activities which require constant coordination with their owners (e.g. agility) show a higher propensity to look back in such tasks than dogs with no specific training or dogs trained for more independent tasks. Konno et al. (2016) found that spontaneous gazing behavior towards humans was associated with genetic similarity to wolves rather than with particular working breeds. Ancient breeds (Afghan Hound; Akita Inu; Saluki; Shiba Inu; Siberian Husky) engaged in less gazing behavior than any other group and the authors suggested that a dog's communicative ability to convey visual signals to humans may be linked to their genetic similarity to wolves, providing support to the 'wolf remnant' hypothesis.

Taken together, these results highlight that the degree and type of interaction with humans, and possibly breed, has strong effects on their 'looking back' behaviors in such tasks.

Previous work has also suggested that dog's responses to human cues (such as pointing) and their perceived trainability varies with breed characteristics like their cephalic index (skull length) (Bognár et al., 2018; Gácsi et al., 2009b; Helton, 2009) and breed function (Bognár et al., 2018; Gácsi et al., 2009b; Udell et al., 2014). Bognár et al. (2018) found mesocephalic dogs looked at portraits longer than at profiles, independent of the species in the image. Overall, brachycephalic dogs and dogs of unspecified breed function displayed the longest looking times. Among dogs with 'unspecified' breed function, females observed the images longer. The results suggest that short-headed dogs are more attentive to faces, while sex and breed function may influence looking times through more complex interactions. Bognár et al. (2018) further postulated that skull length, which was previously shown to indicate quality of vision (McGreevy et al., 2004) and may also be related to retina structure, attention for visual cues (Gácsi et al., 2009b), and trainability (Helton, 2009), was the most relevant breed characteristic to predict dogs' facial perception.

Skull length did not only affect how dogs of different sexes approached food in the presence of the images in the Foraging Situation Condition, but even more importantly, how looking time changed for different picture types. Moreover, independent of the picture type, brachycephalic skull length predicted longer looking times, suggesting that between dogs of different cephalic index, differences in gazing behavior might arise from differences in visual processing (McGreevy et al., 2004). Bognár et al. (2018) showed that mesocephalic and dolichocephalic females approached the food more slowly than males of the same skull length, but in brachycephalic dogs the relationship with sex was reversed i.e. males approached slower.

Skull length might have an impact due to associated differences in the position of the eyes (Bognár et al., 2018) and 'cooperative worker' breeds (i.e. gundogs and herding dogs which work with continuous visual contact of their human partner) were found to be better at following human cues than 'independent worker' breeds which work without human visual contact (e.g. sled dogs, hounds, guarding dogs) (Gácsi et al., 2009b; Wobber et al., 2009). As I did not measure the gazing behavior differences were not reflected by data. If gazing behavior necessitates closeness to the owner, the "independent worker" breeds (Borzoi, HuskyMix; ShepherdMix) were reflected by Group 3, which

would be in accordance with Gácsi et al. (2009b) and Wobber et al. (2009) and conversely Group 1 dogs could rather be grouped as “cooperative workers” (Collie, Labrador, Pug), **Table R2.2.1**.

The success of cooperative dog breeds in following human pointing might be specifically related to the demands of human-dog cooperation, but alternatively they could be due to a more persistent predatory response (Udell et al., 2014) i.e. to fixate and follow moving stimuli, since pointing implies movement and directionality. Nevertheless, research also suggest that gazing behaviors towards humans are not necessarily a direct effect of domestication, but potentially a behavior that emerged as a result of dogs’ acceptance of humans as social partners (Marshall-Pescini, 2017; Udell et al., 2010). Herein I did not gather data on breed specific gazing behavior; however, differences in gazing could of course also be based on these differences.

Cimarelli et al. (2018) proposed that dog-owner relationships in general differ from dog-dog relationships only in terms of reference but not regarding affiliation and stress, notably, mainly gazing behaviors (total gaze duration and alternation of gaze between the partner and the novel object), showing that dogs payed more attention to a human demonstrator than to a conspecific one. This increased gazing may be a behavioral expression of the unique dog-owner relationship (Miklósi & Topál, 2013) or dogs are more attentive to their owners as a result of their previous history of reinforcement (Wallis et al., 2015). Dogs herein might have looked more at their owners than conspecifics because they might regard their owner as partner likely to tell them what to do, for instance whether to change walking direction. In particular if they live in a single dog household and rely on the owner in a specific context as partners from whom to acquire information regarding novel environment/stimuli (Merola et al., 2012). Merola et al. (2012) in their Social referencing paradigm (seeking of information from another individual to form one's own understanding and guide action) found that most dogs (83 %) looked referentially to the owner after looking at a strange object, apparently seeking information about the environment from the human. This could also be perceived during the walks whenever new stimuli could be seen e.g. horses or jogger. This social referencing behavior may have been transferred to the conspecific whilst exploring together (i.e. when the owner was not being visible and a different valence of relationship in a specific situation was present). Furthermore, dogs might have looked at their owner based on prior learning experiences or training methods (e.g. food reward or “click-for-Blick” training).

Differences in reliance on owner gaze, i.e. the distance of travelling and non-availability of the owner, thus deciding situations for themselves, (see different Groups and clusters **Table R2.2.1**; **Table R2.3.2**; **Table R2.14.6**) may be due to learning, temperament, a team partner and personality of the dog (or the owner, see discussion below). Arguably Group 1 dogs displayed a higher incidence of gazing behavior due to the fact that they were more insecure and had learned less independent behavior compared to Group 2 and particularly Group 3 dogs. Thus relying on perpetual reassurance mixed with breed dispositions (Gácsi et al., 2009b) and physiological factors like skull length (Bognár et al., 2018) and training methods (Deldalle & Gaunet, 2014) as well as the relationship with the owner and the potential second dog (Cimarelli et al., 2018). However, it may alternatively be argued that they displayed a stronger attachment behavior, enhancing the establishment of an affiliative relationship.

1.4.1.3 Olfactory communication

Interestingly 90 % of the owners (see owner questionnaire Part 3) when asked how their dog would find back to them stated by olfaction – however, not in the sense that the dog would utilize olfactory cues of the owner, but that the dog would trace back its own route through olfactory cues. Based on this strong owner preconception this sense will be discussed forthwith, even though data could only be collected descriptively by observation and video footage.

Dogs are able to spontaneously recognize individuals by their smell (Bradshaw & Rooney, 2016) and are able to discriminate body odor of two identical twins living in the same environment (Pinc et al., 2011). Dogs prefer specific parts of human body for olfactory investigation (Bradshaw & Rooney, 2016), suggesting that different body parts produce specific odors conveying different information, and respond spontaneously to metabolic changes of their owner on the base of their scent (Chen et al., 2000). Therefore in respect to orientation and finding the owner, the odor of the owner could arguably be discriminated and utilized by the dogs as one cognitive orientation tool conveying allocentric information.

Moreover, dogs associate human odors with previous experiences: They show an increased arousal state when presented with a negatively associated/stressful experience (e.g. veterinary sweat odor -Siniscalchi et al., 2011), but associate familiar human odors with positive outcomes (Berns et al., 2015). Furthermore, dogs detect the emotional content of human odors, which induces changes in their behavior and cardiac ac-

tivity (Siniscalchi et al., 2016; D'Aniello et al., 2018), in particular during fearful situations. Therefore it may be argued that the dogs herein with fearful or uncertain owners were able to perceive that emotion and adjusted their behavior accordingly for instance by staying closer and/or being more stressed themselves; stress also influencing exploration behavior and spatial orientation competencies (van Gerven et al., 2016). It has been postulated that dogs adjust their social behavior toward humans according to the valence of the odor perceived, showing more stranger-directed behavior when presented with the "happiness" odor, and more owner-directed behavior when presented with the "fear" odor (D'Aniello et al., 2018). Contrary to that which has been observed for conspecific odors, during the sniffing of human fear, bias in the use of the left nostril (i.e., left hemisphere activity) has been shown (Siniscalchi et al., 2016), suggesting that chemosignals communicate intraspecific and interspecific emotions using different sensory pathways.

These findings demonstrate that chemosignals carry contextual-related information, supporting their specific role in dog-human communication. Within this context they may also influence exploration and orientation behavior in that dogs used the specific smell of their owner to find back or to gather information about the owners' emotional state. This information in turn affects their own behavioral response including their exploration behavior with respect to distance and/or time travelled as well as the allocentric or egocentric exploration strategy used.

Polgar et al. (2015) found that dogs rely primarily on visual, social, cognitive and spatial cues rather than olfactory ones and that a variety of factors influence what strategy a dog decides to use. They predicted a "win-stay" strategy, whereby a dog returns to an area where it was previously successful, which was not the case in their or my study. Dogs did not return to a previous owner location first. Polgar et al. (2015) examined the strategies dogs use in two types of olfaction-based problems as well as their success at various distances. Results suggested that despite their ability to successfully collect information through olfaction, dogs often prioritized other strategies to solve basic choice tasks. Thus, many untrained pet dogs, like the ones used herein, seemed to first focus on solutions based on other sensory cues before using olfaction, in particular vision. Szetei et al. (2003) also showed that dogs rely primarily on visual, social, cognitive and spatial cues rather than olfactory ones, which is in accordance with the theories postulated by Miklósi (2007) and Horn et al. (2013) and consistent with the behavior observed in this study.

1.4.1.4 Tactile communication

For the sake of completeness tactile communication behavior will be discussed, as it also could be observed during the walks.

Many humans, whether familiar or unfamiliar to a dog, try to show their affection by initiating physical contact, arguably due to the fact that the tactile contact during human–dog interactions causes a series of benefits with regard to the physiology, the mental states, and the immune system of humans (Charnetski, 2004; Glenk, 2017; Westgarth et al., 2016). Tactile communication during human–dog interaction can result in positive or negative canine emotional states, leading to corresponding approach or withdrawal behavior (Miklósi, 2016). Furthermore, physical contact in social interactions has different features in interspecific and intraspecific communication, in terms of both frequency and duration. Dogs use less physical contact intraspecifically, even though social cohesion for instance is maintained by specific activities, such as resting in close contact (Siniscalchi et al., 2019) but tactile interactions like grooming are generally short lasting.

A significant influence of human-dog familiarity on dogs' behavioral responses during tactile human-dog interactions has been shown. Kuhne et al. (2012) presented in their study that dogs being petted by a familiar person showed significantly more appeasement gestures (e.g., blinking, looking elsewhere etc.), redirected behaviors (e.g., sniffing/licking on the floor etc.), and social approach behavior than dogs being petted by an unfamiliar person. However, dogs' reactions to handling depend on different factors e.g., genetics and early experience, including socialization with humans, as well as physical and mental health, breed, learning and especially the context in which the interaction takes place (Siniscalchi et al., 2018; Vas et al., 2008).

During the walks tactile interaction could be perceived in that dogs either regularly briefly touched their owner during the walk (hand or knee area), or if they had explored, upon return. They displayed tactile greeting behavior with the second dog (if applicable) on return of exploration in case where the second dog had remained with the owner. However, tactile behavior was displayed with great variance, as some dogs e.g. the Group 3 dogs travelled longer and further thus spent less time with the owner and therefore displayed less tactile behavior during the walks. Additionally learning and training played a role: dogs who had learned a “touch” signal at a return or for a reward displayed this signal, often to receive a food reward (which was not given during these walks to discourage dogs from being glued to the food bag and to encourage exploration behavior).

1.4.1.5 Vocal communication

For group living animals it can be essential to differentiate group members, both at the individual and the group level (Trivers, 1971). Vocalization signals are under the regulation of developmental and genetic factors and the properties of the vocal signal can provide identity cues of the individual (Taylor & Reby, 2010). Besides using specialized calls that can function as signatures (Janik et al., 2006), the modulation of frequency (Owren et al., 1997), its noisiness (Fitch et al., 2002) and temporal features (Rendall et al., 1996) may serve as cues for recognition of identity. The structure of the frequency can further inform listeners regarding the quality (Charlton et al., 2012), age (Fischer et al., 2002), dominance position (Fischer et al., 2004) and inner state of the signaller (Manteuffel et al., 2004). During social interactions, signals of inner state can be especially important to predict the future behavior of social partners (Ohala, 1996). All frequency components of a vocal signal and also its time parameters may carry information about the caller's physical, emotional, physiological state, identity and group membership (McComb & Reby, 2009; Taylor & Reby, 2010).

Dogs' vocal behavior underwent considerable changes during the domestication process, generally considered as a result of dogs' adaptation to the human social environment (Feddersen-Petersen, 2000). The effect of living in proximity to humans has been demonstrated by a study showing that, after a 40-year selection, tame red foxes emitted more human-directed vocalizations than their ancestors (Gogoleva et al., 2012). Belyayev & Trut (1964) showed that selection on tameness led to the emergence of traits in the domestication syndrome (floppy ears, curly tails, stress hormone level decrease (glucocorticoid); adrenal gland decrease; serotonin levels increase, more juvenilized facial features (shorter, rounder, more dog-like snouts) and body shapes (chunkier, rather than gracile limbs). Additionally, domesticated foxes, unlike wild foxes, were capable of following the human gaze as well as dogs (Hare et al., 2005). Changes associated with domestication have been located on fox chromosome 15 (Kukekova et al., 2018), here specifically SorCS, a gen linked with synaptic plasticity, which itself is associated with memory and learning, implicating changes in cognitive abilities (Wang et al., 2018). Dogs similarly have acquired a tendency to vocalize more during interactions with humans. Concurrently they display other socio-cognitive abilities and developed novel forms of vocalizations, with different acoustic and functional characteristics, thereby facilitating their communication with humans (Pongrácz et al., 2010). Vocalizations are also breed dependent, however (Feddersen-Petersen, 2000).

Petterson et al. (2011) demonstrated that dogs regulate their behavior according to the humans' intentions expressed by different verbal utterances, following human gestures when they are given with a cooperative intention, but ignoring them if given with a low-pitched/prohibiting voice. The ability of the dog to correctly interpret the emotional valence of a sound also extends to human vocalizations. Specifically, using a cross-modal paradigm, it has been shown that dogs can correctly match "happy" or "angry" human faces with a vocalization expressing the same emotional valence (Albuquerque et al., 2016). On the other hand, dogs use vocalizations to communicate with humans, particularly to solicit their care and to attract their attention when faced with an unsolvable problem (Miklósi et al., 2000). They mainly use short-distance calls in interactions with humans, like barks, growls, and whines, compared with long distance calls, which are used instead to communicate with conspecifics (Feddersen-Petersen, 2000). Despite little information about the intentional control of vocal productions (Gruber & Grandjean, 2017), a growing body of literature demonstrates that dogs' vocalizations are effective means for interspecific communication, conveying information for humans (Pongrácz et al., 2006; Faragó et al., 2017).

Dogs and humans use vocal signals in cross-species communicative interactions that produce changes in the other species behaviors (Andics & Miklósi, 2018). Dogs understand the meaning of some human words and perceive the emotional content of human vocalizations (Kaminski et al., 2004). They can use human voice intonation as a social referential cue, extracting information about people's reaction to novel or ambiguous objects and act accordingly (Colbert-White et al., 2018). Although vocal signals are less significant than visual ones in guiding dogs in ambiguous choice situations (Colbert-White et al., 2018), the tone of human voice is efficient in communicating the human's motive (Petterson et al., 2011).

During the walks dogs vocalized overall very little, perhaps due to the absent (vocal) interaction of the owner or due to the fact that the owner walked continuously and that neither food nor play invitation was given. Tamina (Terrier-Chinese Crested Mix) and Emma Lea (Miniature Pinscher) vocalized while flushing birds; Emma Lea also vocalized on every external stimuli (jogger, horse, dog), Amy and Nele (Labrador) vocalized during play interactions, as did Mala (Perro de Aqua Espanol); Raffaele (Italian Greyhound) and Dr.Pepper (Silken Windsprite) vocalized when conspecifics were encountered, Amanda (Collie) vocalized when exiting the owner car. The other sighthounds and

Ridgebacks did not vocalize even when following game. None of the far ranging dogs (Group 3) could be heard vocalizing (see also Videos).

Some humans are also able to derive information from dogs' vocalizations, not only about the dogs physical characteristics (rating growls produced by larger dogs as more aggressive than those of smaller dogs; Taylor et al., 2009), but also about its emotional state (Pongrácz et al., 2005; Faragó et al., 2010). The development of different vocal signals in dogs could thus have been modulated by their efficacy of conveying specific information to communicate with humans. Anecdotal evidence was collected on the walks in that owners could describe emotional states (excited) of their dog or potential prey (deer versus boar or birds). This is further supported by the existence of individual variability of acoustic features of barks directed to humans (during ball play, in requesting situations, or before going for a walk), which can be shaped according to the owner's response (Pongrácz, et al., 2010). The specific role of auditory signals in communication with humans is confirmed by the significant decrease of their production in feral and stray dogs (Pongrácz, et al., 2010), suggesting that dogs' social contact with humans represents the main regulatory factor of their expression. This is interesting as most dog owners do not want a dog that barks or vocalizes excessively and is often a reason why owner abandon their dog to a shelter or seek professional help. As the owner was not to call or speak with their dog vocal communication was arguably suppressed, which in turn however, may have impacted the dogs behavior as well.

Overall, humans' ability to categorize dogs' vocalizations demonstrates that dogs' vocal signals have a communicative relevance for humans and that they represent effective means for dog-human communication (Sinischalci, 2018).

In conclusion, having discussed different communication channels between the dog-owner dyad, studies show that the majority of dog owner do not understand the communication signals of (their) dog(s), either by not noticing dogs' stress signalling and misinterpreting dogs' attempts to signal (Kerswell et al., 2009; Mariti et al., 2012); or by misinterpreting the signals altogether (Bloom 2013; Meints et al., 2010). Furthermore dog ownership does not predict correct understanding of dogs' behavior (Tami et al., 2009; Wan et al., 2012) and research has demonstrated that there is over all very little knowledge regarding dog behavior (Kuhne 2016; Firnkes et al., 2017; Mariti et al., 2017; McGreevy et al., 2012; Meints et al., 2018; Reisner & Shofer, 2008) including stress and appeasement signals (Mariti et al., 2012; Meints et al., 2018).

Thus, while dogs are very good at interpreting human signalling (e.g., Huber et al., 2013; Kaminski et al., 2012; Racca et al., 2012; 2010; Somppi et al., 2014) humans do not seem to be equally equipped to interpret dog's signalling and communication attempts.

1.4.2 Dog-owner attachment

Dogs form bonds with specific humans and make decisions by attending preferentially to social signals from them (Cimarelli et al., 2019) and attachment is the highest within the owner-dog dyad (Cimarelli et al., 2019; Sundman et al., 2018; Topál & Gácsi, 2012). Dogs have been shown to develop attachment bonds with humans allowing them to interact securely with their environment in the presence of the owner (Gácsi et al., 2013; Horn et al., 2013; Rehn et al., 2017). Therefore only owner-dog dyads were used as the motivation to return was assumed the highest (as compared to familiar persons). The learning history of a dog is also relevant to the attachment relationships it forms and its social referencing capabilities. It has been argued that dogs perform poorly in problem solving tasks due to owners' training/intervention and a lack of opportunity to independently solve tasks and generally, that dog' day-to-day behaviors are overregulated by their owners (Udell, 2015).

All dogs herein, independent of sex, age, reproductive status or breed, found and returned to their owner in different environments subsequent to having travelled at least 20 m away from their owner, see **Table R1.0**. However, length and number of the runs varied greatly; see **Table R2.1.1**; **Table R2.3.1**; **Table R2.2.1** and data demonstrated large intraspecific differences between the dogs, see **Table M1.2.4**; **Table M1.2.1**.

Dogs display behaviors indicative of an attachment relationship, for instance proximity seeking, where the dog will seek the owner as a means of coping with stress (Rehn et al., 2017; Schoeberl et al., 2012, 2016). The presence of the owner may also reduce the effect of a stressful event, constituting the so-called safe haven effect (Gácsi et al., 2013). About 25 % of the dog-owner walks indicated a distance of less than 400 m overall difference between dog and owner, **Table R1.2.1** indicating a lack of independence and potential overregulation (see, Udell, 2015). Looking at the three Groups the majority of dogs explored less than 150 m away from the owner (13 of 30 dogs = 43 % see **Table R2.2.1, Group 1**); eight (27 %) of the dogs showed a median maximal difference away from the owner of less than 350 m (**Group 2**), which may be an indicator of the safe haven effect. Furthermore in Group 1 the distance explored by the dogs was independent of the area (known or unknown) **Fig. R2.3.1**; **Fig. R2.2.1**; **Table R2.2.1**,

and these dogs predominantly displayed the exploration pattern of running ahead of the owner and waiting or following **Table R2.14.2, Table R2.14.3**. This moreover applied to all dogs of one owner. Significant linear correlations for distance measures could be found between two/three dogs of one owner **Fig. R1.4.2.1 - Fig. R1.4.2.5 Table R1.4.3.1. Table R1.4.1.1. Table R1.4.3.1**. Therefore the majority of dogs stayed within a limited radius to the owner, seldom leaving the walking path, and if the owner participated with more than one dog all displayed similar behavior **Table M1.2.1; Table R1.4.3.1** (with exception of team 2, 5, 7 **Table R2.15.1**).

The Zurich Model of Social Motivation by Bischof (1975, 1993; Zürcher Modell der sozialen Motivation, **Fig. 1 Appendix**) is used to explain and predict processes of social distance regulations, which have also been described by attachment theorists such as Bowlby (1969). The owner-dog attachment and the factual distance displayed may be influenced by these regulatory processes. The model postulates three basic motivational systems: the security, the arousal, and the autonomy systems, all of which have negative feedback loops and are considered homeostatic. Security is defined as the feeling of intimacy, warmth and protection, typically received from the primary caregiver like the owner. The closer the relationship the more security the dog obtains, thus an emotional variable increases with familiarity and proximity resulting in distance regulating behavior. The reference variable is the degree of dependency the dog feels. If dependency exceeds security, the dog shows attachment behavior and reduces the distance to the owner. The opposite situation would result in avoidance of the owner.

Arousal is defined as feelings of interest or curiosity, as well as feelings of alarm or fear. Like security, arousal is increased with the individual's proximity and relevancy. The reference value of the arousal system is enterprise. Again, a distinction between an aversive and an appetent behavioral response can be made. Aversion against arousal and subsequent fear behavior result from arousal exceeding enterprise. If arousal is less than enterprise, an appetite for arousal develops which leads to exploratory behavior. The reference variables—dependency and enterprise—are assumed to be negatively correlated.

The autonomy system is analogous to the security and the arousal systems. The detector which provides the amount of felt autonomy senses experiences of success, and autonomy underlies the connection of the security and the arousal system by affecting dependency negatively and enterprise positively. For an overview see, **Part1 Fig. 1 Appendix**)

The great variation of exploration distance and time between dogs of Groups 1, 2 and 3 is also influenced by the dog-owner attachment. Links between owner attachment style and dog behavior implied that dogs may develop different strategies to handle particular situations, based on the type of support they get from their owner (Rehn et al., 2017; Dodman et al., 2018). How a dog seeks support from their owner in challenging or new situations is influenced by the owner's caregiving strategy, as well as by experience from their previous interaction history (Rehn et al., 2017). The median age of the dogs was 63, 5 months, see **Table M2.2.1** and thus dogs displayed behavior during the walks based on prior learning experiences, which is congruent with the answers given in the owner questionnaire: Group 1 dogs for instance were customarily called at every external stimuli or if they were beyond the range of vision (for details see Part 3), whereas the Group 3 dogs were only called in case of emergencies.

Attachment behavior in dogs toward their owners has been studied by using, e.g., adapted versions of the Ainsworth's Strange Situation Procedure (ASSP) and studies indicate that dogs express attachment behavior toward their owners, including aspects of secure base effects (Topál et al., 1998). The secure base effect balances the dogs' exploration behavior with maintaining a close proximity to the owner. Based on the behavior expressed in the ASSP, dogs could be divided into different groups similar to the secure-insecure attachment dimensions, further suggesting parallels among the relationship between child-parent and dog-owner (Topál et al., 1998). Owners with a more secure attachment style have dogs that show behavior similar to that of securely attached children (Siniscalchi et al., 2013), whereas dogs who received less social support from their (insecure) owners became overly dependent on them, i.e. stayed closer to the owner and explored less. Schöberl et al., (2016) found that physiological responses in dogs were affected by the attachment profile of the owner: The higher the owner scored on anxious attachment, the higher the dog's cortisol reactivity during the ASSP, indicating a stress reaction. They further showed that owner neuroticism, on the other hand, was related to low cortisol reactivity in dogs, but that these dogs approached their owners often and were in proximity with them for long periods. Dodman et al. (2018) also found a relationship between owner personality and psychological status in that the behavior of the dogs was mediated by the quality or style of the owner's interactions with the dog. They found anxious and neurotic dog owners were overprotective of their dogs, thereby limiting the dogs' ability to socialize or familiarize themselves with novel social and non-social situations and stimuli.

Studies have shown that securely attached individuals show lower stress responses (physiologically) when accompanied by their caregiver (Julius et al., 2013). Avoidant caregivers restrict support seeking and acknowledgment of distress, whereas anxious-ambivalent caregivers show increased attention to negativity and heightened expression of distress (Kobak & Sceery, 1988). Thus securely attached dogs would show little distress even in unknown areas and arguably would explore further (like Group 3 dogs) knowing their owner to be in the vicinity and having learned to explore without permanent owner restriction (see also, Siniscalchi et al., 2013). Upon reunion from an exploration secure dogs sought proximity with the owner. Avoidant owners would not show support even when the dogs was distressed and avoidant dogs would respond to reunion by actively avoiding and ignoring the owner. Anxious-ambivalent owners were always worried (increased attention to negativity) and stressed. On „normal” walks (see owner questionnaire) they tended to call their dogs at every external stimuli. Ambivalent dogs may seek proximity, comfort, and physical contact with the owner but usually without calming down, or deactivating their attachment behavior (in comparison, see Ainsworth et al., 1978). Insecure dogs receive less social support from their owners or become overly dependent on them (Schöberl et al., 2016) which would indicate Group 1 dogs.

Studies suggest the Big Five personality dimension of neuroticism may provide some indication of the dogmanship of individual dog owners: High neuroticism scores have been associated with poor canine performance in operational tasks (Schoeberl et al., 2012; Kis et al., 2012), handlers’ use of excessive signalling during training and delayed responses to owner commands (Kis et al., 2012). These results suggest that high neuroticism in dog owners contributes to poor dyadic functionality.

In a longitudinal study of the search & rescue dogs deployed at the WTC and Pentagon following the 9/11 terrorist attacks, Hunt et al., (2012) found that owner’s post-traumatic stress disorder (PTSD) and depression symptom scored one year after deployment predicted the development of behavioral problems such as attention-seeking, separation anxiety and aggression in their dogs up to a year later, reflecting the impact of owner on dog behavior.

Using the analog of the parent – child relationship it has been established that two parenting dimensions have been consistently associated with the development of anxiety in children: overprotection and anxious rearing (e.g., Wood et al., 2003). Overprotection has been described as parental behaviors aimed at guiding children during their daily activities thereby reducing the development of autonomy (Rapee et al., 2009). Anxious

rearing pertains to the explicit encouragement of anxious cognitions and avoidance behaviors in children (e.g., Muris et al., 2011; Grüner et al., 1999). Overprotective and anxious parenting have been found to play a pivotal role in the development of childhood anxiety symptoms when examined together with behavioral inhibition (Van Brakel et al., 2006), as well as inhibited temperament (Rubin et al., 1999). Muris et al., (2011) found effects of anxious rearing and parental trait anxiety, whereas behavioral inhibition and attachment had an interactive effect on anxiety symptomatology. This corresponds with owner answers in that especially Group 1 dog owners did not know how far their dog would travel, if it would return if not called, if it would find its way back or if the dog displayed particular travelling patterns whilst exploring (because these dogs were normally called back if they left owners range of vision and on every external stimuli). Along this line Herwijnen et al. (2018) assessed dog-directed parenting styles, evaluating authoritarian (strict rules set by parents, reasoning is not explained and failure to adhere to rules results in punishment; exerting high levels of control, with low levels of responsiveness), authoritative (high demands and high responsiveness: rules are expected to be followed, but judgements, values and goals are explained; parents are willing to negotiate) and permissive/indulgent parenting styles (low levels of demandingness, few rules to follow and little guidance). The most successful style in terms of performance and high self-reliance levels was the authoritative style, with high responsiveness (empathy) to the need of the dogs resulting in self-reliant dogs interacting on a basis of trust and voluntary participation.

It may be argued that Group 1 dogs are more insecure ambivalent dogs (or belong to insecure/ambivalent owners) are less flexible in their attention during a stressful situation and thus focus most on the safe haven, the attachment figure, their owner. Furthermore, they may have experienced an authoritarian or permissive (Herwijnen et al., 2018) parenting style. The exploration (or lack thereof) behavior would be determined by prior learning experiences and a lack of cognitive development in that these dogs did not have opportunities to explore, develop orientation strategies and garner experiences, in particular as compared with Group 3 dogs, for details see also **Table R2.14.6; Fig. R2.14.1; Table R2.14.1; Table R2.14.6.**

Proximity is generally related to the attachment figure being available as a secure base (in case of stressful situations), which leads to calming effects (Ainsworth, 1989, Bowlby, 1969) supported through oxytocin increase and cortisol decrease (De Vries et al., 2003). Rehn et al. (2017) postulated that an owner who is supporting the dog's at-

tempts to independently deal with problems (or herein explore) leads to more confident dogs. This may apply to Group 2 and particularly Group 3 dogs, who were secure enough to explore away from their owner at significant distances and who had previously learned appropriate strategies to find their owner again. Following this argument Group 3 dogs would be more secure dogs (or belong to more secure owners) having learned independent exploration behavior and self-reliance, being able to develop different exploration patterns and greater cognitive orientation applications. Taking into account our current perspective on what constitutes a “good/obedient” dog (including the legal regulations), however, the Group 1 dogs would probably be considered thus, which may raise further questions with regard to dog welfare, cognitive development and learning issues (cf. Coe et al., 2014).

Kovács et al. (2018) found genetic variations in dogs' OXTR gene were associated with their attachment behavior to their owners. All behavioral aspects measured (Attachment, Anxiety, and Acceptance) showed significant association with all three dog OXTR SNPs investigated. Both dog and owner OXT genetic variation shaped their attachment in an interactive manner. Earlier research had also shown a mutual effect of both dogs and their owners on the oxytocin levels of both parties (Nagasawa et al., 2009, 2015). Kovács et al. (2018) showed that the oxytocin system of owner and dog impacts on dogs' attachment behavior. They found significant effects of two human OXTR SNPs (rs2254298 and rs1042778) on the Attachment score and one SNP (rs53576) on Acceptance with significant interactions of the effects of the human and dog OXTR gene on the attachment behavior of dogs.

Dog owners' behavior is likely to be one of the paramount environmental factors influencing the dogs' attachment behavior and possibly the owners' behavior mediates the link between the owners' genotype and the dogs' relationship to them. Kovács et al. (2018) argued that the owner's genetic background may have an influence on their parenting style or other relevant behavior that, in turn, through epigenetic processes, affects the dogs' attachment behavior or the effects of the dogs' own OXTR genotype on it. Importantly they also found an effect between the subjects of different countries on two of the three behavioral components (Attachment and Anxiety scores) with dogs in Hungary showing higher Attachment and Anxiety, than dogs in Austria. In this study, some of the adopted dogs came from different countries and prior factors in this respect could not be controlled for. However, adopted dogs were present in all 3 Groups (even though from different countries), see **Table M1.2.1**.

Cimarelli et al. (2019) looked at dogs' inter- or intra-specific relationships and proposed that the type of relationship, rather than the partner species, predict how dogs react to for instance a social threat. They stated that the dogs' interactions with their conspecific and human partners could be described in terms of reference/information seeking, affiliation and stress alleviation. The results obtained from the comparison indicated that dog-owner relationships in general differed from dog-dog relationships only in terms of reference but not regarding affiliation and stress. Dogs form similar relationships with humans and dogs and with both kinds of partners the quality of the bond varies more with the individual partner than the species. Both with the owners and with conspecifics relationship types were characterized by either high affiliation and low stress (friend dog-dog and close dog-owner), low affiliation and high stress (insecure dog-dog and tense dog-owner) or low affiliation and low stress (independent dog-dog).

Thus, dogs affiliated more with the owner than with a dog companion only if they had a close relationship with him/her but, even in this case, only if they had an insecure or independent relationship with the dog partner. Herein were teams, in which one dog presented greater variances to the owner compared to the other dog(s), see e.g. Dr. Pepper; Nina; Marley. Pronounced differences within the teams became apparent in time of runs > 20 m away from the owner, **Fig. R2.16.1.3** and **Table R2.16.1.1** for details. The total distance of runs > 20 m varied within the teams, **Fig R2.16.2.2**: Some teams displayed minor variances (Amanda, Wantje; Amy, Nele) which according to Cimarelli et al., (2018) may indicate friend dog-dog and close dog-owner relationships. The largest variance of distance explore existed between Manja (181 m) and Raffaele (1721 m - 851 % difference); Balou_Mix and Lili (5866 m vs. 1142 m - 414 % difference), and between Dr. Pepper and Raiya (568 m vs. 3283 m - 478 % difference). These dogs did not explore together. The dog that travelled less essentially stayed closer to the owner and the second dog explored alone indicating an independent dog-dog relationship. Cimarelli et al. (2019) further proposed that when dogs had a tense relationship with their owner they affiliated less with her/him than with a companion dog, not only when the dog was a friend but even when they had a more insecure relationship with it. For instance Bill, Kaito and Lou covered long distances outside the 20 m owner radius, but as a triad they travelled comparable distances -**Table R2.16.2.1**; **Fig R2.16.2.2**. Travelling long distances, however, may also be due to a secure relationship and positive learning experiences see discussion above.

The main finding of the Cimarelli et al. (2019) study is that individual partners play a more important role in shaping dogs' relationships than the species the partner belongs to. This suggests that, at least in terms of affiliation and stress-coping, the relationships dogs build with humans are not necessarily special and unique; rather the ability to form enduring, affiliation-based bonds that can socially modulate coping with stressful situations is also present in dogs' intra-specific relationships. These results have major practical relevance since pet dogs do not have the possibility to choose their social partners (either human or conspecific – which may also be reflected in the results above). Being obliged to engage in non-optimal relationships can increase dogs' chronic stress levels and, consequently, reduce their welfare. Looking at the results of the owner dog dyads/triads it could be seen **Table R1.4.3.1** that Group 1 dogs stayed with their owner and did not display dyadic intra-specific exploration behavior compared to Group 2 and Group 3 dogs **Fig. R1.4.2.1 - Fig. R1.4.2.5** Group 1 dogs displayed little cognitive variance regarding exploration patterns and overall walks, independent of known or unknown area, basically ran ahead of the owner or followed on the path.

Therefore regarding dog owner attachment numerous factors come into play: The attachment style and behavior of the owner, the learning, memory and training experience of the dog therewith; the presence of a second dog and the attachment between the dog dyad; personality of the individual dogs; and the interactions of the effects of the human and dog OXTR gene on the attachment behavior of dogs and owners.

1.4.2.1 Synchronization

It has been proposed that synchronized behavior between humans and dogs exist based on their attachment (Duranton et al., 2018), and this synchrony is based on dogs 'sensitivity to humans' behavioral cues through previous learning experiences (Naderi et al., 2001). During the dog-owner walk behavioral synchronization may therefore be an evolutionary adaptive mechanism fostering social cohesion of the team. Dogs may benefit by synchronizing their behaviors with that of their owners, as it might increase affiliation and prosociality. Prosociality toward conspecifics has been shown in dogs (Quervel-Chaumette et al., 2016a), but studies have so far failed to observe prosociality towards humans (e.g., Marshall-Pescini et al., 2016; Quervel-Chaumette et al., 2016b). Duranton et al. (2018c) argued that the ability to synchronize with humans and the sensitivity to human's behavioral synchronization are two skills that have been selected for at different times in dogs' evolutionary history. The first one early on in domestication, as it is

adaptive and found in all dogs, and the second with later artificial selection linked to a specific breed's abilities.

When considering the ontogeny of dogs' social skills with regard to humans, including behavioral synchronization, parallels in the socialization processes of humans and dogs could explain the similarities. MacLean et al. (2017) proposed that as both dogs and children develop in a human environment with similar learning opportunities both show common social behavioral patterns across species. This led to the two-stage hypothesis (Udell et al., 2012; Wynne, 2016) suggesting that ontogeny impacts on dogs' social cognition regarding humans (e.g. Udell et al., 2010) and that the two stages are essential for a species to acquire sensitivity to humans' communicative signals. In stage 1 dogs are socialized with humans during early development, allowing them to regard humans as social companions, while stage 2 consists in life experiences that allow dogs to flexibly learn the body movements important for them, depending on their environment (Udell et al., 2010). Research yielded data consistent with this hypothesis. Dogs from different subpopulations (and with different levels of interaction with humans) exhibit differing degrees of behavioral synchronization with humans (Duranton et al., 2018b).

Various behavioral mechanisms influence the dogs' synchronization. In daily life, owners control access to the dogs' leash, leisure time, activities, and food. The owners choose the timing, direction, and duration of walks. They also choose the time and place where the dog encounters other dogs, humans, and so forth which may be considered as a type of leadership (Duranton et al., 2017a; Akos et al, 2014). Social cognition, learning, and affiliation are involved in the synchronization of dogs' behavior with that of the human. One could argue that these studies only evidenced synchronization due to proximity seeking in the dogs. Proximity-seeking behaviors are behaviors aimed at keeping or regaining contact/proximity with an individual mainly during anxious reactions (Fallani et al., 2007). As proximity seeking is linked to affiliation (Gácsi et al., 2001), it could be argued that a lower degree of behavioral synchronization may result in lower affiliated dog-human dyads.

To conclude, it is proposed that behavioral synchronization has a genetic basis (maintained through evolution and domestication), but can be modulated by life experiences (i.e., effect of affiliation), including learning (e.g., positive reinforcement when synchronizing with their owners).

Behaving similarly to others is typical of many groups and dyads and has various adaptive values, such as increasing the efficiency of anti-predator strategies and increas-

ing social cohesion (Duranton & Gaunet, 2018). Synchronization encompasses different types of synchronies, such as temporal synchrony (switching actions at the same time, the actions can be identical or different, the important feature is the timing), location synchrony (being in the same place at the same time, the actions can be identical or different, the important feature is the localization), and activity synchrony (exhibiting the same behavior at the same time, also behavioral matching, social mimicry or allelomimicry; for a review see Duranton & Gaunet (2016a). All types of synchronies are present at the dyadic level, between two interacting individuals (Gaunet, 2016a).

Duranton et al. (2017a) found that, when allowed to move freely in an enclosed, unfamiliar space, dogs synchronized their (location, activity and temporal) locomotor behavior with that of their owners. Duranton et al. (2018a) further showed that, when allowed to move freely in a familiar (enclosed?) outdoor space, dogs synchronized both their location (staying in close proximity and going to the same direction) and their activity (moving when their owner moved, at the same pace, and standing still when their owner stood still) locomotor behavior with their owners'.

Dogs may also show behavioral synchronization with humans, including social referencing, defined as the seeking of information from another individual to guide one's behavioral reaction (see, e.g., Duranton et al., 2016), for instance when facing an unfamiliar object. Here dogs synchronized their reaction with that of their owners: If the owners reacted in a positive manner, approaching the unfamiliar object, the dogs also approached it, whereas if the owners reacted in a negative manner, moving away from the unfamiliar object, then the dogs also avoided it and stayed as far as possible from it (Merola et al., 2012a). Similar findings have been evidenced when the dyad is facing an unfamiliar person. The dogs synchronized their reaction with that of their owners in the retreat condition taking a longer time to approach the stranger, using their owners' reaction as the signal of a potential threat, and thus synchronizing with them (Duranton et al., 2016).

Investigating the existence of behavioral synchronization between dogs and humans, Duranton et al. (2017b) further proposed that breed did not influence the dogs' behavioral synchronization towards their human, whatever the condition. However, when Duranton et al., (2018c) investigated dogs' sensitivity to human behavioral synchronization, they found breed differences: Molossoid dogs preferred an unfamiliar human who synchronized their behavior with them, whereas shepherd dogs did not. This is in line with a previous study showing that when owners are neutral, not providing any

cues that could influence their dogs' behavior, dogs behave differently, according to the temperament for which their breed was selected during domestication (Duranton et al., 2016; Mehrkam & Wynne, 2014).

Arguably the dogs in Group 1 (range <150 m) displayed spatial, behavioral and temporal locomotor behavior synchronicity of walking behavior with their owner (and conspecifics), even though in the studies cited neither temporal nor locational synchronicity is defined in terms of distance or time. Significant linear correlations could be shown between the duration of the travelling round, difference in walking time (owner/dog), and time inbound and time outbound for Group 1 dogs, **Table R1.4.1.1. Fig. R1.4.1.1 - R1.4.1.5**, as well as speed for those teams, **Fig. R1.3.1 and Table R1.3.1**.

Synchronization is linked to affiliation between the partners and it has been argued that being synchronized strengthens social bonds between individuals, and conversely, the more affiliated two individuals are, the more they behave synchronously (Duranton et al., 2018; Guéguen et al., 2009; Lakin et al., 2003). Synchronization is present in various situations for instance in walking side by side (Zivotofsky & Hausdorff, 2007). Social interaction with visual contact between the partners is sufficient to elicit behavioral synchronization, even in common activities such as walking together, and affiliation increases the degree of synchrony (Oullier & Scott Kelso, 2009). Studies suggest that all conditions for synchronization between the dog-human dyad are given: dogs are integrated into human societies, are highly sensitive to our behavioral cues (such as e.g. direction of attention), have typically developed strong affiliative bonds with humans (Duranton & Gaunet, 2015) and are even proposed to resemble their owners concerning temperament (Roy & Christenfeld, 2004). Studies have investigated dog-human behavioral synchronization while walking: Guide dogs with their blind partner, as well as pet dogs with their blind-folded owner, and the dogs presented non-conscious behavioral synchronization when walking, for instance in the start of movement or in the direction of walk (Naderi et al., 2001). During silent walks in the street, owners and their dogs also presented synchrony in their direction and speed (Gaunet et al., 2014). However, in both studies the majority of dogs were observed on a leash (although in one study 6 % were off-leash (Gaunet et al., 2014). Therefore, rather than non-conscious synchronization, most dogs observed had no choice but to synchronize their movements with those of their owners.

How does synchronicity work at an interspecific level? Various mechanisms could be at play that would explain the non-conscious behavioral synchronization ob-

served in some dog owner teams. One could argue that not talking to the dogs would have put them in an unnatural setting, making them more stressed. I do not reject this possibility and it could be that dogs followed their owner because they were seeking proximity due to anxiety (though all dogs were evaluated by their owners as behaving normally – however if the bonding is always insecure the behavior displayed would always be like this) - which may indicate that an insecure dog will stay closer to the owner or vice versa that the dog will stay closer to an insecure owner. Elevated physiological measures which could influence their behavior could have been at play: Even if not visibly stressed, dogs could have been more alert due to the new situation and could have been seeking proximity to owners as social support. I thus encourage further study to control for physiological parameters, however for that reason the dogs were also walked in familiar places (known areas). Dogs did show a tendency of less distance and time travelled in unknown areas **Table R1.2.2; Table R2.4.1.**

Another mechanism could explain the behavioral synchronization; Dogs affiliative bonds with their owners (Horn et al., 2013; Mariti et al., 2013) based on leadership parameters (Bonanni et al., 2010). The owner is mainly making decisions, such as initiating new directions of walks, indicating leadership (see also, Ákos et al., 2014) and the possession of special skills about for instance the environment. One could also argue that the results did not evidence an after-effect of affiliation, i.e. leadership, but instead local enhancement, a form of information transfer that can be observed in mixed-species stable groups (Goodale et al., 2010). Local enhancement means the presence of a group mate at a specific location increases the probability that an observer goes to that location (Miller et al., 2009), which is often linked to foraging contexts.

In the present setting, I was careful for the dogs not to be in a foraging context: the owners were not allowed to have food with them nor to provide food to the dog during the whole walk. In order to rule out the possibility that only local enhancement in the broad sense was at play, future studies might measure duration of ownership and owner's attachment to their dogs to determine if dyads with stronger reported attachment would also display stronger synchronization. Another, probably more likely, explanation for location and activity synchrony between dogs and humans is that dogs are reinforced for following their owners under many different circumstances. When dogs are on-leash, many owners tug on the leash whenever the dog tries to pull away, creating painful sensations that stop when the dog follows them: this is negative reinforcement for synchronizing their movements with those of their owners (Gaunet & Deldalle,

2014) and suggests that social cognition, learning and affiliation are involved in the synchronization of dogs' behavior with that of the owner.

Whether dogs are on- or off-leash, many owners pet their dogs or give them treats for following them, or for coming back when called: this is positive reinforcement for synchronizing their movements with those of their owners. All of these phenomena may contribute to fostering the dog-human relationship and to making it beneficial for dogs to synchronize their movements (location, direction, walking speed) with those of their owner. Staying close to their owner may also be an indicator of an insecure dog (safe haven). Furthermore dogs of Group 1 belonged to owner who normally called their dogs very frequently on their walks (every external stimuli, change of direction, beyond the range of 20 m or visibility – see owner questionnaire) therefore learning experiences cannot be discounted. Duranton et al. (2019) found the effect of learning through life experiences confirmed by findings that the older the dogs, the greater temporal synchrony they observed when switching activities.

Also, not moving in synchrony may be costly for the dyad (e.g. decrease of cohesion and communication) (Oullier & Scott Kelso, 2009) or at least not being synchronized with their owners may be too costly for the dogs (by receiving punishment e.g.). Finally, it is worth mentioning that all dog-owner dyads tested were recruited over voluntary participation. It is thus possible that only owners with an interest in their dog's behavior, indicating a strong relationship with their dogs, participated in the study, explaining the level of synchronization observed in some Groups. That would be consistent with the finding that hormonal state synchronization has been found in dog-human dyads with a strong relationship (Buttner et al., 2015).

A question that arises is whether behavioral synchronization between dogs and humans is an invariant phenomenon across situations and different populations of owners and dogs. As can be seen herein that is not the case as the other groups, in particular Group 3 travelled extensively and even though they did always return to their owner the distance and time was of their choosing and only partly in accordance with the findings of Ákos et al. (2014) where the dogs spontaneously returned towards their owners but mainly stayed within a 20 m radius.

With respect to the travelling patterns it would have been interesting to test the effect of the owner's sex. Due to unbalanced sex ratios, the design of my study did not allow me to properly test this parameter. However, since at least two studies have revealed that male and female owners do not behave in the same way with their dogs (Ko-

trschal et al., 2009; Prato-Previde et al., 2006), the effect of owner sex on the degree of behavioral synchronization would be interesting to study.

Furthermore, different populations of dogs with different affiliative bonds to humans, such as pet dogs owned since they were puppies or pet dogs that were later adopted, have been postulated to differ in their degree of sensitivity to humans' behavioral cues (Duranton & Gaunet, 2016; Duranton et al., 2018b). Herein seven of 11 dogs that lived from puppyhood with their owner were in Group 1.

Although there are a few studies that focused on dogs' social interactions in natural contexts (Bekoff & Meaney, 1997; Westgarth et al., 2010; Rezá et al., 2011), there are no data on dog human attention in such contexts. In the lack of other data on spontaneous attention in a non-laboratory environment, it is not simple to contextualize the findings.

The figures obtained seem to tell a different story if compared with the data obtained in the laboratory. However, in a day-to-day living context, many different factors are likely to modulate dogs' attention to their human partners. For instance the amount of time a dog could use for exploring was influenced by the inherent requirements of walking, because the owner continued on their walk. Furthermore, while walking dogs must dynamically acquire information from and about the environment and attention must also be paid to control the direction of movement, avoid obstacles, observe direction of owner movement, so that less attention may be paid to other stimuli. Beyond the requirement of motor action, the allocation of attention also reflects the individual dogs emotional and behavioral needs in that the dogs would most likely turn preferentially to stimuli that could be important for the fulfillment of its current goals.

1.4.3 Object permanence

The simplest question that has been posed to animals within the Piagetian framework is that of object permanence—that is, whether the animal appears to know that an object that has disappeared from view (or from the range of other senses) continues to exist.

For pet dogs scientific findings have been contradictory. While early works suggested that dogs can solve invisible displacement tasks as adults (Gagnon & Doré, 1992, 1994), this conclusion was later revised by Doré et al. (1996), who found that dogs failed to track objects in transposition tasks and were unable to predict the new position of the hidden object by inferring its movement (see also, Fiset & Plourde, 2013; Miller et al. 2009). Collier-Baker et al. (2004) found that dogs used the location of a displacement

device as a cue to make their choices in invisible displacement tasks (see also Fiset & Leblanc, 2007). Also, both in rotation tasks and in transposition tasks dogs had problems (Miller et al., 2009) as well as in switch and substitution transposition tasks (Doré et al., 1996; Fiset & Plourde, 2013). These results indicate that dogs tend to follow competing location or object cues, at least when they are uncertain about the target object's location. Dogs in these studies were furthermore only able to retain the memory of a displaced object for a short period of time, cf. Fiset et al. (2003; up to 240 seconds).

Herein the mean time travelled away from the owner in known areas over all dogs was 18 +/- 15 min. compared to 15 +/- 18 min. in unknown areas, **Table R2.4.1**. Therefore the dogs displayed a longer memory of the displaced object, the owner, as in particular the long ranging Group 3 dogs travelled extended time periods and went beyond the range of visibility (and perhaps other senses).

Müller et al. (2014b) found in their study that only two dogs (of 38), i.e., 5 % of the complete sample, passed all visible displacement conditions and proposed that dogs appear to rely on associative cues, such as the location of the displacement device.

Sex specific differences have been proposed as a consequence of differential selection on particular cognitive skills in male and female dogs (Halpern, 2000; Rooijakkers et al., 2009), or as a side effect of sex-specific brain differentiation (Halpern, 2000). Müller et al. (2011) found that female dogs outperformed males in a physical cognition task related to object permanence. The effect was independent of sterilization status in both sexes (Müller et al., 2011) but in a later study performance did not differ between males and females (Müller et al., 2014; see also, Bräuer & Call, 2011; Pattison et al., 2013). Sex differences identified in physical cognition appeared to be independent of sex hormones, as sterilization had no effect on performance (Müller et al., 2011). In another study, dogs and different ape species were compared in their physical cognitive abilities using a transposition task under the same expectancy-violation paradigm (Rooijakkers et al., 2009). No significant differences were identified between males and females; however.

With respect to sex differences different distance and time traveling pattern could be shown: Male dogs travelled significantly longer distances than females **Fig. R2.7.1; Table R2.7.1**. Females displayed a higher number of runs (n=1660) than male dogs (n=1485) but female dogs had more short runs, male dogs fewer runs which were more extensive timewise and distancewise, see **Table R2.7.1**. However, both female and male dogs found their owner consistently. Comparing intact and castrated dogs no sig-

nificant differences with respect to distance and time travelled were found **Table R2.10.2**.

With respect to age Müller et al. (2014) in accordance with Gagnon & Doré (1994) postulated that dog's skills in displacement tasks were fully developed before they reached adulthood and did not improve further thereafter, but did decrease with age. Group 1 dogs always saw their owner, therefore the question of object permanence did not arise. Group 2 and particularly Group 3 dogs travelled out of the range of vision (and perhaps other senses) and as the owner continued to walk (thus changing its location, therefore its local object permanence) they did display an understanding of the invisible displacement concept. Particularly those dogs that did not return to their starting point of exploration (star pattern) but instead displayed what I call an anticipatory travelling pattern, in that they went to a point where the owner was and was expected to be by continuing to walk at normal owner speed, for example see Kaito **Fig. M 2.2.4.6** have an understanding of invisible displaced object permanence.

Looking at **Fig M 2.2.4.5**, Lou and **Fig. M 2.2.4.6** Kaito, one can see that these dogs travel a large loop and do not trace back any part of their track. Instead they explore to a point where the owner is/should be if the owner continues on his/her walk at his/her owner specific walking speed. This means that these dogs also have an understanding not only of the direction the owner will travel but also of the owner speed, which implies the dogs not only perceive their own movement and travel in time and space, including distance and speed, but also the movement of their owner. They furthermore reset their cognitive map each time they explore outbound, because they do not return to the location the owner was last (i.e. where the dogs started its run) but instead meet the owner in the location he/she was in by continuing the walk in their "normal" pace. Thus their map is anticipatory/prognostic, which implies a higher cognitive skill and understanding than returning to a stationary location by e.g. path integration.

This necessitates learning and memory by the dog from owners who offer them the opportunity to explore freely and who are reliable in their walking patterns and speed. It would be interesting to see whether the group of dogs displaying anticipatory behavior would adjust their behavior if the owner were to travel by bike thus changing the travelling speed. It could be assumed that the dogs then would always end up behind the owner and not at the same location or slightly ahead of the owner on the path. This anticipatory behavior was only displayed by a small group of dogs (and mainly Group 3

dogs) and dogs belonging to owners who call their dogs rarely on a walk (see owner questionnaire).

Looking at experienced hunting dogs (Foltin, 2014) these display anticipatory behavior more often but they also explore longer distances than pet dogs – a behavior that is encouraged by hunters but rather discouraged by pet dog owners. Furthermore, when during the trials in the Master thesis the owner was hiding, the dogs were confused not to find the owner at the place where he should have been had he continued to walk. For far ranging dogs this may implicate for practical reasons that an owner who thinks his dog is lost should not return to the starting point of the walk because the dog will look at the continued path for him/her.

A similar idea was voiced by Kubinyi et al., (2003) in that learning contributes to the development of mutual mimicry in group mates. In their study owners performed a detour on their way home. During the first 30 detours all dogs followed the owner on the new route. Between trials 151 and 180, four dogs started to walk the detour before the owner displayed any intention to walk in that direction in 50-93 % of the cases. They described this phenomenon in the framework of social anticipation when the dog learned the proper sequence of an act performed by another (here the owner), so that it could (1) predict the action in this sequence, and (2) as a result start either a similar or a complementary action as a response. These observations suggest that the dogs' social anticipation ability contributes to behavioral synchronization and cooperative processes between dog and owner.

1.4.4 Welfare and walking issues

Data obtained herein reflects the explorative behavior of the dogs whilst off leash: All dogs travelled significantly longer distances than their owners ($p < 0.001$), see **Table R1.2.1, Fig. R1.2.1** even though a majority of the dogs displayed a travelling pattern of merely running back and forth of the owner (or following) not exploring off the path at all **Table R2.14.3, Fig. R2.14.3**. Results show that the distance and speed between owner and dog differs strongly, independent of the group the dogs belonged to or factors like age, size or exploration patterns see **Fig. R1.3.1; R1.3.2; R1.3.3**.

The importance of regular exercise for dogs is well known. The benefits to physiological and psychological well-being are widely documented by the veterinary world and organizations that support animal welfare (McConnell, 2006; DEFRA, 2006). Providing a dog with daily exercise can help maintain the heart and circulation, keep the dog at

a healthy weight and ensure the dog is less susceptible to psychological conditions such as depression (Reusche, 2011; Stilwell, 2014a). Feddersen-Petersen (1997) proposed for a healthy adult dog two to four hours off leash walking time per day; Hallgren (1997) postulated for an adult shepherd size dog three hours per day.

Dog ownership, however, does not guarantee that owners will regularly walk their dogs (Bauman et al., 2001). Walking behavior varies widely depending on country, culture and numerous other factors, including the opportunities offered to walk with the dog (for a review see Holland, 2019). Olsen (2008) found in Germany 43 % of the owners questioned (n=300) regularly walked their dog and let their dog off the leash. In the United Kingdom a questionnaire based study showed that the average dog spend 17 minutes off leash per walk, maximum half the time of the walk and 1 in 4 owners said they never let the dog off the leash, with 31 % of the owners thinking it is too dangerous, because the walking area is not safe. One in ten dog owners walked the same route every day with their dog. (<https://www.harringtonspetfood.com/dogventures>).

Sediva et al., (2017) found in the Czech Republic that the proPORTion of unleashed and leashed dogs was 60 % and 40 %, respectively and dogs were unleashed 2.8 times more likely in parks than in streets, because of dangers to the dog.

Christian et al., (2013) stated that in the US and Australia approximately 60 % of dog owners walked their dog, with a median duration and frequency of 160 minutes/week and 4 walks/week (for a review see, Christian et al., 2013) in concurrence with Westgarth et al., (2013) who found in Australia 40 % of people who live with a dog are not walking it at all. Demographic and behavioural factors that contribute towards owner's motivation to walk their dog was owning a larger dog; having an increased level of attachment to the dog; knowing the dog enjoys going for a walk; believing walking keeps the dog healthy; and having high social support from the family to go walking (Westgarth et al., 2016).

1.4.4.1 Walking gait

Each dog has an individual walking pattern, based on size, breed, and age etc. its gait being defined by step frequencies, velocity, length and width of step. A gait is formed through complex interactions between the musculoskeletal and the central and peripheral nervous system, where ambulation requires constant adaptation to both intrinsic and extrinsic factors. Conditions like walking on a leash, thus restricting the dog's individual natural gait, affects the function of the nervous and/or the musculoskeletal sys-

tem and disrupts their interactions, possibly leading to gait disturbances (Bruna et al., 2015). To be on a leash restricts the normal walking pattern of a dog, as the dog has to subsume its gait pattern to that of its owner (for differences in speed and distance, see **Fig. R1.2.1** and **Table R1.2.1; Fig. R1.3.1; R1.3.2; R1.3.3**).

It is understood that gait has the potential to be used as a window into neurodegenerative disorders and to classify markers of subclinical pathology. Parameters (or micro-gait features) in the gait cycle that have been identified as sensitive predictors of disease can be characterized into spatial or temporal categories: temporal parameters pertaining to intra-leg based timing events (e.g., velocity, length, width), and spatial parameters being related to measurements between the environment and skeletal features (e.g., pitch, roll, joint flexions) (VanUden & Besser, 2004).

Maes et al. (2008) demonstrated that the majority of these parameters differed between on-lead, off-lead and play activity in that the maximum velocity, acceleration and deceleration were greatest during play, least during on-lead walks and intermediate for off-lead walks with off-lead activity enabling the dogs' greater performance than on-lead activity. For all gaits, limb coordination involves coordinated movements of the forelimbs, coordinated movements of the hind limbs and a relationship between these two pairs for steady locomotion (Maes et al., 2008). This may be critically impaired by pulling on the leash and by frequent owner step modulations.

1.4.5 Walking speed of owner and dog

The results herein clearly show that the speed between owner and dog differs strongly, independent of the group the dogs belonged to or factors like age, size or exploration patterns see **Fig. R1.3.1; R1.3.2; R1.3.3**. The difference between owner and dog speed was statistically significant ($p < 0.001$; Wilcoxon Test). Ladha et al. (2016) also found that healthy dogs walked significantly further during off-lead than on-lead walks ($p < 0.001$; representing a 32 % greater distance) displaying a wide range of step frequencies and great variance of number of steps taken (Ladha et al., 2016). Therefore dogs display biomechanical differences compared to the owner and whilst on a leash subsume their pattern to that of their owner, which some may call synchronicity (Duranton et al., 2018) but basically reflects the inability to walk naturally, which in turn may lead to health problems.

Gaits and gait transitions play a central role in the movement of animals and symmetry is thought to govern the structure of the nervous system and constrains the

limb motions of quadrupeds (Wilshin et al., 2017). The leash and even the leash side influences gait symmetry (Maes et al., 2008; Peham et al., 2013). Furthermore, when analyzing a dog's gait, it is important that different dog breeds have diverse conformation/structure as a result of having been bred for different functions (Carr et al., 2015). As a result, structurally dissimilar breeds have significantly different quantitative gait characteristics. Carr et al. (2015) in their study argued that comparing gait characteristics of different breeds (here Border Collies to Labrador Retrievers) were related to differences in the original purposes for which these dogs were bred: Border Collies, being bred for herding sheep, required rapid changes in movement and speed. In contrast, Labrador Retrievers, bred for hunting, required straight runs to retrieve game and return directly to the hunter.

These contrasting functions might lead to structural differences that would then be reflected in quantitative modifications in gait characteristics for different breeds. Herein I did not assess gait characteristics, but the temporal and distance as well as speed measures do reflect differences **Fig. R2.13.1**, **Fig. R 2.13.2** including the over all significant speed variance of all dogs, **Fig. R2.13.1**; **Fig R2.14.1** implicating the importance for off leash exploration and exercise. Likewise, there might be significant alterations in quantitative gait characteristics between other breeds with differing functions (and therefore different structure) as well, such as the sight hounds (e.g. Whippets, Greyhounds and Borzoi see herein), which were bred to chase game using their vision over open fields at high speed for short distances, and the herding dogs (e.g. Collies) or the hunting dogs (Labrador Retriever). For breed and size of all participating dogs see **Table R2.12.1**.

1.4.5.1 On the leash: Physical Health implications of collar and harness use

In addition, the negative physiological impact of a collar has long been shown: Neck Injuries due to pulling or running fast to the end of the leash including bruising, whiplash, headaches, crushed trachea, damage to larynx, and fractured vertebrae. Hallgren (1992) demonstrated significant correlations between cervical (neck) damages and 'jerk and pull' on the dogs on a leash. Pauli et al. (2006) showed that intraocular pressure in the eyes "was significantly increased from base-line values when a force was applied to the neck via a leash to a collar, but not to a harness, in the dogs of this study." Intraocular pressure can cause serious injury to dogs already suffering thin corneas, glaucoma, or eye injuries. Based on the results of the study, dogs with weak or thin corneas, glaucoma,

or conditions for which an increase in IOP (like the sighthounds) could be harmful should wear a harness instead of a collar, especially during exercise or activity.

However, even with a harness dogs should not always be on the leash. Kis (2018) found that due to the pull of the leash the dog changed to a slower gait pattern (from trot to walk) on the ground. When off leash the dogs showed significant deviations in stride length, step length, and step width. Significant deviations of the parameters were the result of the different walking speeds. On the treadmill, dogs walked at a predefined walking speed, a pattern identified as walk or amble. On the ground, the mostly applied gait type was trot. This indicated significant reductions in many gait parameters compared to ground walk without leash: stride length, step length and step widths of the pelvic limbs were significantly reduced. The suspected cause of the deviations was the reduction in speed of the dog due to the reaction to retracting leashes. Dogs are trained to slow down on the pulling of the leash. Most dogs in the study switched from trot to walk and it was observed that during ground walking the dogs exerted a one and a half time larger pulling force compared to treadmill walking, while they switched to a slower gait type.

Peham et al. (2013) looked at the pressure distribution under different types of harnesses used for guide dogs and found that since guide dogs usually walk on the left side of the person to be guided an asymmetric tension force was expanded, acting on the dog's trunk. They concluded that a minimum force of about 30 N was necessary for dog handlers to stay in contact with their dog. The maximum force they found in their study was higher than that of dogs pulling a wheelchair or sledge (Coppinger et al., 1998).

Thus, while it is unavoidable for dogs to be on a leash in many situations whilst sharing our urban environment, and while we subject them to this (sometimes necessary) restriction, it is important to realize the impact on physiological and psychological welfare. We should offer all dogs adequate opportunities for cognitive and biomechanical welfare by allowing them to explore the world at their own pace and in their own time.

1.4.6 GPS /Tracking device

It has been proposed that the use of a GPS device may influence the dog-owner behavior (Mancini et al., 2012) in that dogs respond to their (more relaxed) owners' emotional display by reading their facial expressions and body language, changing their behavior accordingly. This factor could not be controlled for in this study. For purposes of collecting data the GPS system was a valuable tool to monitor the movement of freely exploring dogs and to gather a catalogue of information, see **Table M1.2.3; Table M1.2.5.**

Location-tracking technology has been used with animals for a long time, for example to monitor endangered populations of wild species in conservation efforts. In the last years GPS devices have increasingly been used during hunting, to establish the location of the dog: Paldanius et al. (2011) focused in their study on issues of system reliability and usability during the hunting process, while Weilenmann & Juhlin (2011) investigated how the technology allows the hunter to interpret the dog's behavior. Herein the data was used to establish the e.g. distance and time the dogs travelled as well as their travelling patterns, **Table M1.2.5; Fig. M1.2.2; Fig. M1.2.3; Fig M2.2.4.2- Fig. M2.2.4.5.**

In this study all participants (owner and dogs) were novices to the GPS device and prior experience could be precluded. Active hunting dogs were excluded from participation and only pet dogs partook. Owners, nonetheless, may have felt more comfortable or assured having the GPS device on their dog which may have had an impact on their or their dogs' behavior, respectively (see also, discussion 1.4.2).

As the majority of owners were uncertain of their dog's exploration behavior (see also Part 3) one option for the future may therefore be the use of a GPS device while the dog is off the leash. This would also proof a useful tool in case of discussion whether the dog was chasing prey etc. as the owner would have clear documentation of the exploration route of their dog, see for example **Fig. M 2.2.4.2-Fig. M 2.2.4.5.** Because owners are legally responsible for their dogs' welfare and behavior, tracking their movement may be helpful and reassuring and being able to track the dog the owner may then decide whether and when to call the dog back allowing the dog more freedom of exploration.

1.5 Conclusion

As hypothesized dogs did display a high motivation based on a strong bonding to return to their owner, regardless of breed, area or external stimuli whilst free ranging. They displayed the cognitive ability of spatial orientation to find their way back to the owner, in known and unknown areas, regardless of distance explored. As hypothesized the dogs found back to a specified, varying non-stationary locality (i.e. their owner) displaying an understanding of object permanence. As hypothesized most dogs did not explore extensively (> 20 minutes; >2000 m) on runs >20 m neither with respect to distance nor time. The majority of dogs did not explore beyond the radius of 150 m from their owner, adding an argument for offering dogs opportunities to walk off leash and establishing areas where they may run free.

The dogs, depending on their individual traits, character, learning experience, breed, socialization and age utilized different exploration patterns as expected. Dogs, in different degrees used both egocentric and allocentric cues and mechanisms for spatial cognition and displayed great variation in exploration patterns. No significant difference with respect to area (known or unknown) traversed was found.

As hypothesized the length and speed of and on the walks differed between owners and dog based on physiological and biomechanical factors with all dogs travelling longer distances and at a significantly higher speed than their owner. Results were independent of the group the dogs belonged to or factors like age, size or exploration patterns, underlining the importance to offering all dogs the opportunity to explore off leash at their own speed and gait pattern.

Interestingly and as hypothesized dogs of one owner (dyads or triads) displayed similar exploration patterns. Significant linear correlations could be shown between different parameters like distance and time explored of dogs of one owner indicating the influence of owner behaviour as opposed to breed or age determinants.

2 Individual dogs; dyads and triads

2.1 Introduction

In this second Part I consider the exploration and orientation behavior of the individual dogs and the dog dyads/triads. How do they explore in different environments? Do they explore together and do they use similar strategies? How are patterns exhibited between dyads/triads of dogs? Do age, breed, sex and/or reproductive status influence the exploration behavior displayed? Does personality and temperament play a role? Do the individual dogs or the dog teams initiate hunting behavior when not called by their owner? And whilst exploring together how do they communicate?

Data were collected on 30 dogs regarding their exploration patterns in known and unknown areas while walking on four consecutive walks with their owner, without being called. GPS data was collected on each dog and 51 parameters were recorded. Furthermore, if two or more dogs belonged to one owner data were compared to assess whether the dogs explored as a dyad/triad and displayed similar exploration patterns and to evaluate whether they explored in cooperative or synchronized movements (see Section 2.15; 2.16).

2.1.1 Orientation

In considering spatial cognition of dogs it is important to distinguish between small-scale and large-scale conditions (Lea & Osthaus, 2018). Most studies involve a small scale in which the dog is finding its way within a small area like a maze, a laboratory, or at most a field (see e.g. Akos et al., 2014; Duranton et al., 2019; Duranton et al., 2017; Scandurra et al., 2018; Fugazza et al., 2017). Large-scale conditions may involve navigation on the scale of hundreds of meters or even kilometers, like some dogs displayed herein, and it is debatable whether the same cognitive capacities are required for both conditions and thus, whether the studies performed may be generalized from small to large scale.

Dogs are able to perform in a small area well (Fiset 2007: distance and direction from landmarks in a room; Mongillo et al., 2017: T-Maze; Macpherson & Roberts, 2010: radial mazes; Scandurra et al., 2018b: Plus-Maze; Fabrigoule, 1976: simple mazes), using landmarks to establish routes (e.g., Fugazza et al., 2017; Fiset, 2009) and being able to find their way to a designated place by a novel route (e.g., Lea & Osthaus, 2018; Fabrig-

oule & Sagave, 1992), though not without error (Gaunet & Besse, 2019; Seguinot et al., 1998). Reports of large-scale navigation by dogs are largely anecdotal and studies usually pertain to feral or free ranging dogs (Daniels & Bekoff 1989; Dürr et al., 2017; Hudson et al 2017, 2019; Krauze-Gryz & Gryz, 2014) or dogs were on a leash (Gaunet & Besse, 2019: Guide dogs).

In a familiar environment with distinct landmarks, navigators may utilize these as cues (Waller & Lippa, 2007) to find their way. In an unfamiliar environment, however, animals have not associated landmarks with locations of interest and spatial updating, a cognitive process that involves continuously computing the spatial relations between the navigator and objects in the environment as the navigator moves (Farrell & Robertson, 1998) and necessary to maintain orientation (Gallistel, 1990). These spatial reference systems are typically divided into two categories: egocentric, in which the navigator updates an object's location, using a reference system centered on the body, typically defined by the reference directions of front, back, right and left (Scandurra et al., 2018; Wang, 2016) and allocentric, in which the navigator updates his or her position in the environment using a reference system external to the body and anchored in the environment (Fugazza et al., 2017; Gallistel, 1990).

I hypothesize that the area (known versus unknown) will make a significant difference with respect to the dog's exploration behavior and that the distance explored (runs >20 m) by the dogs varies in known areas compared to new areas. I further hypothesize that the time travelled (runs >20 m) by the dogs varies in known areas compared to new areas, as they may show a reduced latency to approach objects and thus spend less time exploring objects (Moretti et al., 2015).

Any spatial cognitive process requires memorizing specific landmarks, positions and locations (allocentric cues), allowing the dog, in its most sophisticated form, to establish a cognitive map in order to orientate itself and navigate in the surrounding environment (cf. Macpherson & Roberts, 2010; Etienne & Jeffrey, 2004). Alternatively or additionally an animal may integrate signals or cues which indicate the extent of self-motion along their locomotion trajectory (Wehner & Srinivasan, 1981; Wittlinger et al., 2007), or by using the geomagnetic field of the earth to establish a sense of compass direction (Hart et al., 2016; Wiltschko & Wiltschko, 2005). Further aspects of successful orientation are learning opportunities (e.g. social referencing or trial and error learning) and cognitive skills which are influenced by having the opportunity to explore, as dogs

likely require more experiences across their lifespan to learn to develop individual navigational strategies.

It has been shown that dogs are able to encode spatial information related to local and global allocentric cues (Fiset 2009, 2007) as well as egocentric cues (Scandurra et al., 2018). Intrinsic (egocentric) cues are provided by the dogs own movement, derived from self-generated kinaesthetic (proprioceptive) and vestibular signals, and extrinsic (allocentrically) cues are provided by environmental information (e.g. optical, acoustical, olfactory or magnetic input). This facilitates the dogs to navigate spatially by using geometric relationships between objects, landmarks, and by computation of distance and direction vectors using multiple landmarks (Scandurra et al., 2018; Fiset & Malenfant, 2013; Macpherson & Roberts, 2010).

Dogs are capable of integrating spatial signals during locomotion, continuously updating the information about the distance and direction from an object (Cattet & Etienne, 2004) and developing novel paths based on knowledge of paths already used before (Séguinot et al., 1998). Fugazza et al. (2017) postulated that dogs, in a social learning paradigm, preferentially relied on allocentric information in matching the location of the owner's demonstration (Fugazza et al., 2017) but dogs have been shown to prefer egocentric strategy to solve an object finding task (Fiset et al., 2000; Fiset & Malenfant, 2013). However, dogs are able to use both egocentric and allocentric references in different type of tasks and are able to flexibly switch even to a non-preferred strategy when the preferred one becomes useless (Cattet & Etienne, 2004; Chapuis et al., 1983; Fiset & Malenfant, 2013). Thus, dogs are able to learn an egocentric strategy when allocentric cues are made unreliable (Scandurra et al., 2018).

Therefore, the dogs tested herein could arguably flexibly switch their strategies depending on whether they explored in known versus unknown areas, utilizing in former more allocentric cues and in latter more egocentric cues, depending, however, on factors like sex, age, reproductive status and prior learning and experiences, which may be reflected by their different exploration patterns.

I hypothesize therefore that domestic free-ranging pet dogs will find back to a specified, varying non-stationary locality (i.e. their owner) in different environments even subsequent to having explored a certain distance i.e. out of range of visibility or/and olfaction based on their ability to establish cognitive maps and the use of spatial reference systems (Fugazza et al., 2017; Scandurra et al., 2018; Wang, 2016) including egocentric and allocentric cues like the geomagnetic field.

2.1.1.1 Male & female dog orientation differences

It has been postulated that sex differences exist in regard to spatial orientation (Hawley et al., 2012; Mongillo et al., 2017; Scandurra et al., 2018; Shah et al., 2013) based on the argument that male dogs' advantage in solving spatial navigation tasks could have been inherited from competition for mates, which in most cases encompasses an extended home range compared to females. Literature postulates that male dogs perform in orientation trails better than females, Lang (2014) proposes that males hunt longer distances and faster than females, Koster & Tankersley (2012) state that male dogs and older dogs are significantly associated with greater hunting success. Wells & Hepper (2003) assert that male dogs identified the correct direction of the trails more frequently than females. Sparkes et al. (2014) also found a significant effect of sex; male dogs utilized a larger area than females and males travelled further each day compared with females which is, however, in contrast to Van Kesteren et al. (2013) and Dürr & Ward (2014), where no difference between male and female area used or distance travelled per day was found.

Male dogs showed more flexibility in changing the navigation strategy from allocentric to egocentric (Fugazza et al., 2017) but females learned faster and made fewer errors in learning a task in a T-maze (Mongillo et al., 2017). Scandurra et al. (2018b) found no effect of sex on strategy preference in a plus-maze, the probability of success in changing the navigation strategy however, increased in females and decreased in males with age. Scandurra et al. (2018) pointed out however, that as a side effect of artificial selection, the differences between males and females, which are maintained in nature through natural/sexual selection, could have changed during and after domestication. Furthermore, living in close proximity with and depending on humans could have made it less essential to maintain sex-specific traits.

Sex differences are typical of polygynous, rather than monogamous species, underlining the link between reproductive strategies (finding a mate) and spatial cognitive abilities (Ecuyer-Dab & Robert, 2004). Ecuyer-Dab & Robert (2004) stated that females' higher involvement in protection of the offspring may have favored a superior spatial ability in spatially restricted areas, whereas male dogs possess better spatial orientation abilities in unrestricted areas. Males may prefer an allocentric navigation – i.e. using the relative position of the objects inside the surrounding space to orientate – and females an egocentric navigation strategy, referring primarily to their motor responses (Hawley et al., 2012). Mongillo et al. (2017) showed that female dogs were faster than males in acquiring a spatial learning task, but no difference emerged between sexes in a reversal

learning task. Therefore, I hypothesize that male and female dogs explore differently with respect to distance and that males and females may utilize different spatial navigational patterns.

2.1.1.2 Neutered& intact dogs

Different performance in spatial navigation has also been proposed between intact and spayed/neutered dogs (Scandurra et al., 2018). Sexual hormones are proposed to be the physiological factors for sex differences in spatial navigation as they act at the organizational level by shaping the brain during development (Isgor & Sengelaub, 1998; Williams et al., 1990) and additionally they have activational effects, leading to differences between sexes in adult individuals (Daniel, 2006; Martin et al., 2007). It has been argued that castration adversely affects working memory - a limited capacity resource used for temporarily preserving information while simultaneously processing the same or other information-, but not reference memory - a long lasting memory used to store information that remains constant over time- during navigation (Gibbs & Johnson, 2008; Locklear & Kritzer, 2014). Mongillo et al. (2017) proposed that castration affected spatial learning in females, with ovariectomized females performing significantly worse than intact females and showing a bias towards egocentric strategies to solve a spatial task, indicating a potential role for ovarian hormones in strategy use, whereas no effect was found for the castration in male dogs (Mongillo et al., 2017). Scandurra et al. (2018b) similarly postulated an effect of gonadectomy in females with a preference for using an egocentric strategy and even proposed that ovariectomy could impair a female's ability in a socio-cognitive task (Scandurra et al., 2019). Sparkes et al. (2014) advanced that neutered male dogs used significantly larger areas and travelled further than spayed female dogs. Therefore I hypothesize differences exist in distance and exploration patterns based on reproductive status of the dogs.

2.1.2 Exploration and neophobia

Exploration is important for animals to be able to gather information about features of their environment that may directly or indirectly influence survival and reproduction (Moretti et al., 2015) as it enables them to collect information about food distribution and abundance, shelters, predators, escape routes or potential mates (Dall et al., 2005). To acquire such knowledge, an individual may assess its environment alone (Day et al., 1998), by intraspecific observational learning (Range & Virányi, 2014; Scandurra et al.,

2016) or by using public information (Valone & Templeton, 2002). The extent of exploration of each animal is balanced against its level of neophobia. Highly neophilic animals are quick to approach and explore a novel object, while highly neophobic animals are slow to do so (Day et al., 2003). The exploration behavior of the dogs and thus their exploration patterns should therefore be influenced by their prior learning, experience, training, personality and perhaps breed and sex.

A preference for novelty, neophilia, has been linked to the neurophysiology of temperament traits associated with behavioral activation, extraversion and persistence (Depue & Collins, 1999; MacLean et al., 2019; Rao et al., 2018). It has been argued that neophilia might be an adaptive consequence of selection during domestication for animals living in association with man (Rao et al., 2018; Sheppard & Mills, 2002). Neophilia has been associated with both an increased tendency to approach novel environments and more innovative behavior, and dogs might be naturally predisposed towards neophilia (Kaulfuß & Mills, 2008).

Neophobia is linked to exploration because individuals only explore if they are interested in an object and the same is true for active avoidance. Accordingly, neophobia has been defined as *'the avoidance of an object or other aspect of the environment solely because it has never been experienced and is dissimilar from what has been experienced in the individual's past'* (Stöwe et al., 2006, p. 1079). Neophobic responses are important because they can reduce exposure to danger but, on the other hand, they can also constrain explorative behavior and thus opportunities for learning. Arguably, dogs that are always on a leash or who are inhibited by the owner due to restrictive walking patterns are repressed in their learning behavior. Depending on a species' ecology and the animal's motivation, individuals approach and investigate changes in their environment with different latencies and for variable periods which may also be influenced by the social context (Day et al., 2003; Rao et al., 2018; Stöwe et al., 2006). Studies propose that dogs are less cooperative than wolves within groups of conspecifics, and thus that with novel objects, potentially perceived as a source of danger, wolves might rely more on support from conspecifics than dogs (Moretti et al., 2015; Rao et al., 2018). Thus wolves could be more prone to synchronize than dogs because cooperativeness with conspecifics is more important for their daily survival than for dogs.

On the other hand, the presence of a familiar conspecific, the second dog, has been shown to be more effective for social buffering, namely in alleviating stress responses (Kiyokawa et al., 2014). Therefore, in potentially stressful situations, as when

confronted with a novel object or area, the presence of a conspecific might be a valuable resource reducing the potential stress, which would lead to the expectation that familiar dogs would explore together.

Thus dogs owned by the same individual were assessed individually and together to see whether they actually explored as a dyad and displayed similar exploration patterns. Furthermore, whether differences in exploration patterns emerged, depending on whether an area was known or unknown to the dog(s). Kaulfuß & Mills (2008) proposed that neophilia is an adaptive consequence of selection by living in association with humans, which then may decrease the dependency on a group in their exploration of novel objects/areas (see also, Rao et al., 2018). Moretti et al. (2015) demonstrated that the presence of a conspecific facilitated the manipulation of novel objects longer, however, they also stated that dogs not approaching a novel object often indicated less interest by the dogs (as compared to wolves) rather than neophobia.

Exploration performance may also be influenced by breed typical biological dispositions, including differences in the organization of motor patterns associated with foraging (predatory) responses or differences in motivation. Lifetime experience may also play a significant role in the behavior of individuals (Udell et al., 2014; MacLean et al., 2019) as well as adaptations to their respective feeding ecologies (Fleming et al., 2017) and different ecological niches (Rao et al., 2018). Furthermore, owner attitudes and behaviors have been shown to influence exploratory behavior in dogs (Huber et al., 2017; O'Farrell, 1997).

Exploratory behavior is considered as an aspect of sensory processing involved in investigating novel stimuli rather than an instinctive behavior (Kelley et al., 1989) depending on motor and spatial capabilities, motivation (Caston et al., 1998) and stress. Studies have also demonstrated a linkage between learning, memory, exploratory behaviors and genetics (MacLean et al., 2019; Puurunen et al., 2018; Shin et al., 2016), and breed differences (reaction to social threat; reaction to novel objects, fear of strangers and of new situation; MacLean et al., 2019;) have been proposed (Cimarelli et al., 2019 Border Collies vs. other breeds; Sarviaho et al., 2019 German shepherds; Tiira et al., 2016 German shepherd/Great Dane/Lagotto Romagnolo/Saluki; Turcsán et al., 2018 Border Collies).

Fearfulness, thus an inhibitor of exploration, has been linked to genetics. Puurunen et al. (2018) found nine metabolic features associated with fearfulness across breeds. Zapata et al. (2016) found two distinct genomewide association loci which were

associated with several traits, including fear and aggression and each was previously shown to be associated with morphological traits (MacLean et al., 2019; Zapata et al., 2016). Sarviaho et al. (2019) identified novel loci for fearfulness on chromosomes 20 (the oxytocin receptor gene *OXTR*, a Rho GTPase gene *SRGAP3*, a metabotropic glutamate receptor gene *GRM7* and a plasma membrane calcium ATPase gene *ATP2B2*) and 7 (a region that is largely syntenic to a human 18p11.2 locus), respectively, loci overlap genomic regions that include candidate genes affecting glutamatergic and dopaminergic neurotransmission.

However, even if breed-typical genetic predispositions (e.g. Sarviaho et al., 2019 fearfulness in German shepherd; Tiira et al., 2016 Lagotto Romagnolo; Turcsán et al., 2018 Border Collies) account for some of the variability seen between dogs exploration performance, lifetime experience, physical attributes and other biological or psychological variables function to compound this effect (Udell et al., 2010a). Some behavioral traits attributed to breeds are rather influenced by the lifestyle and behavior of the owner (Gladwell, 2006). Environmental factors such as lack of socialization, poor maternal care (Foyer et al., 2016) and aversive learning are known risk factors for canine fear (Tiira et al., 2016), thus increased neophobia and decreased explorative behavior. Breed stereotypes can also alter both dog and owner experiences (Twining et al., 2000), which may in turn contribute to the development of something like the expected behavior in a dog of a particular breed, for instance hunting behavior - a self-fulfilling prophecy effect - which cannot be discounted for in this study.

2.1.3 Breed

Inherent in observations of dog behavior is the notion that much is breed typical and will persist, even in the absence of training or motivation (Spady & Ostrander, 2008). Thus, herding, pointing, tracking, hunting, and so forth are likely to be controlled, at least in part, at the genetic level which would also impact on the exploration behavior as it applies for instance to chasing prey. The domestic dog displays great levels of morphological and behavioral diversity and its phenotypic radiation is a product of restricted gene flow, artificial selection and breeding (MacLean et al., 2019; Ostrander & Kruglyak, 2000). Morphological changes of dogs are smaller cranial volumes and mandibles, smaller auditory bulla as well as widened snouts, decreased tooth size, decreased body size, altered coat color and pattern, and altered tail and ear carriage (Spady & Ostrander, 2008). These factors have generated a great level of diversity among the more than 400

breeds of dog recognized worldwide, many of which were developed for highly specialized tasks (MacLean et al., 2019; Sarviaho et al., 2019; Wilcox & Walkowicz, 1995) which may also account for different exploration behaviors displayed herein.

Parker et al. (2017) divided modern dog breeds into five major groups, with the members of each group sharing some common ancestry (Parker et al., 2017; Parker et al., 2007). Lawson et al. (2012) found the term “breed” problematic and divided into ancient (basal) breeds (including the Akita, Basenji, Eurasian, Finnish Spitz, Saluki, and Shar-Pei) based on high bootstrap values. They suggested that, combined with known demographic fluctuations in numerous breeds, throughout history global populations experienced numerous episodes of diversification and homogenization (Larson et al., 2012). They pointed out that the majority of modern breeds were only created in the past 150 years, emerging from a relatively homogeneous gene pool, formed as a result of human migration and the subsequent merging of multiple, previously independently evolved dog lineages (Larson et al., 2012). Parker et al. (2017) postulated that the change from hunting to agricultural endeavours initiated early breed formation which occurred in multiple regions and that these geographical regions defined a foundational canid population within which selection for universally relevant behaviors occurred independently, separating the regional groups also by function (Parker et al., 2017). To what extent such genetic radiation affected the socio-cognitive skills of the dogs still has to be determined.

Herein, I use the term “breed” when referring to modern dog breeds recognized by kennel clubs.

Identifying the genetic basis of behavioral traits, which are typically assumed to have a more complex genetic architecture, has proven to be a challenging endeavour (Sarviaho et al., 2019; Wayne & Ostrander, 2007), however several studies have uncovered genetic variants associated with behavioral differences between breeds (Cagan & Blass, 2016; Rigterink et al., 2014; Sarviaho et al., 2019; Wayne & vonHoldt, 2012). MacLean et al. (2019) quantified the heritability of 14 behavioral traits across breeds. Cagan & Blass (2016) identified 11 genes with fixed functional differences between dogs and wolves pointing towards selection on both morphological and behavioral phenotypes, three of which involved brain development potentially contributing to the behavioral differences between dogs and wolves, including behavior like fear and aggression. Puurunen et al. (2018) further proposed that nine metabolic features were significantly associated with fearfulness. The most prominent change included increased plasma glutamine and γ -glutamyl glutamine (γ -Glu Gln) levels in fearful dogs across breeds, which

of course may have an impact on exploration behavior. Sarviaho et al. (2019) identified novel loci for fearfulness on chromosomes 20 (the oxytocin receptor gene OXTR, a Rho GTPase gene SRGAP3, a metabotropic glutamate receptor gene GRM7 and a plasma membrane calcium ATPase gene ATP2B2) and 7.

The idea that dog breeds should differ in social behavior and intelligence is often assumed. While it has been shown that some breeds differ in developmental rate (Scott & Fuller, 1965), motor pattern presentation (Coppinger & Coppinger, 2001) and approach avoidance response (Plutchik, 1971), it has been difficult to demonstrate consistent breed differences in other areas, including social cognition (Doréy et al. 2009; Pongrácz et al. 2005; Udell et al., 2014, but see MacLean et al., 2019 for the heritability of 14 behavioral traits across breeds).

Cultural expectations about which breeds are considered cooperative (or independent) might result in differential treatment, and thus differential performance (Udell et al., 2014), which may have little to do with inherent differences between individual breeds. Helton & Helton (2010) pointed out another potential setback: the failure to account for physical (or biologically determined) explanations first. In fact, breeds with some morphological traits (larger size, frontally placed eyes) tend to outperform other breeds on pointing tasks (Gácsi et al., 2009a; Helton & Helton, 2010). This is likely due to superior visual acuity and depth perception. Bognár et al. (2018) further postulated that skull length, which was previously shown to indicate quality of vision (McGreevy et al., 2004) and may also be related to retina structure and attention for visual cues (Gácsi et al., 2009b) influences cognitive processes.

Yet, to date, relatively few studies have considered the influence of specific breeding criteria on socio-cognitive task performance (MacLean et al., 2019; Udell et al., 2014). Differential treatment by owners based on a dog's size, form, breed designation, or individual predispositions could influence a dog's behavior on social or problem solving tasks such as finding their owner or the level of exploration itself in a multitude of ways. Differences in behavior among dog breeds are often seen as temperament differences. However to understand any behavior biologic determinants must be understood, whether regarding motor patterns, critical periods, or innate behavior, which may be differences in size or shape or small differences in the chemical structure of a neurotransmitter or a hormone. As we define breed by a structural standards derived through a process of selecting breeding stock from among dogs that performed a particular task, innate behavior implies the structural capacity to perform. In this study no significant

breed or size specific differences regarding exploration patterns could be found, which however may also be due to the small sample size.

2.1.4 Personality

Personality has been defined as the individual consistency in behavioral responsiveness to stimuli and situations (Gosling & John, 1999), or behavioral consistency across time and contexts (Miklósi et al., 2014) and is recognized in a wide range of animal species, including dogs. A large number of studies have used various questionnaires to test for associations between behavioral/personality traits and genetic, demographic, management, lifestyle, and owner-related factors. Studies also indicate that personality plays a role in the cognitive processing of environmental stimuli in the domestic dog (Barnard et al., 2018; Ishikawa et al., 2018) which would impact on exploratory behavior.

Published tests of dog personality mainly fall into three categories: puppy tests designed to predict adult behavioral tendencies (e.g. Riemer et al., 2014; Aher et al., 2013; Svobodová et al., 2008), tests for assessing dogs' potential problematic behavior (e.g. Netto & Planta, 1997; Bollen & Horowitz, 2008), and tests for working dogs (Rüfenacht et al., 2002; Svartberg, 2002). Most existing dog personality tests have very specific aims and focus only on a limited aspect of dogs' personality. Turcsán et al. (2018) introduced the Vienna Dog Personality Test (VIDOPET) consisting of 15 subtests and yielding five factors: Sociability-obedience, Activity independence, Novelty seeking, Problem orientation, and Frustration tolerance, a behavior test developed to evaluate and measure pet dog personality without falling into one of the three categories above. This test has not been validated in German and could therefore not be used herein to assess individual dogs' personality.

Of studies that examined multiple breeds, breed had a significant effect on a number of behavioral traits (MacLean et al., 2019; Rugbjerg et al., 2003; Duffy et al., 2008; Blackwell et al., 2013; Starling et al., 2013b; Temesi et al., 2014; Asp et al., 2015). Also genetic effects have been documented within breeds, including subdivision differences between working dogs and pet or show dogs (MacLean et al., 2019; Serpell & Hsu, 2005; Lofgren et al., 2014).

Other factors associated with dog behavior or personality are for instance sex and reproductive status (Temesi et al., 2014: dog-directed fear; McGreevy & Masters, 2008: separation-related anxiety; Blackwell et al., 2013: fear of noises; Starling et al., 2013a: boldness) and age (Starling et al., 2013a: older dogs showed lower scores for boldness;

Kubinyi et al., 2009: trainability; Vas et al., 2007: inattentiveness; Lofgren et al., 2014: human- or object-directed fear; Temesi et al., 2014: neuroticism). Furthermore, the experience of the dog influences specific characteristics, for example, the level of daily exercise was associated with several personality traits (Lofgren et al., 2014) and personality traits of the owner also influence dog behavior (Konok et al., 2015; Turcsán et al., 2012).

Thus, both evolutionary (selective) changes and developmental experience (learning) clearly contribute to dogs' behavioral phenotype, including the ability to solve social problems in the anthropogenic environment (Hare & Tomasello, 2005; Miklósi & Topál, 2013; Udell et al., 2010).

With respect to exploration behavior the risk-reward hypothesis (Sih & Del Giudice, 2012), postulates that boldness makes individuals more proactive and explorative. In dogs, boldness is described as an individual characteristic providing less aversion to risk or novelty that enables the animal to actively seek out and engage in social interactions (at both cooperative and competitive levels), as well as toward non-social objects or events (Starling et al., 2013; Svartberg, 2002; Svartberg, 2005; Turcsán et al., 2018). Kubinyi et al. (2009) applied a principal component analysis, and demonstrated that boldness was age-dependent, with younger male dogs (younger than two years) scoring higher on the boldness factor scale than older or female dogs. Overall, intact males were the boldest group, whereas spayed females were the least bold.

Sociability, also a personality trait of dogs (Barnard et al., 2018; Ishikawa et al., 2018), may influence the exploration patterns of the dogs in that they either choose to explore alone or with a conspecific. Dogs, when given the option, live in social structures in which affiliative interactions may prevail against anti-social behaviors. Sociable individuals may seek the presence of conspecifics during a walk, while more unsociable dogs would be expected to explore alone. In the realm of behavioral ecology, it is proposed that the social behavior of males and females is differentially targeted by selective pressures (Scandurra et al., 2018b). It has been postulated that males are more sociable than females in intraspecies contact but females are more likely to interact interspecifically, i.e. with humans (see e.g. Starling et al., 2013: male dogs appeared to be less sociable than females, with a pronounced effect in dogs belonging to the 4–8 years age group). A recent study proposed that canine sociability may be the result of the canine homologous Williams-Beuren syndrome (vonHoldt et al., 2017), a genetic disorder that in humans causes hyper-sociability. I therefore hypothesize that dogs of one owner (dyads/triads) display similar exploration patterns.

2.1.5 Hunting behavior

One of the main issues with the owners (and main difficulty with finding volunteers) was to what extent the pet dogs would display hunting behavior when not being called and under constant supervision (for the owner assessment of the expected hunting behavior of their dogs see Part 2 and discussion Part 3).

Hunting behavior has been defined by Coppinger & Coppinger (2001) as canine predatory motor sequence: orient > eye (body still, gaze fixed, head lowered) > stalk (slowly forward, head lowered) > chase (full speed) > grab-bite (disabling the prey) > kill-bite > dissect > consume. In wolves, the full canine predatory motor sequence is reliably triggered by the movement of prey. The predatory sequence has become relaxed in dogs, however, due to a shift in niche from hunter to scavenger (Coppinger & Coppinger, 2001). Importantly, there are similarities between behaviors associated with the predatory motor sequence and those required of dogs in many socio-cognitive tasks like spatial orientation (Lord et al., 2016).

Dogs are primarily scavengers (Marshall-Pescini et al., 2017a; Fleming et al., 2017), dependent mostly on human refuse and even free ranging dog hardly engage in active hunting behavior (Atickem et al., 2009; Vanak & Gomper, 2009; Newsome et al., 2014; Marshall-Pescini et al., 2017a; Fleming et al., 2017).

Many pet breeds do not display a consistent predatory motor sequence (Udell et al., 2014) and individual dog's uniquely developed predatory sequence (or lack-there-of) may influence performance on cognitive tasks; especially those related to tracking movement (orient, eye) and goal directed navigation (stalk, chase). Thus, relevant components of the predatory sequence may influence canine performance on a range of cognitive tasks based on biological predispositions (Udell et al., 2014). These cognitive patterns however are required for spatial orientation egocentrically and/or allocentrically in order to navigate the dogs own position in space and time as well as the anticipation of the owner movement (if not visible) to find him/her again.

Cooperative hunting is believed to have important implications for advanced cognitive abilities and the evolution of sociality and variation in the level of hunt organization may be influenced by the cognitive, behavioral and athletic adaptations of the dog (Bailey et al., 2013). Group decision-making, focusing on the rules governing group movements and information transfer amongst individuals (King & Cowlshaw, 2009) depend, to some extent, on the cognitive abilities of the dogs (for instance their memory

capacity, see e.g. Brosnan et al., 2010) and hunting success is likely also limited by locomotor performance (Bailey et al., 2013) of the individual dogs.

In the context of hunting behavior, cooperation can simply mean two or more individuals (kin or non-kin; but more common amongst kin than non-kin, due to the additional indirect benefits associated with helping related individuals, for example, kin selection; see Nowak 2006, for review of the evolution of cooperation) increasing their fitness by acting together to achieve a common goal (Brosnan & Bshary, 2010). On average, cooperative hunting is expected to increase fitness benefits to the individuals involved, even if some individuals incur a temporary cost (e.g., Krebs & Davies, 1987). The fitness benefits derived from cooperative hunting seem to arise from, for example, prey being captured more effectively (in less time or over a shorter distance) and larger prey being captured (thus the risk of injury and energetic costs are reduced and per capita rate of food intake is increased) (Creel & Creel, 1995; Rasmussen et al., 2008).

Cooperative hunting behaviors require a high level of awareness of each other's behavior and coordination between group members (e.g. include fanning out before approaching prey, chasing prey into ambush groups, surrounding and distracting prey) (Bailey et al., 2013), behaviors which may be observed in domestic dogs and some of which were displayed during the walks. Range et al. (2019) postulated that dogs show limited cooperation with conspecifics (in comparison to wolves), but enhanced interspecific cooperation with humans. Brucks et al. (2018) in this line argued that based on effects of socio-ecological factors (wolves are cooperative hunters and breeders, while dogs predominately scavenge and raise their young alone) no longer rely on coordinated actions (but see, Bonanni et al., 2010; Bonanni & Cafazzo, 2014; Cafazzo et al., 2014).

Furthermore behavioral synchronization, an evolutionary adaptive mechanism, fostering social cohesion between conspecifics, may be displayed by the dyad. Different types of synchronicities exist, such as temporal synchrony, location synchrony, and activity synchrony. Dogs have been shown to demonstrate behavioral synchronization with conspecifics in a number of activities, for instance movement (Scott & Fuller, 1965). Dogs have been observed to synchronize their behavior and pace when running together (Scott & Marston, 1950; Scott & McGray, 1967). It has also been shown that dogs follow their conspecifics' direction of walking during group departures (Bonanni et al., 2010) and that they synchronized (both location and activity synchrony) with their social partners (Bonanni et al., 2010). Synchronization is linked to affiliation between the partners: being synchronized strengthens social bonds between individuals; it has been

argued that the more affiliated two individuals are, the more they behave synchronously (Duranton et al., 2017).

Duranton et al. (2017) proposed that synchronicity may reflect rules evolved for adaptation to the environment before domestication, because dogs may be predisposed to follow their favorite partners and/or the more experienced individuals in their group. Thus we would expect within the dyads that dogs display either temporal, location or activity synchronicity with one leading or initializing individual. The dynamics of the social group are likely to influence strongly the potential for cooperative behaviors but as it is a complex behavior it can be modulated by life experiences, attachment structures or learning history. Thus, it is easy to see how cognitively advanced social skills and other social behavior adaptations may affect the dogs' ability to cooperate as may be displayed by the exploration behavior of the dyads/triads herein.

2.1.6 Communication intraspecifically

Communication takes place between members of the same species (here the dog dyad), as well as between interspecific individuals (dog-owner), based on the co-habitation process and inter-dependent relationship present in domestic dogs and humans. Communication “...a stylized signal or display by one individual modifying the response of another” (Barnard 2006, in Bradshaw & Rooney, 2016, p.139) may further encompass passive transmission of information like identity or reproductive status (Bradshaw & Rooney, 2016). Dogs engage in a multitude of communicative patterns: visual communication by modifying different parts of their body; tactile communication; auditory and olfactory communication, with vocalizations and body odors, respectively, which of course would be necessary for any cooperative action.

Dogs communicate visually with other individual modifying the position of different parts of their body. Control by voluntary muscles allows dogs to display a wide range of postures and body part positions that convey different information about the signaller's inner state and intentions (Handelman, 2012) like exploration or having observed prey. Therefore, individuals' proximity and direct interactions are required during visual communication (Wells, 2017). In close-range social interactions, dogs can also obtain and deliver information about their inner state through their facial expression, modifying gaze, ears, and mouth position (Siniscalchi et al., 2018).

Gaze following has been defined as “visual co-orientation with another individual's head direction allowing the gaze follower to gain information on its environment” (Wer-

hahn et al., 2016, p.188). In their study Werhahn et al. (2016) found that in contrast to wolves, dogs did not follow human gaze into distant space but that pack-living dogs and wolves, similarly vigilant to environmental stimuli, followed the spontaneous gaze of their conspecifics similarly often. They suggested that domestication did not affect the gaze following ability of dogs itself. Gaze following in dogs has also been linked to OXTR gene polymorphisms (Oláh et al., 2017).

A study aimed to assess the preferred communicative channel between verbal and gestural messages underlined a general preference for visual cues in dogs (D'Aniello et al., 2016). This may also have an implication on this study because I observed that dogs even when exploring out of range of vision would determine owner's location at intervals through visual cues and dogs with cameras could be observed to use visual cues instead of olfactory ones in seeking their owner (own observ.).

Among the different vocal signals, the bark is the most typical vocalization of dogs. The acoustic character of the bark, probably a product of adaptation as well as an expression of the signaller's internal motivational state, occurs in a wide range of behavioral contexts (Lord et al., 2009). Contrary to previous beliefs, which claimed that barks are a byproduct of domestication lacking any functional value, recent studies demonstrated the context-related acoustical features of barks (McCowan, 2004; Pongrácz et al., 2014), suggesting that they are means of communication in dogs and a form of referential signalling. Lord et al. (2009) proposed that barking is associated with mobbing behavior in dogs.

Herein vocalization changing travelling patterns of the second dog were barks when animal tracks were found, however, during the majority of walks dogs did not vocalize at all.

There are relatively few studies about the role of olfaction in dogs' communication with both conspecifics and humans. Body odors contain chemical signals that have specifically evolved to communicate with other individuals (Wyatt, 2015) and dogs' high olfactory sensitivity allows them to access social and contextual information through their sense of smell (Hecht & Horowitz, 2015; Wells, 2017).

Although rarely studied, tactile communication is an equally important aspect of dog communication. Tactile communication between dogs is used during agonistic interactions but also to maintain a social bond (Handelman, 2012; Kuhne et al., 2012) and during the walks most dogs established brief tactile contact with the owner and, if applicable, the second dog, in particular upon return from an explorative run.

2.2 Materials and Methods

2.2.1 Animals and Parameters

During a four year period from 2014 to 2018, I collected GPS data on trials ($n = 3145$) of free ranging, freely exploring domestic pet dogs ($n=30$) of different breed, size, reproductive status, sex and age (see, **Tables M1.2.1; M1.2.4**) while walking with their owner on four consecutive walks in two known and two unknown areas ($n=120$). Dogs had to travel at least 20 m away from their owner to collect data, see **Fig. M1.2.1** and seven travelling patterns were differentiated for the dogs, see **Fig. M1.2.2**. Length of the walks depended on age and physical ability of the dogs, the average length (median) was 1:17:17h per walk; (median) 5:24:53h over all walks, for details see **Table M1.2.4**.

The median age of the dogs was 63.5 months (see **Table M2.2.1**). 40 % were male ($n=12$), of which 75 % (9/12) were castrated and 60 % were female ($n=18$), of which 72 % (13/18) were castrated; of all dogs 30 % were intact and 70 % castrated (see **Table M2.2.2**). 33 % ($n=10$) of the dogs were mixed breeds and 67 % ($n=20$) of the dogs were pure breeds (see **Table M1.2.2; Table M2.2.2**). Of the pure breeds nine were sighthounds, two herding dogs; four hunting dogs, three working dogs and two toy dogs, ranging in size from > 60 cm to <40 cm shoulder height (see **Table M1.2.2**). The mixed breeds had the same size range (see **Table M1.2.2**). GPS data was collected on each dog and 51 parameters recorded (**Table M1.2.5**). Out of the 30 dogs eight belonged to a single dog household owner, 22 to a two or more dog owner – in this group ten owners accounted for 22 dogs (see **Tables M1.2.1; M2.2.2**). The owner had to subjectively assess their dogs hunting behavior on a scale from 1 (weak) – 6 (strong), see **Table M2.2.3.1** in the owner questionnaire (see Part 3 Material and Methods for owner questionnaire).

Table M2.2.1: *Dogs birthdate, data collection dates and age in month during trials.*

Dogs	Date of birth	Runs dates	Age in month
1. Amanda	19.06.17	19.11-22.11.18	17
2. Amy	23.04.14	15.06.18-19.06.18	50
3. Arthur	28.04.17	23.04.18-08.05.18	12
4. Balin	22.02.14	04.12-22.12.17	46
5. Balou RR	24.06.07	20.04-18.06.18	132
6. Balou	11.11.12	15.12.17-11.01.18	73
7. Bill	18.2.11	26.12.15-25.9.18	60
8. Dr Pepper	01.05.17	29.12.17-18.11.18	8
9. Emma Lea	28.05.14	23.05.18-11.07.18	48
10.Emma	01.10.09	29.10.17-2.1.18	121
11. Freya	23.07.16	02.11-05.12.17	16
12. Honey	15.06.11	7.7.16-8.7.16	61
13. Kaito	18.2.12	20.12.15-1.1.16	60
14. Kimi	19.02.12	12.1.18-1.2.18	72
15. Lili	1.1.2011	15.12.17-11.1.18	84
16. Lou	5.10.2007	3.1.16-31.7.16	105
17. Luna	29.11.10	4.5-18.6.18	96
18. Maloca	1.7.2007	22.10-1.11.17	123
19. Manja	21.4.2009	14.10.17-24.10.17	102
20. Marley	14.03.15	7.12-20.12.17	33
21. Molly	18.4.16	24.11-30.11.17	18
22. Nele	9.12.2007	5.6.18-19.6.18	114
23. Nina	8.9.12	12.1.18-1.2.18	65
24. Odin	25.6.2009	25.5.18-15.6.18	108
25. Raffaele	23.1.14	1.8.16-26.11.17	36
26. Raiya	14.2.17	31.10.17-18.11.18	10
27. Tamina	1.1.14	7.12.17-20.12.17	47
28. Thorin	27.6.13	6.11.15-15.6.18	60
29. Wantje	30.3.14	19.11.-22.11.18	56
30. Zlata	22.6.11	3.8.16-1.11.17	72
			Median 63.5 month

Table M2.2.2: Overview all dogs: sex; reproductive status; mixed/purebred; owner number of dogs.

Dogs n=30 total n= 3145 runs >20 m	Intact/neutered	Mixed/Purebred	Owner 1+ dog
Female n=18/30= 60 %	Intact n=9/30 = 30 %/ neutered n=21/30= 70 %	Mixed n=10/30 = 33 %	17 % 1 dog = 8 owners
Male n=12/30 = 40 %	Male neutered (n=9/12) 75 % Female spayed (n=13/18) 72 %	Purebred n=20/30 = 67 %	83 % 22 dogs = 10 owners

2.2.2 Global positioning devices

GPS data were collected during four walks with each dog-owner dyad (n=120). I analyzed 3145 data points (runs > 20 m). GPS collars Garmin T5; DC™ 50 were attached to the dogs while the owner carried a handheld GPS Garmin Astro® 320. The GPS devices had a time resolution of 0.2 s. Weight of the dog collars were for the T5 collar: 198 g and the DC™ 50 collar: 289g respectively, with dimensions of T5: 7.8x4.5x3.5; DC™ 50: 9 x 4.9 x 4.6 cm. The task of the owner was to walk continuously and with a constant speed as far as possible during the walks. The dogs were allowed to walk and run freely, and the owner called the dogs back only in emergencies. The accuracy of GPS/margin of error for the Garmin Astro® 320 lies within +/- 3.65 m.

The Video camera used was a Garmin VIRB® Elite. Size: (H x B x T): 32 mm x 53 mm x 111 mm; weight 170g, Datatype: MP4; 1080p-HD-Video: 1920 × 1080; 30 fps. Data was displayed on Garmin Basecamp. The camera however was only used on the larger dogs as it was too heavy and difficult to attach to the small dogs. For more details see also Part 1 Material and Methods.

2.2.3 Hunting behavior assessment sheet

Based on the owner questionnaire (see Part 3 Material and Methods) a subjective owner assessment of the hunting behavior of their individual dog(s) on a scale from 1 (weak) to 6 (strong) was established to evaluate the subjective owner assessment (see **Table M2.2.3.1**). It was then compared to the objective travelling behavior of the dog indicating hunting behavior either through distances travelled (out of visibility) or through video analysis if applicable (no video analysis possible on small dogs due to camera weight/size).

Table M2.2.3.1: Assessment hunting behavior by owner on a scale from 1 (weak) – 6 (strong).

No.	Name	Owner	Breed	Hunting behavior 1 (weak)-6 (strong)
1	Amanda	H.M.	Collie	4
2	Amy	S.S.	Labrador Retriever	1
3	Arthur	V.B.	Standard Poodle	3
4	Balin	S.W.	Great Dane Mix	3
5	Balou RR	C.C.	Rhodesien Ridgeback	4
6	Balou	C.B	Husky Shepard Mix	3
7	Bill	S.L.	LabradorMix	5
8	Dr. Pepper	S.M.	Silken Windsprite	4
9	Emma Lea	E.M.	Miniature Pinscher	4
10	Emma	A.S.	Perro de Aqua espanol Mix	3
11	Freya	N.P.	Pug	2
12	Honey	D.S.	Whippet	4
13	Kaito	S.L.	MastiffMix	4
14	Kimi	M.K.	Whippet	4
15	Lili	C.B.	Pastor Mallorcin Mix	1
16	Lou	S.L.	Shepherd Mix	3
17	Luna	C.C	Rhodesien Ridgeback	5
18	Maloca	A.S.	Perro de Aqua Espanol	1
19	Manja	A.U.	Italian Greyhound	1
20	Marley	G.B.	Labrador Mix	2
21	Molly	N.W.	Pug	3
22	Nele	S.S.	Labrador Retriever	1
23	Nina	M.K.	Greyhound Mix	6
24	Odin	A.W.	Whippet	3
25	Raffaele	A.U.	Italien Greyhound	2
26	Raiya	S.M.	Borzoi	5
27	Tamina	G.B.	TerrierMix	5
28	Thorin	S.W.	Borzoi	2
29	Wantje	H.M	Collie	6
30	Zlata	A.S.	Borzoi	3

2.2.4 Data collected for each dog

A data sheet was established for each dog indicating the number of runs >20 m and the respective travelling patterns (for pictogram of Travelling pattern see **Fig. M1.2.1; M1.2.2, M1.2.3**), pausing times of each run and over all runs and if a point of return (POR) could be established the outbound (from owner to POR) and inbound (from POR to owner) time and distance travelled. For each dog a diagram indicating the percentage of each of the seven possible travelling patterns was prepared (see **Fig. M1.2.1; M1.2.2, M1.2.3; M2.2.4.1**). Furthermore for each dog all walks (n=4) in known and unknown areas with respective walking time; owner average speed; dog average speed; total distance owner walk; total distance dog walk; distance difference owner/dog; number of runs >20 m; time moving of dog runs >20 m; minimum /maximum speed of dog; time away from owner runs >20 m; maximum distance of run >20 m; known area versus unknown area time and distance travelled runs >20 m; difference in percent known versus unknown area; if applicable (POR) distance, time and speed outbound and inbound; travelling patterns known versus unknown area and whether if applicable two dogs belonging to one owner showed similar travelling patterns were recorded. For an example sheet see **Table M2.2.4.1 Appendix** and **Fig. M2.2.4.1** for an exemplary diagram of exploration patterns. For exemplary dog dyads travelling patterns see **Fig. M2.2.4.2-7**.

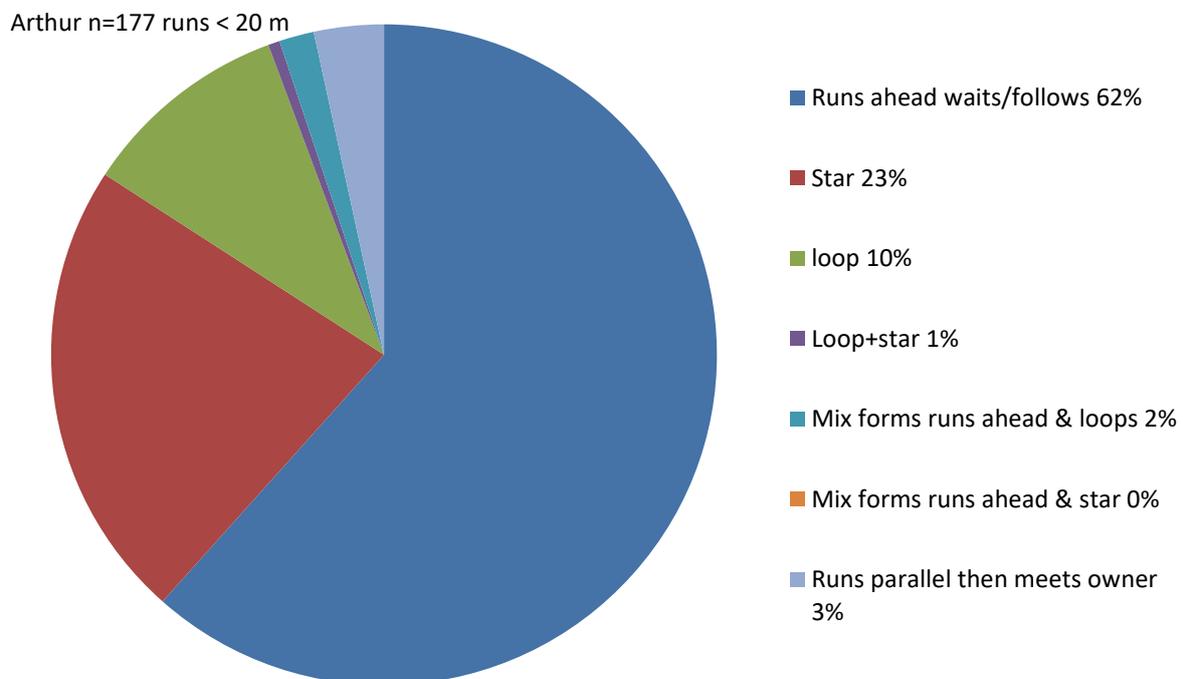


Fig. M2.2.4.1: Diagram: Travelling patterns of an exemplary dog (Arthur) depicting percentiles of seven possible patterns displayed on all runs >20 m.

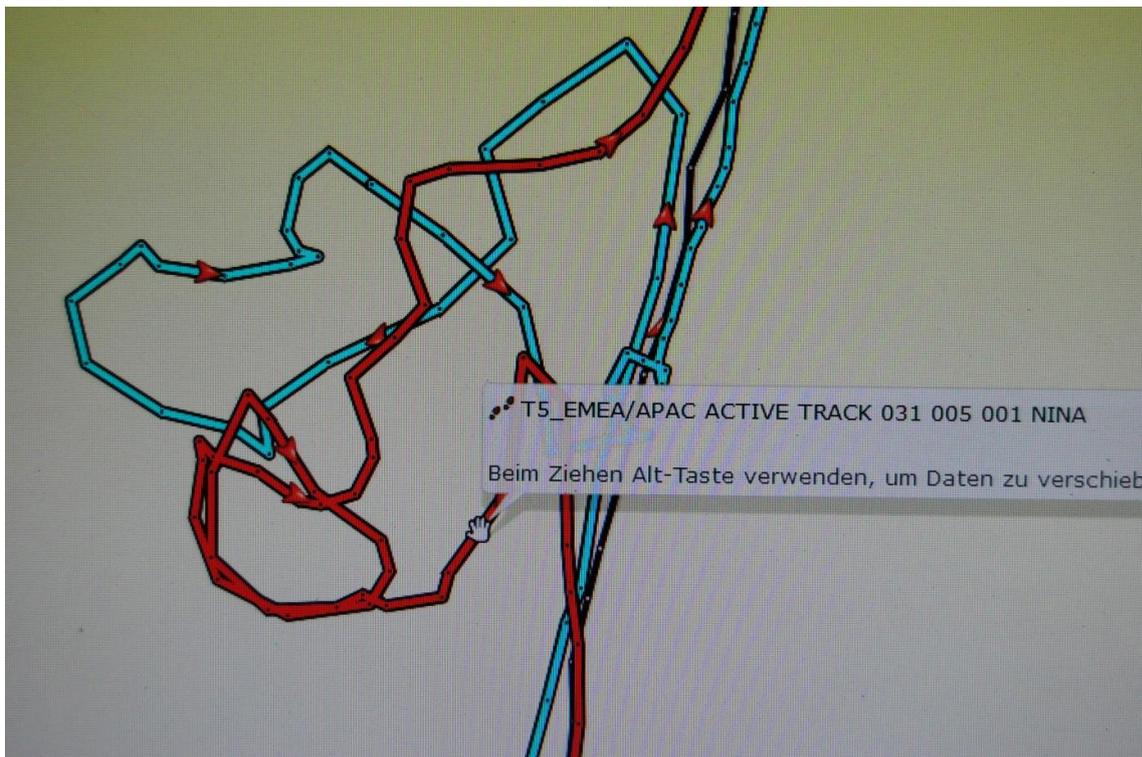


Fig. M2.2.4.2 Kimi (blue) and Nina (red). Owner track black. Every black dot indicates a 2 sec segment. Here: Dogs travel in similar area but not identical track/route.

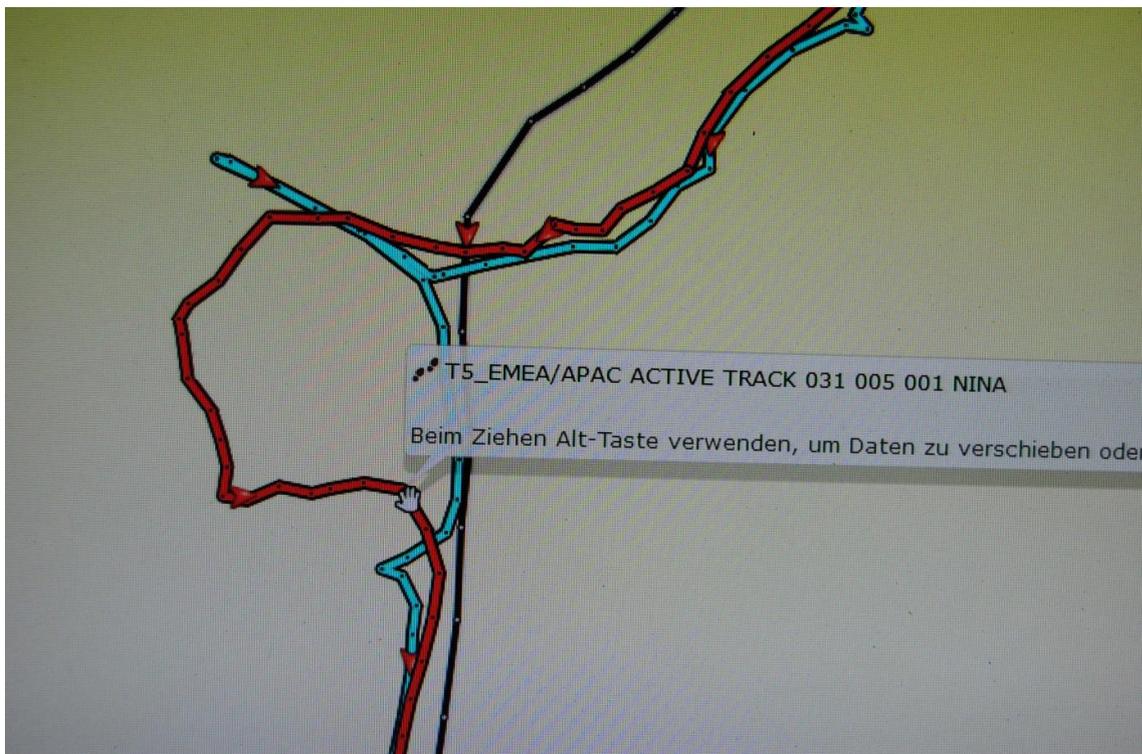


Fig. M2.2.4.3 Kimi (blue) and Nina (red). Owner track black. Every black dot indicates a 2 sec segment. Here: Kimi (blue) Star pattern and Nina (red) loop pattern.



Fig. M2.2.4.4 Lou (blue) star pattern and Bill (pink) loop and stars. Owner track yellow. Dogs do not explore together and use different patterns.



Fig. M2.2.4.5 Lou (blue) loop pattern and Bill (pink) loop. Owner track yellow. Lou returns earlier. Initiating or leading dog Bill.

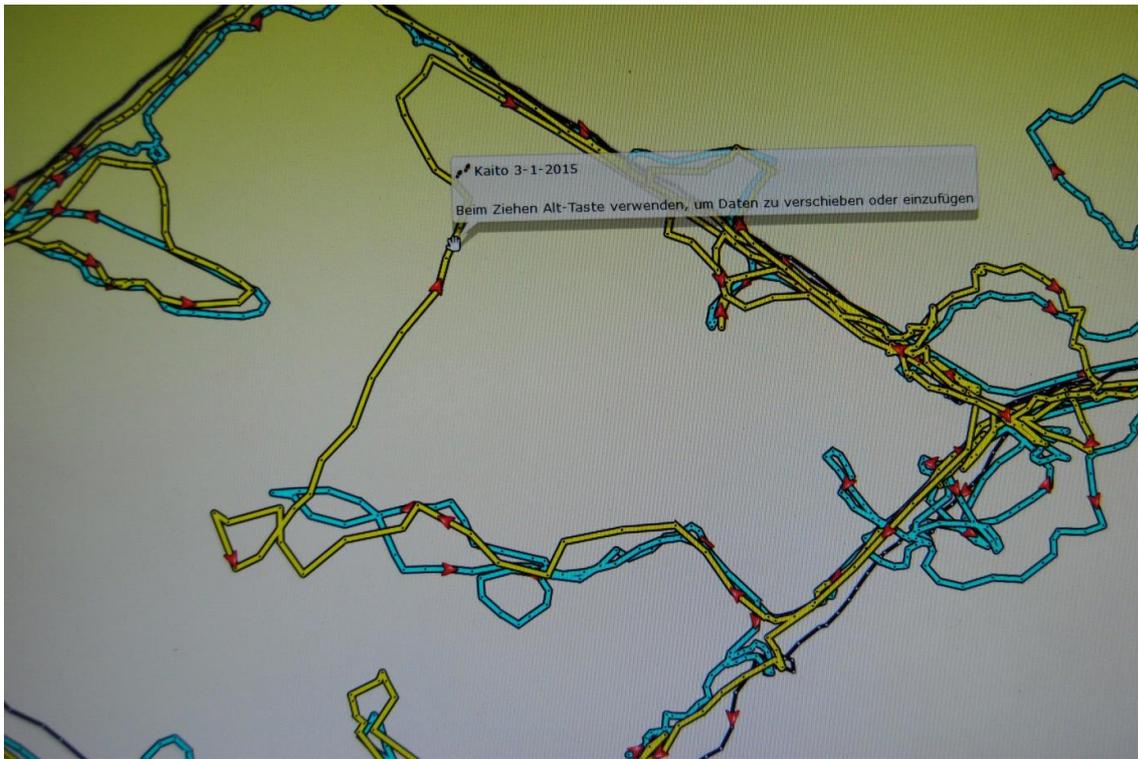


Fig. M2.2.4.6 Kaito (yellow) and Bill (blue) star pattern. Owner track black. Dogs do not explore together, but start off together. Initiating/leading dog Bill. And see left hand side exploring together star/loop.

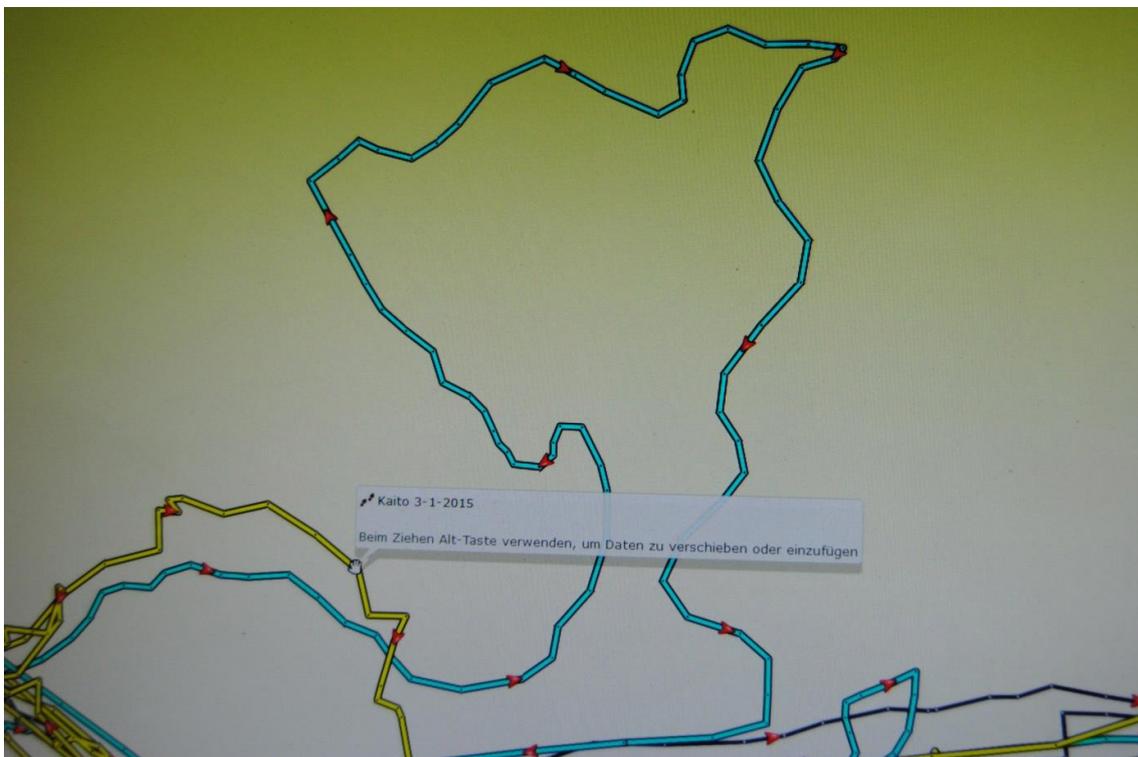


Fig. M2.2.4.7 Bill (blue) and Kaito (yellow). Owner track black. Dogs do not explore together. They start off together then Kaito returns Bill continues.

2.2.5 Statistics and graphics

SPSS version 25, IBM Inc. was used for analyzing the data. All tests were performed two-tailed on a 5 % level of significance. Standard Bonferroni correction of p-values < 0.05 was applied in case of multiple testing. Two-tailed tests were performed unless otherwise denoted. StatKey (<http://www.lock5stat.com/>) was used for performing randomization tests using a simulated sample size of $n = 5000$.

Descriptive analysis was performed calculating number of valid measurements (n), mean (m), median, quartiles and standard deviation (SD). Relationships were plotted using scatterplots, bar charts, boxplots or mean \pm 95 % confidence interval. Boxplot charts display the distribution of data within groups or overall groups, for details see Part 1 Material and Methods and **Fig. M1.2.4**.

Nonparametric tests were used for inductive statistics. Mann-Whitney U Test was used to compare two independent samples, Wilcoxon test for dependent samples. Also randomization (or permutation) tests were applied for comparison of dependent or independent groups of interval scaled data, for details see Part 1 Material and Methods.

Spearman correlation coefficients were used to examine the monotone relationship of two continuous variables, whereas Pearson correlation coefficients are applied for describing linear relationships. In case of linear correlation, a linear regression model was calculated to quantify the effect of the variables. For bivariate nominal data (yes/no) exact binomial test was applied to compare frequency of occurrence between two groups. Exact Chi-Square Test was used for testing differences in crosstabs. Hierarchical cluster analysis was applied to find walks with similar running patterns and to find the appropriate number of clusters. Squared Euclidian distance was used as measure of distance and ward method was used as linkage method. K-Means clustering with 3 Clusters was applied to assign walks to the cluster (for more details see Section 1.2.5 Statistics and correlative values).

2.2.6 Circular Statistics

Directional preferences of dogs while freely exploring were analyzed and tested by means of circular statistics using Oriana 4.02 (Kovach Computing, Anglesey, Wales). Statistical significance of deviations from random distributions was investigated using the Rayleigh test of circular statistics. Level of significance was set at 5 %. A “clustered” analysis was examined using the Rao’s spacing test. Level of significance was set at 1 %, for details see Part 1 Material and Methods.

Oriana supplies two options: Angles, the basic circular type, where data are measured within the range of 0° - 360° . Angles were not used herein. The second option is the Axial type, used herein, which is similar to the Angles type, but the data are bidirectional rather than unidirectional. Data can still be entered in the full 0° - 360° range, but when analyses are performed, the data are doubled and then back converted, so that they are within the range of 0° - 180° .

Rayleigh's Uniformity Test calculates the probability of the null hypothesis that the data are distributed in a uniform manner. A probability less than the chosen significance level (0.05) indicate that the data are not distributed uniformly and that they show evidence of a preferred direction. Rao's Spacing Test also takes as its null hypothesis that the data are uniformly distributed. This is tested by looking to see if the spacing between adjacent points is roughly equal around the circle (using the equations on the above cited pages). For uniform distribution the spacing between points should be roughly $360^{\circ}/n$. If the actual spacings deviate too much from this value then the likelihood that the data are uniformly distributed is reduced. Watson's U^2 Test performs a goodness-of-fit test against a specified distribution, either uniform or von Mises. It does this by calculating the mean square deviation for the fitted distribution. If the deviation is too high (resulting in a high U^2 and a low probability) then the null hypothesis that the data fit the chosen distribution is rejected.

2.3 Results

2.3.1 Runs >20 m: Distance of dogs explored in known areas compared to unknown areas

The median distance explored in known areas was 2351 m in unknown areas 1585 m respectively (33 % decrease). Clear differences could be perceived between known and unknown areas. About 25 % of the walks in known areas had a distance of runs >20 m in excess of 3649m (upper quartile), in unknown areas the third (75 %) quartile lay at 3364 m, **Table R2.1.1**. The mean distance (all runs >20 m) of the individual dogs varied greatly, with over all dogs a mean distance in known areas of 2815 +/- 2482 m compared to 2275 +/-2122 m in unknown areas, **Fig. R2.1.2**. The standard deviation was almost as high as the mean and thus over all dogs no significant difference ($p = 0.373$) between known and unknown areas with respect to the overall distance explored for dog runs > 20 m could be shown. However, 20 of 30 dogs explored shorter distances in unknown areas, **Table R2.1.1**. The probability of 20 or more dogs out of 30 exploring shorter distances in unknown areas was not significant, however ($p = 0.099$), see also, the randomization test for one mean difference, **Fig. R2.1.3 Appendix**.

2.3.2 Radius of dog runs >20 m - grouping of dogs: Group 1: radius < 150 m; Group 2: 150 m <= radius <350 m; Group 3: radius >= 350 m

Due to the fact that there were large variances in the maximal distance of runs > 20 m between the dogs, see **Fig. R2.2.1**, dogs were classified in to three radius groups to differentiate data in more detail: The majority of dogs showed a difference of less than 150 m away from the owner (13 of 30 dogs = 43 %); Group 2 (n= 8), about 1/3 of the dogs never explored beyond the 350 m radius (27 %); Group 3 (n=9) dogs explored at least once beyond the median maximal difference of the 350 m radius (30 %), see **Table R2.2.1**.

2.3.3 Differences between known and unknown areas in relation to maximal median difference from the owner Group 1; Group 2; Group 3

Between the three Groups distinct differences between known and unknown area exploration distance could be observed. In Group 1, which always stayed close to the owner (max. radius 150 m), no change was apparent between the areas **Fig. R2.3.1**. However, Group 2 and 3 travelled longer distances in known than unknown areas, **Fig. R2.3.2**. In

Group 2 50 % of the runs >20 m displayed a maximum median distance of 273 m in known and 175 m in unknown areas, a reduction by 36 % (mean 291 +/- 86,5 m; 246 +/- 170 m). Most pronounced was the difference in Group 3 (radius > 350 m): here the maximum median distance in known areas was 652 m versus 434 m in unknown areas (decrease of 34 %), the 75 % quartile in this group was reduced from 1000 m in known to 574 m in unknown areas, a decrease of 42,6 %, see **Table R2.3.1; Table R2.3.2; Fig. R2.3.2.**

Large intraspecific differences could be seen, **Fig. R2.3.1.** Looking at the median of the total runs >20 m in known and unknown areas, values of Group 1 were almost identical (known 572 m/unknown 435 m). In Group 2 dogs explored shorter distances in unknown areas (known 3101 m/ unknown 2524 m – reduction 19 %). Group 3 displayed the clearest reduction in exploration distance of runs >20 m from known 5709 m to unknown 4378 m (decrease 23 %), see **Table R2.3.2; Fig. R2.3.2. Fig. R2.3.3.** For no group a significant reduction could be shown however, **Fig. R2.3.4 - Fig. R2.3.6 Appendix.**

2.3.4 Runs >20 m: Time travelled by the dogs in known areas compared to unknown areas.

In addition to the distance explored by the dogs (runs >20 m, **Table R2.2.1; Table R2.3.2**) the time of exploration of runs >20 m for each dog as well as each Group (1, 2 and 3) was determined. Here again large intraspecific differences could be seen, **Fig. R2.4.1; Fig. R2.4.3.** Between the Groups however, no time differences were apparent, **Fig. R2.4.2.** The time difference between the two areas was not significant over all dogs. No significant differences between known and unknown areas could be shown within the above defined groups ($p = 0.656$ (radius <150 m), $p = 0.291$ (150 m <= radius <350 m) and $p = 0.229$ (radius >350 m). Between the three groups differences in exploration time could clearly be seen, with an increase from Group 1 to Group 3. All groups showed longer exploration times in known than unknown areas (mean time away from owner), **Fig. R2.4.3; Fig. R2.4.4.** For no group a significant reduction of duration of runs >20 m could be demonstrated however, **Fig. R2.4.5 - Fig. R2.4.7 Appendix.**

2.3.5 Distance outbound versus inbound (runs>20 m) travelled by the dogs.

Assuming that the dogs on their way away from the owner (outbound) were exploring the environment I expected them to travel longer distances on their outbound than in-

bound (back to their owner) routes and furthermore that they would be slower on their outbound exploration than their inbound travel. For each dog, where pertinent travelling patterns were shown, the distance outbound: away from the owner up to a determined point of return (POR) as well as the distance inbound: from the point of return back to the owner was analyzed. For a pictogram describing a point of return, see **Fig. M1.2.2; Fig. M1.2.3**. Not all dogs displayed a point of return (see Mala, Odin) .in these cases no outbound/inbound data were collected and evaluated.

Large inter-individual differences could be observed, **Fig. R2.5.1** with respect to the distances explored on runs >20 m, **Table R2.5.1 Appendix**. The variances between inbound and outbound distance travelled did not differ significantly ($p = 0.068$; Wilcoxon Test), however. Over all dogs the mean distance of inbound travel (588 +/- 656 m) was lower than the mean distance of outbound travel (609 +/- 651m), see **Table R2.5.1 Appendix**. Looking at the median, however, large differences between the dogs became apparent: 50 % of the outbound median distance was ≤ 407 m; 50 % of the inbound median distance was ≤ 274 m, a decrease of 33 %, see **Table R2.5.1**. Using the randomized test for one mean difference between inbound and outbound distance travelled no significant difference could be shown ($p > 0.05$), **Fig. R2.5.2 Appendix**. Looking at Group 1, 2 and 3 also no significant differences between outbound and inbound distance travelled could be observed, **Fig. R2.5.3; Fig. R2.5.4**.

2.3.6 Time and speed outbound versus inbound (runs>20 m) explored by the dogs

2.3.6.1 Time outbound versus inbound (runs>20m) explored by the dogs

A different result was established with respect to the time inbound and outbound explored by the dogs. The time inbound was significantly shorter than the time outbound, see **Table R2.6.1 Appendix; Fig. R2.6.1; Fig. R2.6.2**. A significant difference between the two travelling routes could be shown ($p < 0.001$, Wilcoxon Test). Looking at Group 1, 2, and 3 inbound and outbound duration increased with ascending radius of the dogs. Differences between groups were significant in inbound and outbound duration ($p < 0.001$, Kruskal-Wallis Test), **Table R2.6.2; Fig. R2.6.3**. In particular the Group 3 dogs displayed much longer outbound than inbound times, **Fig. R2.6.2, Table R2.6.2; Fig. R2.6.3; Fig. R2.6.4** thus the dogs that travelled the longest distances away from the owner were the fastest dogs on their return route, **Table R2.6.1 Appendix**. The mean time on outbound travel was 5 +/- 8 minutes, on inbound travel 3 +/- 3 min. The median

time was doubled (00:02:00h) on outbound compared to inbound (00:01:00h) travel, with the lower quartile being equal, the upper quartile showing a differences of 00:07:00h outbound versus 00:05:00h inbound travelled time, an increase of 40 % on outbound travel time, **Table R2.6.1 Appendix**.

2.3.6.2 Speed outbound versus inbound (runs>20m) explored by the dogs

As there was no significant difference between the distance of the dogs travelled outbound and inbound see **Section R2.5**, but a significant difference with respect to the time travelled, **Table R2.6.1 Appendix, Table R2.6.2; Fig. R2.6.3; Fig. R2.6.8** the speed of the dogs was additionally analyzed. Compared was the speed outbound, away from the owner, versus inbound, back to the owner. The speed on inbound travel was significantly higher than on outbound travel ($p < 0.001$, Wilcoxon test) over all dogs, **Fig. R2.6.4; Fig. R2.6.7; Table R 2.6.3 Appendix** as well as for Group 1, 2 and 3. In all three groups differences between inbound and outbound speed was observable and significant speed differences could be shown, **Fig. R2.6.5; Fig R2.6.6; Fig. R2.6.8; Fig. R2.6.9; Fig. R2.6.10 Appendix**. Dogs travelled with higher speed and took less time on their inbound route, **Fig. R2.6.7.and Table R 2.6.3, Appendix**.

2.3.7 Distance travelled male versus female dogs (runs>20 m)

It has been postulated that sex differences exist in regard to exploration distance between male and female dogs, therefore the distance of runs >20 m with regard to sex was analyzed. The variance between female and male dogs with respect to the distance explored of runs >20 m was significant. Male dogs explored significantly longer distances than female dogs, **Fig. R2.7.1; Table R2.7.1; Fig. R2.7.2; Fig. R2.7.5 Appendix**. The mean distance of runs >20 m was larger for male dogs (3464 +/- 2732 m), **Table R2.7.1; Fig. R2.7.1** than for female dogs (1862 +/- 1739 m) by an increase of 86 %. The median showed even greater differences: 50 % of the male dogs travelled more than 3151 m, 50 % of the female dogs more than 1532 m distance on the runs > 20 m, with a distance on the higher quartile of 5342 m by the male dogs and 2713 m by the female dogs, an increase of 97 % distance travelled by the male dogs, see **Table R2.7.1. Fig. R2.7.2**.

2.3.8 Time travelled male versus female dogs (runs>20 m)

Looking at the duration explored by female and male dogs' similar results became apparent, see **Fig. R2.8.1; Table R 2.8.1**. The difference in the duration of runs >20 m between female and male dogs was significant. Females displayed a higher number of runs (n=1660) than male dogs (n=1485), **Table R2.8.1** It seems that female dogs have more short runs, male dogs fewer runs which are more extensive timewise (and distancewise, see **Table R2.7.1**). The median showed a time difference of females with 77 minutes versus males with 88 minutes, a 14 % increase **Fig. R2.8.1; Table R2.8.1; Fig. R2.8.2 Appendix**. The duration over all runs >20m was longer in male dogs (22 +/- 16 min.) than in female dogs (13 +/- 16 min.), **Table R2.8.1**. The median time over all runs also differed between males and females: 50 % of the male dogs travelled longer than 00:22:00h whereas 50 % of the females travelled longer than 00:12:00h (55 % difference) away from their owner, with an upper quartile of male dogs of 00:34:00h versus females of 00:19:00h, an over all time difference of 56 %, see **Table R2.8.1**. Males therefore explored almost twice as long as females.

2.3.9 Distance travelled castrated versus intact dogs (runs>20 m)

It has been postulated that differences exist in regard to distance explored between castrated and intact dogs, therefore the distance of runs >20 m with respect to reproductive status of the dogs was analyzed. Differences in distance explored between all castrated and all intact dogs could be observed, these were not significant, however, **Fig. R2.9.1; Table R2.9.1; Fig. R2.9.2; Fig. R2.9.5 Appendix** and see **Fig. R2.9.3** and **Fig. R2.9.4** for the total runs > 20 m of all castrated versus all intact dogs, individually.

2.3.10 Time travelled castrated versus intact dogs (runs>20 m)

Differences in duration explored between all castrated and all intact dogs could also be observed, **Fig. R2.10.1**. The duration travelled of runs >20 m was larger for intact dogs (18 +/- 21 min.) than for castrated dogs (16 +/- 15 min.), **Fig. R2.10.1**. 50 % of the castrated dogs explored less or equal to 00:12h, whereas the intact dogs showed a median of 00:16h, **Table R2.10.1, Fig. R2.10.2**. The difference between castrated and intact dogs was not significant, **Fig. R2.10.5 Appendix; Table R2.10.1**.

2.3.10.1 Dogs of one sex: distance and time travelled – female dogs

It was further analyzed whether the time and distance between neutered and intact dogs of one sex differed. For the females the spayed dogs had 1181 total runs >20 m with a mean of 1862+/-1905 m compared to intact females with 479 runs >20 m and a mean of 1861+/-1250 m. The mean was identical, however, looking at the upper quartile total runs >20 m the spayed females explored further (median 7842 m) compared to the intact females (median 4890 m), however the intact females explored longer away from the owner, see **Table R2.10.2; Fig. R2.10.4 Fig. R2.10.5; Fig. R2.10.6; Fig. R2.10.7**. The differences displayed between intact and spayed females were not significant however, **Table R.2.10.3; Fig. R2.10.9 Appendix**.

2.3.10.2 Dogs of one sex: distance and time travelled – male dogs

The intact male dogs had a high number of runs >20 m (n=651) for three dogs. The median distance of total runs >20 m was almost identical between intact and neutered males (intact male dogs 3127 m versus 3156 m of the neutered males). Thus for intact male dogs runs >20 m made up 47 % of the dogs distance, for neutered male dogs 43 %. No difference could be observed in time of runs >20 m between the intact and neutered male dogs, see **Table R2.10.2M; Fig. R2.10.3; Fig. R2.10.5**. The differences between intact and neutered male dogs were not significant, **Table R.2.10.3; Fig. R2.10.8 Appendix**. Intact and neutered female and male dogs exhibited differences in travelling time and distance, **Fig. R2.10.4**. Neutered male dogs displayed over all higher distance and higher travelling time away from their owner than intact male dogs. Female spayed dogs travelled over all equivalent distances and displayed less travelling time than intact female dogs, see **Fig. R2.10.5; Table R2.10.2; Fig. R2.10.3; Fig. R2.10.4**. Neutered males displayed the longest distances of total walks followed by the neutered females, intact males and intact females, **Fig. R2.10.4**. The total distance of runs >20 m was highest for male dogs. No difference distancewise between neutered and intact dogs could be seen within the female group (median 1861 m vs. 1861 m), **Table R2.10.2**. A summary of the results can be seen in **Table R2.10.3**. Diagrams of the travelling patterns can be seen in **Fig. R2.10.9a/b**.

2.3.11 Does the age of the dog influence the distance/time travelled?

To determine whether correlations existed between the age of the dogs and their average travelling speed of runs >20 m; time away from the owner; time inbound and outbound travelled and the duration of the entire walking time was analyzed. Looking at Spearman correlation coefficient only the dogs' average speed and the duration of the dogs' entire walk showed a significant relation with age, see **Table R2.11.1; Fig. R2.11.1; Fig. R2.11.2.**

2.3.12 Does the size of the dog influence the speed the dogs travel?

To determine whether the size of the dog per se had an influence on the speed travelled the data were analyzed accordingly. Three groups were distinguished: Dogs >60 cm shoulder heights (large n=11); dogs <60 cm >40 cm shoulder heights (medium n=13) and dogs >40 cm shoulder heights (small n=6). Looking at the boxplot no differences in average dog speed between small size dogs (<40 cm), medium size (between 40 cm and 60 cm) and large dogs (>60 cm) could be observed (p=0.449, Kruskal-Wallis Test), see **Table R2.12.1; Fig. R2.12.1 Table R2.12.2.**

2.3.13 Individual speed differences between the dogs and overall dogs

Between the 30 dogs great differences could be observed regarding their overall speed during the walks as well as their speed patterns. Some dogs displayed an overall low average speed during all walks independent of breed or size. Some dogs displayed a high speed variance, thus these dogs alternated between very fast as well as moderate or slower runs. Some dogs travelled over all at very high speed, **Table R2.13.1 Appendix; Fig. R2.13.1.** For all individual dogs, see **Table R2.13.2.**

2.3.14 Classification of dogs according to their travelling patterns

Seven different travelling patterns were established to classify runs > 20 m away from the owner. According to these seven categories all 120 walks were examined to group dogs or walks with similar patterns (for details, see **Fig. M1.2.1, Fig. M1.2.2, Fig. M1.2.3** pictograms). The dogs displayed various travelling patterns, **Table R2.14.1 Appendix.** Out of all runs >20 m (n= 3145) the dogs utilized primarily (62 %) the travelling pattern of running ahead of the owner on the path and waiting or following the owner on the path, **Fig. R2.14.1.** Looking at the individual dogs, great differences could be observed,

Fig. R2.14.2. Based on the great individual variance displayed by the dogs a hierarchical Cluster analysis using Ward linkage and squared Euclidean Distance measure was applied to establish an appropriate number of clusters **Table R2.14.2 Appendix**. Lowest distances and therefore typical running patterns for the clusters as well as high distances (extreme, most untypical patterns) of the groups were summarized in **Table R2.14.3**. **Fig. R2.14.3** shows the distribution of patterns between the cluster groups. 14 dogs displayed a change in pattern cluster, 16 had constant pattern clusters for all four walks. Seven dogs had different patterns in known versus unknown areas, **Table R2.14.4**; **Fig. R2.14.4** shows the distribution of patterns between Group 1, 2 and 3 (radius traveled away from the owner) and travelling patterns of each Group. **Table R2.14.5** illustrates the Groups and Cluster values. It could be demonstrated that dogs belonging to the different radius groups (Group 1, 2 and 3) have different distribution patterns: dogs with a low maximal distance away from their owner could be characterized by Cluster 2 (nearly no runs away from owner) or Cluster 3 (high frequency of runs forward/backward and waits) whereas dogs with a radius >350m were overrepresented in Cluster 1 and underrepresented in Cluster 3 thus characterized by occurrence of star and loop patterns and a medium number of runs ahead waits/follows. **Table R2.14.6** depicts the individual dogs in Groups and Clusters, with breed and age.

2.3.15 Travelling patterns of dog dyads/triads – correlations

To assess whether dogs of one owner displayed similar travelling patterns the data were analyzed accordingly. The seven travelling patterns of two (or three) dogs of one owner were compared to establish possible correlations of dog dyads/triads. The dogs were viewed as teams and between and within the team the travelling patterns were evaluated. In total 10 teams were established, two teams (#9, 10) with three dogs belonging to one owner, **Table R2.15.1 Appendix**; **Fig. R2.15.1**.

As can be perceived in **Fig. R2.15.1** some teams had similar numbers of runs and pattern distributions, while within other teams a leading dog with a higher number of runs > 20 m could be observed. The leading dog was also characterized by a larger number of star and loop patterns, whereas runs ahead waits/follows was the dominating pattern of the dependent, following dog. In some teams all dogs exhibited a small number of runs > 20 m compared to other teams. For exemplary dog dyads travelling patterns, see **Fig. M2.2.4.2-7**.

2.3.16 Comparison of duration; difference in walking time; time travelled >20 m; time inbound /outbound; total distance of the dog walks, total runs > 20 m, the maximum distance of runs in meter and inbound/outbound travelling distance for each team (dyad/triad)

Between and within the dogs of one owner (dyads/triads) a number of factors were analyzed to determine whether the dog teams displayed similar travelling patterns with respect to time and/or distance variables. **Table R2.16.1.1 Appendix** shows the duration of dogs travelling rounds in minutes and differences in walking times between the teams, **Table R2.16.1.2** shows the time away from the owner of runs > 20 m and inbound/outbound travelling time for each team. The differences within the teams can be obtained from **Fig. R2.16.1.1 -R2.16.1.5**. There were no significant differences between the dogs of one owner with respect to over all dog walk duration. In **Table R2.16.2.2** distance of walks, runs > 20 m and inbound/outbound distances are shown for each team. The differences within the teams can be obtained from **Fig. R2.16.2.1 -R2.16.2.5**. Pronounced differences within the teams became apparent in time of runs > 20 m away from the owner, see **Fig R2.16.1.3, Table R2.16.1.1 Appendix** for details.

Within all teams differences in inbound- and outbound time could be obtained, **Fig R2.16.1.4**. The duration of inbound- and outbound was higher for dogs characterized as leading dog (see Chapter 2.15). Time inbound was less than time outbound, because the dogs travelled faster and without stops directly to their owner see also **Table R2.6.1. Table R2.16.2.2** depicts the distance of all walks, runs > 20 m and inbound/outbound distances for each team. The differences within the teams can be obtained from **Fig. R2.16.2.1 -R2.16.2.5**. The total distance of runs > 20 m varied within and between the teams, **Fig R2.16.2.2**. The maximal distance varied between the teams, within teams however, fewer differences could be denoted, **Fig R2.16.2.3**. Distance inbound (**Fig. R2.16.2.4**) and distance outbound (**Fig. R2.16.2.5**) were comparable as the dogs had to travel back fairly equidistance routes to their owner, see also **Table R2.5.1; Fig. R2.5.1**.

2.3.17 Magnetic field orientation: point of return

Dogs may use the magnetic field of the earth to establish a sense of compass direction, not only of the path traversed but also to return to an always varying location Therefore the point of return, of all dogs (n=28) was analyzed. Two dogs had no point of return in their travelling patterns. Looking at all dogs, they displayed a significant point of return

(n=780) in N-S direction (339°- 169°), **Fig. R2.17.1**. Assessed separately, the female dogs (n=17) did not display a significant point of return (n=348), **Fig. R2.17.2a** whereas the male dogs did (POR n=432) in N-S direction (325°- 165°), **Fig. R2.17.2b**. Looking at the intact male and female versus castrated dogs, results show that the intact dogs displayed a preference in N-S (7°/187°) but no significant point of return (n=206), **Fig. R2.17.3a** whereas the castrated male and female dogs did (n=574) in N-S direction (167°- 327°), **Fig. R2.17.3b**. Differentiating the intact and spayed female dogs results showed that the intact female dogs displayed a preference in NE-SW (37°/207°) but no significant point of return (n=71), **Fig. R2.17.4a** whereas the spayed female dogs did (n=277) in N-S direction (169°- 329°), **Fig. R2.17.4b**. The intact male dogs (n=3) displayed a preference in N-S (166°/306°) direction but no significant point of return (n=135), **Fig. R2.17.5a** whereas the neutered male dogs (n=8) did (n=297) in N-S direction (165°- 325°), **Fig. R2.17.5b**. **Table R2.17.1** shows a summary of all results.

2.3.1 Runs >20 m: Distance of dogs travelled in known areas compared to unknown areas

Every dog partook in two walks in known and two walks in unknown areas to ascertain whether the area influenced the distance and time travelled as well as the exploration patterns. The median travelled distance in known areas is 2351 m in unknown areas 1585 m respectively. Compared to the mean, clear differences can be perceived between known and unknown areas. The lower quartile shows a distance of 579 m in known and 493 m in unknown areas. 25 % of the walks in known areas have a distance of runs >20 m in excess of 3649 m (upper quartile), in unknown areas the third (75 %) quartile lies at 3364 m, see **Fig R2.1.1** for a boxplot of all runs >20 m of each dog and **Table R2.1.1** for values.

As can be seen in **Fig. R2.1.2** the mean distance (all runs >20 m; n=3145) of the individual dogs varies greatly, with over all dogs a mean distance in known areas of 2815 +/- 2482 m compared to 2275 +/-2122 m in unknown areas. The standard deviation is almost as high as the mean and thus no significance can be shown, a tendency that dogs travel less in unknown areas is apparent however, **Table R2.1.2**.

The randomization test for one mean difference of all runs >20 m known versus unknown area of all dogs, **Fig. R2.1.3 Appendix** also showed no difference between known and unknown area.

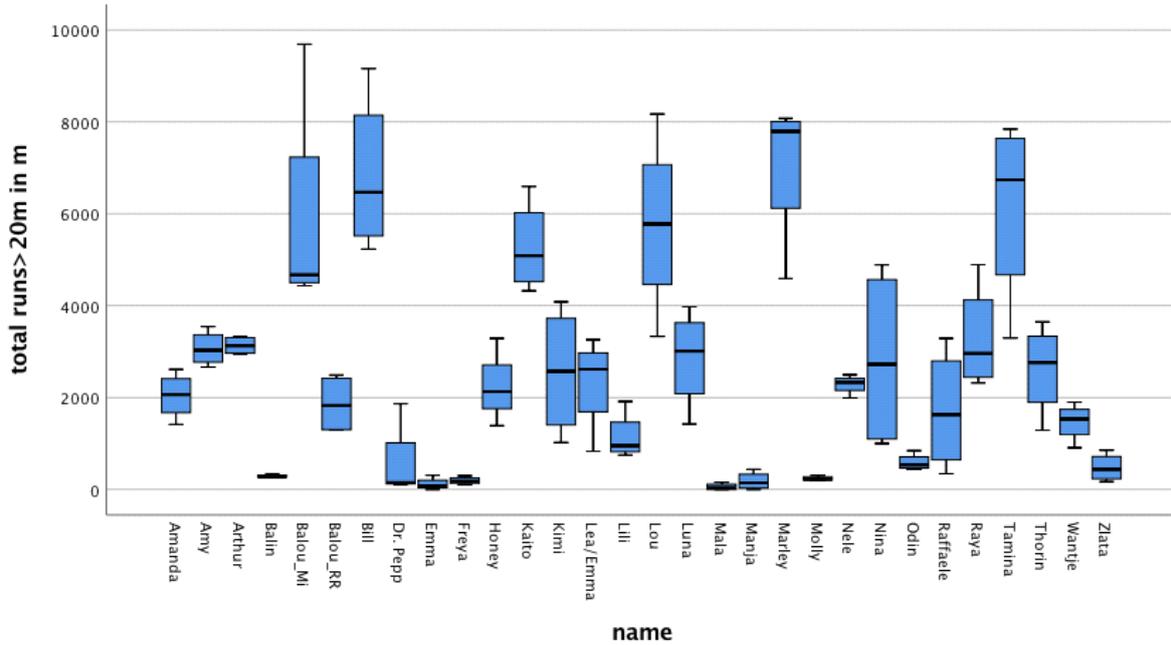


Fig. R2.1.1 *Boxplot: Total distance all runs > 20 m, n= 3145, for each dog in meter.*

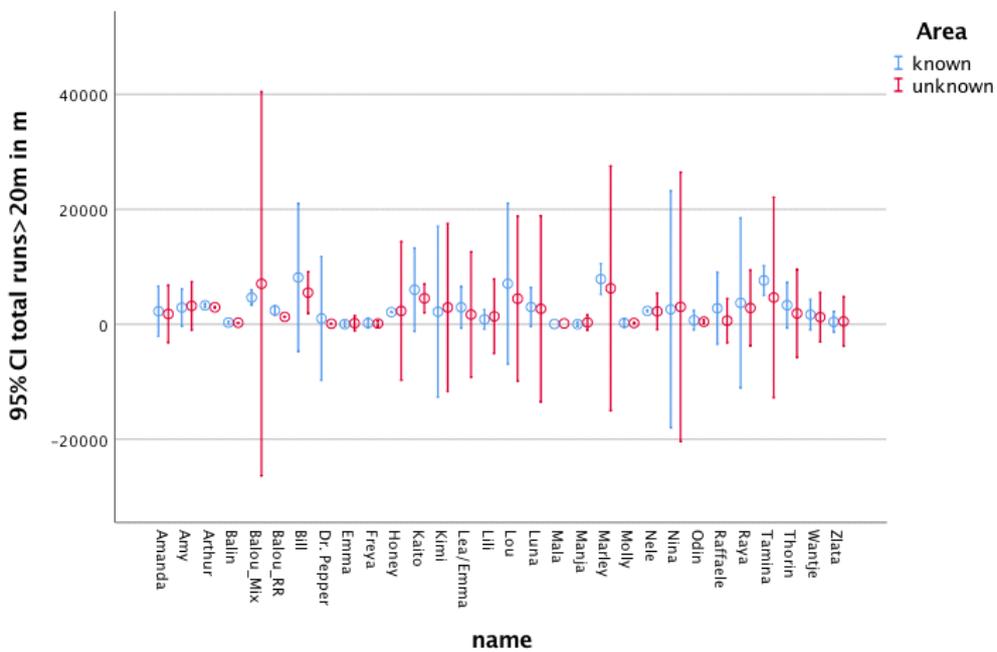


Fig.R2.1.2: *Mean total distance all runs >20 m; n= 3145, unknown (red) versus known (blue) area, each dog in meter.*

Every dog participated in two walks in known and two walks in unknown areas. The deviation from the mean is large for some dogs, i.e. the 95 % CIs are large compared to other dogs. For example Balou_Mix shows a mean distance of 4671 ± 148 m in known areas and 7062 ± 3717 m in unknown areas. Bill displays a mean distance of 8143 ± 1434 m in known and 5520 ± 405 m in unknown areas presenting an increase of 48 % of explored distance in known areas; Dr. Pepper shows a mean distance of 1016 ± 1200 m in known areas and $121 \pm 8,5$ m in unknown areas displaying an increase of 739 % in known areas. Over all dogs, the mean distance in known area is 2815 ± 2482 m compared to 2275 ± 2122 m in unknown areas. The standard deviation is almost as high as the mean and thus no significance can be shown, a tendency that dogs travel less in unknown areas can be observed, however.

Table R2.1.1: Distance of each dog travelled, known versus unknown areas, runs >20 m in meter.

Dogs n=30	area												total					
	known						unknown											
	n runs	mean	median	Q25	Q75	SD	n runs	mean	median	Q25	Q75	SD	n runs	mean	median	Q25	Q75	SD
Amanda	107	2270.5	2270.5	1926	2615	487.2	97	1809	1809.0	1414	2204	558.61	204	2039.75	2065.0	1670.0	2409.5	504.11
Amy	100	2921.5	2921.5	2664	3179	364.16	108	3211.5	3211.5	2879	3544	470.23	208	3066.5	3029.0	2771.5	3361.5	382.02
Arthur	80	3305	3305.0	3280	3330	35.36	97	2962.5	2962.5	2951	2974	16.26	177	3133.75	3127.0	2962.5	3305.0	199.01
Balin	6	307.5	307.5	287	328	28.99	9	274.5	274.5	273	276	2.12	15	291	281.5	274.5	307.5	25.39
Balou_Mix	96	4670.5	4670.5	4566	4775	147.79	78	7062.0	7062.0	4434	9690	3716.55	174	5866.25	4670.5	4500.0	7232.5	2553.03
Balou_RR	90	2419.5	2419.5	2351	2488	96.87	48	1299.5	1299.5	1294	1305	7.78	138	1859.5	1828.0	1299.5	2419.5	649.06
Bill	121	8143	8143.0	7129	9157	1434.01	100	5519.5	5519.5	5233	5806	405.17	221	6831.25	6467.5	5519.5	8143.0	1741.96
Dr. Pepper	39	1015.5	1015.5	167	1864	1199.96	5	121	121.0	115	127	8.49	44	568.25	147.0	121.0	1015.5	864.12
Emma	1	36	36.0	0	72	50.91	5	202.5	202.5	97	308	149.2	6	119.25	84.5	36.0	202.5	132.38
Freya	6	229.5	229.5	162	297	95.46	3	151.5	151.5	110	193	58.69	9	190.5	177.5	136.0	245.0	78.83
Honey	34	2129.5	2129.5	2127	2132	3.54	24	2338.5	2338.5	1389	3288	1342.8	58	2234	2129.5	1758.0	2710.0	784.6
Kaito	71	6022.5	6022.5	5451	6594	808.22	77	4521	4521.0	4322	4720	281.43	148	5271.75	5085.5	4521.0	6022.5	997.82
Kimi	38	2193	2193.0	1022	3364	1656.04	58	2933	2933.0	1782	4084	1627.76	96	2563	2573.0	1402.0	3724.0	1407.09
Lea/Emma	85	2970.5	2970.5	2684	3257	405.17	60	1689.5	1689.5	831	2548	1214.1	145	2330	2616.0	1689.5	2970.5	1045.49
Lili	34	881	881.0	746	1016	190.92	40	1402	1402.0	891	1913	722.66	74	1141.5	953.5	818.5	1464.5	526.03
Lou	78	7069	7069.0	5966	8172	1559.88	104	4461	4461.0	3330	5592	1599.48	182	5765	5779.0	4461.0	7069.0	1982.69
Luna	69	3010.5	3010.5	2742	3279	379.72	80	2699	2699.0	1424	3974	1803.12	149	2854.75	3010.5	2083.0	3626.5	1078.96
Mala	1	69	69.0	69	69	.	1	157	157.0	157	157	.	2	113	113.0	69.0	157.0	62.23

Dogs n=30	area												total					
	known						unknown											
	n runs	mean	median	Q25	Q75	SD	n runs	mean	median	Q25	Q75	SD	n runs	mean	median	Q25	Q75	SD
Manja	1	m0.5	30.5	0	61	43.13	4	331.5	331.5	225	438	150.61	5	181	143.0	30.5	331.5	195.91
Marley	76	7860.5	7860.5	7648	8073	300.52	83	6264	6264.0	4590	7938	2367.39	159	7062.25	7793.0	6119.0	8005.5	1657.68
Molly	7	250	250.0	195	305	77.78	6	224	224.0	213	235	15.56	13	237	224.0	204.0	270.0	48.19
Nele	103	2331.5	2331.5	2318	2345	19.09	98	2242	2242.0	1991	2493	354.97	201	2286.75	2331.5	2154.5	2419.0	211.64
Nina	43	2619.5	2619.5	997	4242	2294.56	60	3045.5	3045.5	1202	4889	2607.1	103	2832.5	2722.0	1099.5	4565.5	2020.19
Odin	33	707	707.0	572	842	190.92	25	464	464.0	435	493	41.01	58	585.5	532.5	464.0	707.0	179.98
Raffaele	35	2797.5	2797.5	2305	3290	696.5	12	645	645.0	341	949	429.92	47	1721.25	1627.0	645.0	2797.5	1329.56
Raya	73	3726.5	3726.5	2563	4890	1645.44	33	2840	2840.0	2320	3360	735.39	106	3283.25	2961.5	2441.5	4125.0	1159.62
Tamina	81	7638.5	7638.5	7435	7842	287.79	66	4669	4669.0	3298	6040	1938.89	147	6153.75	6737.5	4669.0	7638.5	2054.27
Thorin	62	3335.5	3335.5	3022	3649	443.36	60	1894.5	1894.5	1290	2499	854.89	122	2615	2760.5	1894.5	3335.5	1000.65
Wantje	72	1690	1690.0	1479	1901	298.4	51	1247	1247.0	909	1585	478	123	1468.5	1532.0	1194.0	1743.0	413.84
Zlata	6	436	436.0	293	579	202.23	5	511.5	511.5	171	852	481.54	11	473.75	436.0	232.0	715.5	304.67
total	1648	2815.32	2351.0	579	3649	2481.83	1497	2275.05	1585.0	435	3360	2121.6	3145	2545.19	2168.0	493.0	3364.0	2314.82

Over all dogs Mann Whitney U Tests shows no significant difference ($p = 0.373$) between known and unknown areas with respect to the overall distance explored for dog runs > 20 m. Looking at the table reveals that 20 of 30 dogs travel shorter distances in unknown areas (yellow). 10 dogs travel longer distances in unknown areas (red). Using an exact binomial test the probability of 20 or more dogs out of 30 travelling shorter distances in unknown areas is not significant ($p = 0.099$). The median explored distance in known areas is 2351 m in unknown areas 1585 m respectively. Compared to the mean, clear differences can be perceived between known and unknown areas. The lower quartile shows a distance of 579 m in known and 493 m in unknown areas. 25 % of the walks in known areas have a distance of runs >20 m in excess of 3649 m (upper quartile), in unknown areas the third (75 %) quartile lies at 3364 m.

2.3.2 Radius of dog runs >20 m – grouping of dogs: Group 1: radius < 150 m; Group 2: $150 \text{ m} \leq \text{radius} < 350$ m; Group 3: radius ≥ 350 m.

Due to the fact that there are large differences in the maximal distance of runs > 20 m between the dogs, dogs were classified into three radius groups: The majority of dogs show a median maximal difference of less than 150 m away from the owner (13 of 30 dogs =43 % see table below, **Group 1**); eight (27 %) of the dogs show a median maximal difference away from the owner of less than 350 m (**Group 2**); nine of the 30 dogs (30 %) have at least one run over 350 m away from the owner (**Group 3**).

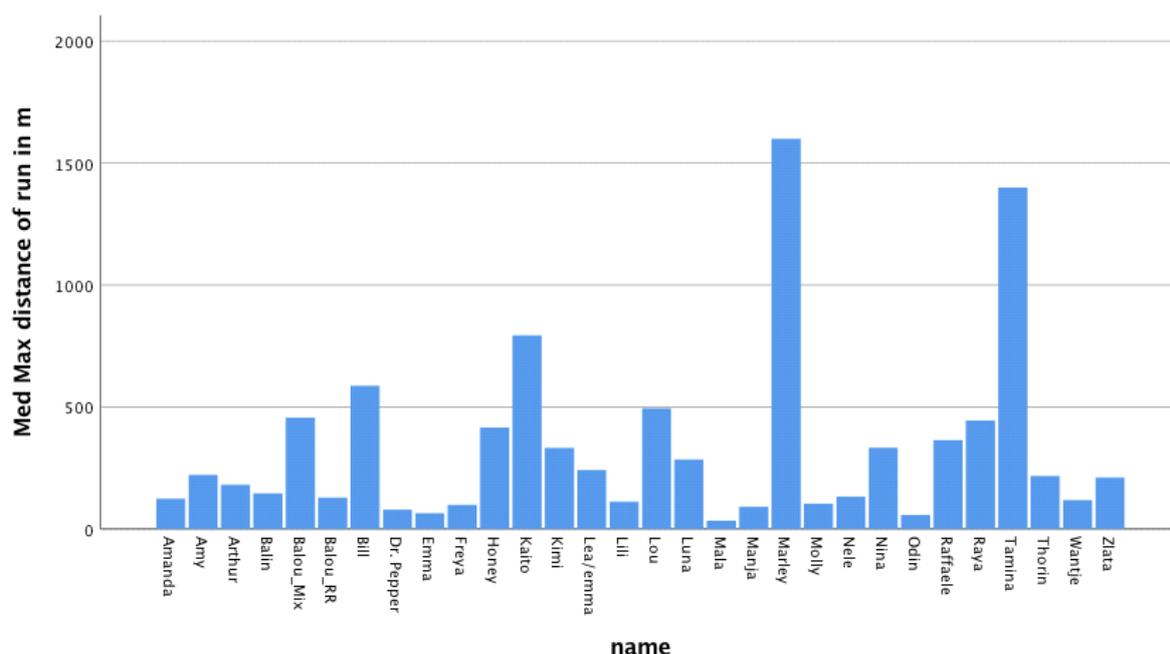


Fig. R2.2.1: Median of the maximum distance in meter of all runs >20 m, $n = 3145$, each dog.

Great intraspecific differences can be perceived between the maximum median distances of runs > 20 m explored by each dog.

Table R2.2.1: Each dog minimum, maximum and median distance of runs >20 m, Grouped: Group 1: radius < 150 m; Group 2: 150 m ≤ radius <350 m; Group 3: radius ≥ 350 m.

Dog/breed	Max distance of runs > 20 m of 4 walks in m			Group (1: radius < 150 m; 2: 150 m ≤ radius <350 m; 3: radius ≥ 350 m)
	Minimum	Median	Maximum	
N=30 F/M; i/n				
Amanda/Collie F/i	87	125	174	1
Amy/Labrador F/n	166	223	303	2
Arthur/Poodle M/i	147	182	239	2
Balin/Great Dane mix M/n	72	146	191	1
Balou_Mix/ Labrador Mix M/i	299	457	839	3
Balou_RR/Ridgeback M/n	111	129	246	1
Bill/Labrador Mix M/n	521	588	646	3
Dr. Pepper/Silken Windsprite M/i	48	80	407	1
Emma/Perro de Aqua Espanol Mix F/n	19	65	126	1
Freya/Pug F/n	78	99	193	1
Honey/Whippet F/n	157	417	479	3
Kaito/Mastiff Mix M/n	250	795	1000	3
Kimi/Whippet F/n	167	333	704	2
Lea/Emma/Miniature Pinscher F/i	105	242	392	2
Lili/Shepard Mix F/n	92	113	173	1
Lou/Shepard Mix M/n	249	495	1000	3
Luna/Ridgeback F/n	239	285	377	2
Mala/Perro de Aqua Espanol F/n	0	35	157	1
Manja/Italian Greyhound F/i	0	92	354	1
Marley/Labrador Mix M/n	374	1600	2300	3
Molly/Pug F/n	90	104	124	1
Nele/Labrador F/n	71	134	217	1
Nina/Greyhound Mix F/n	135	334	607	2
Odin/Whippet M/n	47	58	68	1
Raffaele/Italian Greyhound M/n	115	365	658	3
Raiya/Borzoi F/i	306	445	881	3
Tamina/Terrier Mix F/n	406	1400	1900	3
Thorin/Borzoi M/n	142	218	300	2
Wantje/Collie F/i	89	119	156	1
Zlata/Borzoi F/n	171	211	338	2

Table R2.2.1 shows the differences between known and unknown area in relation to the median maximal distance from the owner. Group 1 (green n=13) with 13 of 30 dogs is the largest group (43 %) - almost half of the dogs never travel beyond the 150 m radius range; Group 2 (yellow n= 8), about 1/3 of the dogs never travel beyond the 350 m radius (27 %); Group 3 (red n=9) dogs travel beyond the median maximal difference 350 m radius (30 %). For each dog the minimum, median and maximum distances are given, classification to the appropriate group can be found in the right hand column. For each dog the applicable breed is allocated. For a boxplot depicting all three groups see **Fig. R2.2.2** below.

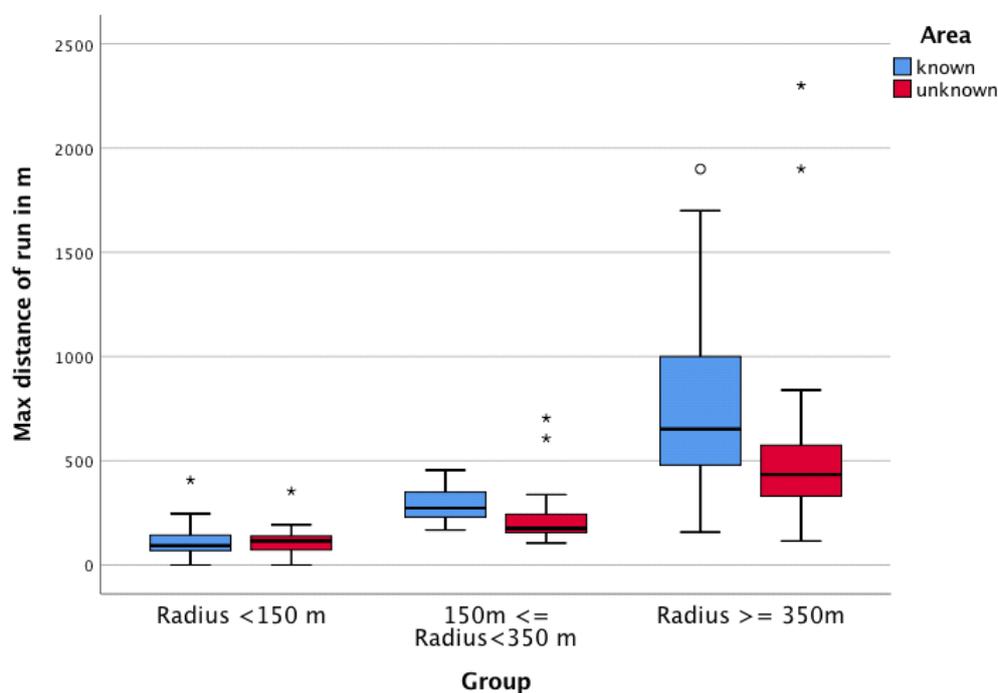


Fig. R2.2.2: *Boxplot: Maximum distance in meter of all runs >20 m, for Group 1, 2 and 3 in known (blue) versus unknown (red) area.*

As can be seen for Group 1 no difference is apparent between known and unknown areas. In Group 2 a tendency to travel further in known areas can be perceived. Most pronounced is the difference in Group 3, the far ranging dogs, which explore more extensively in known than unknown area.

2.3.3 Differences between known and unknown areas in relation to maximal median difference from the owner Group 1; Group 2; Group 3

Dogs with a large exploration radius (Group 3 (red n=9) **Table R.2.2.1**) exhibit a reduction of maximal distance in unknown areas from 794 +/- 478 m to 623 +/- 568 m (mean)

and a median reduction from 652 m in known areas to 434 m in unknown areas, a decrease of 33 % . Also within the second group (Group 2) a reduction of maximal distance in unknown areas can be perceived with a mean of 291 +/- 87 m to 246 +/- 170 m and a median of 273m in known to 175m in unknown areas, a decrease of 36 %, see **Table R2.3.1**. Large intraspecific differences can be perceived, **Fig. R2.3.1** Looking at the median of the total runs >20 m in known and unknown areas, values of Group 1 are almost identical (known 572 m/unknown 435 m) ($p = 0.796$, Mann-Whitney-U Test). In Group 2 a difference can be seen in that the dogs travel shorter distances in unknown areas (known 3101 m/ unknown 2524 m – reduction 19 %, $p = 0.491$, Mann-Whitney-U Test). Group 3 however shows the clearest reduction in travelling distance of runs >20 m from known 5709 m to unknown 4378 m (decrease 23 %, $p = 0.126$, Mann-Whitney-U Test), see **Table R2.3.2; Fig. R2.3.2. Fig. R2.3.3** for a boxplot. For no group a significant reduction can be demonstrated however, see also randomization tests for one mean difference for Group 1, 2 and 3, **Fig. R2.3.4 - Fig. R2.3.6 Appendix**.

Table R2.3.1: Comparison of maximum distances of runs >20 m. Grouped: Group 1: >150 m; Group 2: < 150 m, > 350 m; Group 3: < 350m; known and unknown area in meter.

Max distance of run in m	Radius < 150 m n = 13 dogs					150 m <= Radius < 350 m n = 8 dogs					Radius >= 350 m n = 9 dogs				
	mean	median	Q25	Q75	SD	mean	median	Q25	Q75	SD	mean	median	Q25	Q75	SD
known area	114.42	92.5	69.0	143.0	84.70	290.50	272.5	230.0	349.5	86.51	793.61	652.0	479.0	1000.0	477.84
Unknown area	115.69	115.0	72.0	139.0	65.75	246.06	175.0	154.5	243.5	169.90	623.11	434.0	330.0	574.0	568.46

Between the three groups distinct differences between known and unknown area maximum travelling distance can be observed. In Group 1 (radius <150 m) the median of the maximum distance is 92,5 m in known and 115 m in unknown area, respectively, the respective means 114 m and 116 m in both areas are equivalent. In Group 2 differences in maximum median distance travelled between known and unknown areas become apparent: 50 % of the walks of dogs in this group have a maximum distance of 272 m in known and 175 m in unknown areas. Most pronounced is the difference in Group 3 (radius >350 m): here the maximum median distance in known areas is 652 m and 434 m in unknown areas, the 75 % quartile in this group is reduced from 1000 m in known to 574 m in unknown areas.

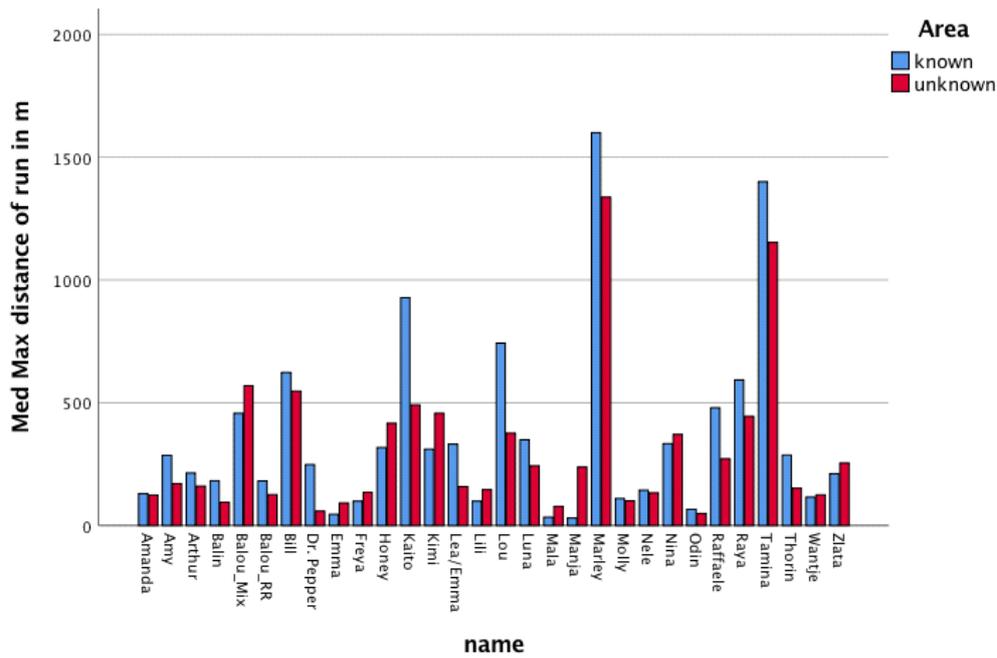


Fig. R2.3.1: Median of maximum distance in meter all runs >20 m each dog in known (blue) versus unknown (red) area.

For each dog the median of the maximum distance away from the owner of runs >20 m in known (blue) as well as unknown (red) areas is illustrated. Large differences can be seen between individual dogs.

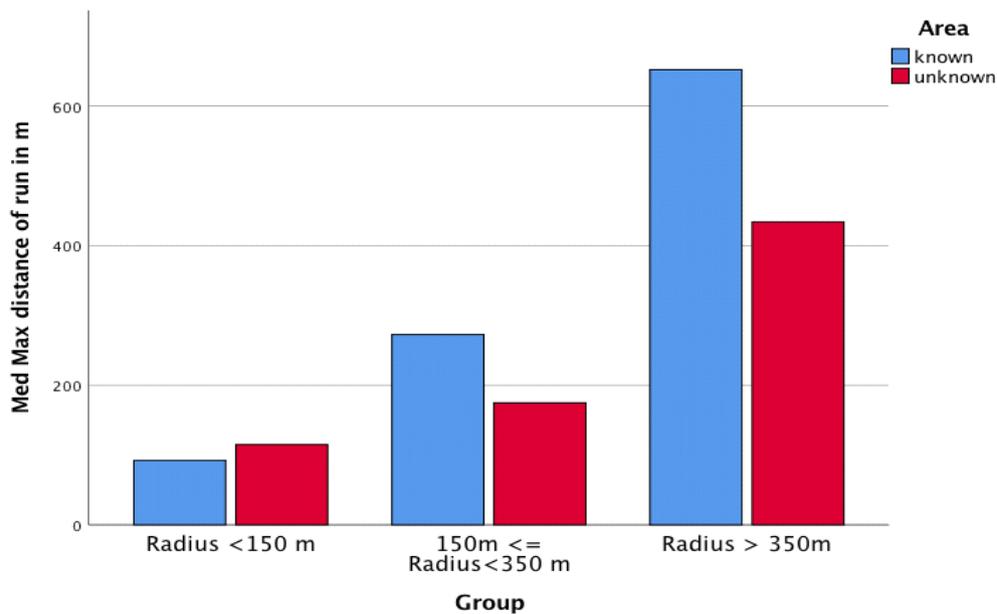


Fig. R2.3.2: Median of maximum distance in meter all runs >20 m; grouped; known (blue) versus unknown (red) area.

Looking at the median of the total runs >20 m in known (blue) and unknown (red) area, values of Group 1 are almost identical (known 572 m/unknown 435 m) ($p = 0.796$, Mann-Whitney-U Test). In Group 2 dogs travel shorter distances in unknown areas (known 3101 m/ unknown 2524 m – reduction 19 %, $p = 0.491$, Mann-Whitney-U Test). Group 3 however shows the clearest reduction in travelling distance of runs >20 m from known 5709 m to unknown 4378 m (decrease 23 %, $p = 0.126$, Mann-Whitney-U Test). For no group a significant reduction can be demonstrated however. See also randomization test for one mean difference, see **Fig. R2.3.4 - Fig. R2.3.6 Appendix**.

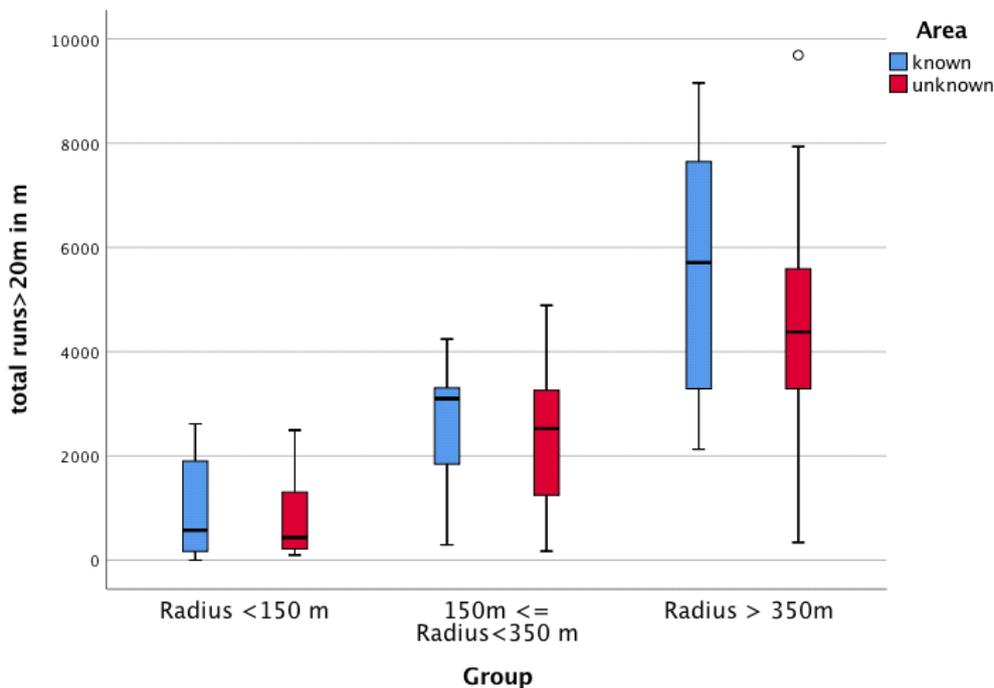


Fig. R2.3.3: *Boxplot: Total runs > 20 m, n=3145; grouped (Group 1, 2 and 3); Median of runs > 20 m in meter; known (blue) versus unknown (red) area.*

Distinct differences can be perceived between the three groups. Group 2 and 3 explore farther in known than unknown areas.

Table R2.3.2: *Distance of total runs >20 m in meter; known versus unknown area; Group 1,2 and 3.*

total runs > 20 m in m	Group 1 Radius <150 m n = 13 dogs					Group 2 150m <= Radius <350 m n = 8 dogs					Group 3 Radius >= 350 m n = 9 dogs				
	mean	median	Q25	Q75	sd	mean	median	Q25	Q75	sd	mean	median	Q25	Q75	sd
known area	976.24	572	167	1901	950.63	2598.94	3100.5	1843	3305	1191.06	5561.94	5708.5	3290	7648	2341.27
unknown area	787.76	435	213	1305	758.98	2368.37	2523.5	1246	3259	1354.59	4257.78	4378.0	3288	5592	2345.45

The median and mean distance of total runs > 20 m is lower in unknown areas than in known areas for all three Groups. Regarding the distances Group 1 displays with a median of 572 m in known and 435 m in unknown areas almost equivalent values. The lower quartiles are at 167 m versus 213 m, the upper quartiles at 1901 m and 1305 m. Group 2 has overall higher values compared to Group 1. A reduction of the distances is observable (median 3101 m versus 2524 m; lower quartile 1843 m versus 1246 m). Most pronounced differences are displayed by Group 3 with a median of 5709 m in known and 4378 m in unknown areas (23 % decrease).

2.3.4 Runs >20 m: Time travelled by the dogs in known areas compared to unknown areas

In addition to the distance travelled by the dogs (runs >20 m) see **Table R2.2.1; Table R2.3.2** and Chapter 2.2, the time travelled for each dog as well as each Group (1,2,3) was determined. Here again large intraspecific differences can be seen, **Fig. R2.4.1; Fig. R2.4.3**, Between the Groups however, no time differences were apparent, **Fig. R2.4.2**. Over all dogs the median time away from the owner was 00:17h in known areas and 00:11h in unknown areas, see **Table R2.4.1 Appendix**. The time difference between the two areas is not significant ($p = 0.267$; Mann-Whitney-U Test) over all dogs. No significant differences between known and unknown areas could be demonstrated within the above defined groups ($p = 0.656$ (radius <150 m), $p = 0.291$ (150 m <= radius<350 m) and $p = 0.229$ (radius >350m), Mann-Whitney-U Test). Between the three groups differences in exploration time could clearly be seen, with an increase from Group 1 to Group 3. All groups showed longer exploration times in known than unknown areas (mean time away from owner), **Fig. R2.4.3; Fig. R2.4.4**. For no group a significant reduction of time travelled runs >20 m could be demonstrated however, see randomization tests for one mean difference for Group 1, 2 and 3, **Fig. R2.4.5 - Fig. R2.4.7 Appendix**.

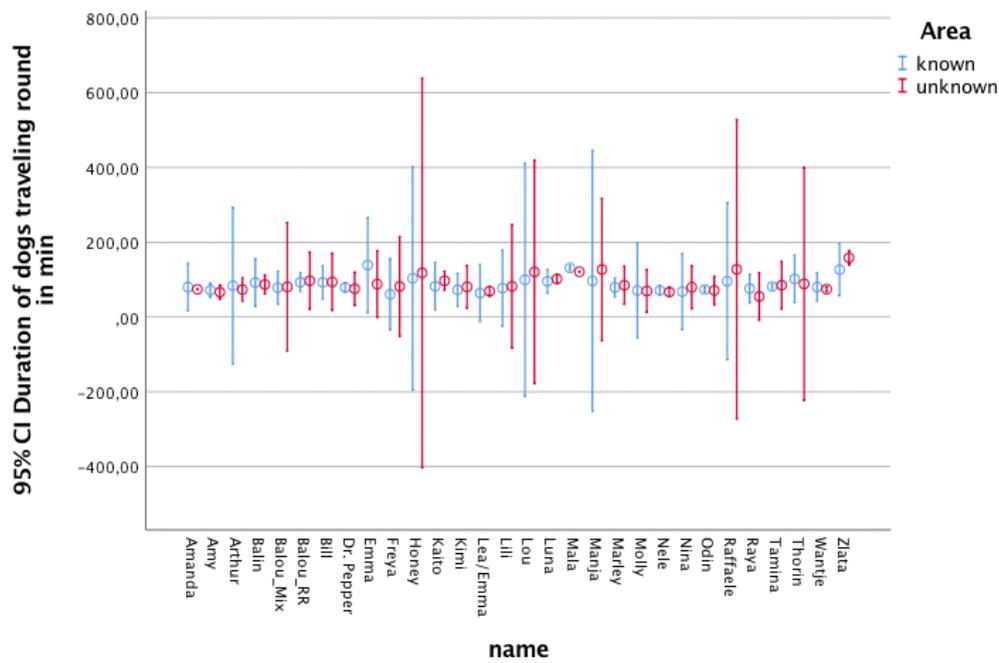


Fig. R2.4.1: Mean duration of travelling round >20 m each dog in minutes; known (blue) and unknown (red) area.

For each dog the mean duration of their exploration round >20 m in minutes away from the owner in known (blue) as well as unknown (red) areas is illustrated. Large variances can be observed between the individual dogs.

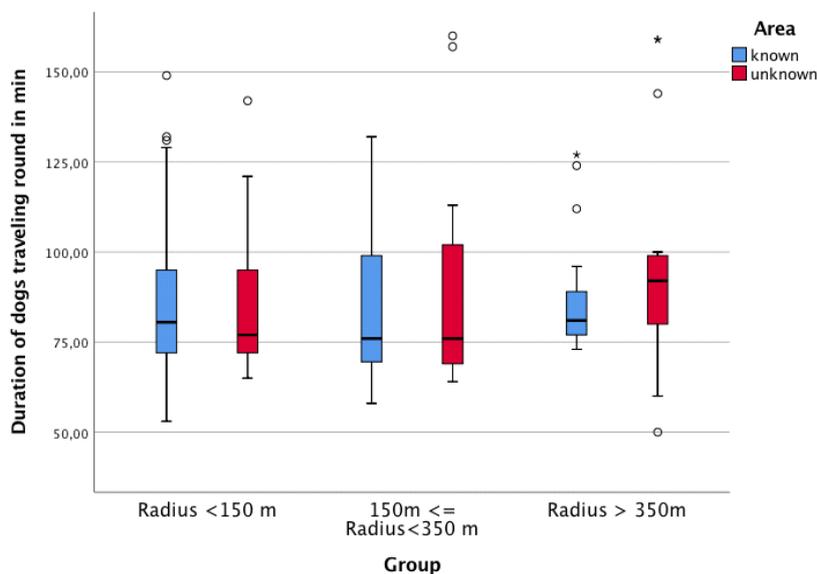


Fig. R2.4.2: **Boxplot:** Duration of travelling round >20 m Group 1, 2 and 3, in minutes; known (blue) and unknown (red) area.

With respect to the time travelled large intraspecific differences can be perceived, **Fig R2.4.1; Fig. R2.4.3**. However, while regarding the distance clear differences could be

ascertained between the Groups, there are no apparent time differences, **Fig. R2.4.2**. Furthermore no differences between Groups and known or unknown area are observable, **Fig. R2.4.2**. A modest increase of median as well as upper quartile can be seen in Group 2 in unknown versus known areas, see **Table R2.4.1 Appendix**. In particular Group 3 dogs explore in known areas substantially longer distances than in unknown areas, see **Table R2.4.1 Appendix**. Time away from the owner however, does not reflect these differences, therefore it can be concluded that Group 3 dogs travel considerably faster in known than in unknown areas.

Over all dogs the median time away from the owner is 00:17h in known areas and 00:11h in unknown areas. The lower quartiles are 00:04h in known versus 00:03h in unknown areas, the upper quartiles 00:24h in known versus 00:23h in unknown areas. The time difference between the two areas is not significant ($p = 0.267$; Mann-Whitney-U Test) over all dogs. No significant differences between known and unknown areas can be demonstrated within the above defined groups ($p = 0.656$ (radius <150 m), $p = 0.291$ (150 m <= radius <350 m) and $p = 0.229$ (radius >350 m), Mann-Whitney-U Test).

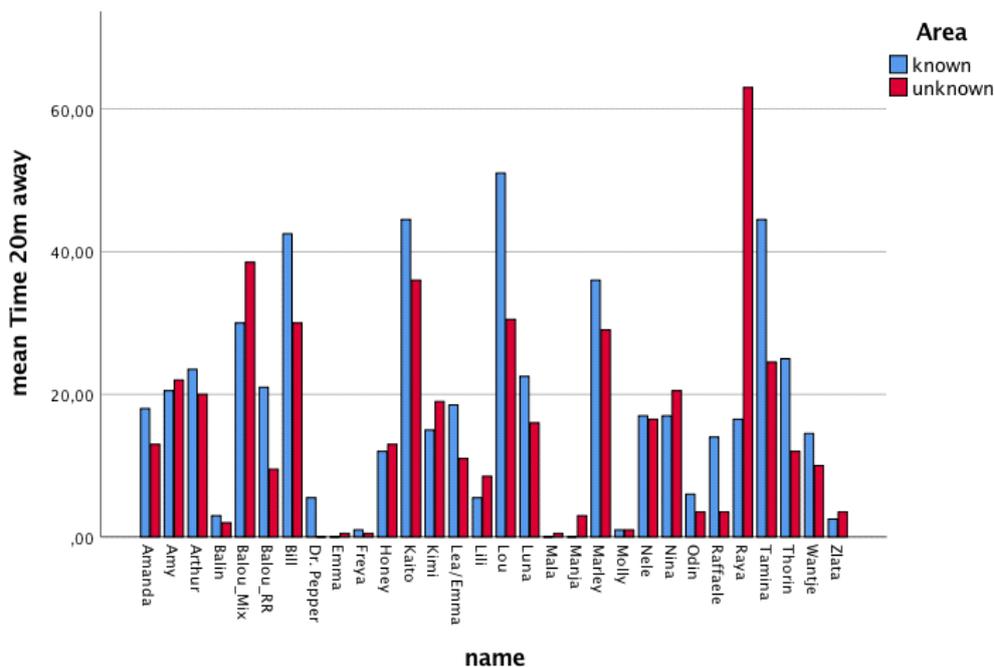


Fig. R2.4.3: Mean time away from owner travelling round >20 m each dog in minutes; unknown (red) and known (blue) area.

Individual differences in duration of runs between known and unknown areas can be seen. With exception of Raiya and Balou_Mix, all other long distance dogs (groups see above) show reduced times away from the owner in unknown areas.

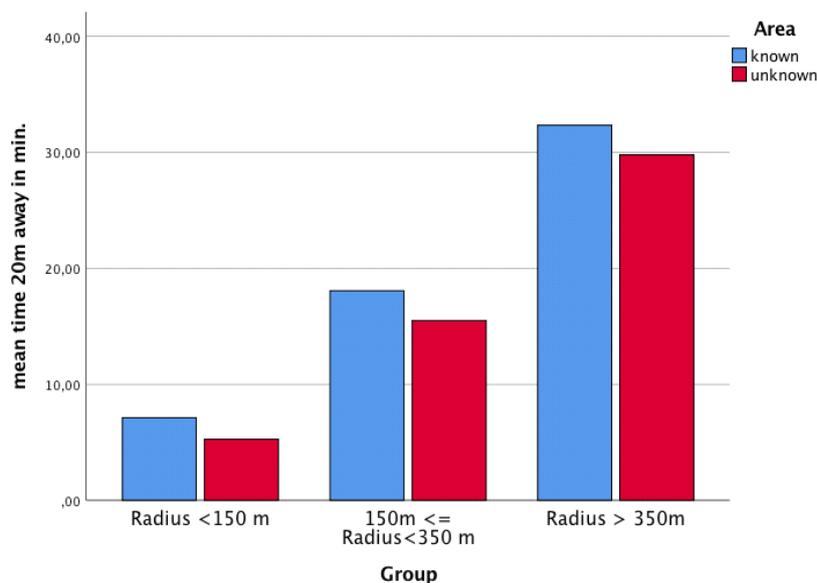


Fig. R2.4.4: Mean time away from the owner travelling round >20 m grouped, in minutes; unknown (red) and known (blue) area.

Between the three groups differences in travelling time can clearly be seen, with an increase from Group 1 to Group 3. All groups show longer exploration times of runs >20 m in known than unknown areas.

2.3.5 Distance outbound versus inbound (runs>20 m) travelled by the dogs

For each dog, where applicable travelling patterns were shown, the distance outbound: away from the owner up to a determined point of return (POR) as well as the distance inbound: from the point of return back to the owner was analyzed. For a description of the travelling patterns and a pictogram describing a point of return, see **Fig. M1.2.2; Fig. M1.2.3**. Not all dogs displayed a point of return (see Mala, Odin) therefore in these cases no outbound/inbound data were collected and evaluated. Over all dogs the mean distance of inbound travel (588 +/- 656 m) was lower than the mean distance of outbound travel (609 +/- 651 m), however the standard deviation (SD) over all dogs was very high, **Fig. R2.5.1; Table R2.5.1 Appendix**. The differences between inbound and outbound distance travelled were not significant ($p=0.068$; Wilcoxon Test). Using the randomization test for one mean difference also no significance could be shown ($p>0.05$), **Fig. R2.5.2**. Differences within the Groups 1, 2 and 3 were not significant ($p = 0.387$ (radius < 150 m), $p = 0.533$ (150 m <= radius < 350 m) and $p = 0.106$ (radius > 350 m) Mann Whitney U Test), see **Fig. R2.5.3; Table R2.5.1 Appendix**.

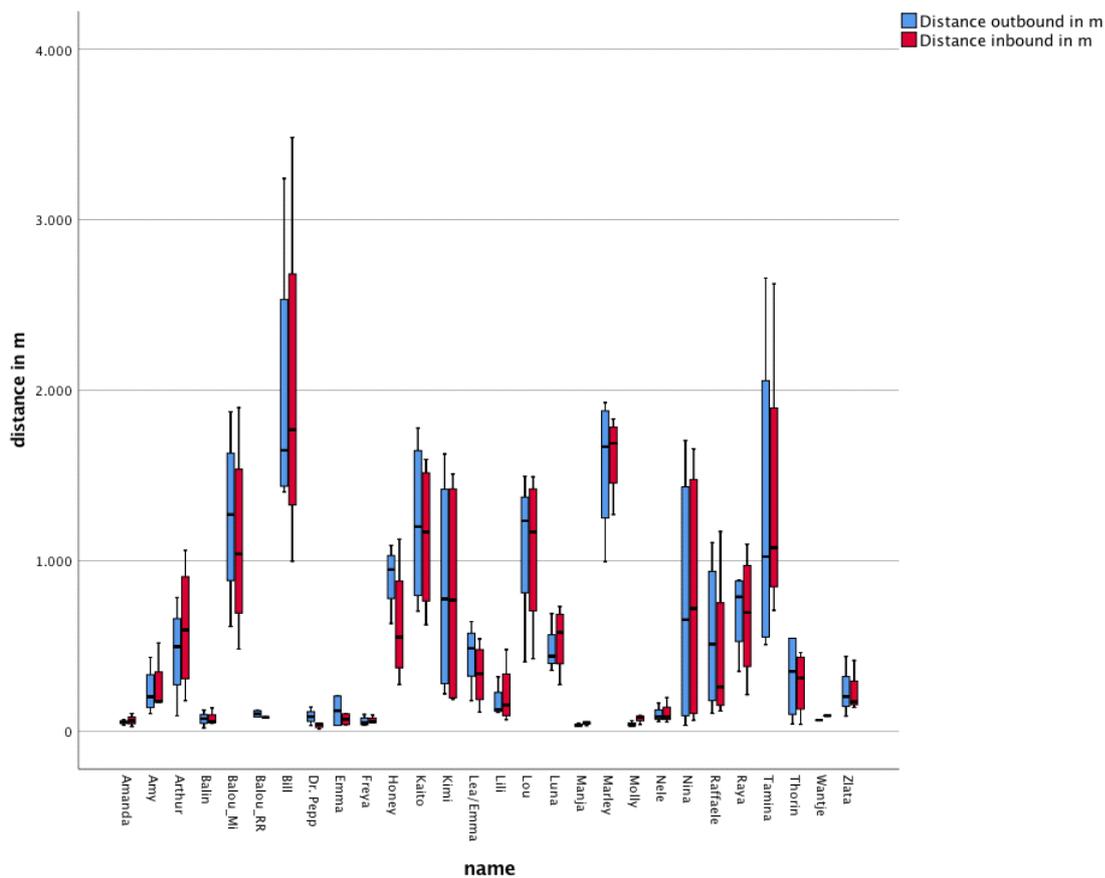


Fig. R2.5.1: *Boxplot: Distance outbound (blue) versus inbound (red) travelled by each dog, runs >20 m, in meter.*

A high inter-individual variance between the dogs can be seen and the standard deviation over all dogs is accordingly very high. The differences between inbound and outbound distance travelled of runs > 20 m are not significant ($p = 0.068$; Wilcoxon Test). Looking at the median, however, great differences between the distances become apparent: 50 % of the outbound median distance is ≤ 407 m; 50 % of the inbound median distance is ≤ 274 m, the upper quartile being almost identical (971 m versus 987 m), **Table R2.5.1 Appendix**. Using the randomization test for one mean difference the distance between outbound versus inbound travel of runs >20 m is also not significant ($p > 0.05$), **Fig. R2.5.2**.

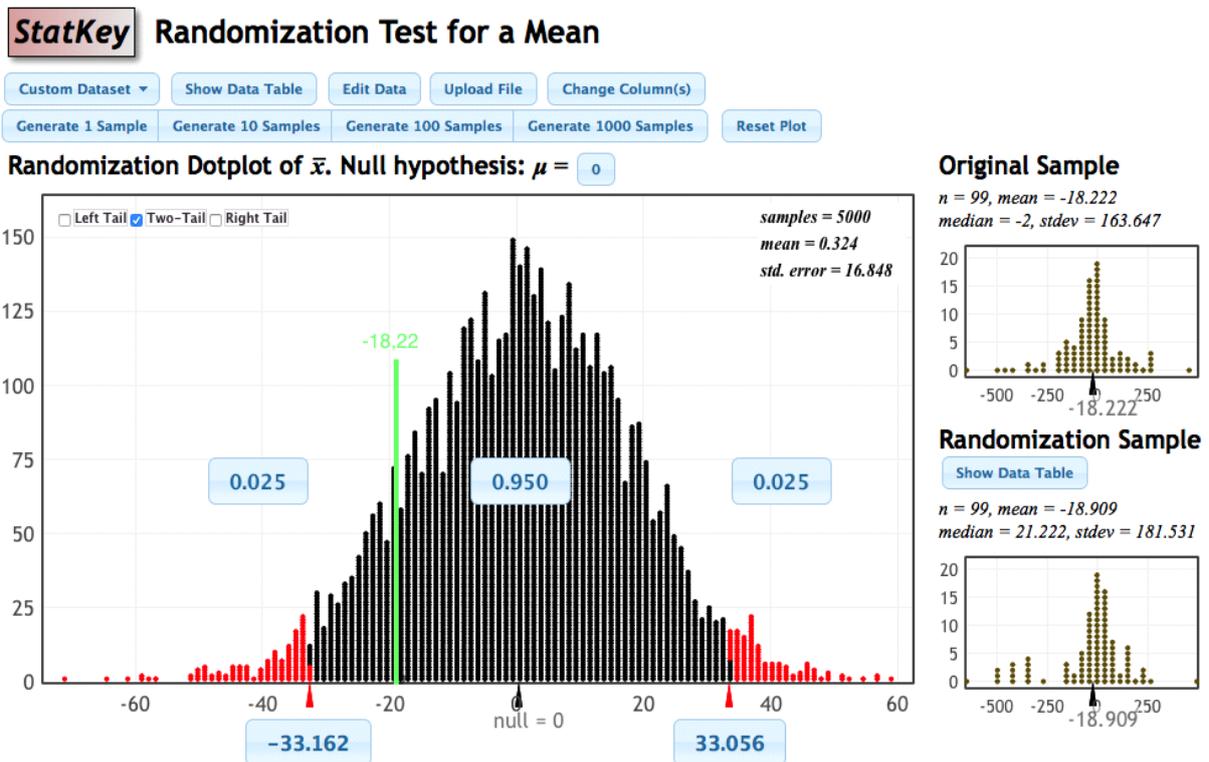


Fig. R2.5.2: Randomized test for one mean difference. Distance outbound versus inbound travel of runs > 20 m.

Between inbound and outbound travel of runs > 20 m a distance difference of -18.22 m was observed. Generating 5000 samples a mean difference of -18.22 m or greater between inbound and outbound distance could be observed in more than 5 % of the resamples (green line). Simulating 5000 samples of identical distributed datasets, critical values to reject the null hypothesis of no effect are -33.162 and 33.056. The observed value is outside these limits, therefore $p < 0.05$, the null hypothesis could not be rejected. No difference between inbound and outbound distance travelled of runs > 20 m could be demonstrated.

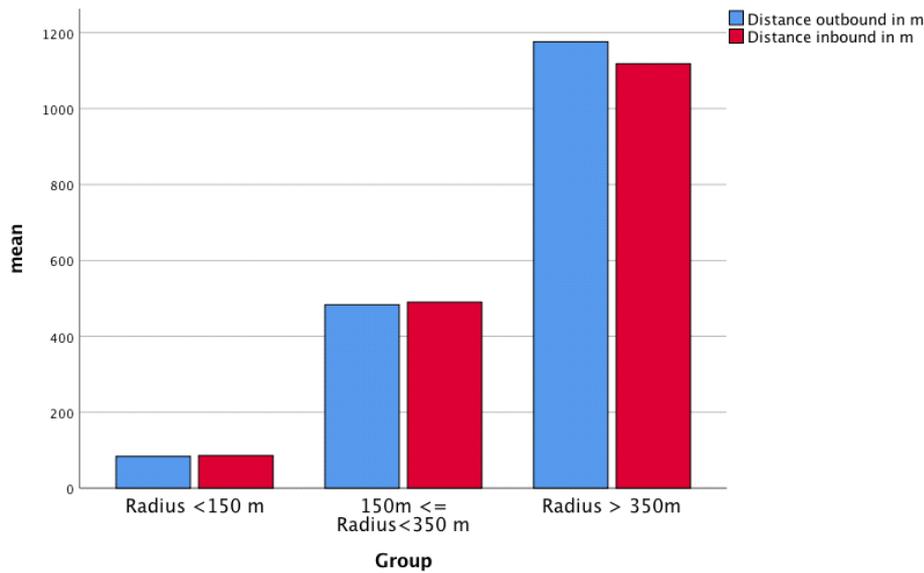


Fig. R2.5.3: Mean Distance inbound (red) versus outbound (blue) travelled of runs >20 m, Group 1, 2 and 3.

Inbound and outbound distances travelled are similar for dogs with mean maximal radius < 350 m. Inbound distance travelled is less than outbound distance in Group 3 (radius > = 350 m). The differences within the groups are not significant (p = 0.387 (radius < 150 m), p = 0.533 (150 m ≤ radius < 350 m) and p = 0.106 (radius > 350 m) Mann Whitney U Test).

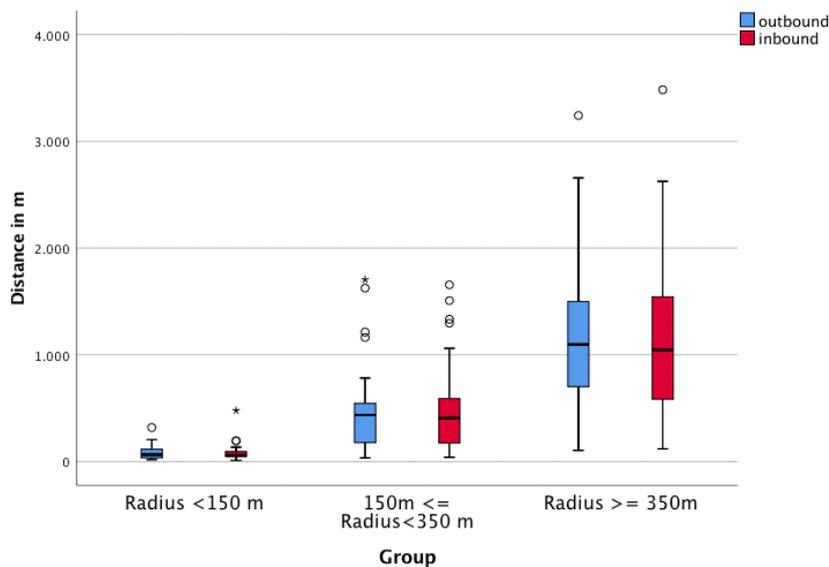


Fig. R2.5.4: Boxplot: Distance inbound (red) versus outbound (blue) travelled >20 m, Group 1, 2 and 3, in meter.

2.3.6 Time and speed outbound versus inbound (runs >20 m) travelled by the dogs

For each dog, where applicable travelling patterns were shown, the time outbound: away from the owner up to a determined point of return (POR) as well as the time inbound: from the point of return back to the owner was analyzed. For a description of the travelling patterns and a pictogram describing a point of return, see **Fig. M1.2.2; Fig. M1.2.3**. Not all dogs displayed a point of return (see Mala, Odin) because of their travelling patterns therefore in these cases no outbound/inbound data were collected and evaluated. A clear difference could be shown between the mean times inbound and outbound travelled looking at all dogs, **Fig. R2.6.1**. The time inbound was significantly shorter than the time outbound travelled, see **Table R2.6.1 Appendix**. A significant difference between the two travelling routes can be shown ($p < 0.001$, Wilcoxon Test). High inter-individual variance could be perceived, **Fig. R2.6.2**. Looking at Group 1, 2 and 3 inbound and outbound duration increased with ascending radius of the dogs. Differences between groups are significant in inbound and outbound duration ($p < 0.001$ inbound and outbound, Kruskal-Wallis Test), **Tab. R2.6.2; Fig. R2.6.3**.

2.3.6.1 Time outbound versus inbound (runs >20 m) travelled by the dogs

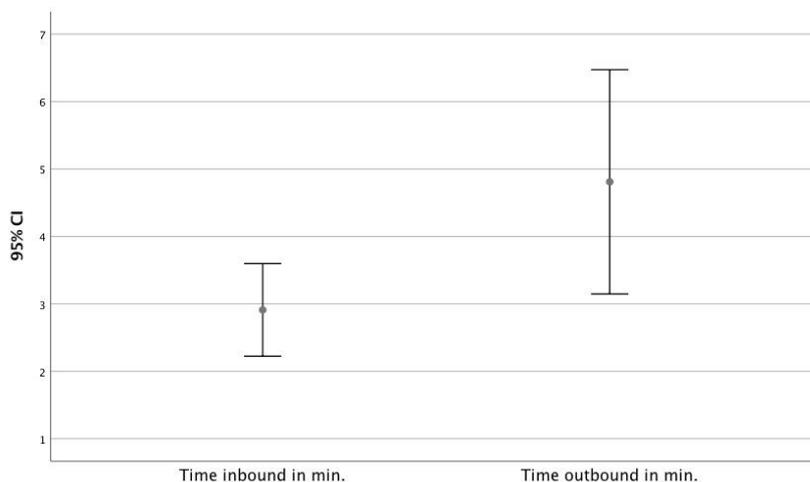


Fig. R2.6.1: Mean time inbound versus outbound time travelled (runs >20 m) all dogs in minutes.

A clear difference can be shown between the mean times inbound and outbound travelled looking at all dogs, see also **Table R2.6.1 Appendix**. The time inbound is significantly shorter than the time outbound.

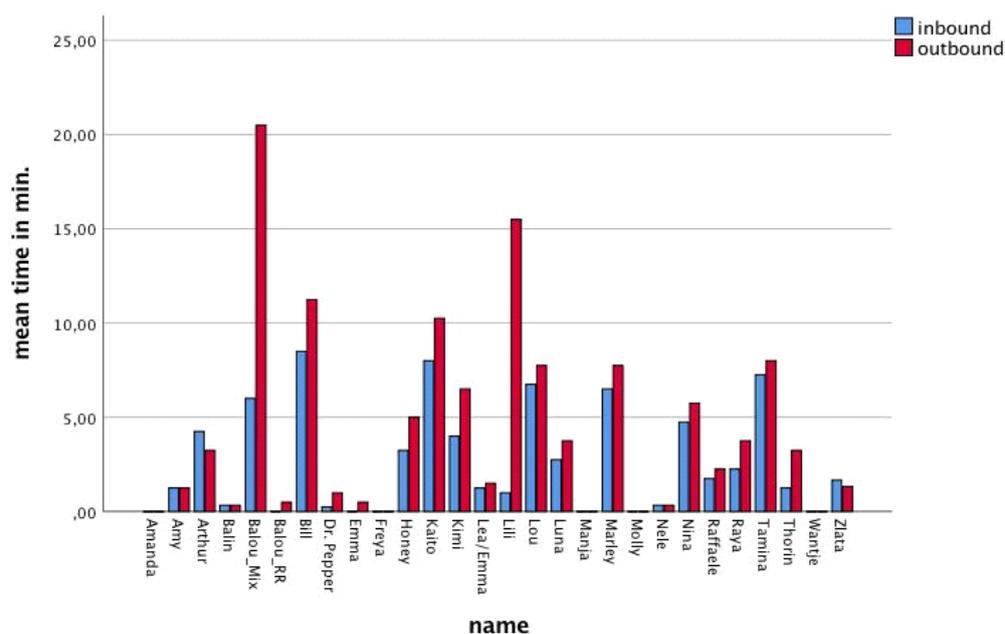


Fig. R2.6.2: Mean time inbound (blue) versus outbound (red) each dog in minutes.

Large inter-individual differences can be seen when looking at the individual dogs and their mean inbound/outbound time travelled, see also **Table R2.6.1 Appendix**. Here in particular the Group 3 dogs Balou_Mix, Bill, Kaito and Lili with much longer outbound than inbound times.

The mean time on outbound travel is 5 +/- 8 minutes, on inbound travel 3 +/- 3 minutes. The median time was double (00:02:00h) on outbound than inbound (00:01:00h) travel, with the lower quartile being equal, the upper quartile showing a differences of 00:07:00h outbound versus 00:05:00h inbound travelled time, an increase of 40 % on outbound travel time, see **Table R2.6.1 Appendix**. Over all dogs the inbound time travelled is less than the outbound time travelled. A significant difference between the two travelling routes can be shown ($p < 0.001$, Wilcoxon Test).

Table R2.6.2: Mean and median duration inbound versus outbound travelled >20 m, Group 1, 2, 3 in minutes.

Groups	Time_inbound in min.					Time_outbound in min.				
	mean	median	Q 25	Q 75	SD	mean	median	Q 25	Q 75	SD
Radius <150 m	0	0	0	0	1	2	0	0	1	10
150m <= Radius <350 m	3	2	1	4	3	3	2	1	5	4
Radius >= 350 m	6	5	3	8	4	9	8	4	11	8

Inbound and outbound duration increases with ascending radius of the dogs. Dogs with a median maximal radius ≥ 350 m (Group 3) show a mean outbound of 9 minutes and a mean inbound of 6 minutes with a median outbound time of 8 minutes and a median inbound time of 5 minutes (38 % decrease inbound time travelled). Within Group 2 the differences between inbound and outbound are nearly equivalent with same mean (3 min.) and same median (2 min.). For dogs with maximal distance < 150 m a mean outbound duration of 2 min and inbound duration of less than 1 minute was observed. Differences between groups are significant in inbound and outbound duration ($p < 0.001$ inbound and outbound, Kruskal-Wallis Test).

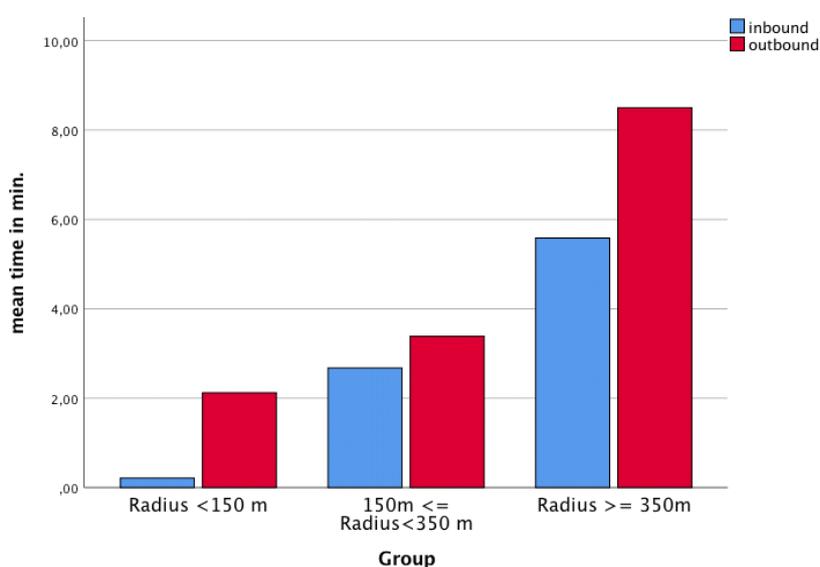


Fig. R2.6.3: Mean Time inbound (blue) versus outbound (red) travelled runs >20 m, in minutes, Group 1, 2 and 3.

All three Groups spent less time on inbound travel back to their owner than outbound travel on runs >20 m.

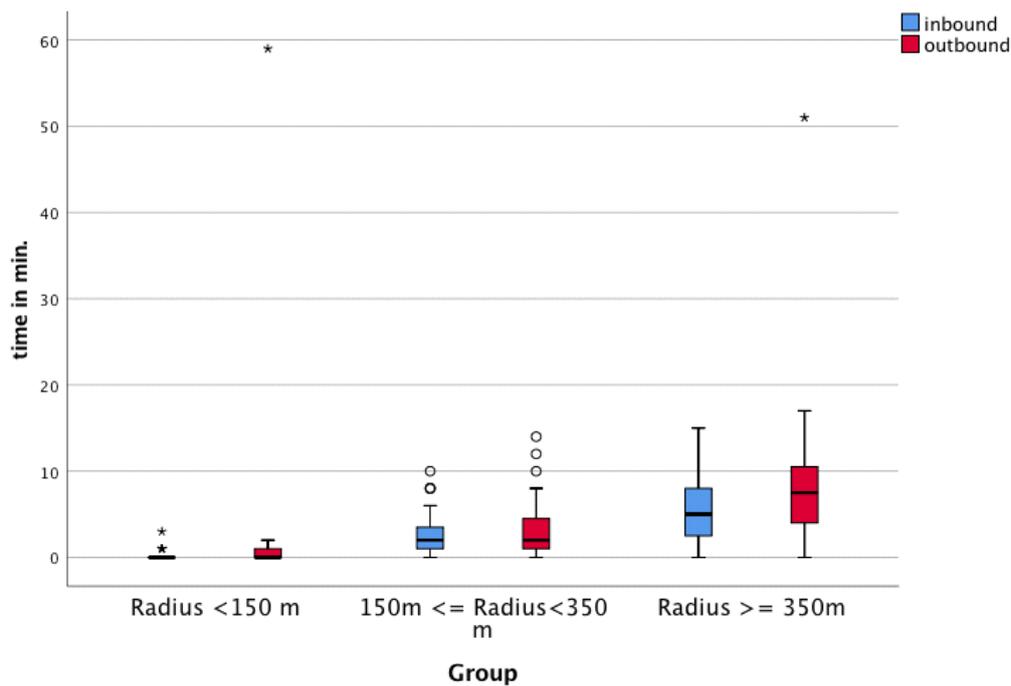


Fig. R2.6.4: *Boxplot: Time inbound (blue) versus outbound (red) travelled >20 m, in minutes, Group 1, 2 and 3.*

2.3.6.2 Speed outbound versus inbound (runs>20 m) travelled by the dogs

As there was no significant difference between the distance of the dogs travelled outbound and inbound see **Section R2.5**, but a significant difference with respect to the time travelled, see **Table R2.6.1 Appendix, Table R2.6.2, Table R2.6.3 Appendix; Fig. R2.6.3** the speed of the dogs was also analyzed. Compared was the speed outbound, away from the owner, versus inbound, back to the owner. The speed on inbound travel was significantly higher than on outbound travel ($p < 0.001$, Wilcoxon test) over all dogs, **Fig. R2.6.4**, as well as for Group 1, 2 and 3. In all three groups differences between inbound and outbound speed was observable. In all groups significant speed differences could be seen ($p^* = 0.018$ (radius < 150 m) $p^* = 0.054$, $p < 0.001$ (150 m <= radius < 350 m) $p^* < 0.002$, $p = 0.001$ (radius >= 350 m) $p^* = 0.003$ Mann Whitney U Test), **Fig. R2.6.5** – dogs travelled significantly faster on their return route back to their owner, **Fig. R2.6.8; Fig. R2.6.9**. See also, randomization test for one mean difference, **Fig. R2.6.10 Appendix**.

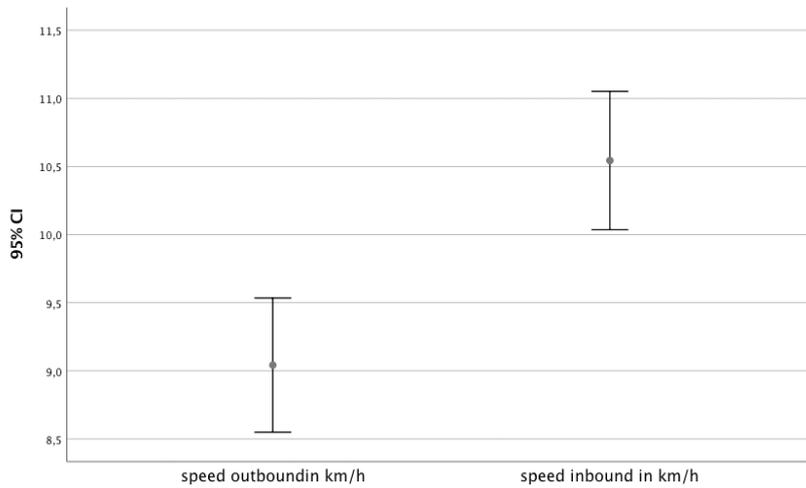


Fig. R2.6.5: Mean speed inbound versus outbound all dogs, in km/h.

The speed of the dogs on inbound travel (back to their owner) is significantly higher than the speed on their outbound travel ($p < 0.001$, Wilcoxon test, over all dogs).

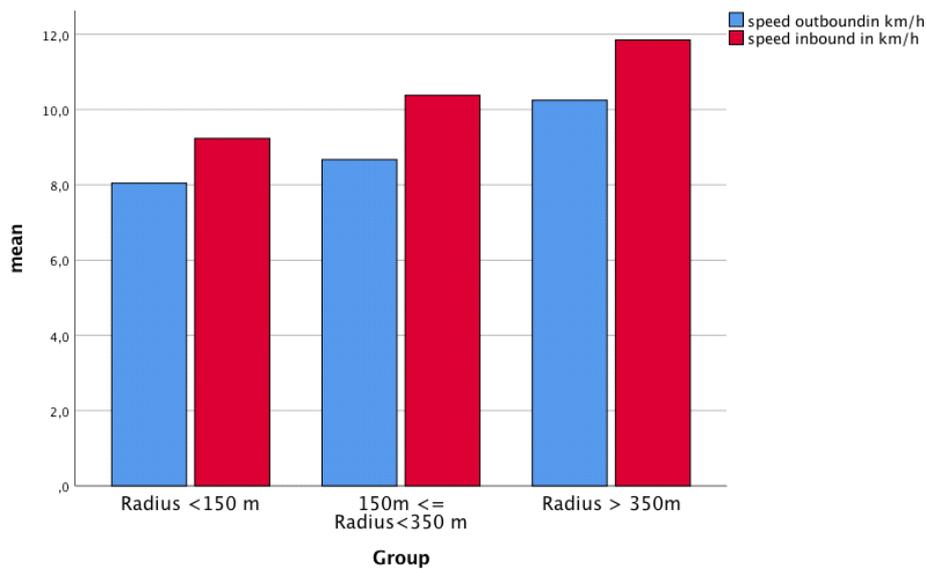


Fig. R2.6.6: Mean speed inbound (red) versus outbound (blue), Group 1, 2 and 3, in km/h.

In all three groups (Group 1, 2 and 3) significant speed differences between inbound and outbound travel runs >20 m are observable ($p^* = 0.018$ (radius < 150 m) $p^*=0.054$, $p < 0.001$ (150 m <= radius < 350 m) $p^* < 0.002$, $p = 0.001$ (radius > = 350 m) $p^*=0.003$ Mann Whitney U Test).

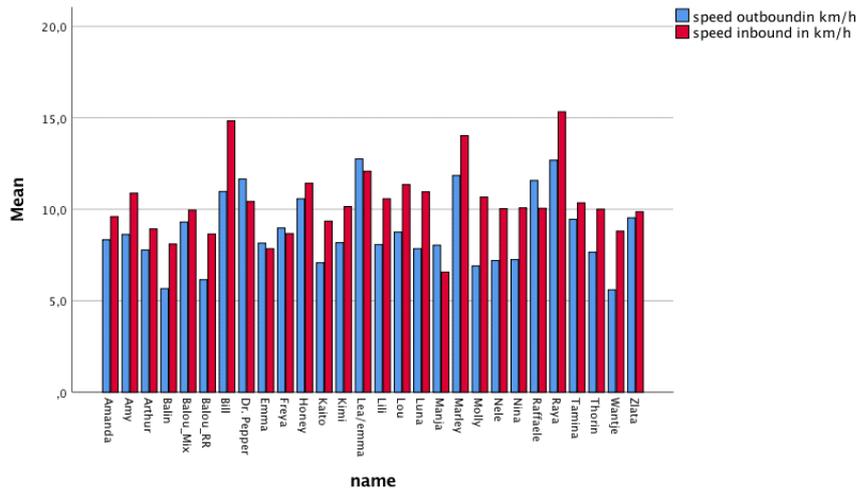


Fig. R2.6.7: Mean Speed inbound (red) and outbound (blue) travel runs >20 m, each dog in km/h.

The speed on inbound travel is significantly higher than on outbound travel and great inter-individual differences can be observed; see **Table R2.6.2**, **Table R2.6.3 Appendix**.

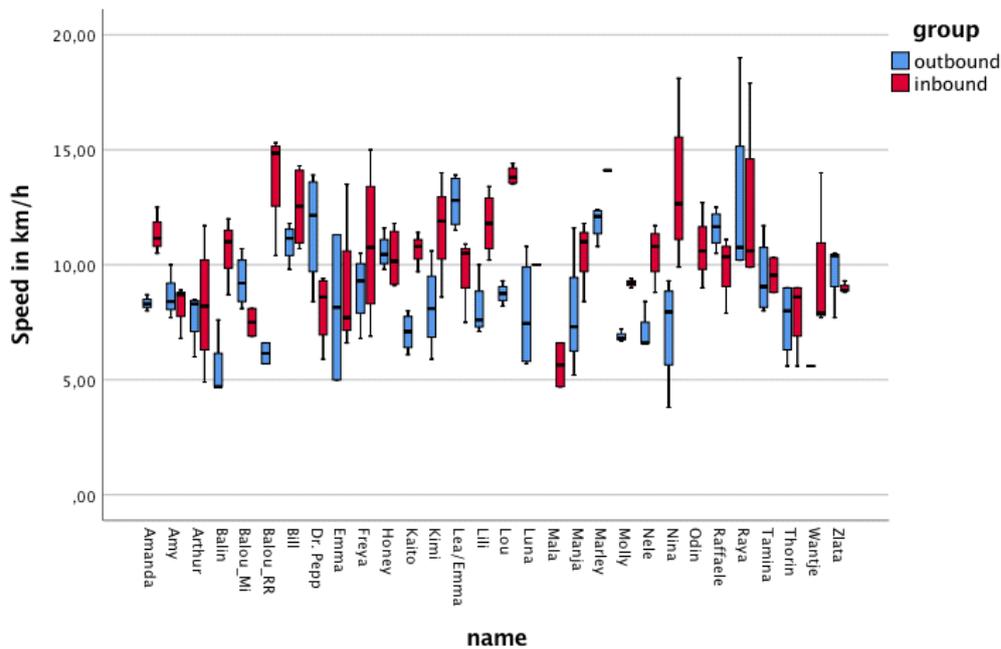


Fig. R2.6.8: **Boxplot:** Speed inbound (red) versus outbound (blue) travel runs >20 m, each dog in km/h.

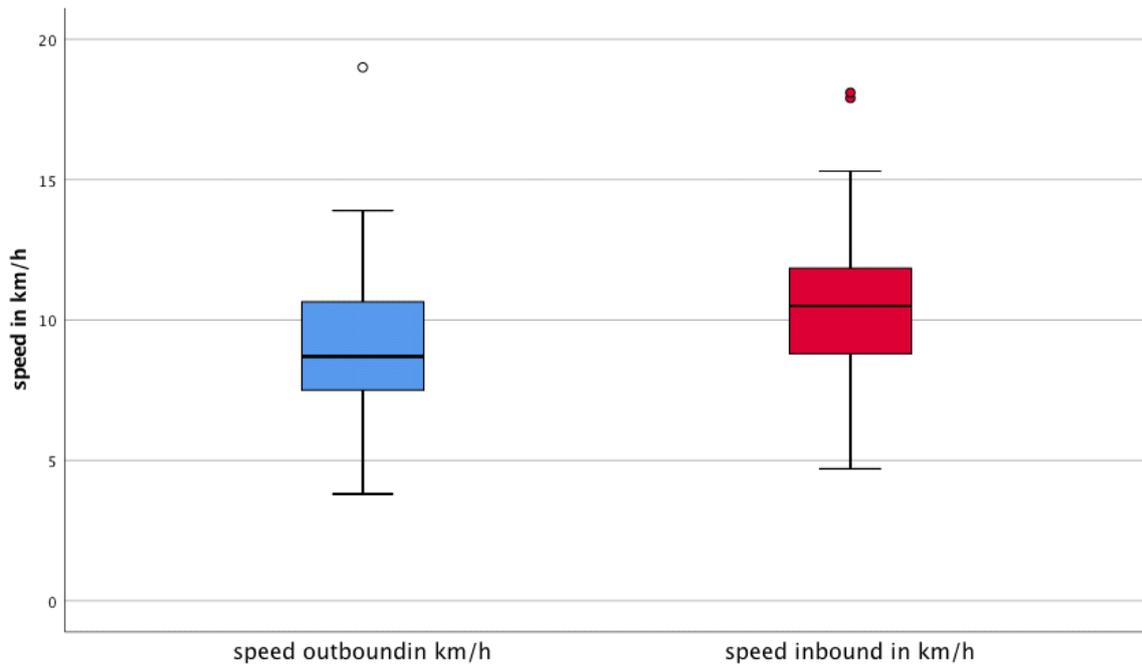


Fig. R2.6.9: *Boxplot: Speed inbound (red) versus outbound (blue) travel runs >20 m, in km/h.*

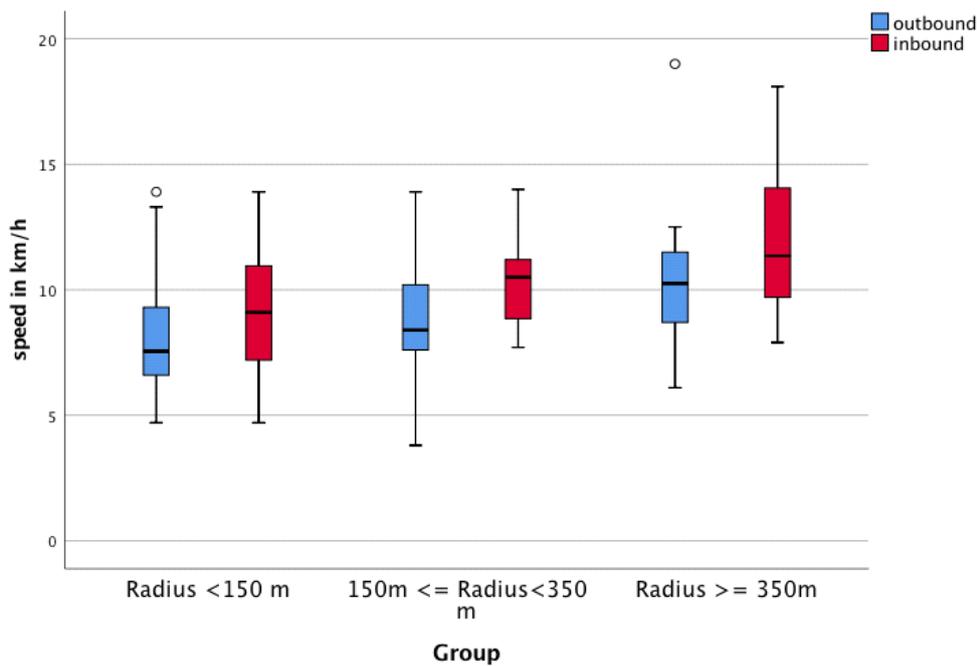


Fig. R2.6.10: *Boxplot: Speed inbound (red) versus outbound (blue) travel runs >20 m, Group 1, 2 and 3, in km/h.*

Over all dogs the mean speed on outbound travel is 9 +/- 2.5km/h versus 11 +/- 2.6km/h on inbound travel. 50 % of the runs show speed <= 8.7km/h on outbound versus 8.8km/h on inbound travel. Lower quartile speed is 7.5km/h on outbound and 8.8km/h on inbound travel an increase of 17 %. On the higher quartile outbound travel speed is 10.5km/h and inbound travel speed 11.9km/h an increase of 13 %, see **Table**

R2.6.3 Appendix. Speed on inbound travel is significantly higher than on outbound travel ($p < 0.001$, Wilcoxon test, over all dogs. In all groups significant speed differences can be seen ($p^* = 0.018$ (radius < 150 m) $p^* = 0.054$, $p < 0.001$ ($150 \text{ m} \leq \text{radius} < 350$ m) $p^* < 0.002$, $p = 0.001$ (radius ≥ 350 m) $p^* = 0.003$ Mann Whitney U Test).

2.3.7 Distance travelled male versus female dogs (runs > 20 m)

It has been postulated that sex differences exist in regard to distances travelled between male and female dogs, therefore the distance of runs > 20 m with regard to sex was analyzed. The difference between female and male dogs with respect to the distance travelled of runs > 20 m is significant ($p = 0.003$; Mann-Whitney-U Test). Male dogs travel significantly longer distances on runs > 20 m than females, see **Fig. R2.7.1**, **Fig. R2.7.2**; **Table R2.7.1**; and **Fig. R2.7.4 Appendix**; **Fig. R2.7.5 Appendix**: Randomization test for one mean difference.

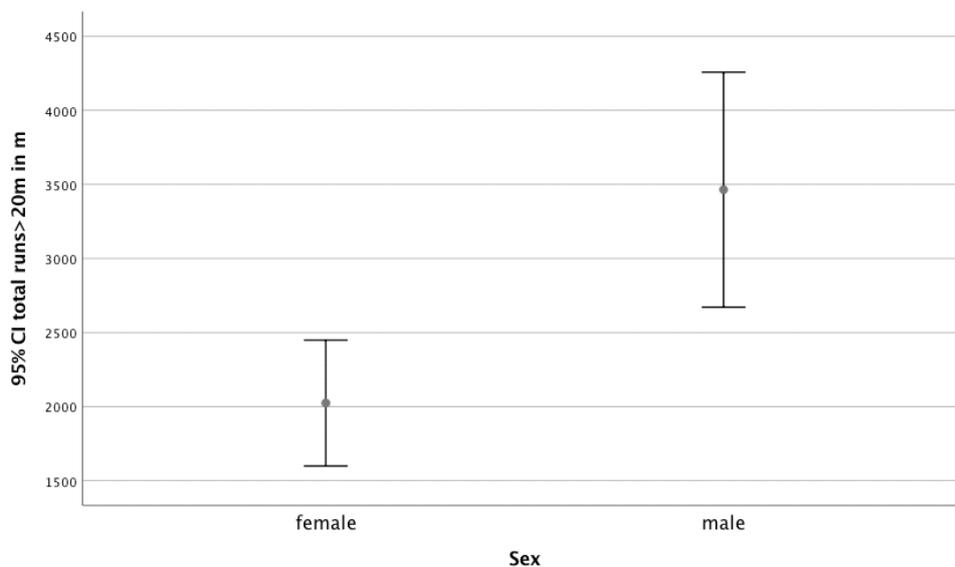


Fig. R2.7.1: Mean distance total runs > 20 m female versus male dogs distance travelled in meter.

The difference between female and male dogs of runs > 20 m is significant ($p = 0.003$; Mann-Whitney-U Test). Male dogs travel significantly longer distances than females.

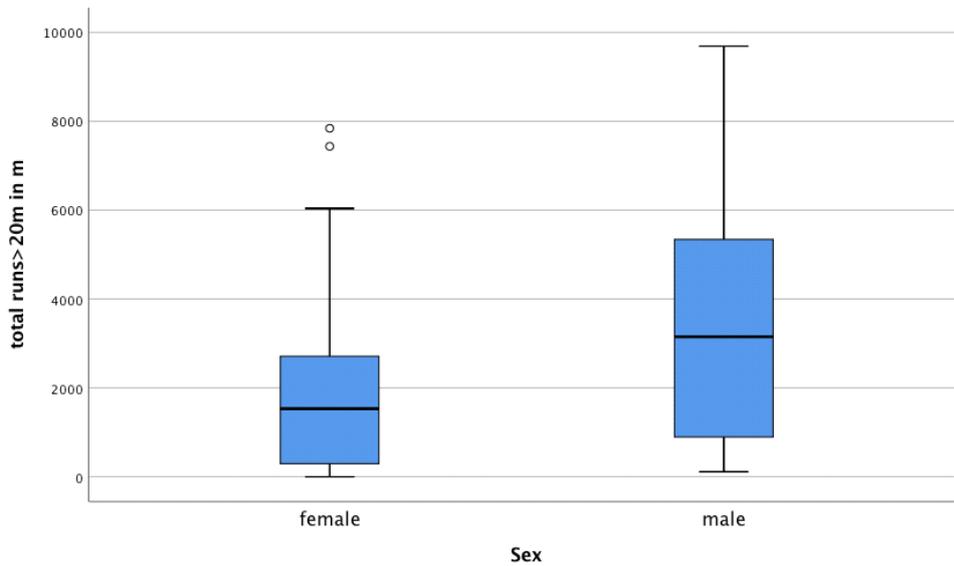


Fig. R2.7.2: *Boxplot: Distance of total runs >20 m female versus male dogs travelled in meter*

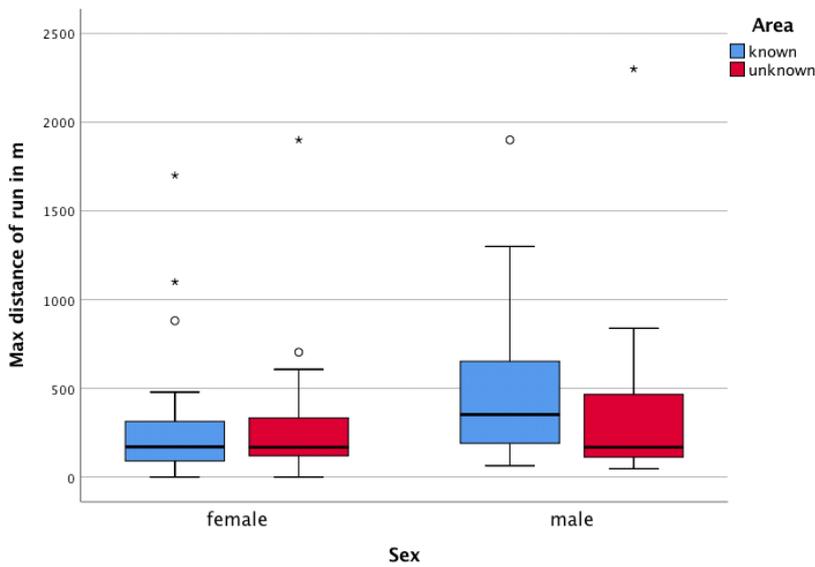


Fig. R2.7.3: *Boxplot: Maximal distance of runs >20 m female versus male dogs in meter, known (blue) versus unknown (red) area.*

Males travel the furthest distance in known areas, female dogs travel less distance than males in known and unknown areas.

Table R2.7.1: Female (n=18) versus male (n=12) dogs travelling distance; runs >20 m and total.

	Female n = 18						Male n = 12					
	n	mean	median	Q25	Q75	SD	n	mean	median	Q25	Q75	SD
total runs >20 m in m	1660	1862	1532	295	2713	1739	1485	3464	3151	896	5342	2732
total distance entire dog walk in m	72	7267	6300	5800	8500	2151	48	7819	7300	6100	9050	2258

The mean distance of runs >20 m is larger for male dogs (3464 +/- 2732 m) than for female dogs (1862 +/- 1739 m) by an increase of 86 %. The median shows 50 % of the male dogs run more than 3151 m, 50 % of the female dogs more than 1532 m distance on the runs > 20 m, with a distance on the higher quartile of 5342 m by the male dogs and 2713 m by the female dogs, an increase of 97 % distance travelled by the male dogs. See also **Fig. R2.7.4 Appendix:** Randomization test for one mean difference: male dogs travel significantly over all longer distances and **Fig. R2.7.5 Appendix:** Randomization test for one mean difference: male dogs travel significantly longer distances on runs > 20 m than female dogs.

2.3.8 Time travelled male versus female dogs (runs>20 m)

It has been postulated that sex differences exist in regard to travelling patterns between male and female dogs, which would include the time travelled respectively, therefore the time of runs >20 m with regard to sex was analyzed.

The difference in the duration of runs > 20 m between female and male dogs was significant ($p = 0.001$; Mann-Whitney-U Test). Females displayed a higher number of runs (n=1660) than male dogs (n=1485). It seems that female dogs have more short runs, male dogs fewer runs which are more extensive timewise. Over all, male dogs travel significantly longer times on their exploratory runs > 20 m than female dogs ($p = 0.001$; Mann-Whitney-U Test), **Fig. R2.8.1; Table R2.8.1** and **Fig. R2.8.3 Appendix:** Randomization test of one mean difference. Difference male versus female dogs, duration of runs > 20 m: male dogs are significantly longer > 20 m away from their owner than female dogs.

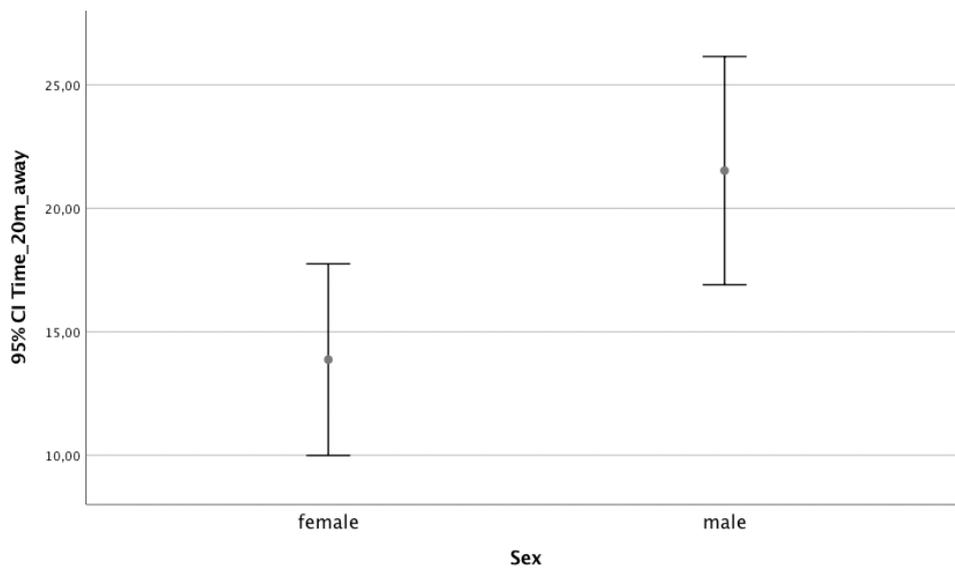


Fig. R2.8.1: Mean time runs >20 m female versus male dogs, time travelled in minutes.

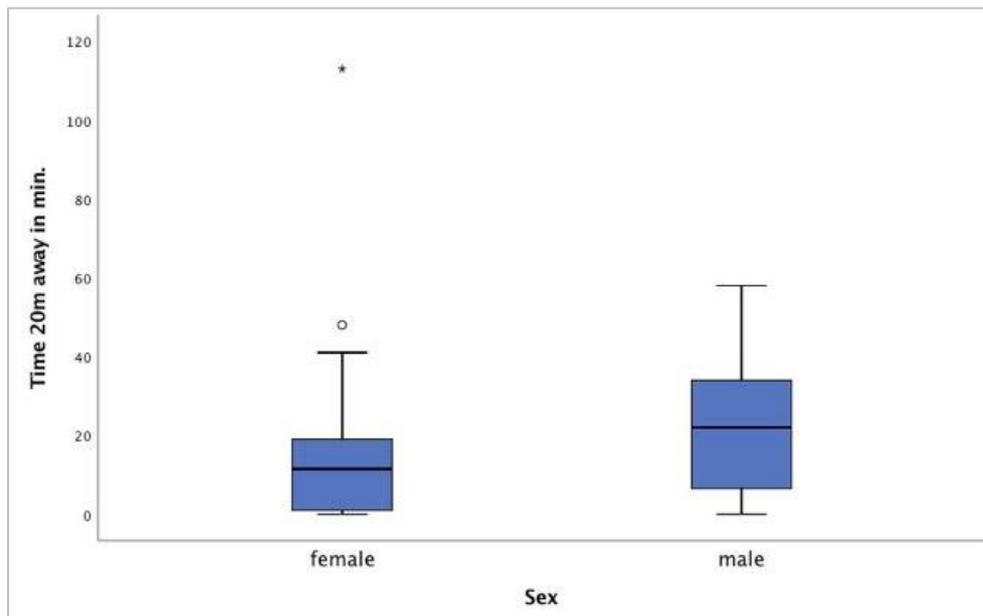


Fig. 2.8.2: Duration of runs >20 m female (n=18) versus male (n=12) dogs, time explored in minutes.

Male dogs explore longer than female dogs on runs > 20 m.

Table R2.8.1: *Time travelled female versus male dogs; runs >20m in minutes.*

	Female n = 18						Male n = 12					
	n	mean	median	Q25	Q75	SD	n	mean	median	Q25	Q75	SD
Time >_20m_away	1660	13	12	1	19	16	1485	22	22	7	34	16
Duration of dog runs in min.	72	88	77	70	97	26	48	89	88	77	97	19

The difference in the duration of runs > 20 m between female and male dogs is significant ($p = 0.001$; Mann-Whitney-U Test). Females show a higher number of runs ($n=1660$) than male dogs ($n=1485$). It seems that female dogs have more short runs, male dogs fewer runs which are more extensive timewise. The total walking time of male versus female dogs is 89 ± 19 min vs. 88 ± 26 min. and thus nearly equivalent. Over all, male dogs travel significantly longer times on their exploratory runs > 20 m than female dogs. The duration of all runs >20m is significantly longer in male dogs (22 ± 16 min.) than in female dogs (13 ± 16 min.). The median time over all runs also differs between males and females: 50 % of the male dogs travel longer than 00:22h whereas 50 % of the females travel longer than 00:12h away from their owner (83 % difference), with an upper quartile of male dogs of 00:34h versus female dogs of 00:19h an overall time difference of 56 %. See also, **Fig. R2.8.3 Appendix: Randomization test of one mean difference:** Male dogs are significantly longer > 20 m away from their owner than female dogs.

2.3.9 Distance travelled neutered versus intact dogs (runs>20 m)

It has been postulated that differences exist in regard to distance travelled between neutered and intact dogs, therefore the distance of runs > 20 m with respect to reproductive status of the dogs was analyzed. Differences in distance travelled between neutered and intact dogs could be observed, these were not significant ($p = 0.995$; Mann-Whitney-U Test), however **Fig. R2.9.1; Table R2.9.1; Fig. R2.9.3 and Fig. R2.9.5 Appendix** Randomization test of one mean difference.

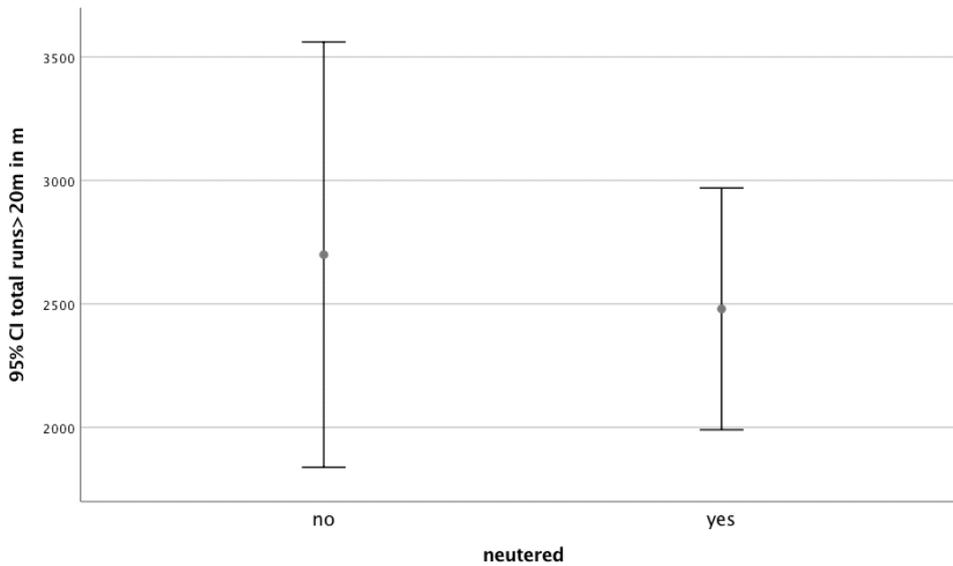


Fig. R2.9.1: Mean distance runs >20 m all castrated versus all intact dogs in meter.

Differences are observable: Intact dogs (n=8) travel further than neutered dogs (n=22) on runs > 20 m. Even though there are fewer intact dogs, they display the largest traveling distance.

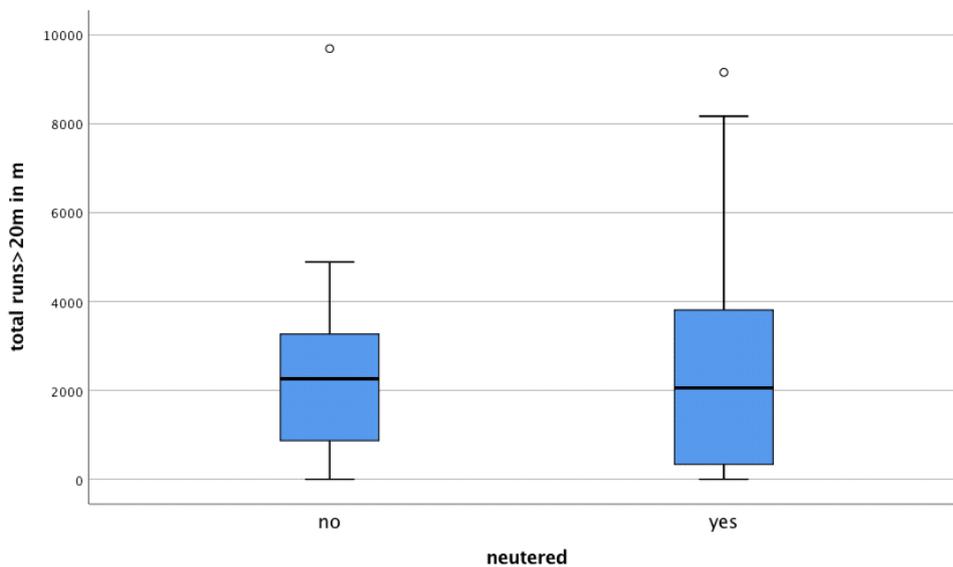
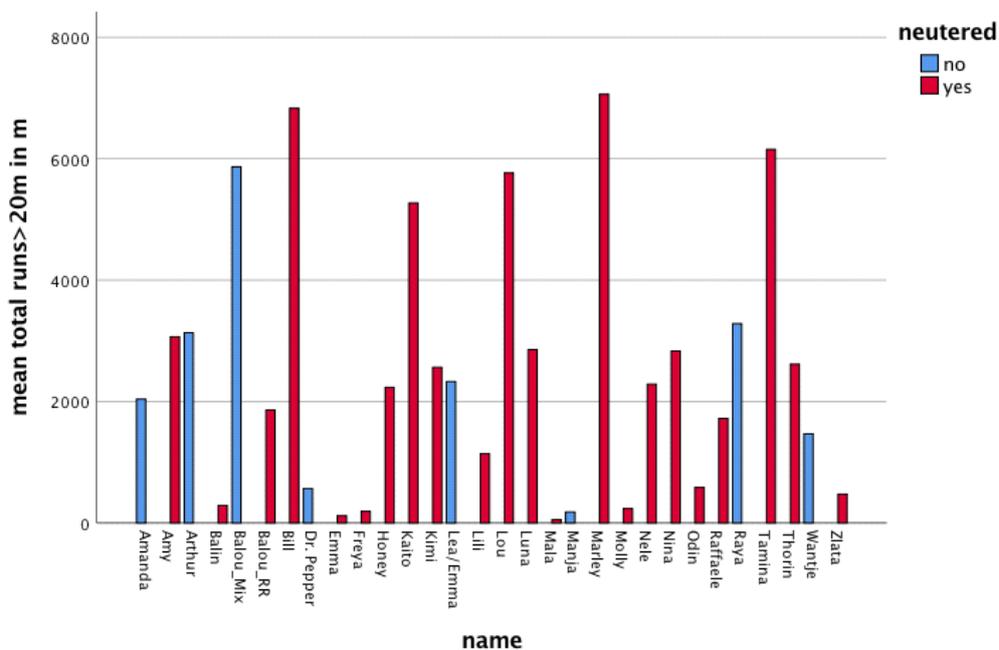


Fig. R2.9.2: Boxplot: Distance of total runs > 20 m all neutered versus all intact dogs, in meter.

Table R2.9.1: Distance travelled runs > 20 m all neutered versus all intact dogs in meter.

	intact n = 8 dogs						neutered n = 22 dogs					
	n	mean	median	Q25	Q75	SD	n	mean	median	Q25	Q75	SD
total runs >20 m in m	1130	2358.84	2262	0	9690	1975.85	2015	2555.10	2059	0	9157	2439.48
total distance dog walk in m	32	6562.50	5950	4800	11900	1852.07	88	7823.86	7350	4700	14300	2231.54

The over all distance travelled of runs >20 m is smaller for intact dogs (2359 +/- 1976 m) than for castrated dogs (2555 +/- 2439 m). The median of runs > 20 m, intact dogs 2262 m, neutered dogs 2059 m shows the opposite. Looking at the total distance of the dog walks in meter of the intact dogs, even though only eight animals, this amounts to 83 % of the distance travelled by the neutered dogs with a much greater number. With only 32 runs compared to 88 of the neutered dogs intact dogs show comparatively long distance runs. Larger differences can also be observed in the upper quartile with 9690 m for intact dogs versus 9157 m for neutered dogs. The difference in runs > 20 m between intact and neutered dogs is not significant ($p = 0.995$; Mann-Whitney-U Test) however.

**Fig. R2.9.3:** Mean runs > 20 m all neutered (red) versus all intact (blue) dogs, distance in meter.

Great inter-individual differences can be perceived when looking at the individual dogs and their mean runs > 20 m. Here in particular the neutered Group 3 dogs Bill, Kaito, Lou, Marley and Tamina display extensive distances of runs > 20 m.

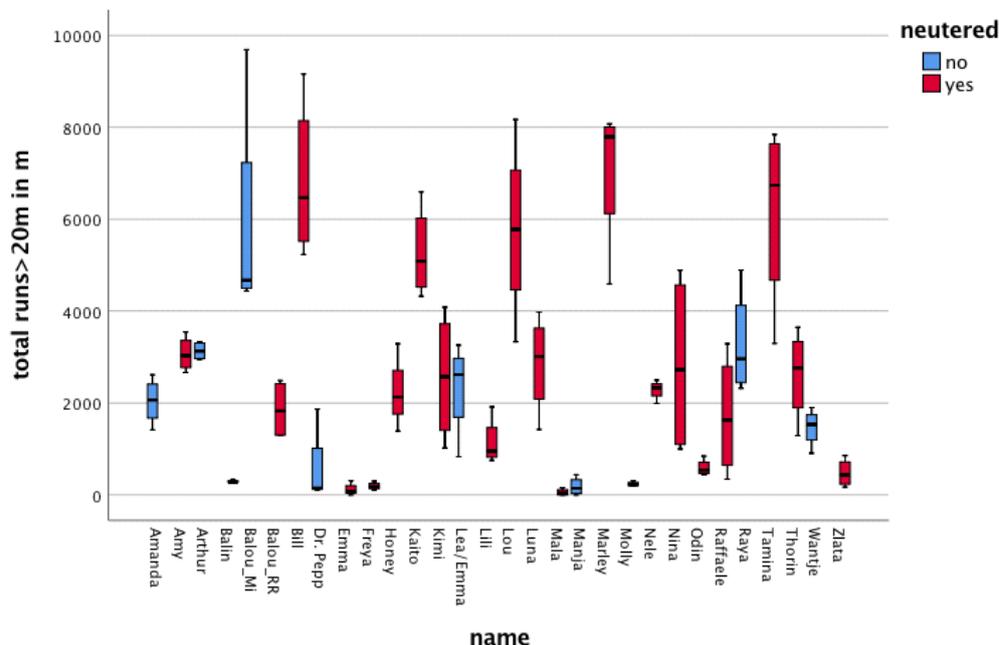


Fig. R2.9.4: Total runs > 20 m all neutered (red) versus all intact (blue) dogs, all individual dogs, distance in meter.

2.3.10 Time travelled neutered versus intact dogs (runs>20 m)

It has been postulated that differences in travelling behavior exist between neutered and intact dogs, which would include the time travelled by the dogs, therefore the time of runs > 20 m with respect to reproductive status of the dogs was analyzed. Differences in time traveled between neutered and intact dogs could be observed, **Fig. R2.10.1**. The duration travelled of runs > 20 m was larger for intact dogs (18 +/- 21 min.) than for neutered dogs (16 +/- 15 min.). 50 % of the neutered dogs travelled less or equal to 00:12h, whereas the intact dogs showed a median of 00:16h, see **Table R2.10.1**. The difference between neutered and intact dogs was not significant ($p = 0.929$; Mann-Whitney-U Test) however; and **Fig. R2.10.5 Appendix: Randomization Test for one mean difference:**

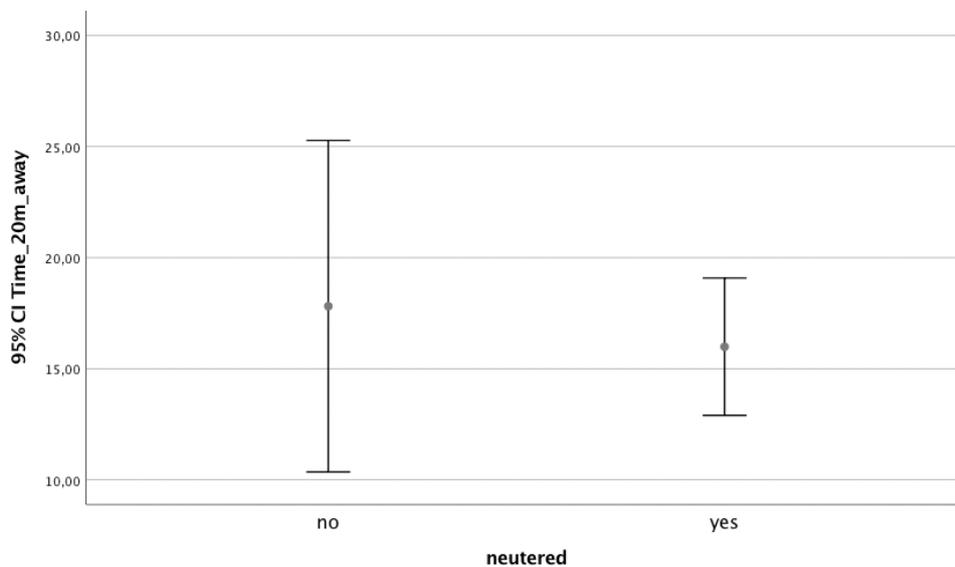


Fig. R2.10.1: Mean time runs > 20 m all neutered versus all intact dogs, in minutes.

Differences in time travelled between neutered and intact dogs can be observed. Intact dogs travel longer than neutered dogs. The mean of the intact dogs is 18 +/- 21 min. whereas the mean for the neutered dogs is 16 +/- 15 min, see also **Table R2.10.1**.

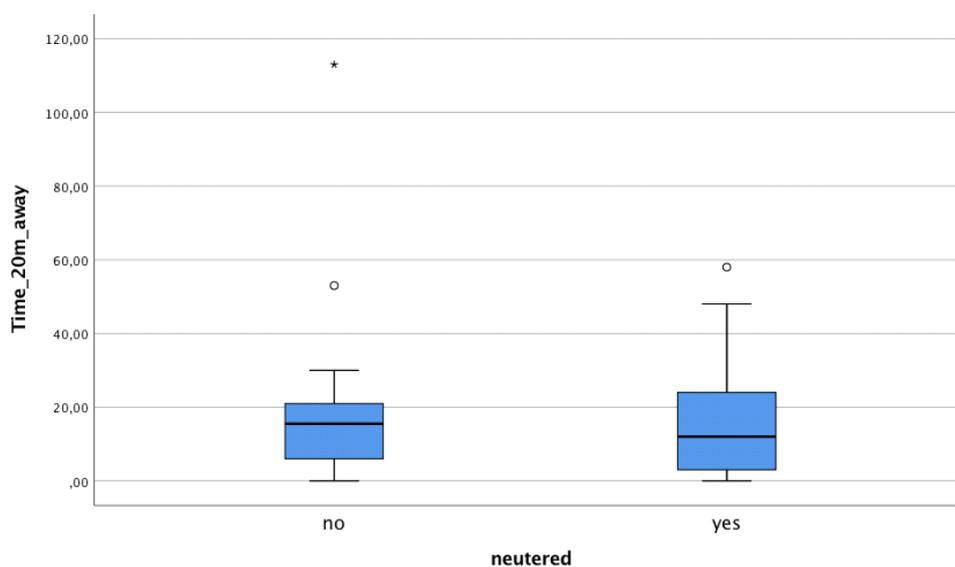


Fig. R2.10.2: Boxplot of time runs > 20 m all neutered vs. all intact dogs in minutes.

The duration explored of runs > 20 m is larger for intact dogs (median 16 min) than for neutered dogs (median 12 min).

Table R2.10.1: Time travelled runs >20 m all neutered versus all intact dogs in minutes.

	intact n = 8 dogs						neutered n = 22 dogs					
	n	mean	median	Q25	Q75	SD	n	mean	median	Q25	Q75	SD
Time_20 m_away in min.	1130	18	16	0	113	21	2015	16	12	0	58	15
Duration of dogs entire walk in min.	32	79	75	50	142	18	88	92	86	53	160	25

The duration travelled of runs > 20m is larger for intact dogs (18 +/- 21 min.) than for neutered dogs (16 +/- 15 min.). The median shows that 50 % of the neutered dogs travelled less or equal to 00:12h, whereas the intact dogs showed a median of 00:16h (increase 33 %). The upper quartile is 01:53h for intact and 00:58h for neutered dogs. The difference between neutered and intact dogs is not significant (p = 0.929; Mann-Whitney-U Test) however.

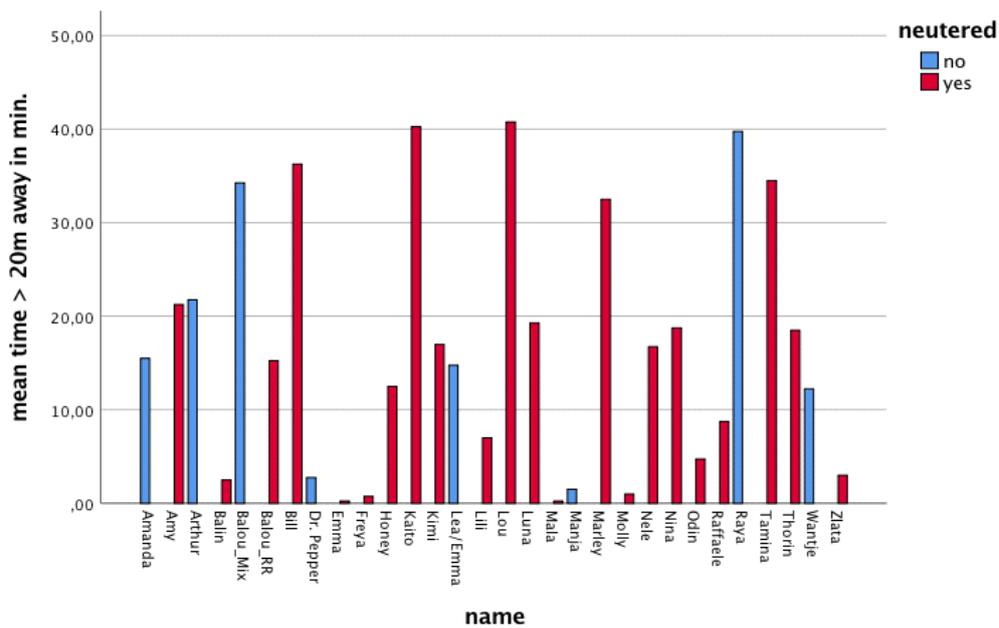


Fig. R2.10.3: Mean time runs > 20 m all neutered (red) versus all intact (blue) each dog, in minutes.

Great inter-individual differences can be perceived when looking at the individual dogs and the duration of their runs > 20 m.

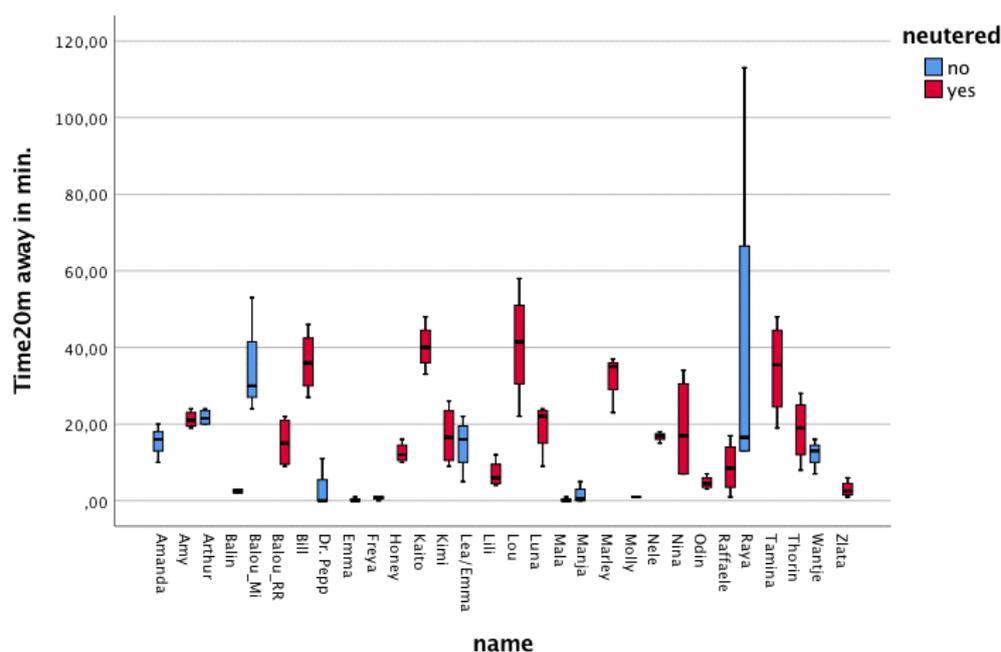


Fig. R2.10.4: *Boxplot: Time runs > 20 m all neutered (red) versus all intact (blue) dogs, all individual dogs, in minutes.*

Dogs of one sex, time and distance travelled

It was further analyzed whether the time and distance between neutered and intact dogs of one sex differed. Out of $n=18$ females five were intact and 13 spayed; of the $n=12$ males three were intact and nine neutered. Looking at the upper quartile total runs >20 m the spayed females explore further (median 7842 m) than the intact females (median 4890 m), however the intact females explore longer away from the owner than the spayed females (intact females mean +00:17h/-00:24; spayed females mean +00:12h /-00:12h; median intact females 00:13h versus median spayed females 00:09h). The intact male dogs have a high number of runs > 20 m ($n=651$) for three dogs. The median distance total runs >20 m is almost identical (intact male dogs 3127 m versus 3156 m of the neutered males). No difference can be observed in time of runs > 20 m, see **Table R2.10.2**.

Female and male dogs neutered and intact show different behavior in travelling time and distance, **Fig. R2.10.4**. Neutered male dogs show over all higher distance and higher travelling time away from their owner than intact male dogs ($p^* = 0.006$ (travelling distance); $p^* = 0.024$, $p = 0.544$ (travelling time); Mann-Whitney-U test) Female neutered dogs however travel equivalent distances and display less travelling time than intact female dogs ($p^* = 0.466$ (travelling distance), $p^* = 0.100$ (travelling time), Mann-Whitney-U test), **Fig. R2.10.5**. Differences were not significant.

Table R2.10.2: Time and distance travelled neutered versus intact dogs of one sex.

		intact						Neutered/spayed					
		n	mean	median	q25	q75	SD	n	mean	median	q25	q75	SD
Female (n=18: 5 intact, 13 neutered)	total runs>20m in m	479	1860.50	1913.5	0	4890	1250.46	1181	1862.29	1295.5	0	7842	1905.10
	total distance dog walk in m	20	6470.00	5850	4900	11300	1882.64	52	7573.08	6750	5000	14300	2185.70
	Time_20m_away in min.	479	17	13	0	113	24	1181	12	9	0	48	12
	Duration of dogs traveling round in min	20	80	74	50	142	22	52	91	81	53	160	28
Male (n=12: 3 intact, 9 neutered)	total runs>20m in m	651	3189.42	3127	115	9690	2664.05	834	3555.83	3156	273	9157	2785.84
	total distance dog walk in m	12	6716.67	6300	4800	11900	1871.72	36	8186.11	7950	4700	14300	2277.86
	Time_20m_away in min.	651	20	22	0	53	15	834	22	22	1	58	16
	Duration of dogs traveling round in min	12	78	77	67	100	10	36	93	90	64	159	19

Overall more neutered dogs participated than intact dogs. For the females the spayed dogs have 1181 total runs > 20 m with a mean of 1862+/-1905 m compared to intact females with 479 runs >20 m and a mean of 1861+/-1250 m. The mean is identical, however, looking at the upper quartile total runs > 20 m the spayed females travel further (median 7842 m) compared to the intact females (median 4890 m). Looking at the time of runs >20 m away from the owner the intact females have a mean of +00:17h/-00:24 whereas the spayed females have a mean of +00:12h /- 00:12h; with a median for intact females of 00:13h versus a median for spayed females of 00:09h (30 % decrease). Thus, the intact female dogs travel longer away from the owner than the spayed females. The duration of the dogs over all travelling rounds in minutes (median) is slightly less for intact females (74 min.) compared to 81 minutes for spayed female dogs.

The intact male dogs are the smallest group (n=3) but all belong to long distance and fast groups (Group 2 and 3). They have a high number of runs >20 m (n=651) for three dogs. The total distance of walks is higher for neutered male dogs than for intact male dogs (8186 +/- 2278 m vs. 6717 +/- 1872 m), which is to be expected due to the higher number of neutered male dogs. Thus for intact male dogs runs > 20 m made up 47 % of the dogs total distance, for neutered male dogs 43 %. Furthermore the upper quartile of the intact male dogs lies at 9690 m versus 9157 m of the neutered dogs, thus

the intact dogs do travel further. No difference can be observed in time of runs >20 m. This may indicate that the intact dogs travel faster than the neutered dogs as they cover more distance in the same amount of time.

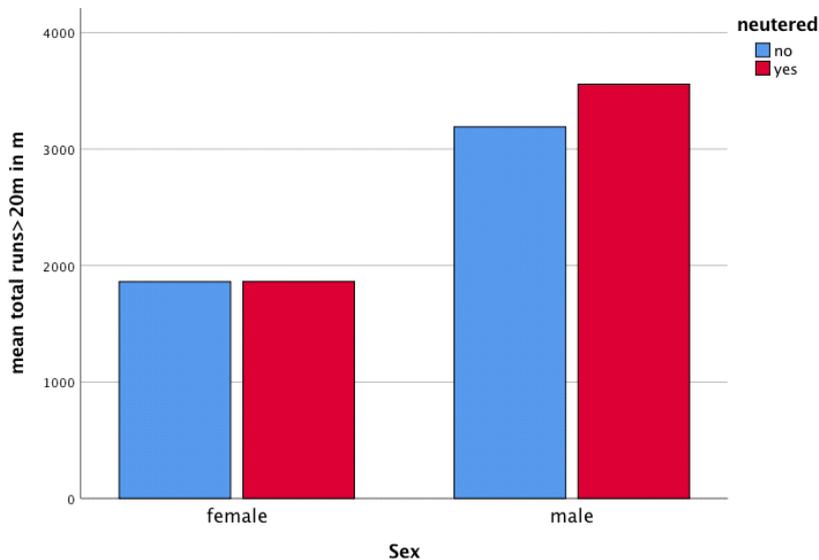


Fig. R2.10.4: Mean total runs > 20 m female and male neutered (red) versus intact (blue) in meter.

The total distance of runs > 20 m is highest for male dogs, with the neutered male dogs displaying the longest distance (3555 m) followed by the intact male dogs (3189 m). No difference between spayed and intact dogs can be seen within the female group (1861 m vs. 1861 m).

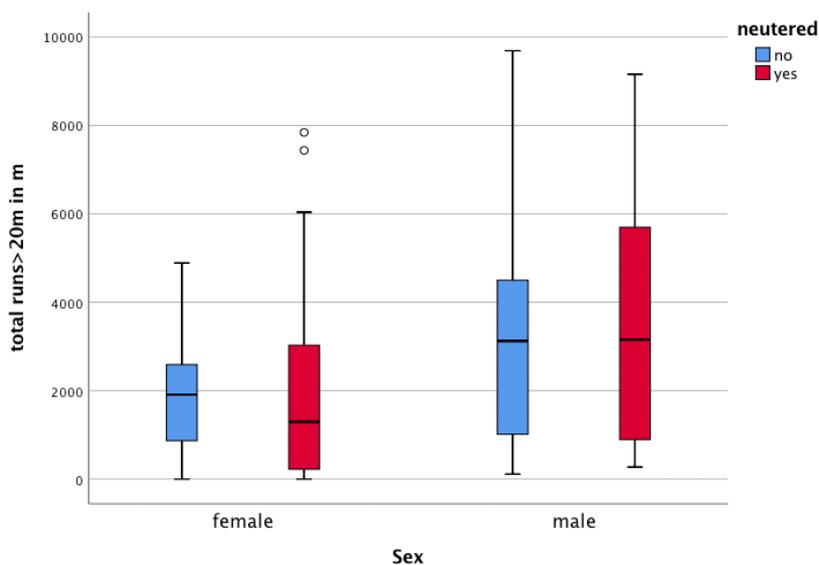


Fig. R2.10.5: **Boxplot:** Total runs > 20 m females intact (blue) and spayed (red) and male intact (blue) and neutered (red) in meter.

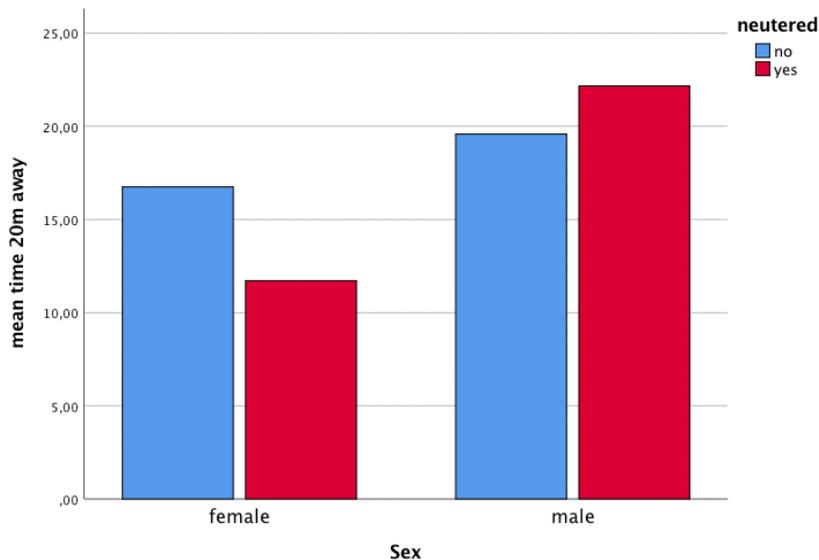


Fig. R2.10.6: Mean time runs > 20 m intact (blue) and spayed (red) females and intact (blue) and neutered (red) males in minutes.

The longest time away from the owner of runs > 20 m are travelled by the neutered male dogs, followed by the intact male dogs, the intact female and lastly the neutered female dogs.

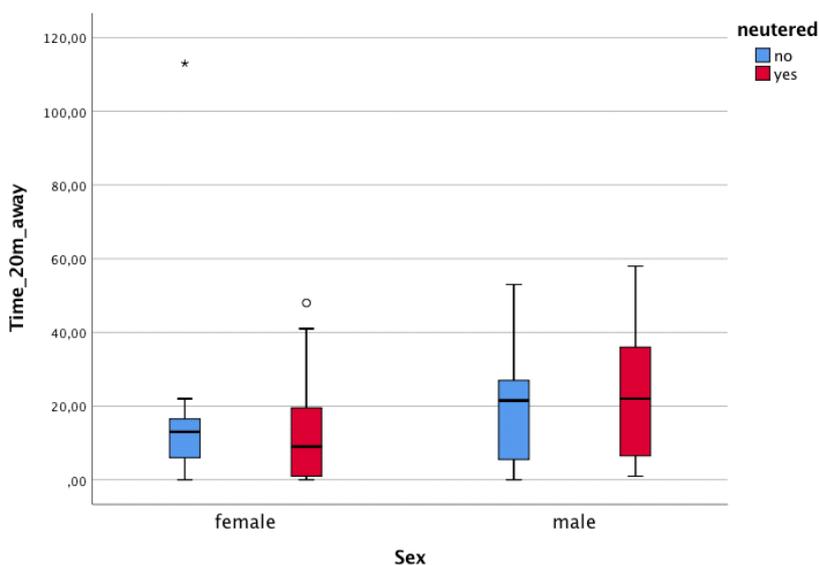


Fig. R2.10.7: **Boxplot:** Time of runs > 20 m intact (blue) and spayed (red) females and intact (blue) and neutered (red) males in minutes.

Neutered males explore the longest time followed by the intact males. Within the female group the intact females explore longer than the spayed females. Female and male dogs show different behavior in travelling time and distance. Neutered male dogs show over all higher distance and higher travelling time away from their owner than intact male

dogs ($p^* = 0.006$ (travelling distance); $p^* = 0.024$, $p^* = 0.544$ (travelling time); Mann-Whitney-U test). Female neutered dogs however travel equivalent distances and show less travelling time than intact female dogs ($p^* = 0.466$ (travelling distance), $p^* = 0.100$ (travelling time), Mann-Whitney-U test).

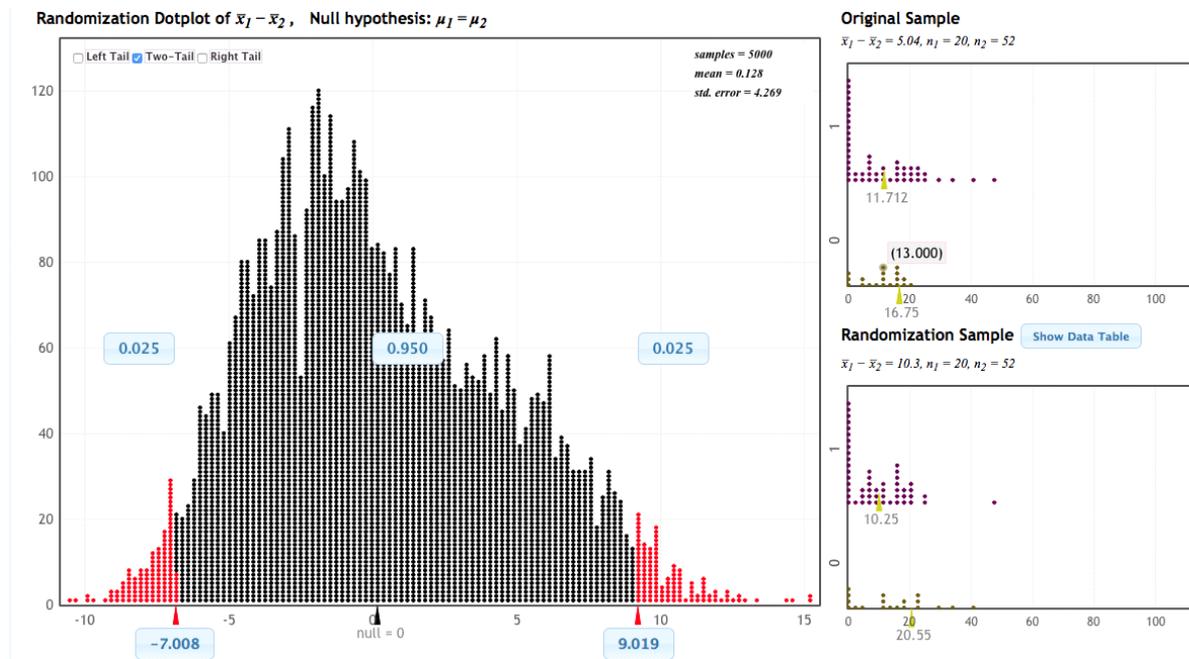


Fig. R2.10.8: Randomization test for one mean difference. Duration of dog runs > 20 m intact and neutered male dogs.

Between intact and neutered male dogs difference between the duration of dog walk (Time_20 m_away) of 5 min was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the null hypothesis of no effect are -7 and 9. The observed value is within these limits, therefore $p > 0.05$, the null hypothesis could not be rejected. No difference between neutered and intact male dogs in duration of runs > 20 m could be shown.

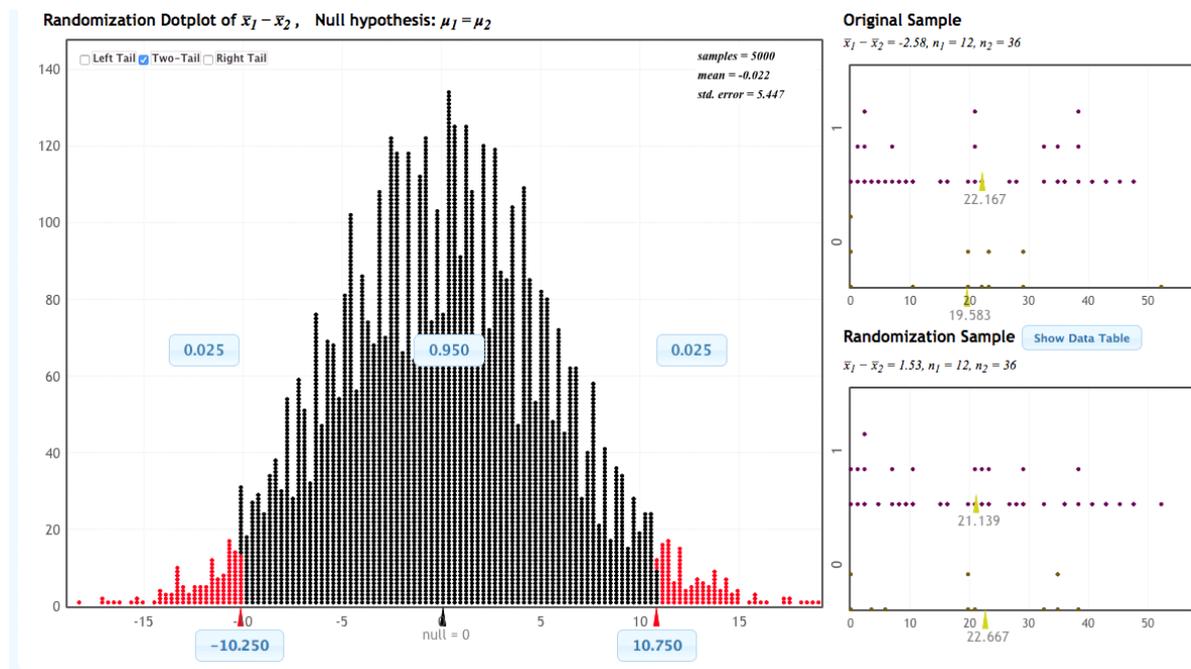


Fig. R2.10.9: Randomization test for one mean difference. Duration of dog runs > 20 m intact and spayed female dogs.

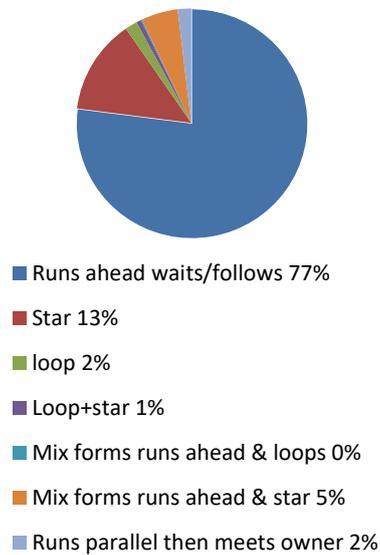
Between intact and spayed female dogs difference between the duration of dog walk (Time_20 m_away) of 2 min was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the null hypothesis of no effect are -10 and 10. The observed value is within these limits, therefore $p > 0.05$, the null hypothesis could not be rejected. No difference between spayed and intact female dogs regarding duration of runs > 20 m could be shown.

Table R2.10.3: Summary male and female dogs, comparison intact versus neutered/spayed dogs of one sex with above mentioned parameters.

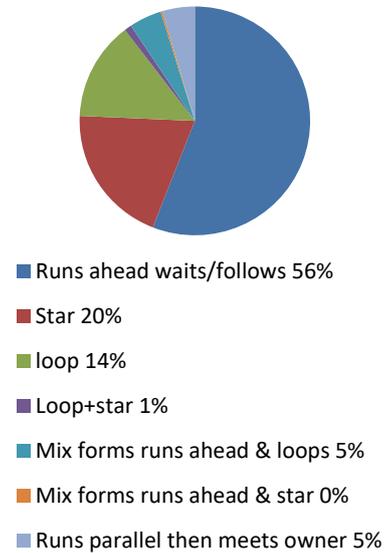
	Total distance dog walk in m	Distance runs >20 m in m	Duration of dogs traveling round in min.	Time runs >20m away in min
Male intact/neutered	6717m vs 8186 m	3189m vs 3556m	78 min vs 93 min	20min vs 22 min
p(Mann-Whitney-U)	0.033	0.521	0.006	0.544
p*(Mann-Whitney-U)	0.132	na	0.024	na
Random Test	Not significant	Not significant	significant	Not significant
Female intact/neutered	6470m vs 7573m	1860m vs 1862m	80 min vs 91 min	17 min vs 12 min
p(Mann-Whitney-U)	0.008	0.589	0.100	0.466
p*(Mann-Whitney-U)	0.032	na	na	na
Random Test	significant	Not significant	Not significant	Not significant

Randomized tests of total distance dog walk in m, and total duration are not depicted by Figure herein.

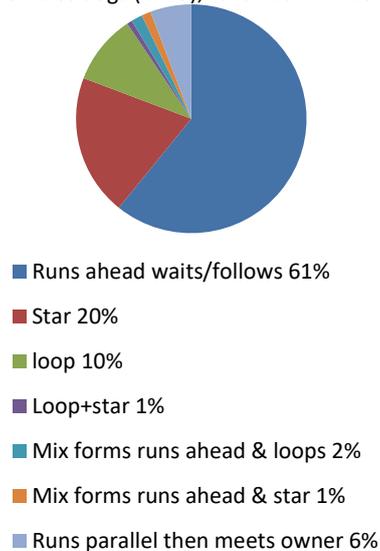
Intact female dogs (n=5); runs > 20m n= 583



Intact male dogs (n=3) runs > 20m n=395



Spayed females dogs (n=13); runs >20m n= 1077



Neutered male dogs (n=9); runs > 20m n=1090

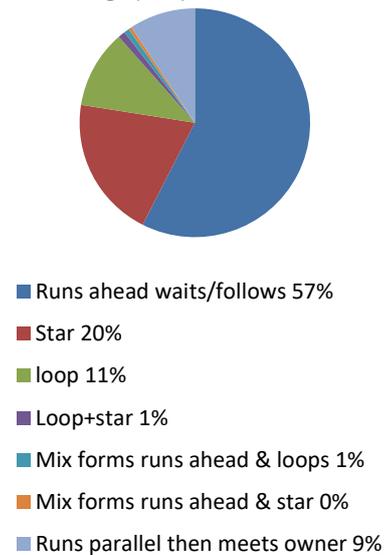


Fig. R2.10.9a: Travelling patterns spayed (n=13) and intact females (n=5).

Fig. R2.10.9b: Travelling patterns neutered (n=9) and intact males (n=3).

Fig. R2.10.9a/b: Travelling patterns spayed (n=13) and intact females (n=5) and neutered (n=9) and intact (n=3) male dogs.

Differences can also be perceived looking at the displayed travelling pattern between intact male and female dogs (**Fig. R2.10.9a/b**) in that intact female dogs display more often the travelling pattern of running ahead and waiting or following the owner (77 % versus 56 %) and the male intact dogs displaying more often the star and loop pattern. The spayed females and neutered male dogs however show fairly similar exploration patterns. For more details see Section 2.14 below.

2.3.11 Does the age of the dog influence the distance/time travelled?

To determine whether correlations existed between the age of the dogs and their average travelling speed; total runs > 20 m; time away from the owner; time inbound and outbound travelled and the duration of the entire walking time was analyzed. Only the dogs' average speed and the duration of the dogs' entire walk showed a significant relation with age, see **Table R2.11.1**; **Fig. R2.11.1** **Fig. R2.11.2**.

Table R2.11.1: Spearman correlation coefficient: Age of dog and time/speed travelled.

		dog average speed in km/h	total runs > 20 m in m	Time 20 m away	Time inbound	Time outbound	Duration of dogs entire walk in min
Age at walk in months	r	-0.256	-0.12	-0.08	-0.077	0.085	0.295
	p	0.01	0.187	0.36	0.445	0.401	0.001
	n	120	120	120	100	100	120

Looking at Spearman correlation coefficient only the dogs' average speed and the duration of dogs' entire walk showed a significant relation with age. The scatterplots are shown below.

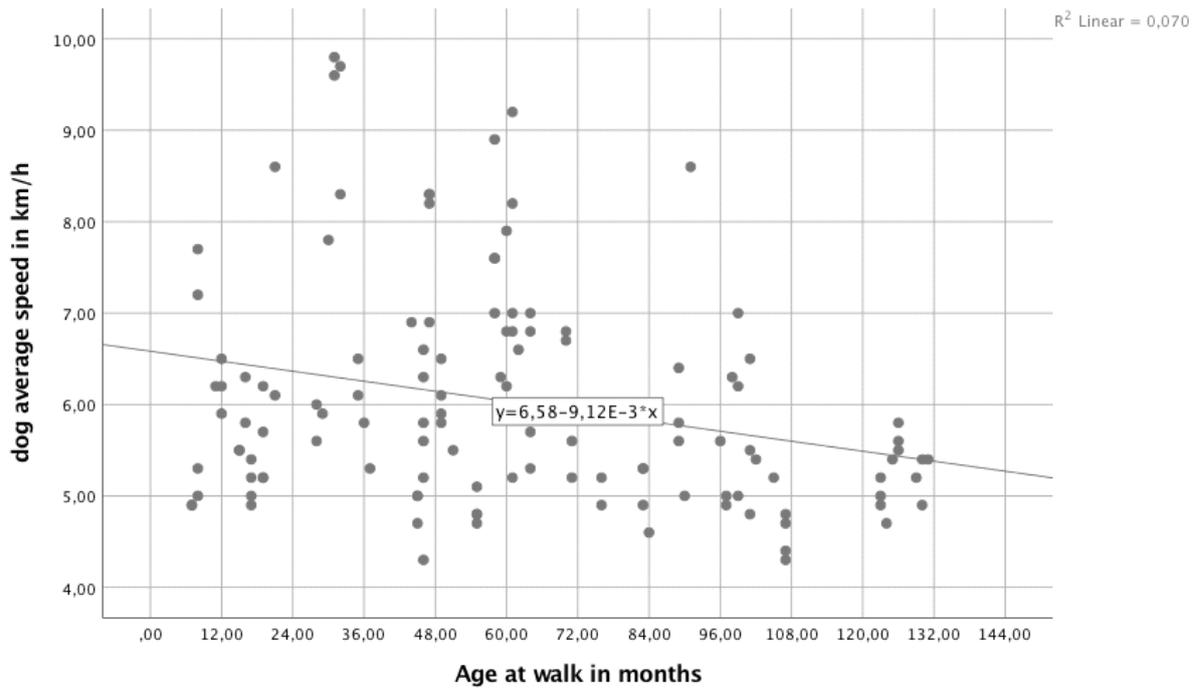


Fig. R2.11.1: Correlation between dogs' average speed in km/h and age of dogs in months.

It can be seen that older dogs travel slower than younger or middle age dogs and display a lower km/h travelling speed.

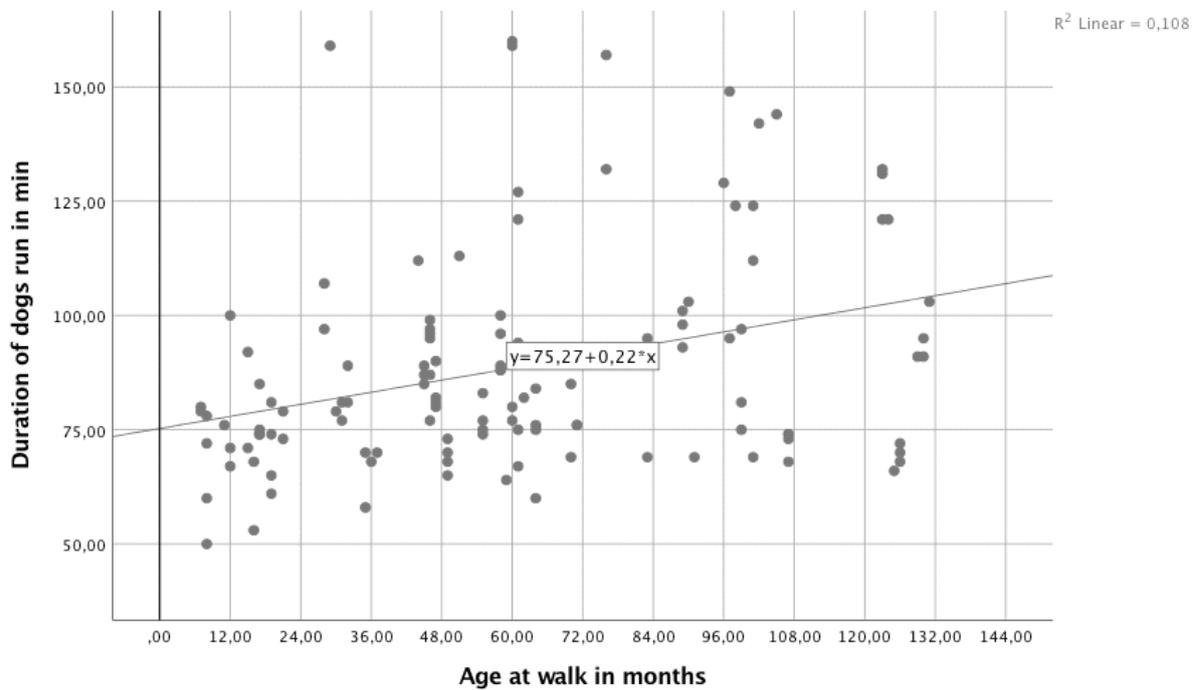


Fig. R2.11.2: Correlation between dogs' duration of the entire walk in minutes and age of dogs in month.

2.3.12 Does the size of the dog influence the speed the dogs travel?

To determine whether the size of the dog per se had an influence on the speed travelled data was analyzed accordingly. Three groups were distinguished: Dogs > 60 cm shoulder height (large n=11, yellow); dogs < 60 cm > 40 cm shoulder height (medium n=13, blue) and dogs > 40 cm shoulder height (small n=6, green). Looking at the boxplot no differences in average dog speed between small size dogs (< 40 cm), medium size (between 40 cm and 60 cm) and large dogs (> 60 cm) can be seen ($p= 0.449$, Kruskal-Wallis Test), see **Table R2.12.1; Fig. R2.12.1; Table R2.12.2.**

Table R2.12.1: Breed and size of dogs in groups >60 cm; <60 cm; <40 cm shoulder height.

Pure breeds n=20	>60cm n=11	<60cm >40cm n=13	<40cm n=6
Size	Large	Medium	Small
Sighthounds n=9	Barsois n=3 (# 26,28,30)	N=3 Whippets # 11,24,13, N=1 Silken Windsprite #8	Italien Greyhound n=2 # 19,25
Herding dogs n=2	Collies n=2 # 1,29		
Hunting/sPORting dogs n=4	Standard Poodle n=1 #3	Labrador Retriever n=2 # 2,22	N=1 Miniature Pinscher #14
Toy breed n=2			N=2 pugs # 10,21
Working group n=3	Rhodesian Ridgeback n=2 #6,17	Perro de Aqua Espanol n=1 # 18	
Mixed breeds n=10	>60cm	<60cm	<40cm
	Great Dane Mix #4	Husky Shepard Mix #5	Terrier/Chinese crested Mix # 27
	Mastiff Mix #12	Labrador Mix #7	
	Greyhound Mix #23	Perro de Aqua espanol Mix #9	
		Pastor Mallorcin Mix #15	
		Collie-Shepherd Mix #16	
		Labrador Mix #20	

Table R2.12.2: Size of dogs in groups >60cm; <60cm; <40cm shoulder height; average speed in km/h mean and median.

		dog average speed in km/h				
		mean	SD	Q25	median	Q75
Size	small	6.12	1.13	5.20	5.65	6.85
	medium	6.16	1.42	5.20	5.80	6.60
	large	5.77	0.95	5.00	5.55	6.25

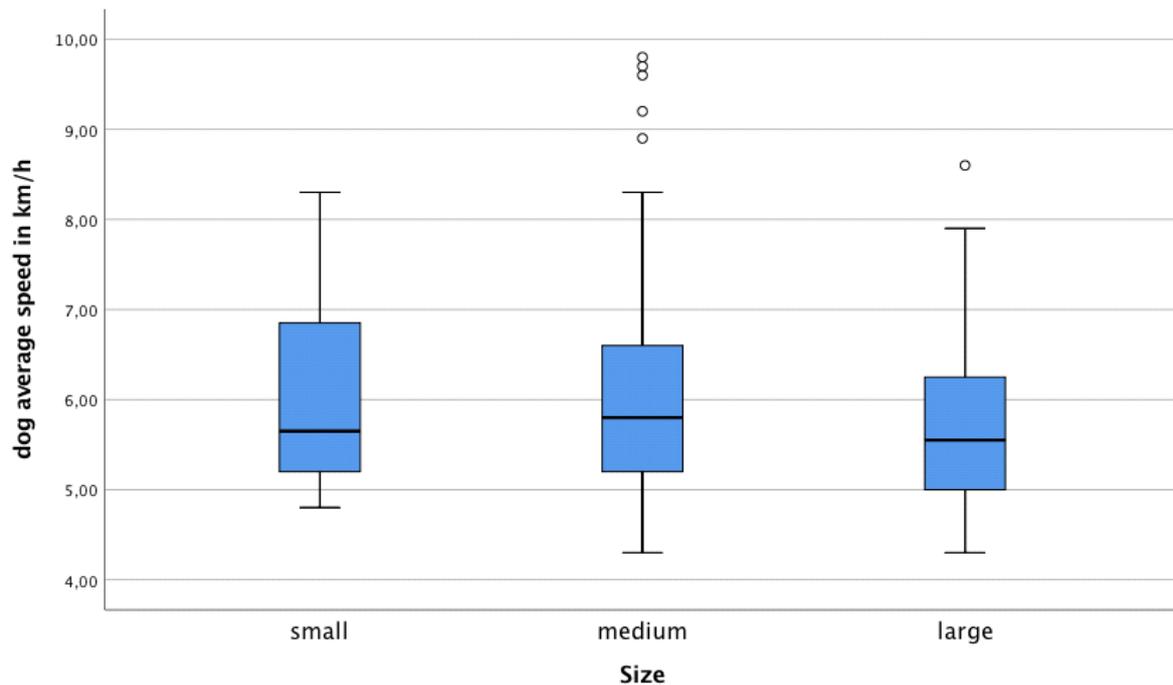


Fig. R2.12.1: Boxplot: Speed of dogs in relation to size of dogs.

Looking at the boxplot no differences in average dog speed between small size dogs (< 40 cm), medium size (between 40cm and 60cm) and large dogs (> 60 cm) shoulder height can be seen. The median of all three groups is about 5km/h. Extreme values can be seen at medium size dogs up to nearly 10 km/h. Differences are not significant.

2.3.13 Individual speed differences between the dogs and overall dogs

Between the 30 dogs great differences can be observed regarding their overall speed during the walks as well as their speed patterns. Some dogs display an overall low average speed during all walks independent of breed or size; some dogs have a high speed variance, thus these dogs alternate between very fast as well as moderate or slower

runs. Some dogs travel over all at very high speed, see **Table R2.13.1 Appendix; Fig. R2.13.1; Fig. R2.13.2.**

Some dogs display an overall low average speed during all walks: Balin: Median 4.9km/h and mean 4.8km/h / -0.3km/h; Amanda: Median 5.1km/h and mean 5.1km/h /-0.2km/h; Odin: Median 4.6Km/h and mean 4.6km/h / - 0.2km/h. Some dogs display a high speed variance: Bill: Median 7.6km/h and mean 7.8km/h/ - 0.8km/h; Balou_Mix: Median 7.6km/h and mean 7.6km/h/ - 1.2km/h; Raffaele: Median 6.4km/h and mean 6.5 km/h / - 1.1km/h, thus these dogs alternated between very fast as well as moderate or slower runs. Some dogs travelled over all at very high speed: Marley: Median 9.7kmh and mean 9.4km/h / -0.7km/h, see **Table R2.13.1 Appendix.**

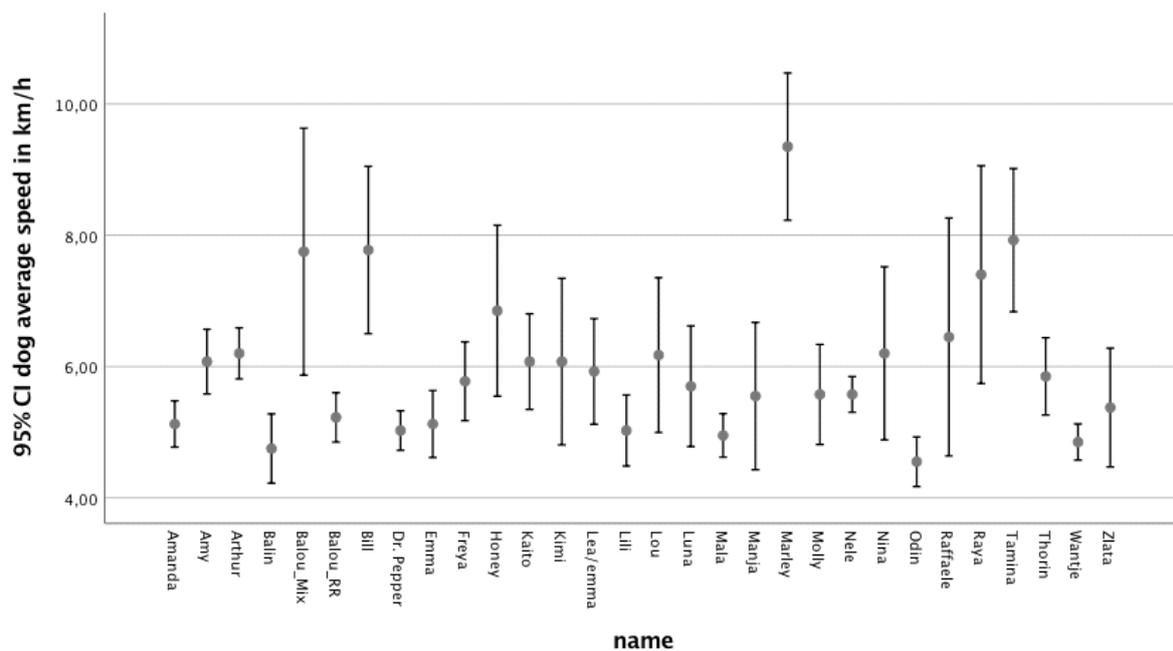


Fig. R2.13.1: Mean speed each dog, in km/h.

The dogs display great inter-individual speed differences and variance. For details, see **Table R2.13.1 Appendix.**

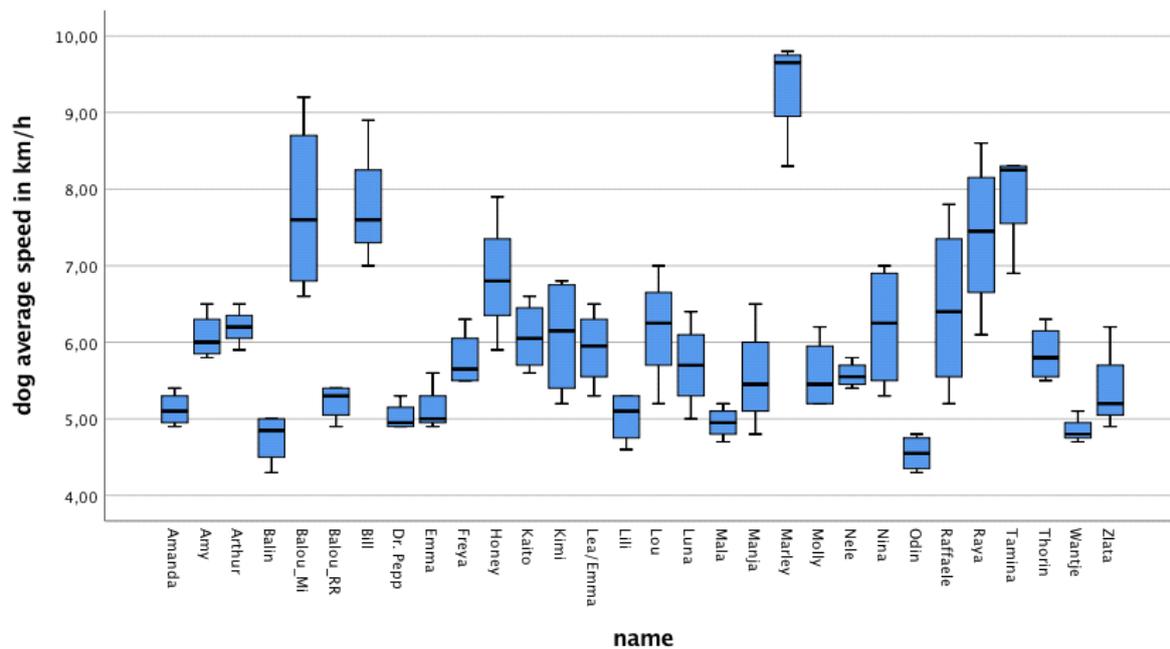


Fig. R2.13.2: Boxplot: Speed each dog, in km/h.

Between the dogs large differences can be observed regarding their speed during the walks. Dogs like Balin (Great Dane Mix), Mala (Perro de Aqua Espanol) and Emma (Perro de Aqua Mix – one owner), Odin (Whippet) or Wantje and Amanda (Collies – one owner) display an overall low average speed during all walks, see **Table R2.13.1 Appendix**. The standard deviation is low, these dogs display very little variance of speed between all four walks which can be seen by the low confidence interval. All belong to Group 1, independent of breed or size. On the other hand, dogs like Balou_Mix (Shepherd-Husky Mix, max speed 37 km/h), Bill (Labrador Mix, max speed 42 km/h) and Lou (Shepherd Mix, max speed 32 km/h one owner), Raffaele (Italian Greyhound; max speed 37 km/h) and Raiya (Borzoi, max speed 46 km/h) display a high average speed during the walks (mean > 6km/h). The variance is high, thus these dogs alternate between very fast as well as moderate or slower runs. Some dogs travel over all at very high speed, for instance Marley (LabradorMix, max speed 50 km/h)) and Tamina (Chinese Crested/Terrier Mix, max speed 38 km/h), one owner), see **Table R2.13.1 Appendix**.

2.3.14 Classification of dogs according to their travelling patterns

Seven different travelling patterns were established to classify runs > 20 m away from the owner: Runs ahead and waits/follows; star; loop: loop and star; mixed form run ahead & loop; mixed form run ahead and star; and dog runs parallel and meets owner.

According to these seven categories all 120 walks were examined to group dogs or walks with similar patterns (for details, see **Fig. M1.2.1**, **Fig. M1.2.2**, **Fig. M1.2.3** pictograms). The dogs display various travelling patterns, see **Table R2.14.1 Appendix**. Out of all runs >20 m (n= 3145) the dogs display mainly (62 %) the travelling pattern of running ahead of the owner on the path and waiting or following the owner on the path, **Fig. R2.14.1**. Looking at the individual dogs great differences can be observed, **Fig. R2.14.2**. Based on the great individual variance displayed by the dogs a hierarchical Cluster analysis using Ward linkage and squared Euclidean Distance measure was applied to establish an appropriate number of clusters. Herein a number of three clusters for classifying all walks (total) seemed an appropriate tradeoff between heterogeneity and number of different cluster groups, see **Table R2.14.2 Appendix**. Lowest distances and therefore typical running patterns for the clusters as well as high distances (extreme, most untypical patterns) of the groups are summarized in **Table R2.14.3**. **Fig. R2.14.3** shows the distribution of patterns between the cluster groups. 14 dogs display a change pattern cluster, 16 have constant pattern clusters for all 4 walks. Seven dogs use different patterns in known versus unknown areas, **Table R2.14.4**. **Fig. R2.14.4** shows the distribution of patterns between Groups 1, 2, and 3 (radius traveled away from the owner) and travelling patterns of each Group. **Table R2.14.5** illustrates the Groups and Cluster values. Thus it can be demonstrated that dogs belonging to the different radius groups (Group 1, 2 and 3) have different distribution patterns: dogs with a low maximal distance away from owner can be characterized by Cluster 2 (nearly no runs away from owner) or Cluster 3 (high frequency of runs forward/backward and waits) whereas dogs with a radius > 350 m are overrepresented in Cluster 1 and underrepresented in Cluster 3, thus characterized by occurrence of star and loop patterns and a medium number of runs ahead waits/follows. **Table R2.14.6** depicts the individual dogs in Groups and Clusters, with breed and age.

All runs > 20 m all dogs n=3145

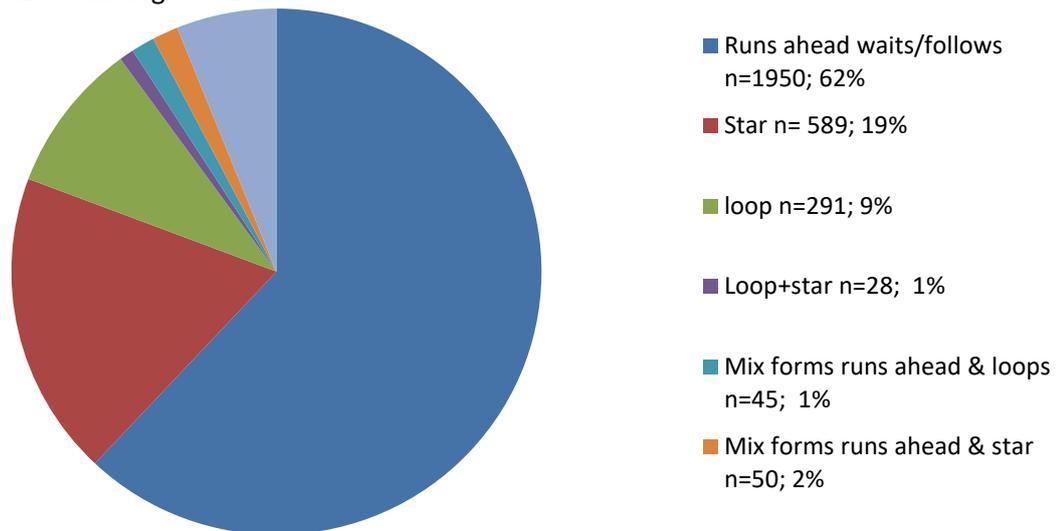


Fig. R2.14.1: Diagram: Travelling patterns displayed over all walks and dogs; runs >20 m.

Out of all runs > 20 m (n= 3145) the dogs displayed n=1950 runs, 62 % the travelling pattern of running ahead of the owner on the path and waiting/following. The star pattern was used n=589 runs; 19 % of the time, thus the dogs basically return on their path. A loop was displayed n=291; 9 % of the time and the mixed forms together n=95 runs; 3 % of the time. Parallel runs to the owner were used n= 192; 9 % of the time, see **Fig. R2.14.1; Table R2.14.1 Appendix.**

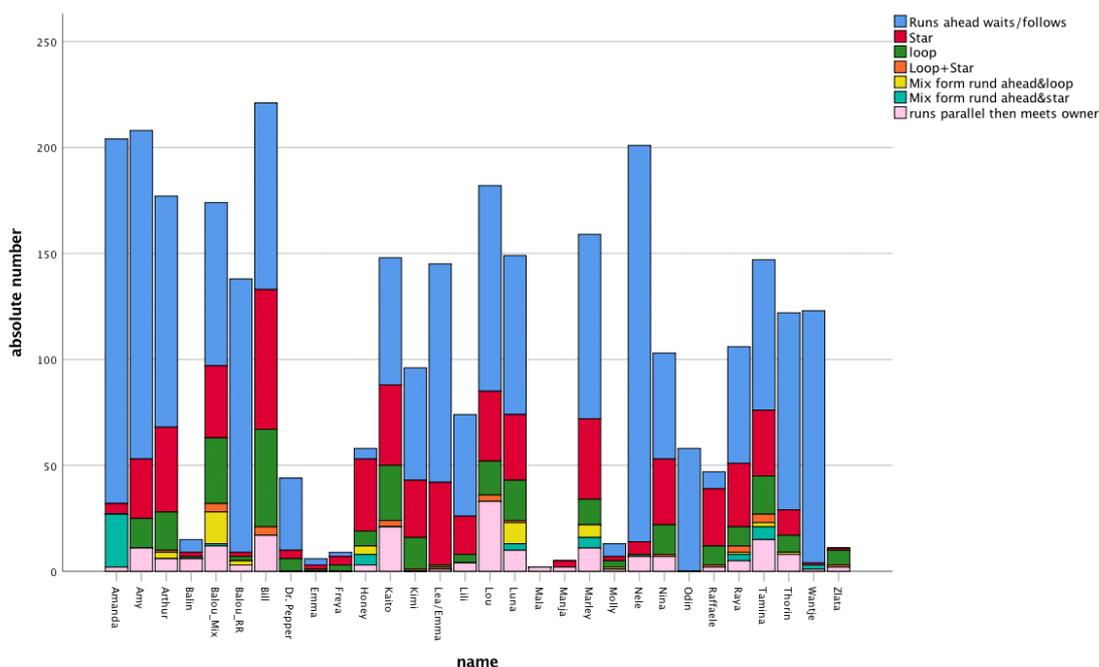


Fig. R2.14.2: Absolute number of runs >20 m subdivided by patterns of the runs, each dog.

Based on the great individual variance displayed by the dogs a hierarchical Cluster analysis using Ward linkage and squared Euclidean Distance measure was applied to establish an appropriate number of clusters. Based thereon a dendrogram was drawn, see **Appendix**. The dendrogram can be read from left to the right side. Increasing values of the x-axis indicate increasing heterogeneity within the clusters. On the left side (y-axis) all 120 individual walks of the dogs are shown. In the first step the walks are grouped with respect to statistical distance and equivalence measures. Firstly 6 groups are built. Within a second step 2 of these groups are combined, so 3 groups are resulting. Furthermore the upper two groups are combined and at the last step the remaining 2 groups are combined to one (overall) group having maximal heterogeneity.

To determine the optimal number of clusters a trade-off between heterogeneity within the clusters and the number of clusters has to be made. Here a number of three clusters for classifying all walks (total) seems an appropriate trade-off between heterogeneity and number of different cluster groups. The number of walks per cluster is balanced and the clusters themselves are distinguished. The results of the clustering algorithm with walks allocated to groups according to their patterns can be seen in **Table R2.14.2 Appendix**. Distance is a measure of how far the walk is away from the clustering centre. Lower values indicate “typical” walks of the group. A summarization of all walks to cluster groups can be seen in **Table R2.14.2 Appendix**. A number of 3 clusters seem appropriate when looking at the dendrogram, **Appendix**. However classifying the dog walks in 3 groups some pattern schemes are less typical for the clusters than others. Information therefore can be obtained from **Table R2.14.2 Appendix**. The distance measure shows the distance of the dog walks from the centre of the cluster. Low distance values indicate “typical” pattern scheme, high values extreme schemes of the cluster groups. Lowest distances and therefore typical running patterns for the clusters as well as high distances (extreme, most untypical patterns) of the groups are summarized in **Table R2.14.3**.

Table R2.14.3: Dog walks with low and high distance to the clustering centre.

Cluster	typical		extreme	
	dog(walk)	distance	dog(walk)	distance
1	Thorin (1)	2.882	Bill (4)	25.722
	Marley (1)	3.189	Bill (3)	13.206
	Balou_Mix (1)	3.355	Arthur (3)	13.144
2	Molly (4)	2.084	Balou_Mix (1)	16.286
	Honey (4)	2.243	Kaito (4)	13.909
	Emma (3)	2.463	Raffaele (1)	11.189
3	Amy (4)	3.971	Amanda (3)	18.804
	Nele (1)	3.894	Nele (2)	14.259
	Balou_RR (2)	3.22	Amy (3)	13.472

The clusters are characterized by the patterns shown in the following figure:

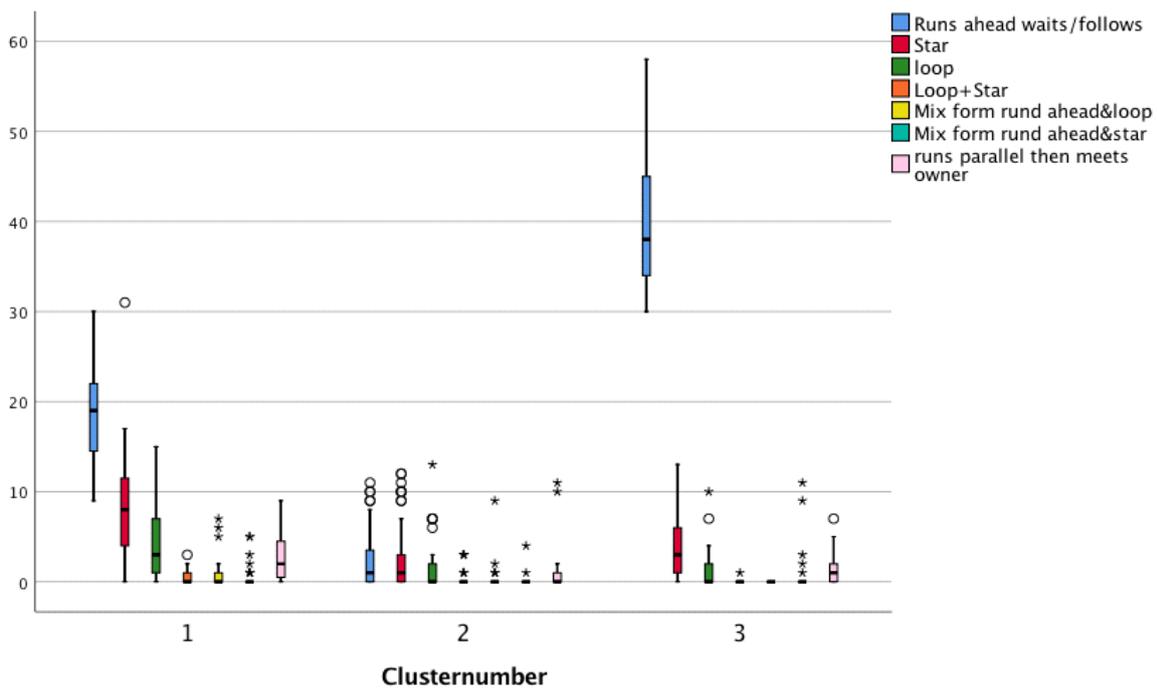


Fig. R2.14.3: Distribution of patterns between the cluster groups.

Walks belonging to Cluster 3 are dominated by a large number of the pattern runs ahead waits/follows. Star and runs parallel can also be observed. All other patterns are rare. Cluster 2 shows a low total number of runs, the most frequent pattern is loop, star and runs ahead. Cluster 1 is mainly characterized by the patterns runs ahead waits/follows,

followed by star, loop and also parallel runs and mixed forms. The number of runs ahead is less compared to Cluster 3.

Table R2.14.4: Cluster groups for all walks. Unknown areas are highlighted in blue. Dogs changing cluster groups between known and unknown area are highlighted in yellow. Changes of Cluster are indicated in the right hand column.

	name	Breed	walk 1	walk 2	walk 3	walk 4	change
1	Amanda	Collie	3	3	3	3	n
2	Amy	Labrador Retriever	3	3	3	3	n
3	Arthur	Standard Poodle	3	1	1	3	y
4	Balin	Great Dane Mix	2	2	2	2	n
5	Balou_Mix	Husky Shepard Mix	2	1	3	1	y
6	Balou_RR	Rhodesien Ridgeback	1	3	3	1	y
7	Bill	LabradorMix	1	1	1	1	n
8	Dr. Pepper	Silken Windsprite	2	2	3	2	y
9	Emma	Perro de Aqua Espanol Mix	2	2	2	2	n
10	Freya	Pug	2	2	2	2	n
11	Honey	Whippet	2	2	2	2	n
12	Kaito	Mastiff Mix	1	1	1	2	y
13	Kimi	Whippet	1	2	1	2	y
14	Lea/Emma	Miniature Pinscher	1	3	3	1	y
15	Lili	Pastor Mallorcin Mix	1	2	1	2	y
16	Lou	Shepherd Mix	1	1	2	3	y
17	Luna	Rhodesian Ridgeback	1	1	1	1	n
18	Mala	Perro de Aqua Espanol	2	2	2	2	n
19	Manja	Italian Greyhound	2	2	2	2	n
20	Marley	Labrador Mix	1	1	1	1	n
21	Molly	Pug	2	2	2	2	n
22	Nele	Labrador Retriever	3	3	3	3	n
23	Nina	Greyhound Mix	1	1	2	2	y
24	Odin	Whippet	1	2	1	1	y
25	Raffaele	Italian Greyhound	2	2	2	2	n
26	Raiya	Borzoi	2	2	1	1	y
27	Tamina	Terrier/Chinese Crested Mix	1	1	1	1	n
28	Thorin	Borzoi	1	1	3	1	y
29	Wantje	Collie	1	3	3	3	y
30	Zlata	Borzoi	2	2	2	2	n

Fourteen dogs display a change of pattern cluster, 16 have constant pattern clusters for all four walks. Seven dogs (yellow) have different patterns in known (white) versus unknown (blue) areas. Seven dogs (23 %) changed Cluster depending on new or known area, see e.g. Arthur Cluster 3 in unknown area and Cluster 1 in known area, running ahead and following in new areas (82 %) and exploring with very different patterns in known areas (runs ahead/follows 29 %; star 35 %, loop 16 %), **Table R2.14.4**. Balou displaying only half the number of runs in unknown areas; Kimi with more loop and mixed patterns in known areas as compared to unknown areas; Lea with more runs in known areas and more stars and loops displayed in known areas; Raiya with more stars and loops as well as mixed forms and fewer runs ahead/follows in known areas, see **Table R2.14.4** and individual data sheets dogs, **Appendix**.

Relationship between cluster groups and Groups resulting from maximal distance away from owner:

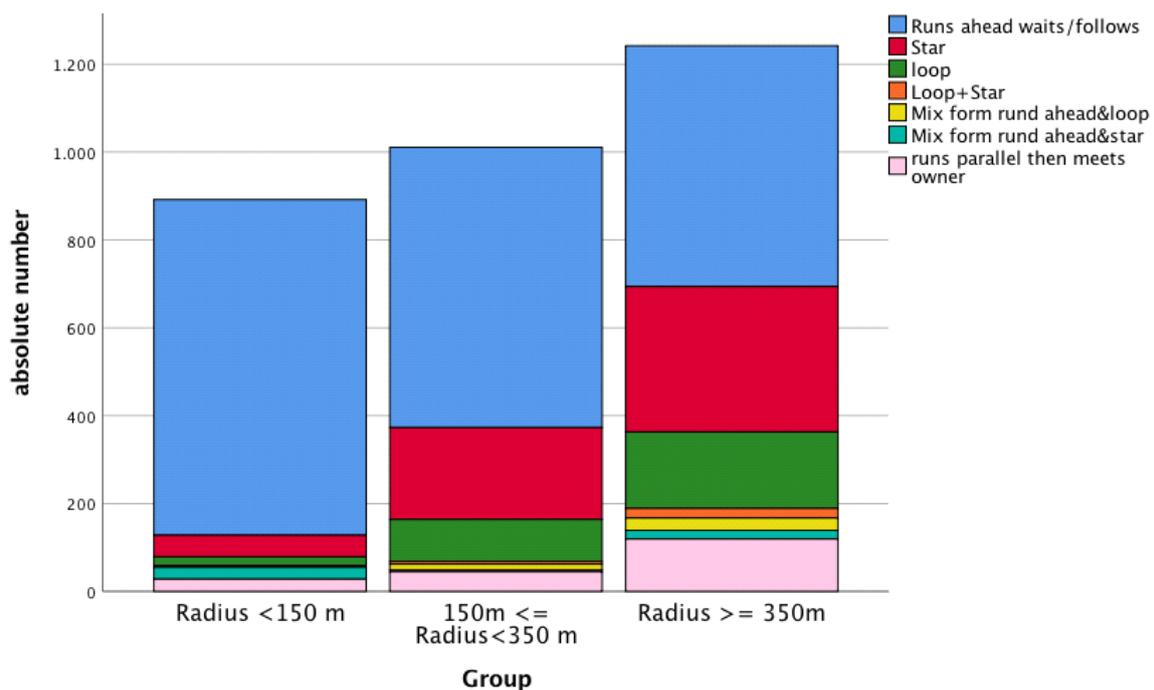


Fig. R2.14.4: Distribution of patterns between Groups 1, 2 and 3 and travelling patterns of each Group.

As can be seen Group 1 dogs display predominantly the travelling pattern of running ahead and waiting or following the owner with little variance of other travelling patterns. With increasing distance of runs (Group 2 and 3) the dogs display a greater variance of travelling patterns including more cognitively challenging patterns like loops or mixed forms. Dogs of different age and breed were represented in the different groups

as well as Clusters. Thus, it can be shown that not primarily old dogs were represented in Group 1, with a radius of <150 m, or young and unexperienced dogs. The Groups vary age wise and different breeds can be found in all Groups and Clusters.

Table R2.14.5: *Groups and Cluster values; observed versus expected.*

Group 1,2,3		Cluster 1	Cluster 2	Cluster 3	Total
Radius <150 m	observed	8	30	14	52
	expected	19.1	22.1	10.8	52
150m <= Radius<350 m	observed	15	8	9	32
	expected	11.7	13.6	6.7	32
Radius > 350 m	observed	21	13	2	36
	expected	13.2	15.3	7.5	36
Total	observed	44	51	25	120
	expected	44	51	25	120

Observed values count the number of walks belonging to the row/column category. The expected value for each cell is equal to (row total*column total)/120 and can be interpreted as values that would be expected under the hypothesis of no association. A measure of deviation is the Chi-Square statistic. High values indicate a great divergence from equal distribution among the groups. Here the Chi-Square Statistic is 23.193 resulting in a p-value <0.001. Thus it can be shown, that dogs belonging to the different radius groups (Group 1, 2 and 3) have different distribution patterns.

Looking at the cells of the two way table dogs with radius <150 m are underrepresented in Cluster 1 (observed: 8 vs. expected 19) and overrepresented in Cluster 2 (observed: 30 vs. expected 22) and 3 (observed: 14 vs. expected 11). In other words dogs with a low maximal distance away from owner can be characterized by Cluster 2 (nearly no runs away from owner) or Cluster 3 (high frequency of runs forward/backward and waits). Dogs with a radius >350 m are overrepresented in Cluster 1 (observed: 21 vs. expected 13) und underrepresented in Cluster 3 (observed: 2 vs. expected: 8). Therefore these dogs may be characterized by occurrence of star and loop patterns and a medium number of runs ahead waits/follows.

Table R2.14.6: Individual dogs in Groups and Clusters, with breed and age.

Group 1 n=13 <150 m			Group 2 n=8 > 150 m, > 350 m			Group 3 n= 9 > 350 m		
Dog	Breed	Age month	Dog	Breed	Age month	Dog	Breed	Age Month
Amanda intact	Collie	17 month	Amy spayed	Labrador	50 month	Balou_Mix intact	Husky Mix	73 month
Balin neutered	Great Dane Mix	46 month	Arthur intact	Standard Poodle	12 month	Bill neutered	Labrador Mix	60 month
Balou neutered	Rhodesien Ridgeback	132 month	Kimi spayed	Whippet	72 month	Honey spayed	Whippet	61 month
Dr. Pepper intact	Silken Windsprite	8 month	Lea/Emma intact	Miniature Pinscher	48 month	Kaito neutered	Mastiff Mix	60 month
Emma spayed	Perro de Aqua espanol Mix	121 month	Luna spayed	Rhodesien Ridgeback	96 month	Lou neutered	Shepherd Mix	105 month
Freya spayed	Pug	16 month	Nina spayed	Greyhound Mix	65 month	Marley neutered	Labrador Mix	33 month
Lili spayed	Shepherd Mix	84 month	Thorin neutered	Borzoi	60 month	Raffaele neutered	Italian Greyhound	36 month
Maloca spayed	Perro de Aqua Espanol	123 month	Zlata spayed	Borzoi	72 month	Raiya intact	Borzoi	10 month
Manja intact	Italian Greyhound	102 month	Tamina spayed	Terrier Mix	47 month			
Molly spayed	Pug	18 month						
Nele spayed	Labrador	114 month						
Odin neutered	Whippet	108 month						
Wantje intact	Collie	56 month						
Cluster 1			Cluster 2			Cluster 3		
Bill			Balin			Amanda		
Luna			Dr Pepper			Amy		
Marley			Emma			Nele		
Odin			Freya					
Tamina			Honey					
			Mala					
			Manja					
			Molly					
			Raffaele					
			Zlata					

Within the clusters those dogs are represented that do not change cluster depending on area (known versus unknown). Seven dogs change cluster depending on area, see **Table R2.14.4** (yellow).

2.3.15 Travelling patterns of dog dyads/triads – correlations

To assess whether dogs of one owner display similar travelling patterns data were assessed accordingly. The seven travelling patterns of two (or three) dogs of one owner were compared to establish possible correlations of dog dyads/triads. The dogs were viewed as teams and between in within the team the travelling patterns are assessed. In total 10 teams were established, two teams (#9, 10) with three dogs belonging to one owner. see **Table R2.15.1 Appendix, Fig. R2.15.1**. The seven travelling patterns of dogs of one owner (teams) in comparison can be seen in **Table R2.15.1 Appendix**. As can be seen in **Fig. R2.15.1** there are teams with similar numbers of runs and pattern distributions (Kimi and Nina or Marley and Tamina). Within other teams e.g. Amanda and Wantje, Manja and Raffaele, Balou and Lilli, a leading dog with a higher number of runs > 20 m can be seen **Table R2.15.1 Appendix**. The leading dog is characterized by a larger number of star and loop patterns, whereas runs ahead waits/follows is the dominating pattern of the dependent, following dog. The leading dog shows a more varying distribution of patterns including all seven potential patterns. Between the teams there are differences in the number of runs (see also **Fig. R2.15.1**). In some teams all dogs have a small number of runs > 20 m compared to other teams. Emma, Zlata and Mala for instance almost never travel beyond the 20 m range, whereas Amy and Nina or Bill, Kaito and Lou have a high number of runs > 20 m. But even between those teams differences are displayed in that the team Bill, Kaito, Lou demonstrates a wide variety of travelling pattern including essentially all possible options, whereas some teams, even though they frequently travel beyond the 20 m range primarily utilize one travelling pattern, runs ahead and waits/follows, see e.g. Amanda, Balou RR, Nele, **Fig. R2.15.1**. For exemplary dog dyads travelling patterns see **Fig. M2.2.4.2-7**.

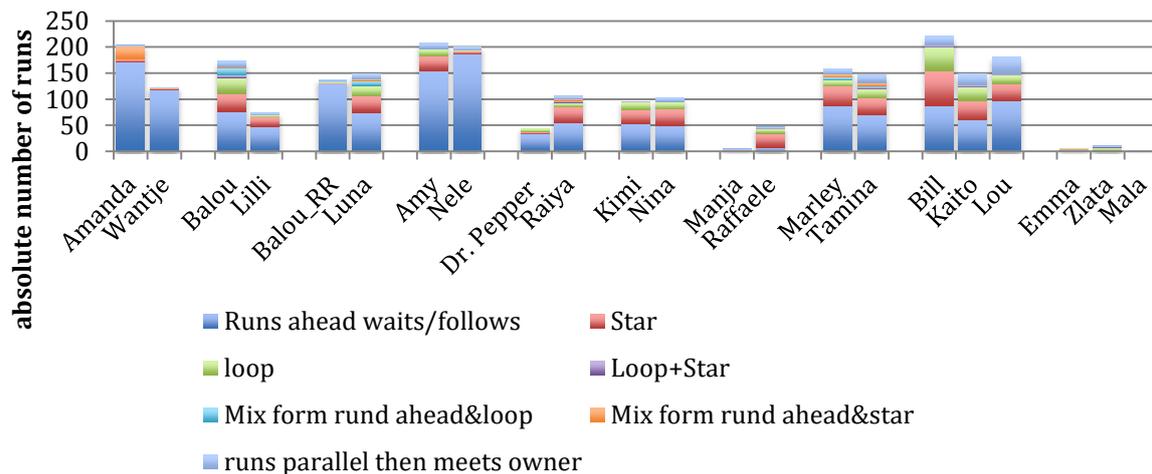


Fig. R2.15.1: Travelling patterns of dog-dyads/triads compared.

Of the 10 teams (dyad/triad) most display similar exploration patterns, but see Maja & Raffaele; Balou RR & Luna – these dogs do not explore together.

2.3.16 Comparison of duration; difference in walking time; time travelled >20 m; time inbound /outbound; total distance of the dog walks, total runs > 20 m, the maximum distance of runs in meter and inbound/outbound travelling distance for Multi-dog teams (dyad/triad)

Between and within the dogs of one owner (dyads/triads) a number of factors were analyzed to determine whether the dog teams displayed similar travelling patterns with respect to time and/or distance variables. **Table R2.16.1.1 Appendix** shows the duration of walks and the difference of walking times; **Table R2.16.1.2** shows the time away from owner of runs > 20 m and inbound/outbound travelling time for each team. The differences within the teams can be obtained from **Fig. R2.16.1.1 -R2.16.1.5**. There were no significant differences between the dogs of one owner with respect to time travelled in any category. In **Table R2.16.2.1** distance of walks, runs > 20 m and inbound/outbound distances are shown for each team. The differences within the teams can be obtained from **Fig. R2.16.2.1 -R2.16.2.5**. There were no significant differences between the dogs of one owner with respect to distance travelled.

2.3.16.1 Duration

The duration of dogs travelling rounds in minutes and differences in walking times between the teams can be seen in **Table R2.16.1.1 Appendix**. Therein the over all duration of walks and the difference of walking times are shown for each dog of each team.

There are no significant differences between the dogs of one owner with respect to time travelled in any category. **Table R2.16.1.2** (below) shows the time away from owner of runs > 20 m and inbound/outbound travelling time of the dogs of each team. The differences within the teams can be obtained from **Fig. R2.16.1.1 -R2.16.1.5**.

Table R2.16.1.2 Teams: Time >20 m runs away from owner; time inbound and outbound for all teams, Mean and Median. Dot indicates no POR.

Team	Time >20 m away					Time_inbound					Time_outbound				
	mean	SD	min	median	max	mean	SD	min	median	max	mean	SD	min	median	max
Amanda	16	4	10	16	20	0	0	0	0	0	0	0	0	0	0
Wantje	12	4	7	13	16	0	.	0	0	0	0	.	0	0	0

Balou	34	13	24	30	53	6	4	2	6	11	21	20	9	11	51
Lilli	7	4	4	6	12	1	1	0	1	3	16	29	0	2	59

Balou_RR	15	7	9	15	22	0	0	0	0	0	1	1	0	1	1
Luna	19	7	9	22	24	3	2	1	3	4	4	1	2	4	5

Amy	21	2	19	21	24	1	1	0	1	3	1	1	0	1	3
Nele	17	1	15	17	18	0	1	0	0	1	0	1	0	0	1

Dr. Pepper	3	6	0	0	11	0	1	0	0	1	1	1	0	1	2
Raiya	40	49	13	17	113	2	2	0	3	4	4	2	2	4	5

Kimi	17	8	9	17	26	4	4	1	4	8	7	5	2	6	12
Nina	19	14	7	17	34	5	5	0	5	10	6	7	0	5	14

Manja	2	2	0	1	5	0	0	0	0	0	0	0	0	0	0
Rafaele	9	7	1	9	17	2	2	0	1	5	2	2	0	2	5

Marley	33	6	23	35	37	7	1	5	7	8	8	2	5	8	10
Tamina	35	13	19	36	48	7	4	4	6	13	8	6	3	7	15

Bill	36	8	27	36	46	9	5	4	8	15	11	4	8	10	17
Kaito	40	6	33	40	48	8	3	4	9	10	10	3	7	10	14
Lou	41	15	22	42	58	7	3	2	8	9	8	3	3	9	11
Emma	0	1	0	0	1	0	0	0	0	0	1	1	0	1	1
Zlata	3	2	1	3	6	2	1	1	1	3	1	2	0	1	3
Mala	0	1	0	0	1	.	.	.	.	.	.	.	.	.	.
dog 1	18	14	0	20	53	3	4	0	1	15	6	9	0	2	51
dog 2	20	20	1	16	113	3	4	0	2	13	6	10	0	3	59
dog 3	21	24	0	12	58	7	3	2	8	9	8	3	3	9	11

Looking at the time away from owner of runs >20 m differences between the teams can be perceived. Some teams (mainly Group 1 dogs) display almost identical short times of runs >20 m away from the owner (Team Emma; Mala, Zlata; Team Amanda and Wantje). These dogs stay close together and never travel far from their owner. Some teams show over all long exploration times (Bill; Kaito; Lou) and within some teams one dog explores extensively while the other stays close to the owner, as a team the dogs do not explore together: Manja and Raffaele; Dr. Pepper and Raiya; Balou_Mix and Lili).

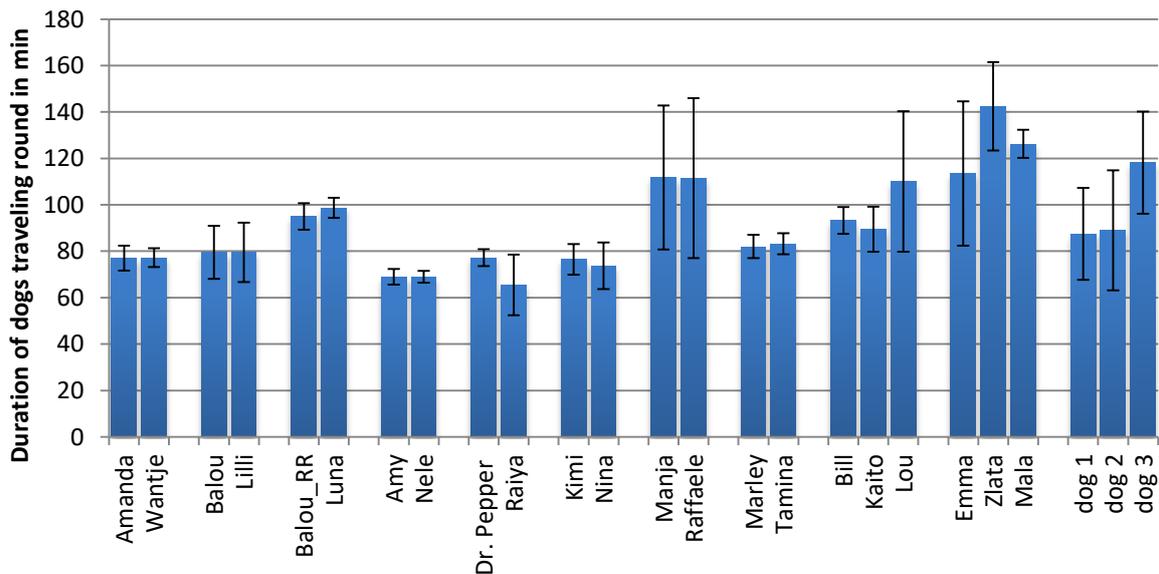


Fig R2.16.1.1: Duration of dogs over all travelling round between and within dog teams, in min.

The total travelling time of the teams can be seen in **Fig. R2.16.1.1** All teams show approximately the same duration of the walks, because dogs of one owner have the same starting point and stopping point for all walks.

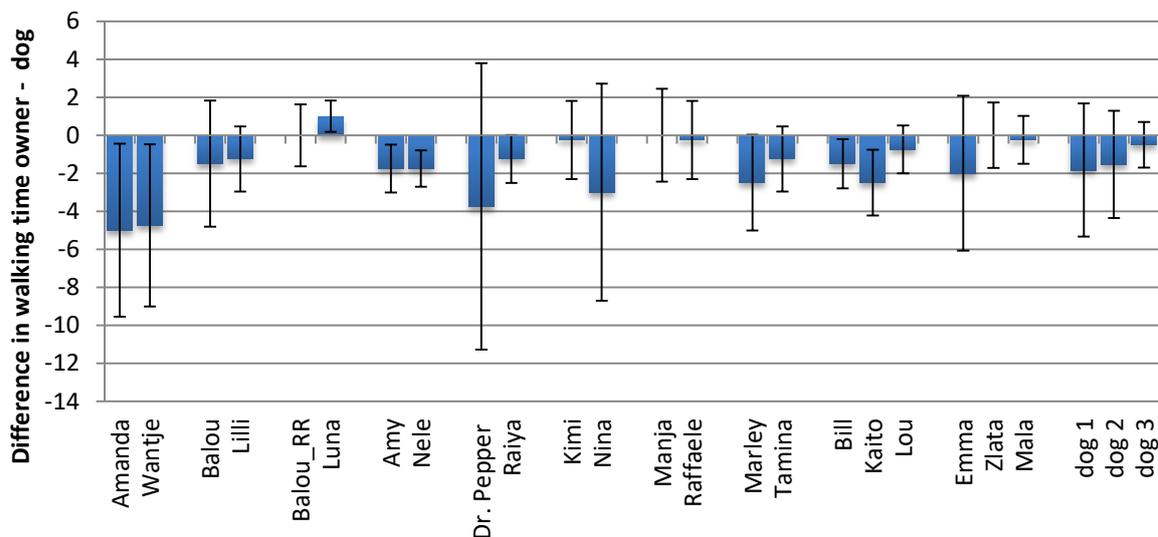


Fig R2.16.1.2: Difference in walking time owner – dog between and within dog teams.

Although the dogs have nearly identical walking times (see **Fig 2.16.1.1**), the duration of walks between owner and dogs of the same team vary. There are teams, in which one dog shows higher differences to the owner than the other dog(s), see e.g. Dr.Pepper, Nina; Marley; Kaito.

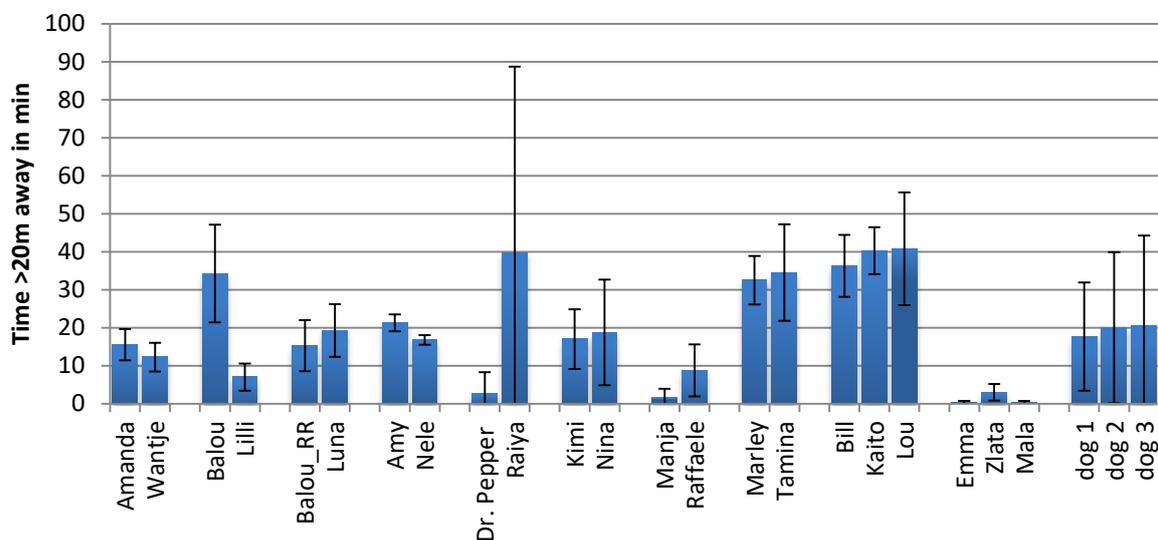


Fig R2.16.1.3: Time >20 m away between and within dog teams, in minutes.

Pronounced differences within the teams can be seen in time of runs > 20 m away from the owner. The variance is most extreme for Dr. Pepper and Raiya. Raiya was nearly 40 min. away (mean), whereas Dr. Pepper has a mean duration of about 3 min. away. Also Balou_Mix and Lili display distinctive time variances (Mean Balou_Mix 13 min. versus Lili 4 min.), see **Table R2.16.1.2** for details.

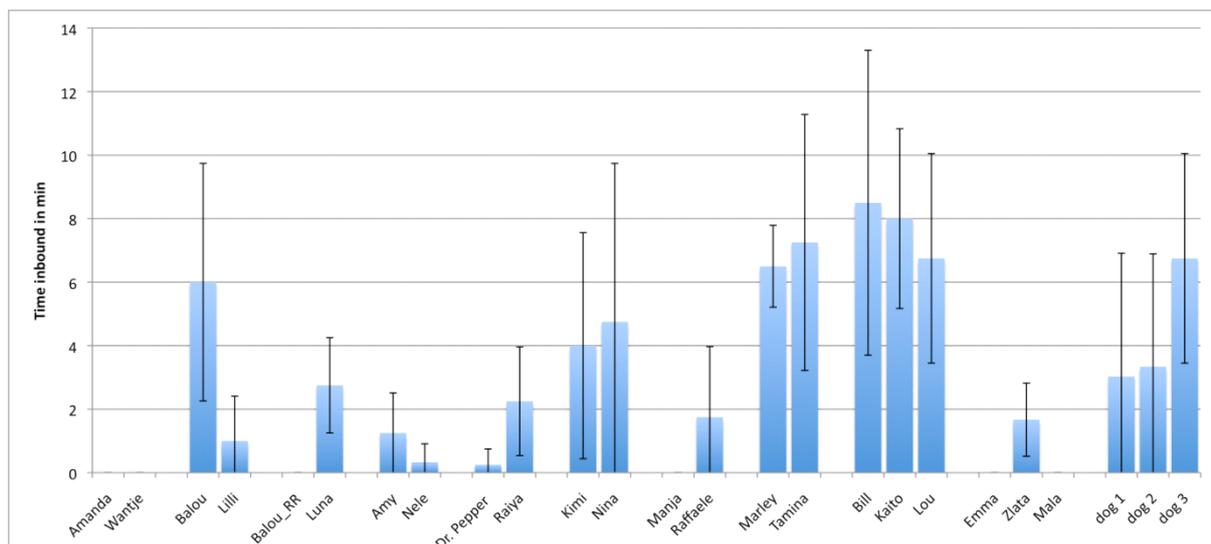


Fig R2.16.1.4: Time inbound between and within dog teams, in minutes.

One team, Amanda and Wantje spent less than 1 minute outside the range of > 20 m showing patterns with POR, thus has no inbound or outbound relevant runs, although the number of runs > 20 m is high, based on the fact that they primarily display the walking pattern of running ahead and waits/follows and therefore no point of return could be established (also Balou RR, Manja, for details see **Table R2.16.1.2**). Within all teams the differences in inbound- and outbound time can be seen. Within teams differences are apparent: some teams display almost identical times: Amy and Nele; Kimi and Nina whereas some teams show distinct differences: Balou_Mix and Lili (mean/median 6 min versus 1 minute inbound; mean 31 minutes versus 16 minutes outbound; Median 11 minutes versus 2 minutes outbound). The duration of inbound- and outbound time travelled is higher for dogs characterized as leading dog (see Section 2.16.1).

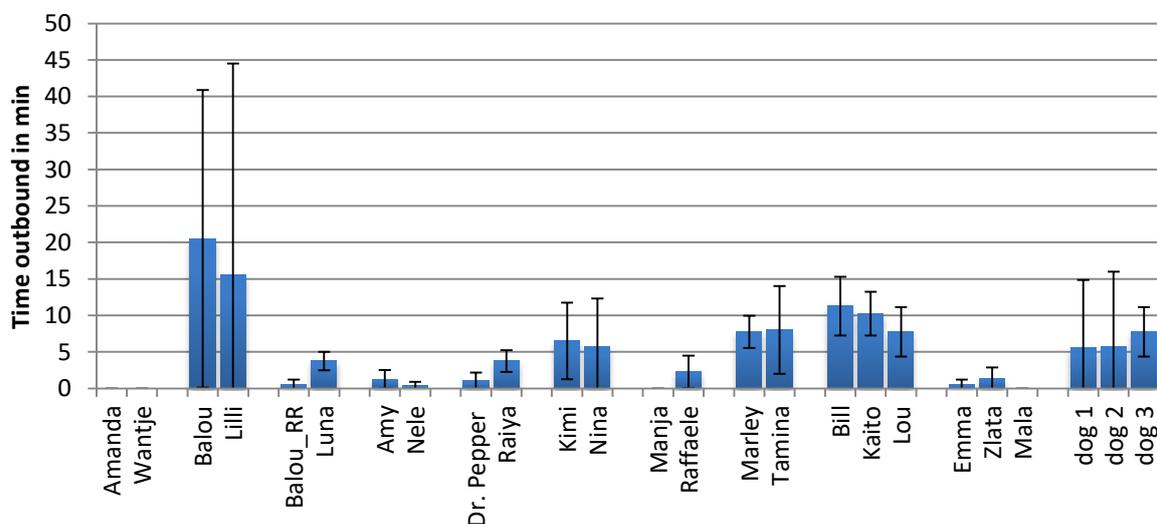


Fig R2.16.1.5: Time outbound between and within dog teams, in minutes.

The time outbound travelled corresponds with the time inbound travelled: Dogs with long outbound duration also show a long inbound duration, see also **Table R2.6.1 Appendix**.

2.3.16.2 Distance

Table R2.16.2.1 depicts the total distance of the dog walks, total runs > 20 m, the maximum distance of runs in meter and inbound/outbound travelling distance for each team. The differences within the teams can be obtained from **Fig. R2.16.2.1 -R2.16.2.5**.

Table R2.16.2.1: Mean and SD for the distance parameters of dogs from one owner.

Team		total distance dog walk in m		total runs >20 m in m		Max distance of run in m		Distance inbound in m		Distance outbound in m	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
1	Amanda	5700.00	355.90	2039.75	504.11	127.50	37.60	64.00	39.04	51.67	15.04
	Wantje	5325.00	377.49	1468.50	413.84	120.75	33.71	91.00	na	65.00	na
	p-Wert	0.257		0.454		0.299		0.504		0.360	
2	Balou	8075.00	2585.05	5866.25	2553.03	513.00	233.93	1114.50	594.66	1257.00	523.24
	Lilli	5625.00	741.06	1141.50	526.03	122.50	35.43	213.00	184.02	171.50	98.86
	p-Wert	0.125		0.125		0.125		0.125		0.125	
3	Balou_RR	6250.00	519.62	1859.50	649.06	153.75	62.85	81.50	3.54	102.50	26.16
	Luna	7750.00	685.57	2854.75	1078.96	296.50	65.29	540.25	198.58	481.25	143.89
	p-Wert	0.125		0.125		0.125		0.500		0.500	
4	Amy	6250.00	251.66	3066.50	382.02	228.50	67.95	259.00	172.71	235.00	141.73
	Nele	5400.00	365.15	2286.75	211.64	138.75	60.08	111.67	75.41	101.33	56.05
	p-Wert	0.125		0.125		0.125		0.250		0.250	
5	Dr. Pepper	5325.00	670.20	568.25	864.12	153.75	169.70	34.50	16.05	86.00	44.17
	Raiya	6150.00	776.75	3283.25	1159.62	519.25	266.97	675.50	381.33	703.50	249.90
	p-Wert	0.375		0.125		0.125		0.125		0.125	
6	Kimi	6575.00	718.22	2563.00	1407.09	384.25	247.96	807.75	711.18	848.75	681.34
	Nina	6500.00	1023.07	2832.50	2020.19	352.25	210.55	790.00	806.31	761.50	807.63
	p-Wert	0.750		0.625		0.375		0.875		0.375	
7	Manja	9200.00	2933.71	181.00	195.91	134.25	154.73	46.33	12.50	36.33	10.21
	Raffaele	10050.00	3591.19	1721.25	1329.56	375.75	228.09	452.00	487.82	558.00	462.83
	p-Wert	1.000		0.250		0.375		0.250		0.250	
8	Marley	9975.00	899.54	7062.25	1657.68	1468.50	837.44	1619.50	245.57	1564.25	420.63
	Tamina	9275.00	655.11	6153.75	2054.27	1276.50	672.56	1371.50	856.05	1303.00	998.13
	p-Wert	0.125		0.125		0.750		0.875		0.625	
9	Bill	10575.00	1539.21	6831.25	1741.96	585.50	52.26	2003.75	1054.43	1984.50	857.65
	Kaito	7900.00	621.83	5271.75	997.82	709.75	325.34	1138.75	453.15	1220.50	508.05

Team		total distance dog walk in m		total runs >20 m in m		Max distance of run in m		Distance in-bound in m		Distance out-bound in m	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
	Lou	9325.00	1596.61	5765.00	1982.69	559.50	315.72	1063.25	475.62	1092.25	473.22
	p-Wert	0.125		0.125		0.625		0.125		0.125	
10	Emma	8325.00	2458.15	119.25	132.38	68.75	44.27	69.50	44.55	120.00	121.62
	Zlata	10050.00	2174.86	473.75	304.67	232.75	73.82	242.00	149.92	243.00	178.40
	Mala	9600.00	668.33	113.00	62.23	56.50	74.48	na	na	na	na
	p-Wert	0.250		0.250		0.125		0.500		1.000	
Total	Dog 1	7625.00	2281.00	3015.70	2790.06	381.78	480.90	705.56	847.61	723.85	821.56
	Dog 2	7402.50	2214.23	2748.78	2014.05	414.48	417.23	625.03	592.56	625.57	607.91
	Dog 3	9462.50	1142.60	3881.00	3298.20	308.00	342.62	1063.25	475.62	1092.25	473.22
	p-Wert	0.257		0.454		0.299		0.504		0.360	

In **Table R2.16.2.1** distance of walks, runs > 20 m and inbound/outbound distances are shown for each team. The differences within the teams can be obtained from **Fig. R2.16.2.1 -R2.16.2.5**. There are no significant differences between the dogs of one owner with respect to over all distance travelled. Changes in Distance measures are analyzed descriptively.

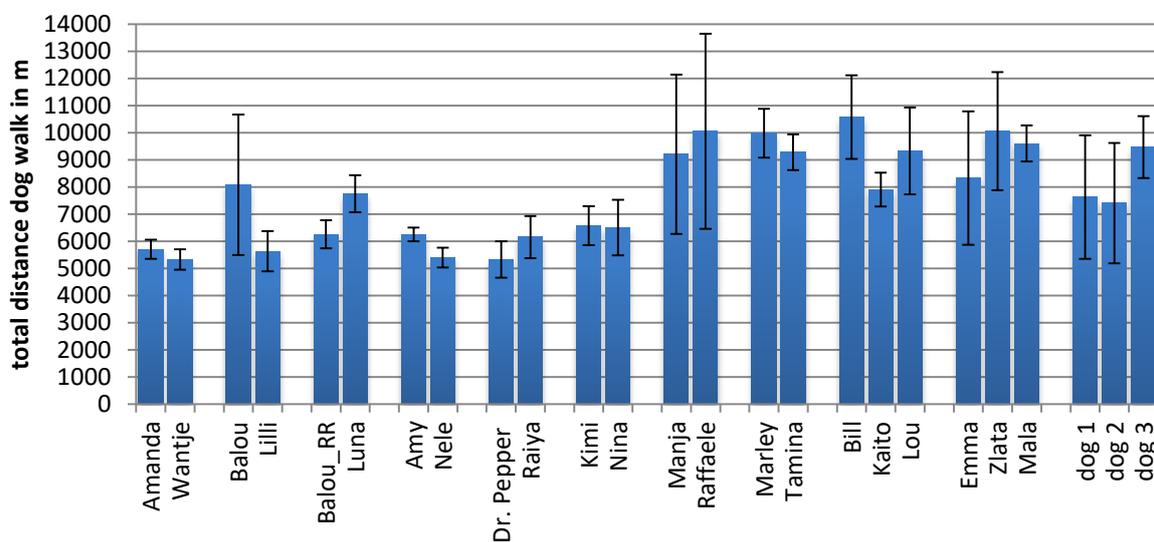


Fig R2.16.2.1: Total distance between and within dog teams, in meter.

Differences between dogs of one team can be seen in the total distance of the walk. There are teams with relatively small differences (Amanda and Wantje, Kimi and Nina), but there are also teams with large differences between the two or three dogs (e.g. Balou and Lilli, Kaito and Bill). Equal distances indicate that the dogs walk close together.

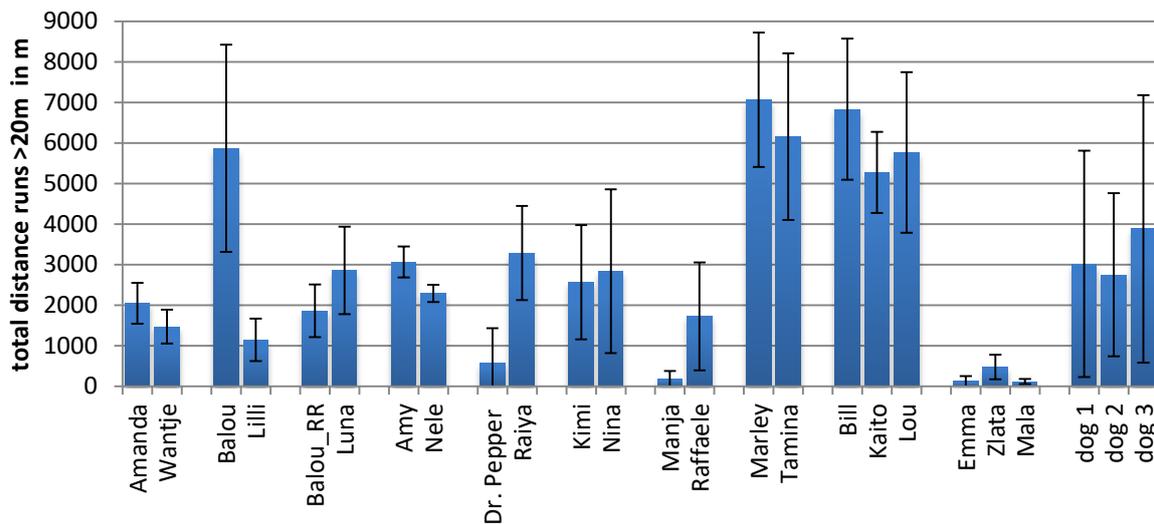


Fig R2.16.2.2: Distance runs >20 m away between and within dog teams, in meter.

The total distance of runs > 20 m varies within the teams. Some teams displayed minor variances (Amanda, Wantje; Amy, Nele), some large differences: The largest difference existed between Manja (181m) and Raffaele (1721m – 851 % difference); Balou and Lilli (5866 m vs. 1142m – 414 % difference) and between Dr. Pepper and Raiya (568 m vs. 3283 m - 478 % difference). These dogs do not explore together. The dog that explores less essentially stays closer to the owner and the second dog explores alone. All dogs of the triad Emma, Zlata and Mala are near to the owner, whereas Bill, Kaito and Lou have large distances outside the 20 m owner radius, but as a triad they travel comparable distances – here all three dogs explore great distances away from the owner. One factor here may also be whether the dogs (are able to) travel at equivalent speed, see **Table R2.6.2**, perhaps due to age differences, see **Table R2.11.1; Fig. R2.11.1-2.11.2**.

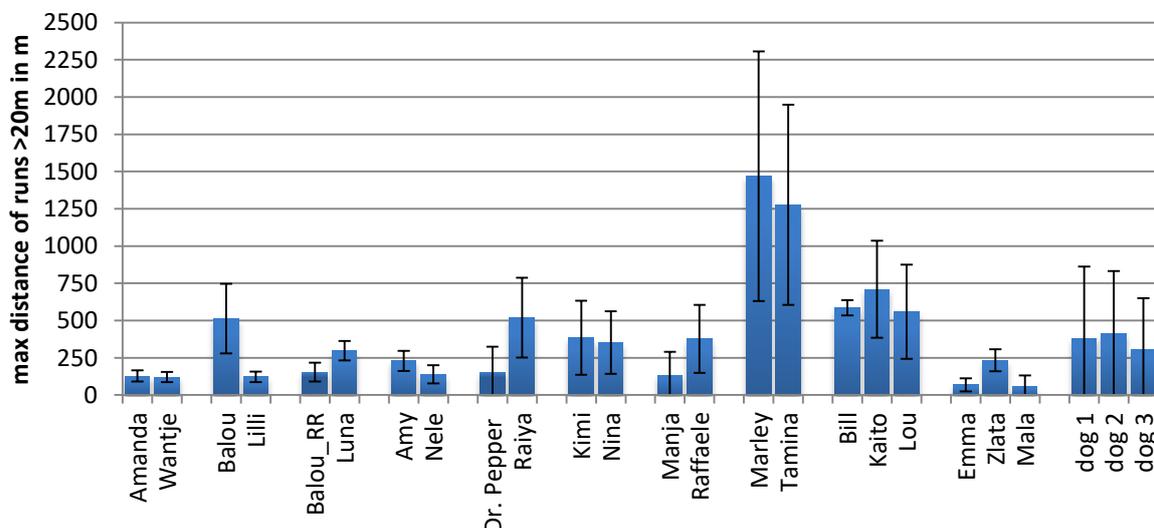


Fig R2.16.2.3: Maximum distance of runs >20 m between and within dog teams, in meter.

The maximal distance varies between the teams, within teams however fewer variances can be denoted. In the team Marley and Tamina both dogs have a large maximal difference to the owner. In other teams e.g. Amanda and Wantje both dogs walk near the owner and the maximum difference travelled from the owner is within the < 150 m radius.

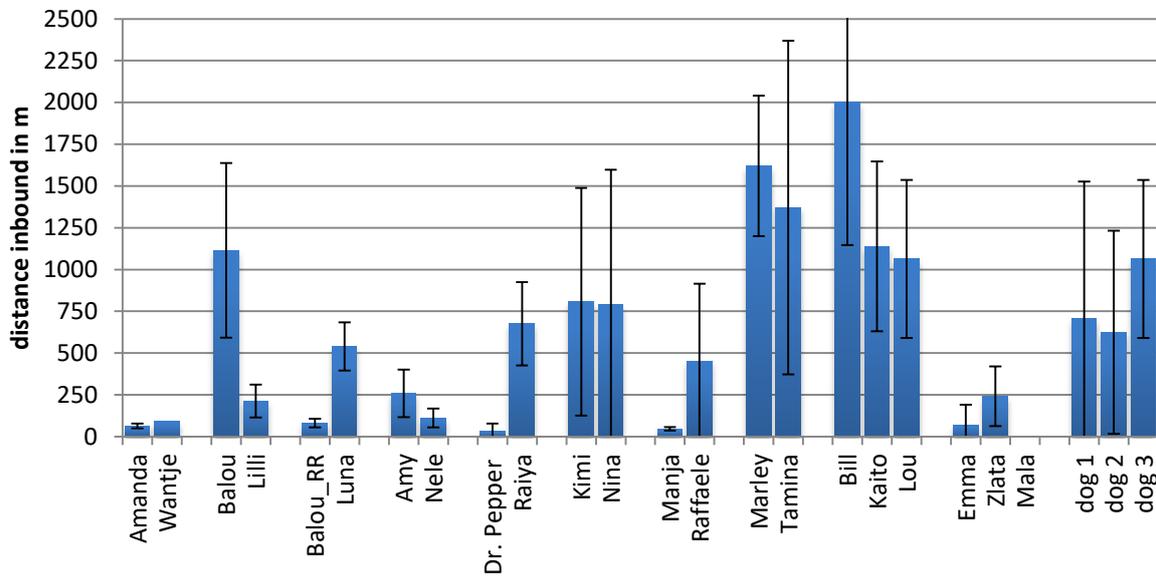


Fig R2.16.2.4: Distance inbound between and within dog teams, in meter.

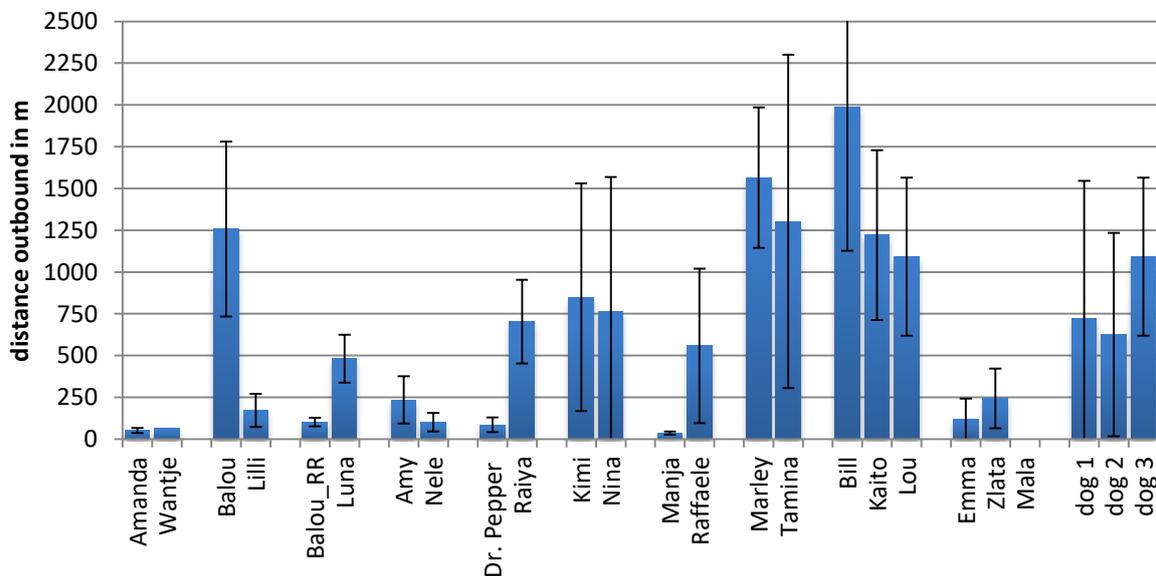


Fig R2.16.2.5: Distance outbound between and within dog teams, in meter.

Distance inbound (**Fig. R2.16.2.4**) and distance outbound (**Fig. R2.16.2.5**) are comparable as the dogs have to travel back fairly equidistance routes to their owner. In comparison one can see that the distance travelled back to the owner (inbound) is less than the outbound distance travelled, see also **Table R2.5.1; Fig. R2.5.1**. Travelling variances between some teams are indicated once more (Balou and Lili, Manja and Raffaele, Dr. Pepper and Raiya). For exemplary dog dyads travelling patterns see **Fig. M2.2.4.2-7**.

2.3.17 Magnetic field orientation of point of return

Spatial orientation may also be maintained by using the geomagnetic field of the earth to establish a sense of compass direction, not only of the path traversed but also to return to an always varying location i.e the owner. The use of allocentric information like the geomagnetic field may be indicated herein by the fact that independently of their travelling direction and prior to their return route, the dogs displayed a point of return in North/South direction, arguably, to calibrate their compass and update their cognitive map. Using the GPS data and the analysis via BaseCamp 4.5.2.1 a point of return was established for each dog and each trial. Point of return (POR) was defined as the point at which the dog decreased its speed and subsequently changed its travelling direction to return to the owner. Data measured were the direction, in degrees, when the dog changed direction to return to the owner as provided by the GPS of the travelling route (in two, respectively, five second segments) of the dog, see Parameters **Table M1.2.5; Table M1.2.3**. The point of return of all dogs (n=28) was analyzed. Two dogs had no point of return in their travelling patterns (Odin, Mala).

Looking at all dogs, they displayed a significant point of return (n=780) in N-S direction (339°- 169°) with an axial Mean Vector (μ): 169°, **Fig. R2.17.1**. Assessed separately, the female dogs (n=17) did not display a significant point of return (n=348), **Fig. R2.17.2a**. The male dogs however displayed a significant point of return (n=432) in N-S direction (325°- 165°) with an axial Mean Vector (μ) of 165°, **Fig. R2.17.2b**. Looking at the intact male and female versus neutered/spayed male and female dogs, results show that the intact dogs displayed a preference in N-S (7°/187°) direction but no significant point of return (n=206) **Fig. R2.17.3a**. The neutered/spayed male and female dogs however displayed a significant point of return (n=574) in N-S direction (167°- 327°) with an axial Mean Vector (μ) of 167° and a Median of 173°. The Grand mean vector for the point of return of all spayed/neutered dogs showed statistically significant differ-

ences between the distributions according to the Rayleigh uniformity test, the Rao's spacing test and the Watson's U^2 Test, **Fig. R2.17.3b**.

Differentiating the female intact and female spayed dogs results showed that the intact female dogs displayed a preference in NE-SW ($37^\circ/207^\circ$) direction but no significant point of return ($n=71$), **Fig. R2.17.4a**. The spayed female dogs however displayed a significant point of return ($n=277$) in N-S direction ($169^\circ-329^\circ$) with an axial Mean Vector (μ) of 169° and a Median of 169° . The Grand mean vector for the point of return showed statistically significant differences between the distributions according to the Rayleigh uniformity test and the Watson's U^2 Test, **Fig. R2.17.4b**. The intact male dogs ($n=3$) displayed a preference in N-S ($166^\circ/306^\circ$) direction but no significant point of return ($n=135$), **Fig. R2.17.5a**. The neutered male dogs ($n=8$) however displayed a significant point of return ($n=297$) in N-S direction ($165^\circ-325^\circ$) with an axial Mean Vector (μ): 165° and a Median of 174° . The Grand mean vector for the point of return of all dogs showed statistically significant differences between the distributions according to the Rayleigh uniformity test, the Rao's spacing test and the Watson's U^2 Test, **Fig. R2.17.5b**. For a summary, see **Table R2.17.1**.

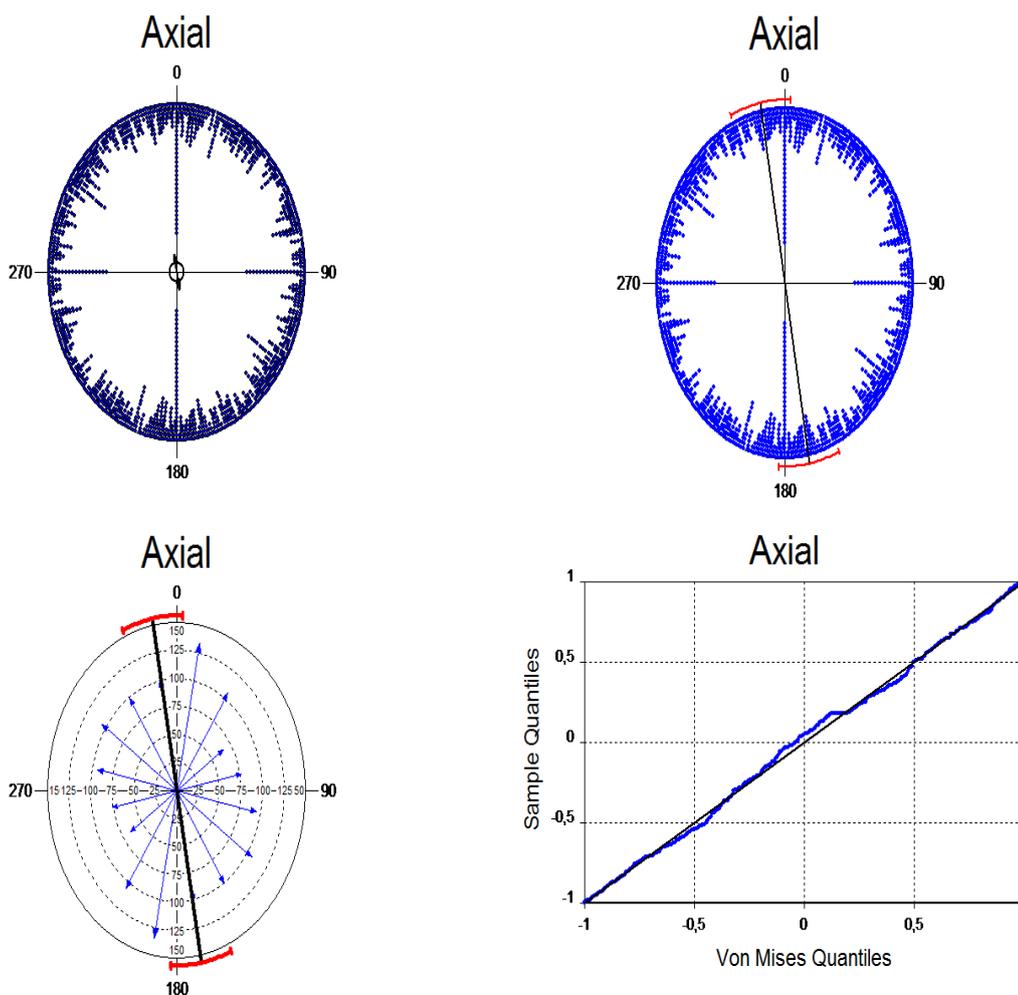


Fig.R2.17.1. Variable axial, all dogs' point of return (POR) Number of Observations: 780. Mean Vector (μ): 169°. Length of Mean Vector (r): 0.11. Median 174° Circular Standard Deviation: 60°. 95 % Confidence Interval (-/+) for μ : 156°/ 183°.99 % Confidence Interval (-/+) for μ : 152°/187°. Rayleigh Test (p) : < 1.08E-4. Rao's Spacing Test (p): < 0.01. Watson's U^2 Test (p) < 0.005. The graph compares the data to the von Mises distribution. Here you can see a close correlation, suggesting that the data follow the von Mises distribution.

Fig.R2.17.1: Point of return all dogs, all runs > 20 m (n=780).

Each pair of opposite dots indicates the axis of the vector of observations of the data points (direction in degree) where each dog decreased its speed and changed its direction to return to its owner, the so-called "point of return" collected during the run >20 m in 2 sec segments by the GPS. The mean vector (μ) and vector length (r) are indicated by the direction and length of the black (double) arrow(s), respectively. Small inner circles indicate the 5 %-significance level of the Rayleigh test. The lengths of the blue arrows indicate the frequencies for each class of observation.

The dogs displayed a significant point of return (n=780) N-S direction (339°- 169°) with an axial Mean Vector (μ): 169°, and a Median of 174°. The Grand mean vector for the point of return of all dogs (n=28/30) shows statistically significant differences between the distributions according to the Rayleigh uniformity test, the Rao's spacing test and the Watson's U^2 Test, **Fig. R2.17.1.**

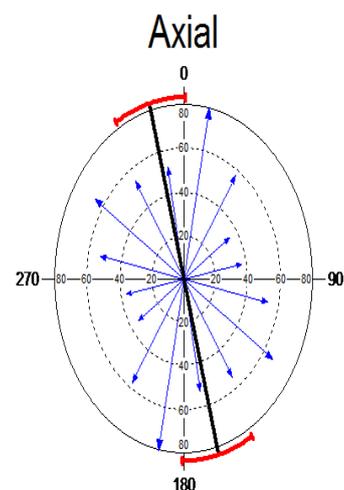
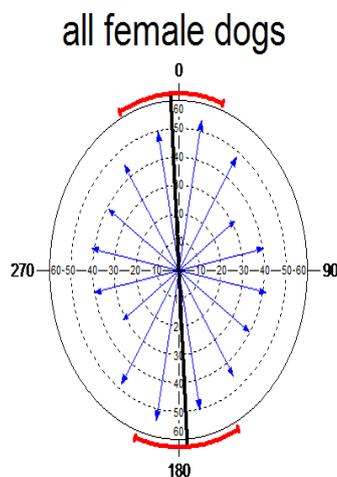
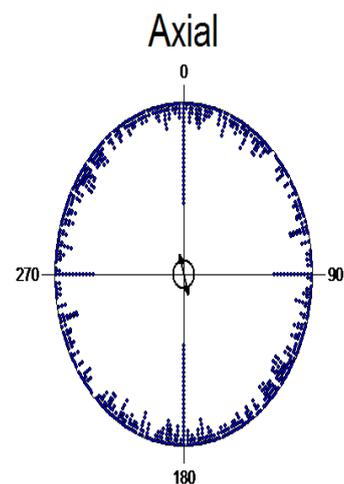
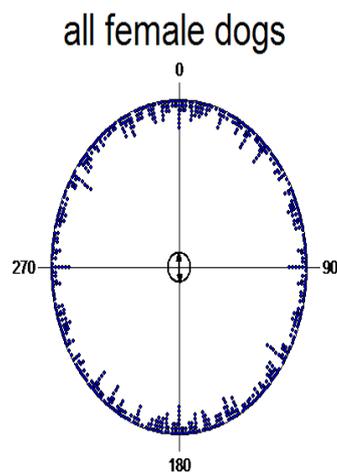


Fig. R2.17.2a. Variable axial, all female dogs' (n=17) point of return (POR) Number of Observations: 348. Mean Vector (μ): 176°. Length of Mean Vector (r): 0.09. Median * Circular Standard Deviation: 62°. 95 % Confidence Interval (-/+) for μ : 154°/ 199°. 99 % Confidence Interval (-/+) for μ : 147°/206°. Rayleigh Test (p): < 0.046. Rao's Spacing Test (p): 0.50 > p > 0.10. Watson's U² Test (p) 0.1 > p > 0.05.

Not significant.

Fig. R2.17.2b. Variable axial, all male dogs' (n=11) point of return (POR) Number of Observations: 432. Mean Vector (μ): 165°. Length of Mean Vector (r): 0.12. Median * Circular Standard Deviation: 59°. 95 % Confidence Interval (-/+) for μ : 150°/ 181°. 99 % Confidence Interval (-/+) for μ : 145°/185°. Rayleigh Test (p): < 0.001. Rao's Spacing Test (p): < 0.01. Watson's U² Test (p) < 0.005.

Fig.R2.17.2a/b: Point of return all female dogs (a) and all male dogs (b), all runs > 20 m.

Each pair of opposite dots indicates the axis of the vector of observations of the data points (direction in degree) where each dog decreased its speed and changed its direction to return to its owner, the so-called "point of return" collected during the run >20 m in 2 sec segments by the GPS. The mean vector (μ) and vector length (r) are indicated by the direction and length of the black (double) arrow(s), respectively. Small inner circles indicate the 5 %-significance level of the Rayleigh test. The lengths of the blue arrows indicate the frequencies for each class of observation.

The female dogs (n=17) do not display a significant point of return (n=348) due to great variation and a large circular standard deviation can be observed, **Fig. R2.17.2a**. The male dogs (n=11) display a significant point of return (n=432) in N-S direction (325°-165°) with an axial Mean Vector (μ): 165°. A large circular standard deviation can be observed. The Grand mean vector for the point of return of all dogs shows statistically significant differences between the distributions according to the Rayleigh uniformity test, the Rao's spacing test and the Watson's U^2 Test, **Fig. R2.17.2b**.

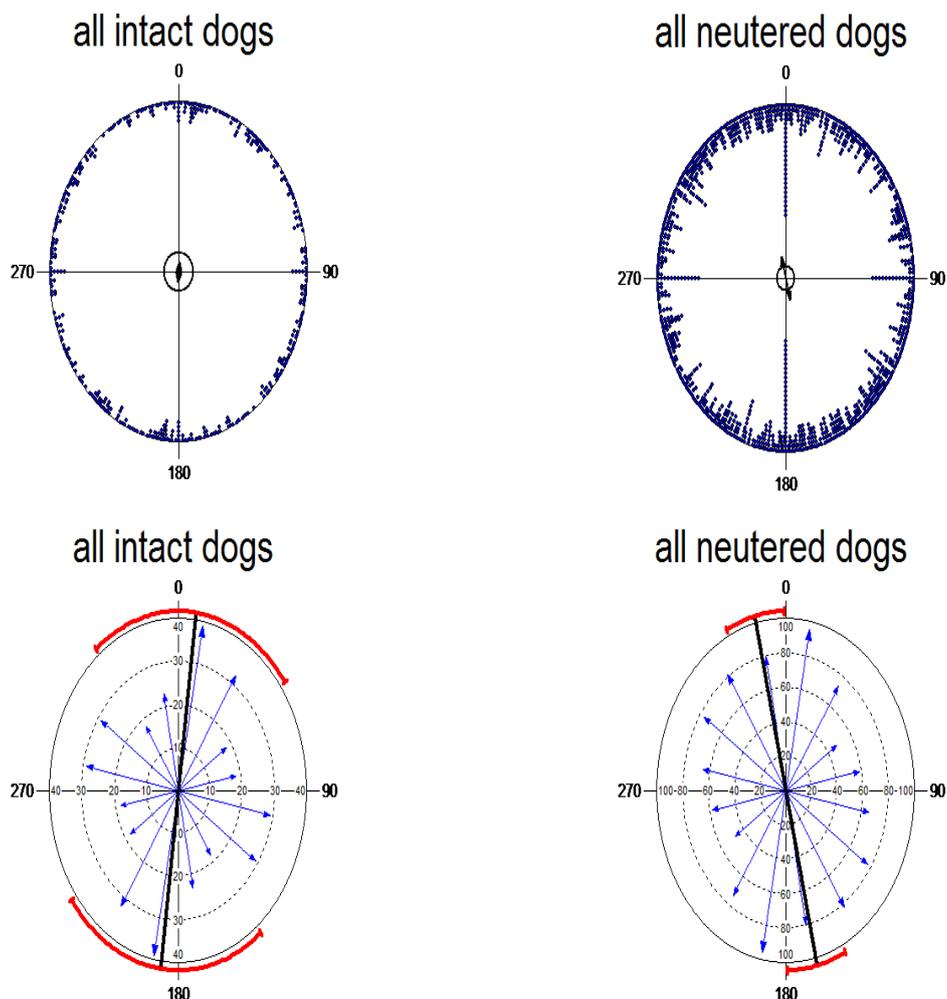


Fig. R2.17.3 a. Variable axial, all intact dogs' (n=8) point of return (POR) Number of Observations: 206. Mean Vector (μ): 7, 4°. Length of Mean Vector (r): 0.06. Median 6, 2° Circular Standard Deviation: 68°. 95 % Confidence Interval (-/+) for μ : 322°/ 53°. 99 % Confidence Interval (-/+) for μ : 308°/67°. Rayleigh Test (p): 0.463. Rao's Spacing Test (p): 0.50 > p > 0.10. Watson's U² Test (p) 0.25 > p > 0.15.

Not significant.

Fig. R2.17.3 b. Variable axial, all neutered dogs' (n=20) point of return (POR) Number of Observations: 574. Mean Vector (μ): 167°. Length of Mean Vector (r): 0.13. Median 172, 6°

Circular Standard Deviation: 58°. 95 % Confidence Interval (-/+) for μ : 154°/ 179°. 99 % Confidence Interval (-/+) for μ : 150°/183°. Rayleigh Test (p): 6.17E-5. Rao's Spacing Test (p): < 0.01. Watson's U² Test (p) < 0.005.

Fig.R2.17.3 a/b: Point of return all intact dogs (a) and all neutered/spayed dogs (b), all runs > 20 m

Each pair of opposite dots indicates the axis of the vector of observations of the data points (direction in degree) where each dog decreased its speed and changed its direction to return to its owner, the so-called "point of return" collected during the run >20 m in 2 sec segments by the GPS.. The mean vector (μ) and vector length (r) are indicated by the direction and length of the black (double) arrow(s), respectively. Small inner circles indicate the 5 %-significance level of the Rayleigh test. The lengths of the blue arrows indicate the frequencies for each class of observation.

The intact dogs (n=8) display a preference in N-S ($7^{\circ}/187^{\circ}$) direction Mean Vector (μ): $7, 4^{\circ}$. Median $6, 2^{\circ}$ but no significant point of return (n=206). The neutered/spayed dogs (n=20) show a significant point of return (n=574) in N-S direction ($167^{\circ}- 327^{\circ}$) with an axial Mean Vector (μ): 167° and a Median of 173° . The Grand mean vector for the point of return of all dogs (n=28/30) shows statistically significant differences between the distributions according to the Rayleigh uniformity test, the Rao's spacing test and the Watson's U^2 Test, **Fig. R2.17.3b**.

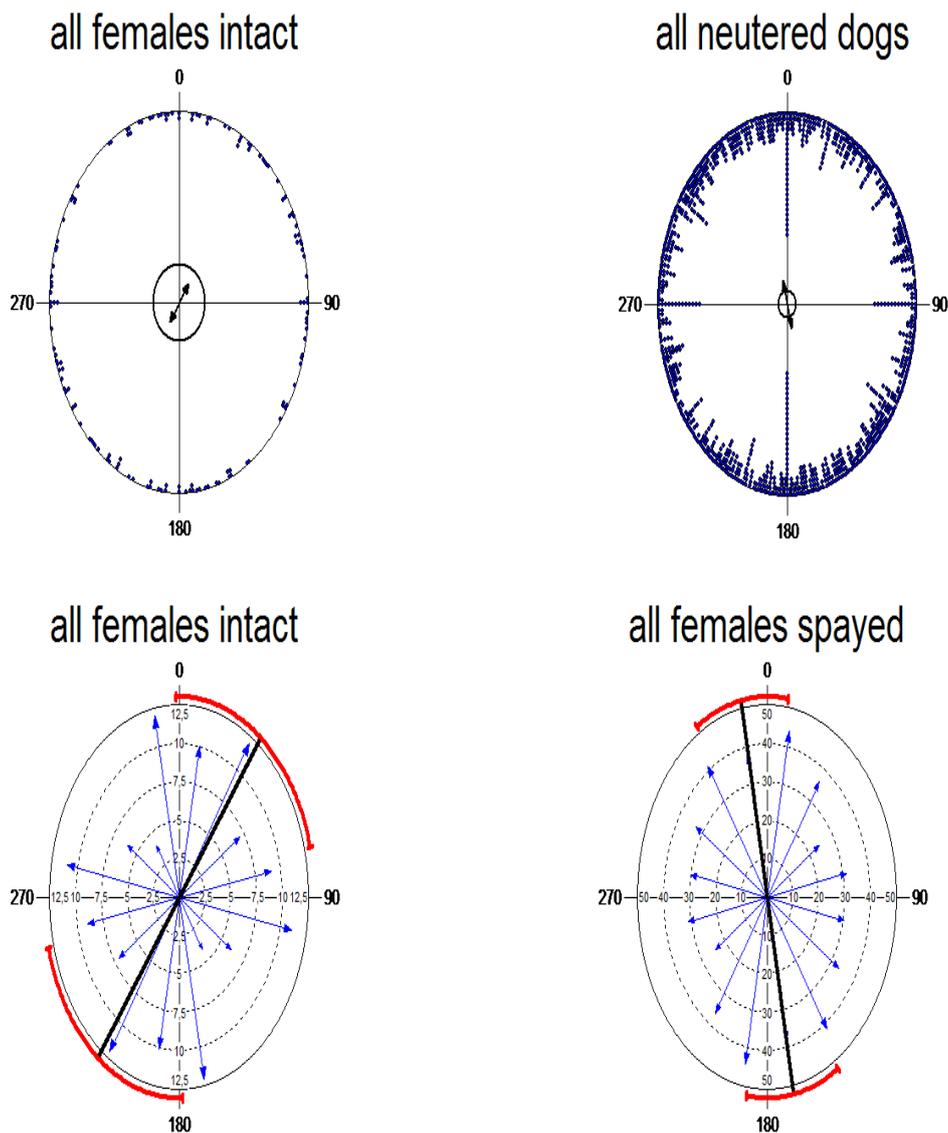


Fig. R2.17.4 a. Variable axial, all intact female dogs' (n=5) point of return (POR) Number of Observations: 71. Mean Vector (μ): 37°. Length of Mean Vector (r): 0.12 .Median 42, 2° Circular Standard Deviation: 59°. 95 % Confidence Interval (-/+) for μ : 359°/ 75°.99 % Confidence Interval (-/+) for μ : 346°/87°. Rayleigh Test (p): 0.347. Rao's Spacing Test (p): < 0.01. Watson's U^2 Test (p) 0.5 > p > 0.25.

Not significant.

Fig. R2.17.4.b. Variable axial, all spayed female dogs' (n=11) point of return (POR) Number of Observations: 277. Mean Vector (μ): 169°. Length of Mean Vector (r): 0.12.Median 168,6°

Circular Standard Deviation: 59°. 95 % Confidence Interval (-/+) for μ : 149°/ 189°.99 % Confidence Interval (-/+) for μ : 142°/195°. Rayleigh Test (p): 0.022. Rao's Spacing Test (p): 0.50 > p > 0.10. Watson's U^2 Test (p) < 0.05.

Fig. R2.17.4 a/b: Point of return all intact female dogs (a) and all spayed female dogs (b), all runs > 20 m.

Each pair of opposite dots indicates the axis of the vector of observations of the data points (direction in degree) where each dog decreased its speed and changed its direction to return to its owner, the so-called "point of return" collected during the run >20 m in 2 sec segments by the GPS.. The mean vector (μ) and vector length (r) are indicated by the direction and length of the black (double) arrow(s), respectively. Small inner circles indicate the 5 %-significance level of the Rayleigh test. The lengths of the blue arrows indicate the frequencies for each class of observation

The intact female dogs (n=5) display a preference in NE-SW (37°/207°) direction Mean Vector (μ): 37° Median 42° but no significant point of return (POR n=71) due to great variation and possibly to a low number of observations. The spayed female dogs (n=11) display a significant point of return (n=277) in N-S direction (169°- 329°) with an axial Mean Vector (μ): 169° and a Median of 169°. The Grand mean vector for the point of return of all dogs (n=28/30) shows statistically significant differences between the distributions according to the Rayleigh uniformity test and the Watson's U^2 Test **Fig. R2.17.4b.**

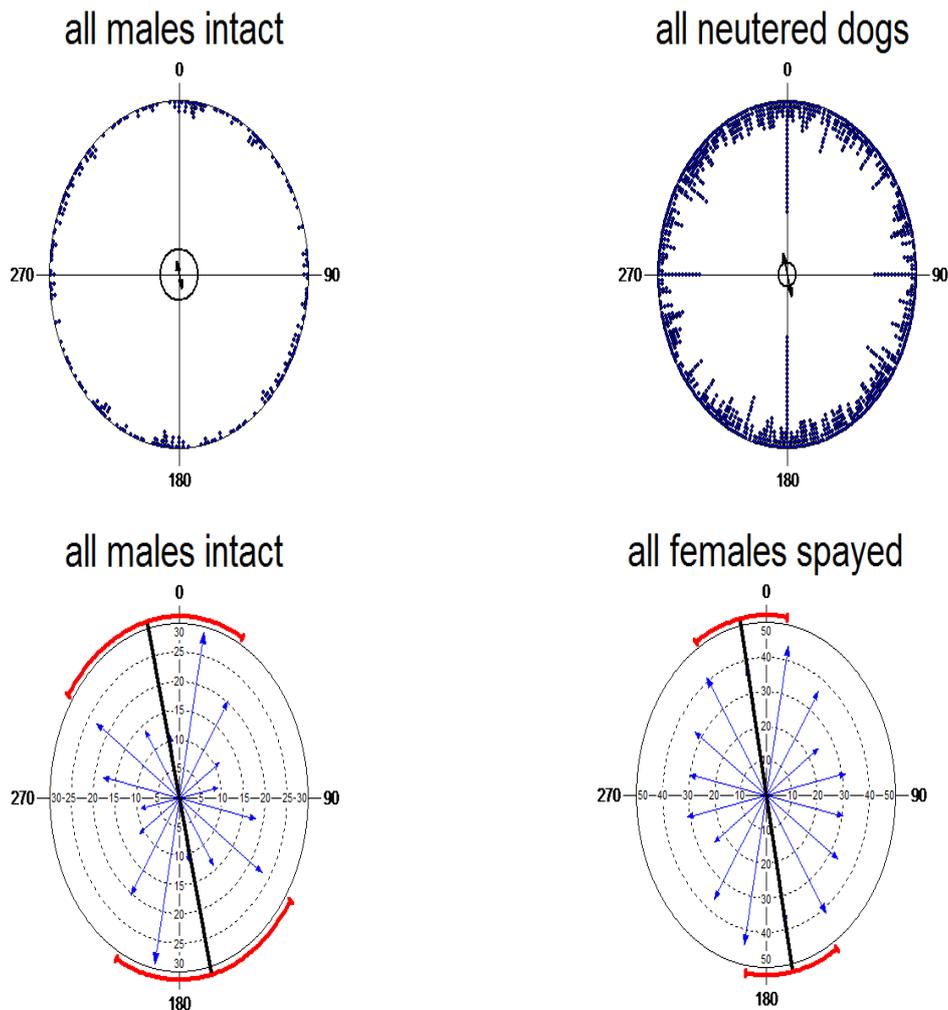


Fig. R2.17.5 a. Variable axial, all intact male dogs' (n=3) point of return (POR) Number of Observations: 135. Mean Vector (μ): 166°. Length of Mean Vector (r): 0.08. Median 3° Circular Standard Deviation: 64°. 95 % Confidence Interval (-/+) for μ : 124°/ 208°. 99 % Confidence Interval (-/+) for μ : 111°/221°. Rayleigh Test (p): 0.406. Rao's Spacing Test (p): 0.50 > p > 0.10. Watson's U² Test (p) 0.15 > p > 0.1

Not significant.

Fig. R2.17.5 b. Variable axial, all neutered male dogs' (n=8) point of return (POR) Number of Observations: 297. Mean Vector (μ): 165°. Length of Mean Vector (r): 0.14. Median 3° Circular Standard Deviation: 57°. 95 % Confidence Interval (-/+) for μ : 149°/ 181°. 99 % Confidence Interval (-/+) for μ : 144°/186°. Rayleigh Test (p): 0.002. Rao's Spacing Test (p): < 0.01. Watson's U² Test (p) < 0.005.

Fig. R2.17.5 a/b: Point of return all intact male dogs (a) and all neutered male dogs (b), all runs > 20 m .

Each pair of opposite dots indicates the axis of the vector of observations of the data points (direction in degree) where each dog decreased its speed and changed its direction to return to its owner, the so-called "point of return" collected during the run >20 m in 2 sec segments by the GPS.. The mean vector (μ) and vector length (r) are indicated by the direction and length of the black (double) arrow(s), respectively. Small inner circles indicate the 5 %-significance level of the Rayleigh test. The lengths of the blue arrows indicate the frequencies for each class of observation.

The intact male dogs (n=3) display a preference in N-S (166°/306°) direction Mean Vector (μ): 166°, Median 3° but no significant point of return (n=135). The neutered male dogs (n=8) display a significant point of return (n=297) in N-S direction (165°- 325°) with an axial Mean Vector (μ): 165° and a Median of 174°. The Grand mean vector for the point of return of all dogs shows statistically significant differences between the distributions according to the Rayleigh uniformity test, the Rao's spacing test and the Watson's U^2 Test, **Fig. R2.17.5b**

Table R2.17.1: Summary: significant point of return for all groups of dogs.

	POR significant	POR Not significant
All dogs	significant point of return (n=780) in N-S direction (339°- 169°)	
All female dogs		no significant point of return
All male dogs	significant point of return (n=432) in N-S direction (325°- 165°)	
All intact dogs		no significant point of return
All neutered/spayed dogs	significant point of return (n=574) in N-S direction (167°- 327°)	
All intact female dogs		no significant point of return
All spayed female dogs	significant point of return (n=277) in N-S direction	
All intact male dogs		no significant point of return
All neutered male dogs	significant point of return (n=297) in N-S direction (165°- 325°)	

2.4 Discussion

2.4.1 Introduction

In this Chapter the individual dog and the dog-dog interaction was analyzed. How did the dogs explore? How far would they explore and for how long? What patterns would they use? How fast would they run and were there differences between their outbound exploration route and their inbound route back to their owner? Would the area make a difference and if more than one dog belonged to one owner would these dogs explore together? Does sex or reproductive status of the dog make a difference with respect to time and distance travelled?

Looking at the runs >20 m in known and unknown areas no significant difference could be established even though the dogs clearly did explore further and longer in known areas. Fairly soon it became apparent that the individual dogs displayed very different exploration radiuses and therefore three groups were established. The majority of the dogs never left the radius of 150 m to their owner, despite external stimuli. Some dogs in this group had hardly any runs >20 m. Within the groups differences could be perceived with respect to exploration time and distance – ascending radius groups displayed longer runs. The intraspecific variance was very great though, with Group 3 dogs having maximum distance runs up to 2000 m and displaying very different and cognitively more challenging exploration and orientation patterns. The majority of dogs however (Group 1 and 2) basically ran back and forth on the owner path, which arguably does not require special spatial orientation abilities. Male dogs herein explored further than female dogs, but reproductive status was not significant. Looking at the exploration patterns outbound and inbound, the dogs clearly returned much faster and in shorter duration, i.e. directly to the owner. Age and size of the dogs was not correlated with speed or distance explored. Great speed differences could be observed however, including travelling mode differences in that some dogs were always fast (or slow) and some dogs displayed great speed variation on their exploratory runs (slow and fast). Most dog teams tended to explore together, however, generally one dog had a leading or initiating position and the second dog followed and usually returned earlier to the owner. In some dog dyads the second dog stayed with the owner and did not explore with its conspecific at all. If the dog teams explored together they displayed similar exploration and spatial orientation strategies, however.

In the following basic theories on orientation will be presented in a nutshell, prior to looking at the variances in orientation patterns between male and female dogs, exploration patterns, the displayed behavior of dog dyads and triads and lastly issues pertaining to hunting behavior of dogs.

2.4.2 Orientation

2.4.2.1 Navigation

Navigation, according to Gallistel (1990), is the capacity to plan and execute a goal-directed path. Herein, the owner was assumed to be the goal. For the dogs to travel goal-directed I had to presuppose motivation and an understanding of displaced object permanence (see Section 1.1.3; 1.1.5 for discussion). True navigation, though, has been defined as *“the ability of an animal to return to its original location after displacement to a site in unfamiliar territory, without access to familiar landmarks, goal emanating cues, or information about the displacement route”* (Phillips et al., 2006, p. 204). This ability requires both a sense of direction (“compass”) and a sense of geographic position (“map”) (Phillips et al., 2006).

2.4.2.2 Path integration

Path integration has primarily been studied through homing, in which for instance an animal returns to its den or nest after foraging for food. According to Etienne & Jeffery (2004) homing without external references like landmarks, for instance at night, is based on internal cues derived from the individuals self-referenced, continually updated, locomotion which may be implied by the distance measures employed by the dogs. Etienne & Jeffery (2004) postulated that path integration *“in itself exerts a functionally important control over navigation only as long as the animal can combine it with learned strategies and/or spatial cues from the familiar environment”* (p. 180). Thus, this would only apply to known areas. Problematic is the aforementioned definition for this study in that the starting point as well as the owner position, i.e. the point they had to return to, was novel in each individual trial, and thus, there was no “home” position or spatial cues from a familiar environment to which the dogs had to return.

Collett & Graham (2004) proposed that in a path integration system without fixed references the animal may store a network of distance and direction vectors that connect different locations, based on visual and nonvisual landmarks. At each location the

animal resets its path integrator. Arguably, the nonvisual landmarks are for instance geomagnetic clues and the alignment and significant point of return in northern, respectively north-south direction, see Section 2.17. These are used to reset or calibrate the path integrator to indicate the bearing of the return route, which still is no explanation for finding an owner in an always varying, novel location unless the dogs were able to incorporate the owner movement in the network of distance and direction vectors (which arguably is similar to anticipating prey movement).

Phillips et al. (2010) proposed a light dependent magnetic compass (LDMC), serving as a source of directional information providing a spherical coordinate system, linking directional and spatial perception. Thereby the magnetic field may be perceived as a visual 3D pattern superimposed on the animal's surroundings, fixed in alignment with a magnetic reference frame with the animal in its centre. A magnetic compass therefore could be viewed as a connection between spatial representations of different surroundings, thus a global reference, and the internal path integration system and would thereby also reduce the errors by referencing turn angles to an external compass system (Cheung et al., 2008). The geomagnetic field would be a highly reliable, constant directional reference, irrespective of distance and could be used in any habitat or at any time of day with equal efficiency. Thus, changing to the use of a path integration system that is assisted by a stable external reference direction decreases the accumulation of errors found in a purely egocentric assessment of direction.

Phillips et al. (2010) further postulated that in novel environments, a 'snapshot' of the new surroundings with the spherical coordinate system provided by the LDMC superimposed aids to encode relationships between landmarks. This could be used to 'anchor' other neural representations of space to the landmark array, which could be one explanation how the dogs oriented in new areas: by "anchoring" their starting position, which may also be implicated by the vector in northern direction, see Section 2.17. As can be seen in **Fig. R2.14.1**, though, the majority of dogs did not return to the starting position, thus an additional factor, arguably anticipation of the continued owner movement has to be taken into account. This may be comparable to hunting strategies where the dogs would have to anticipate prey movement in addition to their own movement, direction and speed, and possibly cooperative hunting movements of other dogs as well (see discussion 2.1.6).

Seguinot et al. (1998) studied path integration in dogs in the absence of landmark information and found in their analysis of the distributions of errors in the return direc-

tion and distance that the dogs made both systematic and random errors and tended to underestimate the correct return distance. These findings I cannot support herein. The return strategy of anticipation actually incorporates an overreaching of the starting point, and systematic errors would have led to not localizing the owner. Additionally, the dogs displayed a correct directional assessment, on their (fast and direct) inbound travel route. It has been argued that errors in path integration increase with distance travelled, cf. Collett & Graham (2004), which however would be reduced by relying on geomagnetic cues, as postulated e.g. for *Spalax ehrenbergi* by Kimchi et al. (2004): If animals assess direction both through internal signals and by estimating its heading in relation to the earth's magnetic field the accumulation of errors due to inaccuracies in the estimation of rotations could be reduced.

2.4.2.3 Spatial orientation

Maglio & Polman (2014) defined spatial orientation as moving toward or away from a place, being a process that enables animals to know their surroundings and identify the optimal path to their targets using multiple resources. All dogs herein found back to a specified, varying non-stationary locality, i.e. their owner (**Table R1.0**) in different environments (known and unknown; **Table R1.2.2**; **Table R2.1.**) even subsequent to having explored a certain distance i.e. out of range of visibility or/and olfaction. This may be based on their ability to establish cognitive maps and the use of spatial reference systems (Fugazza et al., 2017; Scandurra et al., 2018; Wang, 2016) including egocentric and allocentric cues (**Table R2.17.1**; **Table R2.5.1**; **Table R2.6.1**; **Fig. R2.6.1**; **Fig. R2.6.2**).

Spatial orientation may either be maintained allocentrically by memorizing specific landmarks (e.g. roads, trees, etc.), positions and locations in known locations (cf. Etienne & Jeffrey, 2004; Fugazza et al., 2017; Macpherson & Roberts, 2010) in which the dog updates its position in the environment using a reference system external to the body and anchored in the environment (Fugazza et al., 2017; Gallistel, 1990). Dogs may also orient egocentrically by integrating signals or cues indicating the extent of self-motion along their locomotion trajectory (Scandurra et al., 2018; Wehner & Srinivasan, 1981; Wittlinger et al., 2006), in which the dog updates an object's location with respect to the body, using a reference system centered on the body, typically defined by the reference directions of front, back, right and left (Scandurra et al., 2018; Wang, 2016). Dogs primarily employ two sources of allocentric spatial information to navigate: local and global cues (Fiset et al., 2007).

The so-called vector sum model was advanced to explain how animals use distance and direction from landmarks. It assumes that animals encode and combine the components of a single vector between the goal location and each landmark located in the vicinity of the goal (landmark-to-goal vectors) and perceive vectors from their current position and each landmark (self-to-landmark vectors), which are then averaged to find the goal location, cf. Collett et al. (1986); Cheng (1990).

However, studies found that birds did not combine the two components of a vector but encoded them separately, with predominance of direction over distance (Wiltschko & Wiltschko, 2010), which led to the formulation of the Multiple Bearings Hypothesis, cf. Cheng (1994); Kamil & Cheng (2001). This model emphasised that separate bearings from multiple landmarks are computed and that landmark based spatial memory depends on the encoding of two independent spatial parameters from multiple cues, which are hierarchically organized depending on the proximity of the landmarks or their attributes (Spetch & Kelly 2006). Fiset (2009) studied the metric properties of landmark-based spatial memory in the domestic dog and her data supported the predictions of the vector sum model. The dogs, however, did not shift their search by the same extent as the shift of the landmark. It therefore appears that dogs encoded the distance and direction from individual landmarks located in the vicinity of a goal and some distal cues as well, thereby supporting the Multiple Bearings Hypothesis (Gould-Beierle & Kamil, 1999). Arguably, the dogs in this study could have used distal visual landmarks for their spatial orientation in known areas and, albeit unlikely, through one trial learning in new regions. A direct return route, even if the outward trip was a sinuous route, has been shown in interaction with visual landmarks (Etienne et al., 1996); without visual clues animals may rely purely on egocentric information (Etienne et al., 2004). Without fixed reference points the dogs may also store a network of distance and direction vectors that connect different locations which enables them to orient on their return route irrespective of visual cues (O'Keefe & Nadel, 1978). A cognitive map, as suggested by O'Keefe & Nadel, is the same as a mental representation for which spatial (and perhaps also geometric) relationships among locations are memorized in connection to direction and distance. Arguably, as consequences of using a cognitive map the dogs are able to make novel shortcuts between locations, as indicated by their return route, see **Table R2.5.1**.

2.4.2.4 Areas

Therefore one would expect the strategies to differ depending on area (known versus unknown). In known areas the dogs may employ allocentric and egocentric cues, as they could recognize landmarks and other local and global information, whereas in a new area they may primarily rely on egocentric cues. However, Fiset et al. (2007, 2009) explored a landmark-based search paradigm to investigate whether dogs encode distance and direction from local and global cues and the result showed that dogs encoded both distance and direction from local cues, landmarks and global cues, suggesting that they simultaneously encoded both sources of spatial information and then attempt to average the vectors from each cue. Fiset (2009) postulated further that landmark-based spatial memory of domestic dogs is based on the metric properties of space and, specifically, that dogs accurately average the distance from multiple cues to find a position.

The median distance explored in known areas was 2351 m in unknown areas 1585 m respectively (33 % decrease). Clear differences could be perceived between known and unknown areas (20 of 30 dogs travelled shorter distances in unknown areas). The lower quartile showed a distance of 579 m in known and 493 m in unknown areas (14, 9 % decrease). About 25 % of the walks in known areas had a distance of runs >20 m in excess of 3649m (upper quartile), in unknown areas the third (75 %) quartile lay at 3364 m, see **Table R2.1.1; Fig R2.1.1**. Differences were not significant, **Fig.R2.1.3** between known and unknown areas with respect to the overall distance explored for all dog runs > 20 m, **Fig. R2.1.3 Appendix**. Between the three Groups distinct differences between known and unknown area exploration distance could be observed. In Group 1, which always stayed close to the owner (max. radius 150 m), no change was apparent between the areas, **Fig. R2.3.1**. However, Group 2 and 3 travelled longer distances in known than unknown areas, **Fig. R2.3.2**. As in particular Group 3 dogs explored in known areas substantially longer distances than in unknown areas, see **Table R2.4.1 Appendix**. The duration of runs > 20 m did not reflect these differences and it can be concluded that Group 3 dogs travelled considerably faster in known than in unknown areas which might be an indicator for being more certain of their environment, as they did not have to stop or slow down as often to get their bearing.

It has been shown that dogs use a wide range of spatial skills and can solve different spatial tasks, including both egocentric and allocentric signals (Cattet & Etienne, 2004) and they can integrate spatial signals during locomotion, continuously updating information on the distance from and direction to a particular object (path integration).

Of course the longer distances also imply the use of allocentric cues in that the dogs utilize familiar landmarks and thus explore further and longer.

Looking at the time of exploration again large intraspecific differences could be seen, **Fig.R2.4.1; Fig.R2.4.3**, between the Groups however, no time differences were apparent, **Fig.R2.4.2**. Over all dogs the median time away from the owner was 00:17h in known areas and 00:11h in unknown areas, see **Table R2.4.1 Appendix**. The time difference between the two areas was not significant over all dogs. Between the three groups differences in exploration time could clearly be seen, with an increase from Group 1 to Group 3. All groups showed longer travelling times in known than unknown areas (mean time away from owner), **Fig R2.4.3; Fig.R2.4.4**. For no group a significant reduction of duration of runs > 20 m could be demonstrated however, see **Fig. R2.4.5 - Fig. R2.4.7 Appendix**.

The variances between inbound and outbound distance travelled were also not significant either for individual dogs, **Fig.R2.5.2**, nor looking at Group 1, 2 and 3, see **Fig.R2.5.3; Fig.R2.5.4 Appendix**, thus the assessment of distance may be used as one cue for spatial navigation.

As path integration requires the measurement of two parameters: direction and distance, this could also be accomplished by some form of step-counting to estimate distances as has been reported for ants (Wittlinger et al., 2006), indicating a stride integrator function in distance measurement (pedometer). Perhaps the dogs employed a similar mechanism as the stride integrator, in that they were able to integrate some parameter associated with rhythmic leg movement in walking, namely, stride length and stride frequency. For the shortening of their inbound travel may be argued that it either brings them in proximity of a familiar environment which aids orientation, alternatively, having finished their exploration, the most energy saving behaviour is to return on the most direct and shortest route, indicating a cognitive change on the motivational focus shifting from exploration to returning to the owner, as may be shown by the faster return route, see **Table R2.6.1 Appendix; Fig.R2.6.1; Fig.R2.6.2 Appendix**. Fiset & Malenfant (2013) showed that if a linear trajectory exists between the dog's position and the position of a hidden object, the dog primarily uses egocentric cues, by assessing distance and direction of the vector that starts at the animal's position and points towards the target. This may be indicated by the similar distance of outbound and inbound travel, **Table R2.5.1 Appendix; Fig.R2.5.2 Appendix**.

Assuming that the dogs on their way away from the owner (outbound) were exploring the environment I expected them to explore longer distances and durations on their outbound compared to their inbound (back to their owner) routes. Furthermore, that they would be slower on their outbound exploration than on their inbound travel. Arguably on their return path the dogs' aim would be to return to their owner without further interruption shifting their attention from exploring to finding their owner. Applying the Zurich Model of Social Motivation by Bischof (1975, 1993, see Figure Zürcher Modell der sozialen Motivation, **Appendix**) which is used to predict processes of social distance regulations it may be argued for a shift from the autonomy to the security system and a switch in the arousal system from exploratory behavior to dependency behavior (see also Part 1, Attachment).

This can be shown timewise. A clear contrast could be observed between the inbound and outbound duration explored looking at all dogs. The time inbound was significantly shorter than the time outbound, see **Table R2.6.1 Appendix; Fig.R2.6.1; Fig.R2.6.2 Appendix**. Looking at Group 1, 2, and 3 inbound and outbound duration increased with ascending radius of the dogs, **Table R2.6.2; Fig.R2.6.3**. As there was no significant difference between the distance explored outbound and inbound see **Section R2.5**, but a significant difference with respect to the time travelled, see **Table R2.6.1 Appendix; Table R2.6.2; Fig. R2.6.3; Fig. R2.6.8** the speed of the dogs was additionally analyzed. Compared was the speed outbound, away from the owner, versus inbound, back to the owner. The speed on inbound travel was significantly higher than on outbound travel over all dogs, **Fig. R2.6.4; Fig. R2.6.7 Appendix; Table R2.6.3 Appendix** as well as for Group 1,2 and 3. In all three groups differences between inbound and outbound speed was observable and significant speed differences could be shown. Therefore, dogs travelled with higher speed and took less time on their inbound route, thus their return to their owner, even though the distance did not vary significantly, which indicates a motivational shift of attention. Thus distance explored may be a cue for spatial orientation. Even though on their outbound exploration the dogs focused on exploratory behavior (being relatively slow) they were cognitively able on their inbound route to find their owner with higher speed and thus in a shorter amount of time.

Whishaw et al. (2001) in their study showed that rats made periodic outward trips from a home base that were slow, circuitous, and marked by a number of stops, whereas their return trips were rapid and direct. Their locomotor behaviour consisted of movements at a number of speeds and Wishaw et al. (2001) proposed that the out-

ward and homeward PORTions of a rat's exploratory bout were mediated by different spatial navigational strategies, piloting and dead reckoning, respectively (Whishaw et al., 2001; Wallace et al., 2002a). Wishaw et al. (2001) fragmented the rat exploratory behaviour into two components: circuitous outward trips marked by stops, and more direct rapid returns to the home base (Whishaw et al., 2001; Wallace et al., 2002a). Dogs herein displayed similar behaviour; their outbound routes were slower, circuitous, and often marked by a number of stops, whereas their return trips were rapid and direct, see **Table R2.6.1 Appendix; Fig. R2.6.1; Fig. R2.6.2.**

Accordingly, on the outward PORTion of an exploratory trip, the animal may be learning about its piloting space, whereas the course for its return trip is set by computations derived from cues generated on the outward trip. Whishaw et al. (2001) proposal that the homeward trip was mediated by dead reckoning was confirmed by the persistence of direct rapid return trips under conditions in which visual cues were not available (Whishaw et al., 2001; Wallace et al., 2002a). Similar findings were made for mice by Gorny et al. (2002). In their analysis of mouse exploratory behaviour, the homeward velocity was noticeably faster than the locomotor PORTion of the outward trip, with direct homeward trips in both light and dark conditions. They argued that the return trips were mediated by dead reckoning (Gorny et al., 2002). In novel environments or environments in which allocentric cues (visual, auditory, or olfactory landmarks) may become unreliable, dead-reckoning based navigation could be particularly useful (Wallace et al., 2006). Arguably the dogs also utilized this strategy to return directly to the owner independent of visual-cue availability or environmental familiarity during their travelling behaviour, see **Table R2.6.2; Fig. R2.6.3; Fig. R2.6.3; Fig. R2.6.4,** in particular as the speed of their return route was significantly faster than on their outbound route, **Fig. R2.6.4; Fig. R2.6.7; Table R2.6.3 Appendix** which is analogous to the findings of Whishaw et al. (2001) and Gorny et al. (2002).

Whishaw et al. (2002) proposed that although the ability to use landmarks to navigate is advantageous, the dynamic and unpredictable nature of environments precludes a single strategy solution thus animals use a hierarchy of navigational strategies (see also, Maaswinkel & Whishaw, 1999). If the free-ranging dogs explored in familiar environments they may have relied on landmarks or relationships between landmarks to guide their movements. If the environment was novel or unfamiliar, i.e. landmarks were either absent or in conflict with previous experience; the dogs arguably also used self-movement cues to return to their owner.

2.4.2.5 Patterns and strategy use

Clearly not all of the seven patterns displayed needed advanced cognitive spatial navigation strategies or abilities (See **Part 1 M1.2.4; Figure M1.2.2** for pictogram).

When comparing the patterns, with 62 % most dogs displayed pattern 1: runs ahead/follows on runs > 20 m away from the owner, **Fig. R2.14.1**. (dog runs ahead on the path and waits briefly, two – four second segments, for the owner and/or establishes visual contact before continuing/following owner on the path). Therefore the dogs did not need any spatial orientation abilities as the pattern involved usually visual communication and information. The same applies to pattern 7: The dog runs parallel and meets owner. Even though most of the time the dog was out of range of visibility, data showed that the dog stayed parallel to the owner track, arguably being able to hear the owner movement, thus no advanced cognitive spatial abilities were required. Parallel runs to the owner were displayed n= 192; 9 % of the time, see **Fig. R2.14.1; Table R2.14.1 Appendix**. For individual dog patterns displayed, see **Fig. R2.14.2**.

Pattern 2 was the star pattern in which the dog displayed a exploration pattern similar to one arm of a star, thus the outbound route being fairly identical to the inbound route and the starting point being almost identical to the return point (therefore displaying a trace back or part trace back on return, and most of the time a point of return and accordingly an outbound and inbound route), see **Fig. M1.2.3**. The star pattern was displayed n= 589 runs; 19 % of the time, thus the dogs basically returned on the path they travelled out on. Using the star pattern the dogs would utilize the fairly simple strategy of retracing their own way. This could arguably be done by olfaction (if the dog was beyond visual contact) or through visual or auditory cues. However, even if the dog travelled ahead a few hundred meters, based on the high speed back I argue that olfaction was not used due to the overall high speed on the inbound route (olfaction being not necessary or implied, see discussion below). The same applies to pattern 6: a mixed form of runs ahead followed by a star pattern.

Pattern 3: Loop, a circular or semicircular pattern, thus a route which a dog did not retrace to return (therefore displaying a new return route, which however, does not necessarily mean direct return route and which may also be a “route of anticipation”). A point of return was established if the data indicated a decrease in speed and consecutive change of direction within a 2 sec segment to return to owner, in which case there also was an outbound and inbound route. A loop was displayed n= 291; 9 % of the time and the mixed forms together n= 95 runs; 3 % of the time. Pattern 4 was a loop and star pat-

tern and pattern 5 a mixed form of runs ahead & loops. All loop forms require arguably a more specialized form of spatial orientation (in particular with respect to the far ranging dogs) as they did not retrace their own outbound route, were out of range of visibility and often displayed a direct, new and shorter route back to the owner.

If the dogs explored in familiar environments they may have relied on landmarks or relationships between landmarks to guide their movements. If the environment was novel or unfamiliar, and known landmarks were absent, the dogs arguably used self-movement (egocentric) cues like distance or time to return to their owner. This may be indicated by the similar distance of outbound and inbound travel, **Table R2.5.1 Appendix; Fig. R2.5.2 Appendix**. Looking at the time and speed a significant difference could be observed between the duration of inbound and outbound travel, **Fig. R2.6.1**. Inbound duration was significantly shorter, **Table R2.6.1 Appendix** increasing with ascending radius of the dogs, indicating a motivational and cognitive shift from exploration behaviour to directly returning to their owner, a goal orientated movement without further disruption. Furthermore, the speed on inbound travel was significantly higher than on outbound travel, **Fig. R2.6.4 Appendix**. In all three groups differences between inbound and outbound speed was observable, **Fig. R2.6.5 Appendix**, dogs travelled significantly faster on their return route back to their owner, which is in accordance with Wishaw et al. (2001); Wallace et al. (2002a), and Gorny et al. (2002) and the Zurich Model of Social Motivation by Bischof (1993). Age, breed and size of the dogs were not pertinent (see, **Section 2.11; 2.12**).

Looking at the individual dogs, great exploration and pattern use differences could be observed, **Fig. R2.14.2** and a hierarchical Cluster analysis were applied. **Table R2.14.4; Fig. R2.14.4** shows the distribution of patterns between Groups 1, 2, 3 and the exploration patterns of each Group. **Table R2.14.5** illustrates the Groups and Cluster values. It could be demonstrated that dogs belonging to the different radius groups (Group 1, 2 and 3) had different distribution patterns: dogs with a low maximal distance away from their owner could be characterized by Cluster 2 (nearly no runs away from owner) or Cluster 3 (high frequency of runs forward/backward and waits) whereas dogs with a radius >350 m were overrepresented in Cluster 1 and underrepresented in Cluster 3 thus characterized by occurrence of star and loop patterns and a medium number of runs ahead waits/follows, **Table R2.14.6**. 14 dogs displayed a change in pattern cluster, 16 had constant pattern clusters for all four walks. Seven dogs (23 %) changed Cluster depending on new or known area, see e.g. Arthur Cluster 3 in unknown

area and Cluster 1 in known area, running ahead and following in new areas (82 %) and exploring with very different patterns in known areas (runs ahead/follows 29 %; star 35 %, loop 16 %), **Table R2.14.4**. A change of cluster group based on area may indicate a different orientation strategy, in particular if the dogs displayed more “advanced” patterns with loops and stars in known areas versus running ahead and waiting in unknown areas. It may also indicate recognition of landmarks thus the use of an allocentric strategy.

2.4.2.6 Olfaction and exploration patterns

When I questioned owners prior to the trials how they thought their dog would find its way back the majority expected the dog to trace back its route through olfaction and return to the starting point of its exploration (see owner questionnaire).

Polgar et al. (2015) proposed that dogs rely primarily on visual, social, cognitive, and spatial cues rather than olfactory ones and that a variety of factors influence what strategy a dog decides to use. They predicted a “win-stay” strategy, whereby the dog returns to an area where it was previously successful, which was not the case in their or my study. Dogs did not return to a previous owner location first. Polgar et al. (2015) examined the strategies pet dogs use in two types of olfaction-based problems as well as their success at various distances. Results suggest that despite their ability to successfully collect information through olfaction, pet dogs often prioritize other strategies. Thus, many untrained pet dogs, like the ones used herein, seemed to first focus on solutions based on other sensory cues before using olfaction, in particular vision. Szetei et al. (2003) similarly proposed that dogs rely primarily on visual, social, cognitive, and spatial cues rather than olfactory ones, which is in accordance with the theories postulated by Bekoff (1998), Reid (2009), Topál et al. (2005), Miklósi (2007) and Horn et al. (2013). Furthermore, several experiments demonstrated that olfactory clues were not mediating behaviour during dead reckoning (Mittelstaedt & Mittelstaedt, 1980; Wishaw et al., 2001a) and that odour tracking and dead reckoning were associated with qualitatively different movements (Wallace et al., 2002a; Wallace & Whishaw, 2003). Wallace et al. (2002) found that rats trained to track odour trails moved slowly and made many lateral head movements (Wallace et al., 2002a; Wallace & Whishaw, 2003). These findings are analogous to those of Thesen et al. (1993) who proposed three stages of olfaction for dogs, which would be inhibited or precluded by the fast movement displayed by the

dogs on their return path. The video material also indicated that dogs primarily utilized visual cues to find their owner and not olfactory ones.

2.4.2.7 Orientation, learning and memory

At the simplest level, spatial memory may be used to answer the question ‘have I been here before?’ (e.g. Dalziel et al., 2008). When this memory is coupled with a temporal attribute the much more complex question of ‘when was I last at a particular location that is not my current location?’ may be answered, which requires memorization of the spatial and temporal relations between the individual and multiple goals e.g. the owner and different landmarks (Van Moorter et al., 2009). Arguably this spatial memory reproduction was displayed by the seven dogs (23 %) that changed Cluster depending on new or known area, **Table R2.14.4** A spatially linked attribute memory may be used to answer questions ranging in complexity from ‘what do I remember about my current location?’ to ‘which is the least-cost path to return to my owner?’ as can be seen by the Group 3 and Cluster 1 dogs by e.g. displaying the shortest return route to their owner, see **Fig. R2.14.2; Table R2.14.6; Fig. R2.14.4**.

One challenge was the incomplete knowledge about the dog’s information status at the beginning of the study. The owner questionnaire gave some information regarding the “normal” walk and exploration structure of the owner-dog team, but learning and life history could not be assessed. Therefore walks took place in different areas with two novel environments where the dogs had no previous knowledge, thus memory of landmarks etc. Here in particular the Group 2 and 3 dogs did display a change of cluster indicating a different strategy depending on area – first of all a tendency to explore shorter distances and time and secondly some “safer” strategies (running back and forth/star pattern/running parallel) in unknown areas compared to known (loops, loop and star patterns) areas.

Memory is one of many cognitive and information-use processes that affects movement and navigation. One aspect of orientation is the combination of cognitive and movement capacities: the inference of memory use from movement patterns and reversely, the role of movement in shaping memory (Fagan et al., 2013). An animal’s navigation and motion capacity determines its movement relative to external and internal factors (Nathan et al., 2008). The integration of information acquisition (learning) and its retention (memory) is essential for the development of individual movement behaviors and patterns (Fagan et al., 2013). Most studies of dogs’ movement and memory re-

lied on manipulative experiments in fixed arenas (Duranton et al., 2019; Duranton et al., 2017; Scandurra et al., 2018; Fugazza et al., 2017) and the use of GPS tracking technologies herein provided more differentiated movement data from individual dogs in a more natural setting. Cognitive processes, such as sensory perception and memory, are arguably more important within an open and natural environment. Again the importance of an owner providing learning opportunities for his dog(s) in order to establish memories cannot be overestimated.

Memory encompasses the acquisition, encoding, storage and retrieval of information (Baddeley, 2004). Memory acquisition may be genetic (e.g. inherited genetic triggers for migration, inherited avoidance of a predator) or through experience or social communication through conspecifics (see also discussion dog dyads/triads below) (Fagan et al., 2013). Encoding and storage refer to the processing of acquired information, including information reduction and consolidation (Craik & Lockhart, 1972). Retrieval of memorized information is context-dependent e.g. using past experiences for decision making processes and subsequent behaviors, again implicating owner provisions. Thus within this context dogs would have been in similar contexts before (free-ranging) to collect information (past experiences) to establish subsequent exploration patterns.

Two types of memory are usually distinguished: spatial memory which encodes spatial relationships and attribute memory encoding attributes of local features. The spatial information gained give an animal information about its position (e.g. distance and direction) with respect to geographical objects/locations (Fagan et al., 2013) and may include sensory characteristics of a specific location (e.g. the geomagnetic field intensity) as well as the speed and direction of current and past movements. Attribute information confer data with regard to location-independent object characteristics, e.g., the time since a location was last visited (Van Moorter et al., 2009) and may affect the accuracy, precision and persistence of the memory in that a valuable resource/area may be memorized longer than locations with neutral attributes (Wolf et al., 2009). Thus the owner location may be of higher valence than other environmental attributes therefore being prioritized in memory retention.

Duranton et al. (2017) found that dogs remember who and what happened but not the precise time it was done. Fugazza et al. (2016) proposed that dogs recall past events, providing evidence for episodic-like memory, with a decrease of retention over time (1hour), however.

Memory, both memory storage, memory interference as well as encoding and retrieving memories incurs energetic costs (Burns et al., 2011). As memory volume increases, the likelihood that different memories will interact grows and memory interference can occur when new memories vitiating the accuracy of old memories (known as retroactive interference) or if old memories prevent the accurate acquisition of new memories (known as proactive interference) (Bouton, 1993). Therefore memories must be prioritized based on their importance to the life history and the reliability of the information (Burns et al., 2011) and thus dogs must early on have exploration opportunities to collect and store information and by the by prioritize them as the memory storage increases, here arguably the (varying) owner location but of course also successful exploration strategies.

In young animals spatial information is first used to encode egocentric spatial memory and subsequently allocentric memory (Fagan et al., 2013) and encoding memories requires learning periods (Dukas, 2009) which occur via social or cultural transmission. Furthermore capacity, duration and precision of memory are important because memories will deteriorate unless reinforced and maintained (use it or lose it). Thus memory should be particularly valuable in landscapes of intermediate complexity like the ones herein, where remembering several locations and their attributes would be sufficient to accrue benefits (like finding and returning to the owner) through efficient navigation or timely returns as displayed by the dogs herein.

Cognitive mapping is a series of transformations for the acquisition, coding, storing, recalling and decoding of spatial information in order to retain information in memory (Fagan et al., 2013). Besides simpler forms like path integration, some animals are able to establish more complex representations of their worlds (Bingman & Cheng, 2005). Three memory based mechanisms have been proposed (which can be combined or used at the same time) to move towards a specific goal: beacon/gradient-based navigation, location-based navigation (both of which depend on landscape features), and landscape-independent route-based navigation (Fagan et al., 2013).

In beacon-based navigation animals memorize the perceptual (e.g. olfactory) signature of one or more beacons and then move from beacon to beacon (connect the dots so to speak). Gradient-based navigation is somewhat similar, but here the goal location (e.g. the owner) is memorized with respect to stimuli continuously varying in space (gradient fields) rather than isolated objects/beacons. Location-based navigation is based on goal memories established through the spatial relationships between the goal

location and landmarks. In route-based navigation an animal memorizes its position relative to its starting point to which it is seeking to return using path integration (for instance the star pattern) and requires the ability to estimate the direction of movement (e.g. compass-based, relying on the earth's magnetic field) and distance. High movement precision and low navigational variance may also be strong indicators of memory-guided movement processes, such as homing (Hagstrom, 2013).

With respect to spatial orientation and exploration patterns herein the Group 3 dogs are of most interest. Clearly the other groups may be discussed within a different framework: their learning limitation in acquiring strategies and decision making processes. As most pet dogs are inhibited or prohibited from free exploration they have no need to learn and memorize strategies for longer explorations – of course thereby opportunities to explore and thus memorize are constrained, limiting cognitive processes (in addition to psychological processes see Part 1). Arguably the far ranging Group 3 dogs used location-based navigation in assessing the spatial relationship between the owner location and landmarks in known areas as well as gradient-based navigation in that the goal location (the owner) was memorized with respect to stimuli continuously varying in space.

Once return points (POR) and inbound route had been identified, the dogs memory could be analyzed in a time-dependent fashion indicating the prevalence of least-cost paths between return points beyond sensory range (Asensio et al., 2011) and the goal (the owner). Thus the faster and shorter inbound route may indicate memory processes. Similarly, memory may be expressed as return routes became increasingly direct as the dog gained experience providing thereby evidence of memory in movement processes (e.g. Papastamatiou et al., 2011), which would apply in known areas.

One qualitatively different indicator of memory is the emergence of 'systematic' searches in movement pathways (Fagan et al., 2013). For example, a dog relying on systematic searches could adjust its search radius based on previous information of the spatial location of a movement target like the owner (assuming the owner moves at consistent, previously learned speed). Systematic searches require memory because animals must remember and avoid searching in previously visited areas (e.g. Fronhofer et al., 2013). For humans it has been shown that exercise training increases the size of the hippocampus and improves memory (Erickson et al., 2011) which probably hold true for dogs as well.

Gaunet & Besse (2019) studied guide dogs on four navigational tasks: reproducing a previously travelled path and performing a return trip (homing) along a previously travelled path (simple memory of places) and found that few dogs were able to reproduce the path (30.43 %) or manage the return trip (43.47 %) for paths of 300 - 400 m distance, even though trained for it. As pertains to our finding “reproducing” a path would apply to the freely exploring dogs herein that travelled a star pattern, thereby returning to their starting point, which by definition is part of homing. As can be seen in **Fig. R2.14.1** 19 % of the dogs on runs >20 m displayed the exploration pattern star. It also has to be kept in mind that the dogs in this study were not “trained” for the tasks but I rather relied on prior learning and attachment in order for them to return to their owner. It also has to be kept in mind however, that the majority of freely exploring dogs herein did not explore beyond the radius of 350 m away from the owner.

What could be noted in this study is that dogs preferentially followed given trails i.e. game trails, roads, fencelines etc. and repeatedly used the same travel corridors, generally not exploring straight through bush and vegetation. This preference of using other animals’ tracks (or human roads) has also been observed in other species (Muhly et al., 2011) as it generally simplifies travelling movement and saves energy. In addition escape trajectories of prey might have to be taken into account, as prey may have a preferred flight direction (Obleser et al., 2016).

Gaunet & Besse (2019) also found that most dogs detoured to the south (20/23) which would be similar to findings herein, where most dogs used a north-south point of return for orientation, and further that egocentric encoding strategies were used for short paths but not for longer ones, suggesting segmented integration of the path’s characteristics. They also postulated that age (between 1 and 10 years old) of the dogs was not correlated to wayfinding abilities and further that dogs that regularly experienced new journeys performed better showing an effect of earlier navigational experiences.

2.4.3 Sex and reproductive status

2.4.3.1 Male versus female dog orientation differences

Sex differences have been postulated with respect to spatial orientation (Mongillo et al., 2017; Scandurra et al., 2018; Shah et al., 2013) and socio-ecological advantages for males’ in solving spatial navigation tasks have been proposed, which in most cases encompasses an extended home range compared to females.

Results herein are in accordance with expected socioecological differences. Male dogs explored further possibly because of a relevant function in reproduction (Shah et al., 2013), being linked to the competition for mates, which often requires a larger territory and further ranging patterns (Pal et al., 1998) whereas the females' major involvement in reproduction may have favored a superior spatial sense in more limited areas which in nature may be closer to their den (Herman & Wallen, 2007) and herein, closer to the owner.

Molloy et al. (2017) postulated that intact males roamed more than neutered females and neutered male dogs also travelled more per day than intact female dogs. In agreement with Molloy et al. (2017), the total distance of runs >20 m herein was highest for male dogs, with the neutered male dogs displaying the longest distance followed by the intact male dogs. No difference between spayed and intact dogs could be seen within the female group. Intact and neutered male dogs explored significantly further than female dogs (**Table R2.7.2**). Sparkes et al. (2014) also found a significant effect for sex in free roaming domestic dogs; male dogs utilised larger areas than females while there was no effect of reproductive state on the area traversed (see also Dürr et al., 2017).

Furthermore the duration of runs >20 m was also longer in male than in female dogs, **Table R2.7.3**. Female and male dogs displayed different behavior in exploration duration and distance: Neutered male dogs demonstrated over all higher distance and higher travelling time away from their owner than intact male dogs. Female neutered dogs however travelled equivalent distances and exhibited less travelling time than intact female dogs. In accordance with Sparkes et al. (2014) and Dürr et al. (2017) no significant effect of reproductive status was found either in duration or distance travelled on runs >20 m away from the owner, **Table R2.10.2; Table R2.10.3**. Looking at the groups this also became apparent: Group 1 consisted of nine females (three intact/six spayed) and four males (three neutered/ one intact), Group 2 of six females (one intact/five spayed) and two males (one intact one neutered) whereas Group 3 included only three females (two neutered; one intact) but six males (one intact; five neutered), **Table R2.2.1**. Thus the far ranging group was dominated by male dogs.

A tendency to explore longer distances and duration on runs >20 m could be observed, in particular in the far ranging male dominated Group 3 dogs in known areas, indicating a use of allocentric cues like landmarks, **Fig. R2.7.3; Table R2.2.1**. Furthermore, using the magnetic field as an allocentric cue to calibrate their internal compass, as displayed by the point of return, results do indicate a difference between male and

female dogs, in that male dogs exhibited a significant point of return in North-South direction, whereas female dogs did not, **Table R2.17.1**.

Dogs may have additionally integrated spatial signals during locomotion by continuously updating information on the distance from and direction to the (always moving) owner, through path integration (Cattet & Etienne, 2004) which however, by definition would imply that the dogs would return to their starting point i.e. displaying the patterns of star or running ahead and back, **Fig. R2.14.1**. Differences could be observed looking at the displayed exploration patterns between intact male and female dogs in that intact female dogs demonstrated more often the travelling pattern of running ahead and waiting or following the owner compared to male dogs and the male intact dogs displaying more often the star and loop pattern indicating a greater use of allocentric cues. The spayed females and neutered male dogs showed fairly identical exploration patterns.

Dogs are able to switch navigational strategies (Gaunet & Besse, 2019), Fugazza et al. (2017) however, found that male dogs switched from the preferred (allocentric) to non-preferred (egocentric) strategy in fewer trials than females, which may be indicated by the higher percentage of loop patterns displayed by the intact male dogs herein.

It has been suggested that female dogs are more social in interspecific interactions (Persson et al., 2015; Wilsson & Sundgren, 1997) which may be an additional factor for female dogs staying closer to the owner (but see, Asp et al., 2015; Strandberg et al., 2005) than male dogs. Furthermore it has been argued that male dogs are bolder, thus more proactive and explorative than female dogs (Scandurra et al., 2018) indicating a potential to explore further or longer. Kubinyi et al., (2009) held that boldness was also age-dependent, with young male dogs scoring higher than older or female dogs and intact males being the boldest group, spayed females being the least bold. Herein, the total distance of runs >20 m was also highest for male dogs, with the neutered male dogs displaying the longest distance followed by the intact male dogs. No difference between spayed and intact dogs could be found within the female group. The longest duration explored of runs > 20 m was shown by the neutered male dogs, followed by the intact male dogs, the intact female and lastly the neutered females, **Table R2.10.3**.

Hudson et al. (2017; 2019) in their recent studies identified three roaming patterns in free roaming dogs, based on changes in mean home range of each dog. What they called "Stay-at-home dogs" consolidated their home range around their owner's residence. "Roamer dogs" consolidated their core home range but their extended home range increased with longer monitoring durations, suggesting that their roaming pat-

terns were more variable. “Explorer dogs” demonstrated large variability in their roaming patterns, with both core and extended home range increasing.

As the dogs herein also displayed great intraspecific differences I had differentiated three groups (maximum distances of runs > 20 m away from owner. Group 1: >150 m; Group 2: < 150 m, > 350 m; Group 3: < 350 m) to assess data in more detail. Findings herein are comparable to Hudson et al. (2019) in that the pet dogs exhibited similar exploration behavior as free ranging dogs, with Group 1 dogs staying close to their owner <150 m; Group 2 dogs displaying more variability and Group 3 dog demonstrating the largest distance explored and the greatest variability of exploration patterns. **Fig. R2.14.4.** The variability of exploration patterns was furthermore specified through clustering: exploration patterns belonging to Cluster 3 were dominated by a large number of the pattern runs ahead waits/follows and very little variability in exploration patterns. Cluster 2 indicated a low total number of runs, the most frequent pattern being loop and star; and Cluster 1 was mainly characterized by the patterns runs ahead waits/follows, followed by star, loop and also parallel runs and mixed forms (**Fig. R2.14.3**). Thus it could be demonstrated that dogs belonging to the different radius groups (Group 1, 2 and 3) have different distribution patterns: dogs with a low maximal distance away from their owner could be characterized by Cluster 2 (nearly no runs away from owner) or Cluster 3 (high frequency of runs forward/backward and waits) whereas dogs with a radius >350 m were overrepresented in Cluster 1 and underrepresented in Cluster 3 thus characterized by occurrence of star and loop patterns. Therefore, the further and longer the dogs explored the more differentiated the patterns they utilized indicating behavioral and cognitive differences. 14 dogs (six females – three intact, three neutered/eight males – three intact, five neutered) displayed a change in pattern cluster, 16 had constant pattern clusters for all four walks, here in particular female dogs (n=12) and four neutered males, indicating no change in navigational strategy. All intact male dogs displayed a change of cluster pattern. Seven dogs changed Cluster depending on new or known area.

Interestingly, the majority of dogs never explored further than 350 m away from the owner, which is in accordance with findings of Dürr et al. (2017) where the majority of (free-roaming) dogs did not travel further than 250 m in diameter from their owner’s house, with age not being a significant predictor of home range size. Thus, when given the option to explore freely and not being in an enclosed laboratory setting domestic pet dogs display behavior similar to free roaming dogs.

2.4.3.2 Neutered versus intact dogs orientation differences

Different performances in spatial navigation have also been proposed between intact and spayed/neutered dogs (Scandurra et al., 2018). Sexual hormones have been suggested as physiological factors for sex differences in spatial navigation (Isgor & Sengelaub, 1998; Sneider et al., 2015). It has further been postulated that castration adversely affects working memory (but not reference memory) during navigational processes (Gibbs & Johnson, 2008; Locklear & Kritzer, 2014).

As studies postulated differences in regard to spatial orientation between neutered/spayed and intact dogs (Mongillo et al., 2017; Scandurra et al., 2018) I analyzed the distance and duration of runs >20 m with respect to reproductive status. Differences in distance travelled between neutered and intact dogs could be observed, these were not significant however, **Table R2.9.1**. Likewise the duration travelled of runs >20 m was larger for intact dogs (18 +/- 21 min.) than for neutered dogs (16 +/- 15 min.). The time difference between neutered and intact dogs was not significant, **Table R2.10.1**. What could be observed, analyzing the point of return, (indicating the use of the magnetic field as an allocentric cue) was a difference between intact and spayed/neutered dogs: neutered male and spayed female dogs utilized the allocentric cue of the magnetic field significantly in North-South direction, **Table R2.17.1**, whereas intact dogs did not. Arguably the neutered dogs utilized a North-South point of return to calibrate their compass and establish a cognitive map in order to find back to an always varying location, i.e. their owner. Studies have proposed that castration adversely affects working memory during navigation (Gibbs & Johnson, 2008; Locklear & Kritzer, 2014), herein however, all dogs irrespective of reproductive status consistently found their owner in varying location and no significant differences were found with respect to the exploration patterns based on reproductive status.

Of the n=12 males three were intact and nine neutered. The intact male dogs had a high number of runs >20 m (n=651) for three dogs. The median distance of total runs >20 m was almost identical between intact and neutered males and no difference could be observed in duration of runs >20m, **Table R2.10.3**. This may indicate that the intact male dogs travelled faster than the neutered male dogs as they covered longer distances in the same amount of time. Garde et al. (2016) also found no change in home range size in any groups between the pre- and post-intervention measurement of chemically sterilized or surgically castrated male dogs. Again, great inter-individual differences could be perceived when looking at the individual dogs and the duration of their runs >20 m.

Here in particular the neutered Group 3 dogs displayed extensive duration of runs >20 m. Neutered male dogs showed over all higher distance and higher travelling time away from their owner than intact male dogs.

It has been proposed that gonadectomy affects spatial learning in females (Mongillo et al., 2017; Scandurra et al., 2018b) and I further analyzed whether the time and distance explored on runs >20 m between spayed and intact female dogs differed. Out of n=18 females five were intact and 13 spayed; the spayed females had 1181 total runs >20 m with a mean of 1862+/-1905 m compared to the intact females with 479 runs >20 m and a mean of 1861+/-1250 m. The spayed females explored further (median 7842 m) compared to the intact females (median 4890 m), but the intact female dogs explored longer, **Table R2.10.3**. The differences displayed between intact and spayed females were not significant however.

Mongillo et al. (2017) postulated that ovariectomized females performed significantly worse than intact females in spatial learning tasks; Scandurra et al. (2019) found similarly a negative effect of gonadectomy in females including their socio-cognitive abilities, inducing a reduced level of attention to the owner. Thus one would expect them to perform worse compared to intact females, one indication being that they would either not find their owner or fewer times than intact females. This is not in accordance with results herein: All females whether intact or spayed found their owner on all runs. Secondly, if spatial learning is affected in spayed females, it could be expected that they explored shorter distances away from the owner, i.e. that most of the spayed females would be in Group 1. Looking at **Table R2.2.1** however, only six spayed females were in Group 1 and seven in Group 2 and 3, whereas from the intact females three out of five were in Group 1. Thirdly, one would expect that spayed females, due to impaired cognitive skills would utilize "simpler" exploration strategies, i.e. preferably running ahead and waiting/following the owner or at most a star travelling pattern or running parallel: spayed females displayed 61 % runs ahead/ waits compared to 77 % of the intact females, with the star pattern being utilized 20 % of the runs (intact females 13 %).

It has further been proposed that spayed females are significantly more anxious and nervous than intact ones (Lorenz et al., 2019) and display the lowest level of boldness as compared to intact females and intact/neutered male dogs (Kubinyi et al., 2009; but see Gfrerera et al., 2019). Fearfulness would impact on exploration behavior and favour neophobia and one would expect fearful dogs, i.e. spayed female dogs to explore less and stay closer to the owner.

Herein the spayed females had a higher number of runs >20 m, the intact females fewer but longer runs >20 m, however, three out of five intact females were in Group 1, dogs with the least exploration distance away from the owner (<150 m) and displaying the least variability in exploration patterns (Cluster 3) indicating they neither explored very far nor did they utilize variable strategies or exhibit a change from egocentric to allocentric spatial orientation depending on area, **Table R2.14.4**. Great intraspecific variability could be denoted and spayed females could be found in all three Groups and Clusters, showing longer runs and greater variability with respect to exploration patterns than the intact females indicating a switch from egocentric to allocentric orientation strategies. Thus reproductive status does not reflect different strategies or travelling patterns of the male and female dogs and results herein are not in concurrence with Kubinyi et al. (2009), Lorenz et al. (2019), Mongillo et al. (2017) and Scandurra et al. (2019, 2018). Spatial orientation is multifaceted and diverse components should be considered to assess spatial and cognitive performance of the dogs: small-scale and large-scale conditions must be distinguished. Most studies cited herein involve small scale conditions (see e.g. Akos et al., 2014; Duranton et al., 2019; Fugazza et al., 2017; Scandurra et al., 2018) and results are therefore limited in application. Looking at studies of free roaming dogs (Hudson et al., 2017; 2019) similarities in exploration patterns can be observed.

Pertaining to characteristics like fearfulness or boldness, studies show that the use of training methods in particular punishment and/or confrontational or aversive to be associated with anxiety (Arhant et al., 2010; Blackwell et al., 2008); the influence of owner personality and attachment (Dodman et al., 2018); the impact of the timing of castration (McGreevy et al., 2018); and the dogs living style (Corrieri et al., 2018). Therefore caution with regard to assuming a causal association between castration and behaviors as well as socio-cognitive skills is important. No single factor is responsible for e.g. the fearful thus reduced exploratory behavior of dogs but instead there are multiple environmental and genetic factors that contribute to this behavior. The effect of the owner-dog relationship in shaping dogs' personalities and behavior may be an overriding factor and should be applied to all sex-related variables. Literature supports the view that multiple factors influence cognitive behavior, regardless of a dog's reproductive status (Corrieri et al., 2018; Dodman et al., 2018; McKenzie, 2010). Additionally, in reference to Hudson et al. (2017; 2019) domestic pet dogs display analogous behavior to free roaming dogs when given the option to explore freely, further implicating limitations of laboratory studies.

2.4.4 Exploration and neophobia

Exploration is important for dogs to be able to gather information about their environment (Moretti et al., 2015) and confers important benefits as dogs may develop motor skills and engage in novel behavior patterns that may lead to innovative orientation strategies (Power, 2000). Intrinsic motivation, curiosity and learning influence exploration. A preference for novelty (neophilia) has been linked to the neurophysiology of temperament traits associated with behavioral activation, extraversion and persistence (Depue & Collins, 1999; Rao et al., 2018). It might be an adaptive consequence of selection during domestication for animals living in association with humans (Rao et al., 2018; Sheppard & Mills, 2002), since neophilia has been connected with an increased tendency to approach novel environments and more innovative behavior, and dogs might be naturally predisposed towards neophilia (Kaulfuß & Mills, 2008).

To gather knowledge, a dog may explore its environment alone, by social learning through conspecifics (Day et al., 1998) or by using public information (Valone & Templeton, 2002). Depending on an animal's motivation the environment may be investigated with different latencies and for variable periods which may also be influenced by the social context, like a second dog (Day et al., 2003; Rao et al., 2018; Stöwe et al., 2006). Studies proposed that dogs are less cooperative than wolves within groups of conspecifics (Range et al., 2018), and thus that with novel objects, potentially perceived as a source of danger, wolves might rely more on support from conspecifics than dogs (Moretti et al., 2015; Rao et al., 2018).

On the other hand, the presence of a familiar conspecific, the second dog, has been shown to be more effective alleviating stress responses (Kiyokawa et al., 2014). Therefore, in potentially stressful situations, as when confronted with a novel object or area, the presence of a conspecific might be a valuable resource reducing potential stress, which would lead to the expectation that familiar dogs would explore together, see **Table R2.16.1.1**; **Fig R2.16.2.2**; **Fig R2.16.1.3**. Significant linear correlations could be shown between the duration of the travelling round, difference in walking time (owner/dog), and time inbound and time outbound for most teams. The correlations were positive, i.e. the longer one dog of an owner travelled, the longer the second dog of the owner travelled, **Table R1.4.1.1** and high values of one dog were correlated with high values of the other dog(s). In most teams a leader or independent dog with a more extensive time range could be observed, see **Fig. R1.4.1.1 - R1.4.1.5**. This also applied to the distance travelled, **Fig. R1.4.2.1 - Fig. R1.4.2.5**, again indicating one lead-

ing/initiating dog. Significant linear correlations for all distance measures could be found between two/three dogs of one owner, see **Fig. R1.4.2.1 - Fig. R1.4.2.5**.

Kaulfuß & Mills (2008) proposed that neophilia is an adaptive consequence of selection in dogs by living in association with humans, which then may decrease the dependency on a group in their exploration of novel objects/areas (see also, Rao et al., 2018). Moretti et al. (2015) found that the presence of a conspecific facilitated the manipulation of novel objects longer, however, they also stated that dogs not approaching a novel object often indicated less interest by the dogs (as compared to wolves) rather than neophobia.

The experience of novelty through exploration enhances learning and memory retention with a positive feedback loop between curiosity, learning and active navigation, compared to passive viewing during encoding, resulting in a higher accuracy in spatial memory (Oudeyer et al., 2016). Thus dogs that are given the opportunity to explore may be more curious about and interested in their environment thereby learning about and memorizing environmental factors (exploration may of course also be modulated by affect and motivational states). Exploration enables the dog to discover new conditions, potential rewards or threats. Memory enhancements were found in response to novelty (Otmakhova et al., 2013), and exploration of novel environments resembles behavioral responses to reward eliciting approach, behavioral activation, and mesolimbic dopaminergic system activity (Alcaro et al., 2007). It has been proposed that, from an evolutionary perspective, novelty may hold inherent reward value (Krebs et al., 2009). However, exploratory responses to novelty only occur under conditions of expected reward and safety. Threat or negative experiences, on the other hand, are linked with reduced exploration (Hughes, 2007), and fleeing behaviors (Blanchard, 1997) and novelty may actually be aversive because of the uncertain potential for negative outcomes—i.e., “fear of the unknown” (Carleton, 2016). Dogs which have been restricted in their exploration behavior by either being consistently called back (or even being punished) or not having had the option to explore at all (being on the leash for instance) may therefore display an increased fear of the unknown and thus explore less and stay closer to the owner, for group differences, see **Table R1.2.1**, independent of sex, age, breed and reproductive status. Lifetime experience may also play a significant role in the behavior of individuals (Udell et al., 2014). Furthermore, owner attitudes and behaviors have been shown to influence exploratory behavior in dogs (Huber et al., 2017; O’Farrell, 1997), and dog and owner scores on the personality dimension of neuroticism were correlated (Turcsán et al.,

2012), owner neuroticism also being linked to the level of attachment to the dog and to the dog staying close to the owner and being more reserved toward others (Kotrschal et al., 2009, Schöberl et al., 2017; Wedl et al., 2010) which, of course, would also impact on the level of exploration, see **Table R2.14.5; Fig. R2.14.2.**

According to the risk-reward hypothesis (Svartberg et al., 2002), boldness makes individuals more proactive and explorative, which offers greater potential to gather resources; at the same time, it enforces more risks. Shyer individuals take fewer risks; however, they lose opportunities for foraging and mating, thereby reducing fitness. In dogs, boldness is described as an individual characteristic providing less aversion to risk or novelty that enables them to actively seek out and engage in social interactions (at both cooperative and competitive levels), as well as toward non-social objects or events (Svartberg et al., 2002, 2005), and boldness differs between breeds (Starling et al., 2013; Turcsán et al., 2011), which may also be demonstrated by the different travelling groups, see **Table R1.2.1; Table R1.2.2; Table R2.14.1; Fig. R2.14.2.** One of the main components to consider when defining boldness seems to be the level of neophobia. Kubinyi et al. (2009) argued that boldness was age-dependent, with younger male dogs (younger than two years) scoring higher on the boldness factor scale than older dogs or female dogs. Herein the variance between female and male dogs with respect to the distance travelled of runs >20 m was significant. Male dogs travelled significantly longer distances on their exploratory runs > 20 m than females, **Fig. R2.7.1; Table R2.7.1; Fig. R2.7.5** and male dogs travelled significantly longer times on their exploratory runs > 20 m than female dogs see **Fig. R2.8.1; Table R2.8.1; Fig. R2.8.2** which arguably may indicate a higher level of boldness in male dogs.

It has been maintained that to solve ecological and social problems successfully several psychological propensities (referred to as the ‘correlates of problem-solving success’) are required (Rao et al., 2018): neophobia, motor diversity, flexibility (the repertoire of problem-solving behaviors an animal displays, and its ability to find novel solutions to already known problems, or use known solutions to solve novel problems) and persistence (defined as task directed motivation and quantified as the amount of time an animal spends tackling a task) (Rao et al., 2018). These correlates are interconnected: behavioral flexibility is positively correlated with persistence and both are negatively correlated with neophobia (Rao et al., 2018). Furthermore the animal’s personality influences its problem-solving styles (Sih & Del Giudice, 2012) in that a reactive behavioral type is associated with slower, less exploratory behavior and less persistence, while a

proactive behavioral type is associated with faster exploratory behavior and more persistence (Sih & Del Giudice, 2012). Differences in life experience have been shown to affect problem-solving in dogs (Marshall-Pescini et al., 2008). Studies have also demonstrated a linkage between learning, memory, exploratory behaviors and genetics (Puurunen et al., 2018; Shin et al., 2016), and breed differences (reaction to social threat; reaction to novel objects, fear of strangers and of new situations) have been proposed (Cimarelli et al., 2019 Border Collies vs. other breeds; Sarviaho et al., 2019 German shepherds; Tiira et al., 2016 German shepherd/Great Dane/Lagotto Romagnolo/Saluki; Turcsán et al., 2018, Border Collies). Herein no differences could be found for breeds represented by multiple dogs, see **Table R2.14.2**, **Table R2.14.3** and **Fig. R2.14.1**.

Studies found that animals that spend longer engaged in a task also tended to utilize a greater variety of behaviors (Johnson-Ulrich & Holekamp, 2018), which may be reflected in that Group 3 dogs also utilized the most varied exploration strategies, see **Table R2.14.1**; **Fig. R2.14.1**; **Fig. R2.14.2**; **Table R2.14.2**; **Table R2.14.4**; **Fig. R2.14.4**.

Fearfulness, thus an inhibitor of exploration, has also been linked to genetics. Puurunen et al. (2018) found nine metabolic features associated with fearfulness across breeds, Zapata et al. (2016) two distinct genomewide association loci which were associated with several traits, including fear and aggression. Sarviaho et al. (2019) identified novel loci for fearfulness on chromosomes 20 and 7, respectively, loci overlap genomic regions that include candidate genes affecting glutamatergic and dopaminergic neurotransmission.

However, even if breed-specific genetic predispositions (e.g. Sarviaho et al., 2019, fearfulness in German shepherd; Tiira et al., 2016, Lagotto Romagnolo; Turcsán et al., 2018, Border Collies) account for some of the variability seen between dogs exploration performance, lifetime experience, physical attributes and other biological or psychological variables probably function to compound this effect (Udell et al., 2010a). Environmental factors such as lack of socialization, poor maternal care (Foyer et al., 2016) and aversive learning are known risk factors for canine fear (Tiira et al., 2016), thus increased neophobia and decreased exploration behavior.

In summary, the exploration behavior of the dogs and thus their travelling patterns are influenced by their prior learning, experience, training, their personality, whether a conspecific is present, owner personality and to some extent breed and sex.

2.4.5 Travelling patterns of dog dyads/triads – correlations

Family dogs are often kept in groups (for instance, 33 % of owners in Germany have two or more dogs, Kubinyi et al., 2009), however interchange within freely moving dog groups and their relationship with social interactions are hardly explored and the decision of dogs to form robust hierarchies is being debated (Cafazzo et al., 2010; Bradshaw et al., 2009). Clearly within the teams herein some dogs preferred to stay with the owner and not their conspecific while most dog dyads/triads did – at least part of the way – explore together consistently and in a similar manner.

Social referencing is a process by which individuals utilize cues from a social partner to form their response to a new situation. It provides advantages, especially to young, inexperienced individuals, by showing appropriate reactions to novel situations while avoiding the risks of trial and error learning. Arguably within a dyad one of the dogs (the younger/more fearful/less experienced?) learned from the other through social referencing including potential exploration patterns.

To assess whether dogs of one owner displayed similar exploration patterns the data were analyzed accordingly. The seven travelling patterns of two (or three) dogs of one owner were compared to establish possible correlations of dog dyads/triads. The dogs were viewed as teams and between and within the team the travelling patterns were evaluated. In total 10 teams were established, two teams (#9, 10) with three dogs belonging to one owner, see **Table R2.15.1 Appendix; Fig. R2.15.1**.

Teams exploring together often had what I term an initiating dog in that dogs did not stay together (leadership definition) but merely started off together following the perception of an external stimuli by one (or more) dog(s). This can also be observed in the videos: One dog perceived game (first) and the other dogs in the group followed (at different positions) but often returned earlier or followed a different path, see also **Fig. M2.2.4.2-7**.

Decision-making usually involves some form of leadership, i.e. 'the initiation of new directions of locomotion by one or more individuals, which are then readily followed by other group members' (Krause et al., 2000 p 83) and leaders have also been described as socially dominant individuals, i.e. consistent winners of agonistic interactions – which cannot be said for the initiating dogs herein. Leaders, however, may also appear in groups without any dominant individuals, or independently from social dominance (Akos et al., 2014), because they possess special information or skills (Flack et al., 2012). Alternatively behavioral synchronicity may be argued for (see discussion below)

as synchronization of behaviour between members within groups is essential for group cohesion (Engel & Lamprecht, 1997), and such cohesion may be advantageous for group members. In the same way, collective behavior may be triggered by a copying phenomenon (allelomimetic effect), i.e. one dog copying the next dogs behavior.

Also, individuals of a personality type more inclined to lead or preferring not to follow others may initiate collective movements (Krause et al., 2010). In Italian free-ranging dogs leadership interchanged between a small number of high-ranking habitual leaders and affiliative relationships had more influence on leadership than agonistic interactions (Bonanni et al., 2010).

Akos et al. (2014) found that dogs played the role of leader in a given pair about 57– 85 % of the time and that differences in leading tendency remained consistent; thus decision-making during the collective motion was not based on an egalitarian system (the distance the dogs travelled away from the owner was however only 16-20 m). The initiating dog herein also remained fairly consistent, but again the second/third dog did not necessarily stay with the initiating dogs subsequent to the initiating phase/action. Akos et al. (2014) further found that within their family dog group, the highest ranking dog was neutered, thus leadership has little or no relationship with reproductive status, which is in accordance with findings herein: the initiating dogs were mostly neutered dogs (see also same findings for feral dogs in India, Pal, 2011).

Pronounced differences within the teams became apparent in time of runs > 20 m away from the owner, see **Fig R2.16.1.3, Table R2.16.1.1 Appendix** for details. The duration of inbound- and outbound travel was higher for dogs characterized as leading or initiating dog (see Chapter 2.15). Some teams (mainly Group 1 dogs) displayed almost identical short times of runs >20 m away from the owner (Team Emma; Mala, Zlata; Team Amanda and Wantje). Some teams showed over all long exploration times (Bill; Kaito; Lou) and within some teams one dog travelled extensively while the other stayed close to the owner. The variance was most extreme for Dr. Pepper and Raiya (Raiya was nearly 40 min. away (mean), whereas Dr. Pepper had a mean duration of about 3 min. away). Raffaele/Manja and Balou_Mix and Lili also displayed distinctive time variances, see **Table R2.16.1.2** for details.

Similar results were found with respect to distance measures. Some teams displayed minor variances (Amanda, Wantje; Amy, Nele), some large differences: The largest difference existed between Manja (181m) and Raffaele (1721m – 851 % difference); Balou and Lilli (5866 m vs. 1142m – 414 % difference) and between Dr. Pepper and Rai-

ya (568 m vs. 3283 m – 478 % difference), see **Table R2.16.2.2**. **Fig. R2.16.2.1 - R2.16.2.5**. These dogs did not explore together. The dog that travelled less essentially stayed close to the owner and the second dog explored alone. One factor here may also be whether the dogs (are able to) travel at equivalent speed, see **Table R2.6.2**, perhaps due to age differences, see **Table R2.11.1**; **Fig. R2.11.1-2.11.2**. The maximal distance varied between the teams, within teams however, fewer differences could be denoted, **Fig R2.16.2.3**: In the team Marley and Tamina both dogs had large maximal difference to the owner. In other teams e.g. Amanda and Wantje both dogs stayed near the owner and the maximal distance from the owner was within the <150 m radius.

As can be perceived in **Fig. R2.15.1** some teams had similar numbers of runs and pattern distributions (Kimi and Nina or Marley and Tamina), while within other teams e.g. Amanda and Wantje, Manja and Raffaele, Balou and Lilli, a leading/initiating dog with a higher number of runs > 20 m could be observed. The leading/initiating dog was also characterized by a larger number of star and loop patterns, whereas runs ahead waits/follows was the dominating pattern of the dependent, following dog. The leading/initiating often dog displayed a more varying distribution of patterns.

Correlations could be found between the dyads/triads (see Section 2.16). Often a leading/initiating dog could be observed, with the second dog returning earlier (or exploring a shorter distance) see e.g. Nina & Kimi, or the triad Bill, Kaito, Lou. For exemplary dog dyad travelling patterns see **Fig. M2.2.4.2-7**. Between the groups differences were demonstrated in that the group Bill, Kaito, Lou exhibited a wide variety of travelling patterns including essentially all possible pattern options, whereas some teams, even though they frequently travelled beyond the 20 m range, primarily utilized one travelling pattern, runs ahead and waits/follows, see e.g. Amanda, Balou RR, Nele.

Also synchronization may play a role in dyadic/triadic exploration. Synchronization encompasses different types of synchronies, such as temporal synchrony (switching actions at the same time, the actions can be identical or different, the important feature is the timing), location synchrony (being in the same place at the same time, the actions can be identical or different, the important feature is the localization), and activity synchrony (exhibiting the same behavior at the same time). All types of synchronies are present at the dyadic level (Duranton et al., 2017). Dogs have been shown to demonstrate behavioral synchronization with conspecifics in a number of activities, for instance movement (Scott & Fuller, 1965) and when running together (Scott & Marston, 1950; Scott & McGray, 1967). It has also been shown that dogs followed their conspecific-

ics' direction of walking during group departures (Bonanni et al., 2010) which is what the dyads often displayed here: one dog started an exploratory run and the second dog followed in the same direction, see **Fig. M 2.2.4.2- Fig. M 2.2.4.7**.

It has been proposed that synchronization is linked to affiliation between the partners: being synchronized strengthens the social bond between the individuals, and conversely, the more affiliated two individuals are, the more they behave synchronously (Duranton et al., 2017), **Fig. M 2.2.4.2- Fig. M 2.2.4.7**. Behavioral synchronization may be an adaptive mechanism fostering social cohesion of the group/team and dogs may benefit by synchronizing their behaviors with conspecifics, thereby increasing affiliation and prosociality. Clearly behavioral synchronicity could be observed between the dyads/triads in the majority of teams. Possibly also temporal synchronicity in that after the initiating dog explored the second dog followed. Also spatial/location synchronicity may be argued for: even though the dogs did not explore in an identical manner, they did explore in a similar area, see **Fig. M 2.2.4.2- Fig. M 2.2.4.7** and activity synchrony in that the majority of dogs exhibited the same behavior at the same time. However, within in some teams one dog stayed with the owner and thus synchronicity with the owner may be argued for – strengthening the argument that the bond with conspecifics or humans is based on the quality of the interaction not the species. Cimarelli et al. (2019) looked at dogs' inter- or intra-specific relationships and found that the type of relationship, rather than the partner species, predicted the relationship and that dog-owner relationships differed from dog-dog relationships only in terms of reference. They suggested that dogs form similar relationships with both humans and dogs, and that, with both kinds of partners, the quality of the bond varied with the individual partner rather than between dog vs. human partners (for detailed discussion see Part 1).

2.4.6 Hunting issues

Dog chasing wildlife is a sensitive issue. It is however quite difficult to find reliable facts and statistics regarding for instance roe deer (*Capreolus capreolus*) killed by dogs. One statistic from Switzerland reported that 632 deer were killed by dogs in Switzerland in 2012 https://www.tierimrecht.org/documents/384/201407_SHM_Serie_HundWildtier.pdf). Compared to deer shot by hunters (Germany annual statistic deer (*Capreolus capreolus*) shot by hunters for the year 2017/2018: 1190724 <https://www.jagdverband.de/jagdstatistik> Quelle: Deutscher Jagdverband, Handbuch 2019) the issue seems quite out of proportion and reminds one of the wolf discussions.

The majority of owners herein assumed their dog would be interested in or display hunting behavior. Anecdotes in particular from the hunting community (see e.g. <https://www.jagdrecht.de/aufsaeetze/wildernde-hunde/>) assume that pet dogs chase and in some cases kill wildlife and legislation is accordingly favoring/prescribing dogs on a leash.

All dog owners herein feared to let their dogs run free if they could not see them (even though supervised by GPS) because of the danger of the dogs being shot and killed by hunters. Owners further assumed that if two or more dogs participated, they would “hunt” cooperatively.

Taking into account welfare considerations (see discussion Part 1) of letting dogs off the leash it is of great important to assess the factual exploration behavior of free ranging pet dogs and their potential hunting behavior also to argue for a change of legislation making it illegal to shoot domestic dogs and establishing areas for off leash walking.

Based on the owner questionnaire (see Part 3 Material and Methods) an owner assessment of the hunting behavior of their individual dog(s) on a scale from 1 (weak) to 6 (strong) was established to evaluate the subjective owner perspective (see, **Table M2.2.3.1**) and the objective travelling behavior of the dog indicating hunting behavior either through distances travelled (out of visibility) or through video analysis if applicable (no video analysis possible on small dogs due to camera weight/size). None of the owner knew the definition of hunting behavior (see definition introduction Part 2 Section 2.1.5). Most owners described hunting as any kind of flushing, tracking, chasing or stalking behavior of their dog. Furthermore, most owners assumed that their dog was “hunting” when out of visibility. For instance the strong “star-runners” (Raffaele; Raiya) displaying high speed runs back and forth without doing any olfactory work (nosing, tracking on the ground) or chasing anything (see e.g. videos) were assessed as showing a strong “hunting behavior”. They were running without being focused on any external stimuli and arguably because it was a self-fulfilling/rewarding behavior. For these dogs in particular to be on a leash might have physiological and physiological implications. They neither displayed orienting or stalking behavior (see, definition Coppinger & Coppinger, 2001).

In case of dyads or triads owners expected the dogs to explore together and in case of prey sighting chase together with one dog being the “initiator” and accordingly one dog being assessed higher on the scale (e.g. No1/no 29; No 5/No17; No 7/no 16; No

14/no 23). Out of the 30 dogs only five were assessed by the owner with none or very weak hunting behavior, even though some were of hunting dog groups: Labrador retriever #2 Amy and #22 Nele; Italian greyhound #19 Manja; Pastor Mallorcin Mix; #15 Lili; Perro de Aqua Espanol # 18 Maloca, **Table M2.2.3.1**.

No objective statistics or studies describing hunting behavior of pet dogs could be found and hunting behavior of dogs generally is not well documented. If, as is assumed, dogs do hunt cooperatively, multiple observations of hunts in different situations, with different prey types and habitat structures are necessary. One recent study compared the energetic costs of a pack of trained hounds hunting puma (Bryce et al., 2017). Other studies looked at feral dogs. These studies showed that free-ranging dogs typically live in proximity to human settlements (Majumder et al., 2016) their diet consisting predominantly of human waste (between 50 and 88 %) with grains and human faeces (20 %) as major components (Atickem et al., 2009). Scavenging on human refuse is mostly a solitary or dyadic activity (Sen Majumder et al., 2014) and free-ranging dogs appear to be 'facultatively social', depending on food abundance (Macdonald & Johnson, 2015), breeding status of females and season (Sen Majumder et al., 2014). Most studies report that free-ranging dogs form groups of 2–8 individuals although stable packs of up to 27 individuals have been described (Bonanni & Cafazzo, 2014). Despite the effects of domestication (Clutton-Brock, 1995), it seems that the social organization of free-ranging dogs is modulated by the same ecological constraints that influence other wild canid social systems (Bonanni et al., 2010a, b, c; Cafazzo et al., 2010). Therefore, although their morphology, physiology and behavior have been partially modified during domestication (Clutton-Brock, 1995), free-ranging dogs may form stable social groups, characterized by conspecific cooperation and affiliative interactions (Bonanni et al., 2010a; Cafazzo et al., 2010).

Free ranging dogs rarely hunt (including group hunting) (Vanak & Gompper, 2009; Silva-Rodriguez & Sieving, 2012), and mostly if human provided food sources are insufficient (Ruiz-Izaguirre et al., 2014; Silva-Rodriguez & Sieving, 2011) or if the dogs live at great distances from humans (Krauze-Gryz & Gryz, 2014) and both reasons would not apply to pet dogs. The importance of starch, and clear evidence of a shift in feeding ecology from hunting to scavenging, emerges from dogs showing genetic adaptations for starch digestion, which are absent in wolves (Axelsson et al., 2013) but already present in the ancient Newgrange dog (4800 BP-11). The great majority of modern dogs, in fact, are free ranging, living in tolerated association with humans, partly provisioned by hu-

mans and partly scavenging (Coppinger & Coppinger, 2016); and of those dogs that do hunt, they frequently do so individually, suggesting similar behavior to pet dogs. There is little evidence that any social hunting by free-living dogs is coordinated, or more successful than individual hunting (Krauze-Gryz & Gryz, 2014).

Thus in analogy to free ranging feral dogs it may be argued that most pet dogs do not hunt, which is undermined herein by the distances the majority of dogs explored, their exploration patterns, time and speed travelled.

However, dogs have retained the predatory action sequences seen in wolves (Coppinger & Coppinger, 2001) and therefore it is not unreasonable to suppose that they also still possess the cognitive mechanisms required for social hunting. The fact that some working breeds are selected as social hunters supports this supposition however, it is precisely in relation to hunting that it has been argued that wolf and dog cognition may have been affected by social pressures, through the demands for cooperation that social hunting creates (e.g., Range & Virányi, 2014). Brucks et al. (2019) stated in their recent study that wolves are cooperative hunters and breeders, while dogs predominately scavenge and raise their young alone, and accordingly, they predicted that dogs would show impaired inhibitory control abilities since they no longer rely on these coordinated actions. They found however that inhibitory components did not differ between dogs and wolves.

Bailey et al. (2013) classified different stages and strategies of cooperative hunting, established cognitive and social abilities facilitating latter and defined different levels of cooperative hunt complexity amongst the Carnivora (own table based on Bailey et al., 2013):

Passive	The presence of other predators in some way increases the individual hunting success of others without them intentionally interacting or paying attention to each other's actions during the hunt. There is no focal prey animal except by chance and food is rarely shared.
Similarity	Timing and orientation are primarily in response to the behavior of the prey, not that of other hunters. Prey is shared.
Synchrony	Hunters synchronize the timing of their movements in relation both to each other and the position and behavior of the prey. Prey is shared.
Coordination	The positioning relative to one another is not incidental; if prey is approached from different directions, individuals must have spread out at some point to specific positions, e.g. fanning out to flush prey or encircling prey. Prey is shared.
Collaboration	There must be a clear role differentiation resulting in team-like behavior. The same individuals may perform the same specialized roles repeatedly in different hunts. Timing and positioning are strongly based on each other's, rather than on the prey's, behavior than during lower levels of cooperation. Prey is shared.

Bailey et al. (2013) in their research found 18 carnivore species (and four subspecies) reported to cooperate. Evidence of collaborative hunting was documented in 11 out of 21 species. The ability to hunt at a cooperative level has been taken as an indicator of higher cognitive abilities including foresight (Mech, 2007). On the other hand Panzarasa et al. (2002) argued that collaborative decisions mainly involve following simple rules adapted to experience, not anticipatory choice and complex cooperative behavior.

Dogs' social skills and learned decision making processes impact on the ability to cooperate effectively as well as their memory capacity and long-term learning (Brosnan et al., 2010). In addition, their decisions may be influenced by emotion (de Waal, 2011) for instance if the dogs have been punished for following other dogs or the dogs' ability to show restraint when excited (Brucks et al., 2019). Social relationships like the dyads/triads herein and social tolerance favour cooperative behavior (however not in all teams see discussion above) and the ability of information transfer is needed to convey either via intentional signals (communication) or inadvertent behavioral cues information vital to coordination and decision-making processes. Information transmission may be achieved via visual, tactile, vocal or olfactory cues/signals or a multimodal combination of these (see discussion Part 1). For instance the calls of dogs are individually recognizable (Frommolt & Gebler, 2004) providing information of e.g. the leading individual including directionality (Frommolt & Gebler, 2004) thus assisting to coordinate pack movements in areas of poor visibility (Volodin et al., 2006b). It has also been proposed that individuals travel at similar speed, thus synchronized (Buchanan, 2010) and the dyads/triads herein did exhibit comparable speed patterns (see e.g. Section 2.12).

Both visual and vocal information transmission may be of great importance and data would greatly enhance our understanding of how or if hunts are coordinated. There is clearly a need for more detailed rePORting of dog hunting behavior.

In addition to the behavioral interactions the physical factors are important. Looking at the speed of the pet dogs in this study, most of them will de facto not be able to catch (healthy) prey. Prey species typically are reported to have top speeds higher than those of their carnivore predators (Schaller, 1972), but specific data on German prey species are not available. In order to catch faster prey, dogs would arguably have to develop two main strategies: either a high stamina hunt, combined with the ability to track an individual prey animal (sight, hearing and scent), allowing the dogs to catch up with prey by exhausting it over long distances. Alternatively dogs with the ability of rapid acceleration like the sightdogs herein combined with strength and maneuverability (turning, deceleration and discontinuous movements such as jumping and negotiating obstacles: Jindrich & Qiao, 2009) who out-accelerate and catch up with their prey before it has time to reach top speed or take flight.

Will these variations in locomotor ability be reflected during cooperative hunts by position or role of an individual (the fastest chaser and the strongest ambusher?). Will variation in cognitive ability be reflected? Dogs are not equally capable of performing different behavioral options, or have equal motivation, memory, information or leading capabilities (Brosnan & Bshary, 2010). There is very little information on the consistency or variation in roles or positions held by members of hunting groups. Dogs may also have individual preferences for particular strategies arising through variation in personalities, social status and athletic abilities combined with individual learning experiences over a lifetime (Bshary & Bergmuller, 2008) as displayed by some dogs herein. Is there a repeatability of hunting patterns or does the strategy the dogs employ vary from hunt to hunt, even when hunting the same prey type? Behaviors based on simple movement rules would result in repeatable patterns of behavior (Walsh et al., 2010) and behaviors influenced by learning and memory would result in greater variation of behavioral patterns. Long-term records of movement patterns across multiple hunting events for multiple individuals in combination with data on the context of the hunt would enable us to measure within- and between-individual variations in hunting strategies and thus get a better idea of the role cognition plays in shaping hunting strategies.

Detailed descriptions of behavior during hunts are rare, limiting our knowledge on the level of hunt organization and the mechanisms that may contribute to such be-

havior and whether pet dogs de facto hunt at all. Furthermore very limited data regarding maximum performance in terms of speed, acceleration, maneuverability and muscle morphology either of prey or predators are available. Thus, there is need for more detailed data on the locomotor specializations and performance in the field, both for dogs and their prey.

2.5 Conclusion

As hypothesized, the dogs displayed various exploration patterns establishing a cognitive map by using different reference systems and egocentric and allocentric cues, the prevalence depending on area and individual idiosyncrasies.

Most dogs in this study stayed close to their owner on any given walk (radius <150 m), as hypothesized. Unexpectedly, no significant difference of distance or duration explored between known and unknown area either between individual dogs or with regard to groups could be found. A tendency to explore farther in known areas could be observed however as well as shorter durations in unknown area and 20 of 30 dogs explored shorter distances in unknown areas. Thus dogs seem to explore further in known areas and they explore longer maximum distances. For practical reasons this would imply for owners and trainers to change walking areas regularly in order for the dog to explore shorter distances and time whilst off the leash.

The dogs displayed various travelling patterns. Out of all runs >20 m (n= 3145) the dogs utilized primarily (62 %) the travelling pattern of running ahead of the owner on the path and waiting or following the owner on the path. Great intra-individual differences could be observed and dogs were placed in radius and cluster groups. 14 dogs displayed a change in pattern cluster, 16 had constant pattern clusters for all four walks. Seven dogs had different patterns in known versus unknown areas. No effect of breed, age or size could be found.

As hypothesized the distance and time travelled between male and female dogs (runs>20 m) differed. Male dogs explored significantly longer distances over all and on runs >20 m than females and male dogs travelled significantly longer times on their exploratory runs > 20 m than female dogs. As a practical implication this may be one factor to consider for new or inexperienced dog owners.

On the other hand, no significant differences could be found between intact and neutered/spayed dogs. Differences in distance and time explored between all neutered and all intact dogs could be observed, these were not significant, however. Neutered male dogs displayed over all higher distance and higher travelling time away from their owner than intact male dogs, female neutered dogs however explored equivalent distances and displayed less travelling time than intact female dogs.

As hypothesized the time inbound to their owner differed from the time outbound travelled by the dogs. The time inbound was significantly shorter than the time outbound. Also the speed on their return path (inbound) differed from the time out-

bound route. The speed on inbound travel was significantly higher than on outbound travel over all dogs as well as for Group 1, 2 and 3.

The hypothesis that the distance explored by the dogs outbound versus inbound (runs > 20 m) differed could not be confirmed and indicated an egocentric mechanism. Most dog teams displayed no significant differences with respect to time or distance explored. Exploration variances between some teams were indicated and some dogs stayed with their owner and not the conspecific. If dog dyads explored together the teams showed a leading or initiating and a following dog, where the leading dog explored longer and further and the second dog returned earlier.

The free-ranging dogs arguably utilized multiple sources of spatial information including visual landmarks during the day trials, olfactory clues if they retraced part of their trail and egocentric clues like the distance or time travelled. The use of global cues like the geomagnetic field to establish directionality may be indicated by the point of return in north-south direction. I conclude that the dogs employ several individual navigational strategies, in accordance with the Multiple Bearing hypothesis. An interaction of potential cues from the distal and proximal environments including directional information from the Earth's magnetic field as landmarks as well as egocentric information are part of their spatial navigation system and enable them to find their owner in different settings .

3 The owner

3.1 Introduction

Part three will focus on the owner side of the dyad human-dog team. The dog owners had to fill out two questionnaires which were then analyzed and partly correlated. First, an owner questionnaire from which data were used to compare subjective evaluations (e.g. how far/long does your dog explore) with actual numbers and secondly the Lexington Attachment to Pets Scale (LAPS) by Johnson et al. (1992), a widely used instrument to measure attachment of owners to their pets. Herein the German version as translated by Hielscher et al. (2019) was used. Several publications on human-animal attachment are based on the LAPS (Bagley & Gonsman, 2005; Johnson et al., 1992; Reevy & Delgado, 2015; Stoeckel et al., 2014).

Questionnaire one answers pertaining to the exploration behavior of their dog(s), sex, reproductive status or the evaluation of their dog's hunting behavior etc. were then correlated to the LAPS questionnaire to evaluate the attachment level of the owner.

3.1.1 Attachment

An attachment bond is a close, emotional relationship between two individuals (Bowlby, 1958) and refers to a particular type of long-lasting affectional bond which provides a sense of security and reduces feelings of stress and anxiety (Carter, 1998). The dog-human dyad is believed to involve attachment bonds similar to those that characterize human caregiver-infant relationships (Payne et al., 2015; Topál et al., 1998) and these relationships are bidirectional (Kaminski & Marshall-Pescini, 2014). Thus in their relationship dogs or owners may provide comfort in distressing moments by serving as a safe haven (Barker et al., 2016; Barker et al., 2015) or act as a secure base (Bowlby, 1969; Green & Campbell, 2000) for each other, respectively. Originally at least three different attachment styles have been described in human psychology (Ainsworth et al., 1978): secure, ambivalent/resistant and avoidant (see, also **Section 1.4.3**) which may also be found in the owner-dog relationship (Rehn et al., 2013). Attachment styles have well documented cognitive, physiological, and neurological correlates (e.g., Diamond, 2001; Gillath et al., 2005), as well as behavioral and psychological consequences that last into adulthood, including self-regulation of stress and emotions. Studies have focused on

the environmental effects shaping attachment (such as parental behavior, Fearon et al., 2014).

Clearly dog ownership has the potential to sustain personal development and well-being by means of the dog fulfilling its owner's psychological needs for autonomy and relatedness as reflected by different levels of attachment (Kanat-Maymon et al., 2016). Ownership satisfaction with his or her dog reflects several aspects of their relationship such as owner-dog attachment strength (Serpell, 1996). Satisfaction is based on different behavioral traits displayed by the dogs. Owners' descriptions of their ideal dog included a desire for the dog to come when called, to enjoy being petted and to display affection to their owners (Diverio et al., 2016). Owners prefer a dog that is calm, compliant, faithful, and nonaggressive (King et al., 2009). Problematic or unwanted behaviours, like hunting behaviour, have negative effects on the dog-owner relationship and attachment (Bennett & Rohlf, 2007) whereas perceived obedient behaviour has a positive effect on owner attachment (Clark & Boyer, 1993). Forming relationships or simply interacting with dogs has been associated with a number of emotional and psychological health benefits for humans (LaFollette et al., 2019; Eriksson et al., 2018; Kertes et al., 2018). For instance, attachment has been shown to correlate with physical activity and motivation to go on dog walks in dog owners (Cutt et al., 2008; Westgarth et al., 2016; Westgarth et al., 2013).

In the owner-dog relationship similarity of personality may also be advantageous. Studies have shown that dog ownership satisfaction was directly related to owner perceived complementarity of characteristics of their dogs and themselves (Zeigler-Hill & Highfill, 2010). The dog owners reported on dog ownership satisfaction, emotional attachment and their dog adding positivity to life. Warmth was considered one main component of social behavior on dog ownership satisfaction (Zeigler-Hill & Highfill, 2010). Significant correlations have also been demonstrated between the personality aspects of openness and agreeableness and owner satisfaction with the dog-human relationship (Cavanaugh et al., 2008). Similarly, Curb et al. (2013) reported that owner satisfaction correlated with dog-and-owner matching on certain behavioral traits, such as having an active lifestyle and creativity, which correlate with extraversion (de Bruijn et al., 2009) and openness (Sung & Choi, 2009), respectively. An owner with an avoidant attachment to their dog for instance has more negative expectations regarding the behavior of their dog (Zilcha-Mano et al., 2011). A study investigating the influence of certain owner factors on the dog-human relationship found a significant negative correlation between

owners using the dog for 'company only' and emotional closeness (Meyer & Forkman, 2014). Time spent as a dyad may have a critical influence on this observation, as the activities cited by Meyer & Forkman (2014) would arguably require more owner engagement with the dog, an attribute that has been reported as critical in the dog-human relationship (Arhant et al., 2010). Additionally, owners in these dyads were more likely to consider their dogs as social supporters or partners (Schoeberl et al., 2012). Attachment behavior may be influenced by the fact that some owners might project their self-identity onto their pets (Hirschman, 1994) or that they keep their dog as a medium of expression of their own personality and preferences (Veevers, 1985).

It has also been proposed that the owner decision to acquire a specific dog might be influenced by the degree of similarity between the physical appearance and personality of individual dogs and that of the owner, following rules of assortative mating (Payne et al., 2005) thereby increasing attachment and satisfaction. Also the dog's appearance is important in that for some dog owners, the animal's appearance may be considered more important than its health (Holland, 2019) favoring attachment, which arguably is extrinsically motivated display behavior that earns external rewards and social acknowledgment i.e., status (Holland, 2019). Human factors, including personality and attitudes, influence the dog-human relationship which is confirmed by hormonal changes in their oxytocin level that emerge in both dyad members. Oxytocin is believed to have a role in bond formation (Carter et al., 1997). Owners kissing their dogs reportedly have higher oxytocin concentrations, as do their dogs, than owners who do not (Handlin et al., 2012). Kovács et al. (2018) provided the first evidence that genetic variations in dogs' OXTR gene are associated with their attachment behavior to their owners.

Regarding dogs as surrogate humans that offer affective benefits has been described as humanistic view, regarding them as valuable companions with their own interests as protectionistic view (Blouin, 2013). Human behaviors that likely contribute to a positive affective state and consequently more positive expectations in dogs are often those that provide the dog with resources of emotional value, such as affiliation (Horváth et al., 2008), human attention (Schwab & Huber 2006) and safety (Gácsi et al., 2013). Dogs may serve attachment functions (i.e., secure base, etc.) for some individuals, even if, at the same time, the relationship between owner and dog share some features with a parent-child relationship, with the owner as "parent" and the dog as "child" (Zilcha-Mano et al., 2012).

However, expectations of the role dogs should play vary with gender, with having children and with ownership experience (Kidd et al., 1992; King et al., 2009). The presence of children in the household has been shown to negatively affect the owner's attachment to his dog, whereas living alone increases the care of the dog. Also having more than one dog decreases the level of care for the respective dog(s) (Marinelli et al., 2007).

3.1.2 LAPS (and other tests)

The study of dog and owner personality and interaction is of great academic interest but acquiring direct behavioral assessments of large numbers is both time consuming and logistically difficult. An alternative approach that has become common is the collection of questionnaire-based information directly from dog owners.

Several researchers have developed pet attachment scales, measuring the amount of affection owners feel for their dogs and other emotions or attitudes they have toward them, such as the degree to which they view them as similar to humans and their beliefs regarding nonhuman animal rights. These scales include the Pet Relationship Scale (Miller & Lago, 1990), the LAPS (Johnson et al., 1992), the Companion Animal Bonding Scale (Poresky et al., 1987), the Pet Attachment Survey (Holcomb et al., 1985) and the Dog Attachment Questionnaire (Archer, 2011). The MPAWS was developed from the Person–Animal Wellness Scale (Johansson, 1999) and the Questionnaire for Anthropomorphic Attitudes (Topál et al., 1997). It concerns dog attachment and the owner–dog relationship and owner attitude toward their dog. Owner-dog relationship dimensions have also been assessed with the Monash Dog Owner Relationship Scales.

Herein the LAPS, the Lexington Attachment to Pets Scale by Johnson et al. (1992) was used to measure attachment toward pets because a German validated version existed (Hielscher et al., 2019). The LAPS consists of 23 items that are rated on a 4-point scale: agree strongly, agree somewhat, disagree somewhat, and disagree strongly (coded as 0, 1, 2, and 3, respectively). Total scores on the LAPS can range from 0 to 69 and three factors, which the authors labeled “general attachment” (11 items), “people substituting” (7 items), and “animal rights/animal welfare” (5 items). Examples of items for each of the factors, respectively, are: “My pet and I have a very close relationship,” “My pet means more to me than any of my friends,” and “Pets deserve as much respect as humans do.” Johnson et al. (1992) reported validity evidence for the LAPS, including correlations between LAPS scores and (a) interviewers' assessments of participants' attachments to their pets, and (b) respondent characteristics that have been found to correlate with pet

attachment in other research (e.g., respondent gender, marital status, education, and income). There may be some problems with terminology used in the subscales of the LAPS survey; for example, while one subscale has been identified as “people substituting,” there are no comparative questions about individuals’ relationships with humans. Thus, it is a misnomer to imply that this LAPS subscale measures the substitution of one type of relationship for another (Zaparanick, 2008).

3.1.3 Owner perception of time and distance their dog(s) explored

3.1.3.1 Time

In everyday life, emotions impact our relationship with our time perception. When we are worried or afraid we have the feeling that time slows down. Every minute seems like an eternity, as if time had stopped. Threatening, negative, or fearful stimuli tend to give rise to a feeling that time is slowing down (Bar-Haim et al., 2010).

Because the owners were feeling worried whenever their dog was out of sight or if they expected it could or would be out of control (because it was not called back) I asked them to estimate the duration their dogs were exploring. I hypothesized that their assessment would exceed the actual exploration time of their dog.

In everyday life this would impact owner behavior because if owners think their dog explores a long distance or time they arguably call their dog more often. They may even keep it on the leash, thereby restricting its exploration and walking behavior, implicating dog welfare (for discussion, see also Part 1 and Part 2).

Humans do not have any specific sensory receptor enabling them to capture temporal information, however, the brain is inherently capable of processing time (for reviews, see Coull et al., 2011; Van Wassenhove et al., 2011). Two main mechanisms have been suggested to account for fluctuations in the passage of time: (1) an attention-based mechanism and (2) an arousal-based mechanism (Droit-Volet & Gil, 2009). In the case of the first mechanism, when attention is distracted away from the processing of time, the duration is judged relatively shorter because a shortening effect is observed as the amount of attention devoted to time decreases. In the case of the second mechanism, a lengthening effect occurs and the duration is judged longer (Droit-Volet & Wearden, 2002). This has been verified in experiments which have used at least two different duration ranges (a shorter and a longer one) and manipulated the level of dopamine in the

brain through the administration of psychostimulant drugs (methamphetamine, cocaine, caffeine; e.g. Rammsayer 1989, 2009).

Experiments confirm that, in the same way as in other animals, fear distorts time perception in human adults by inducing a lengthening effect. This finding is consistent with the works on fear showing that threatening stimuli elicit fear reactions which automatically trigger a wide variety of behavioral and physiological responses (increased heart rate, higher muscle contraction), because the organism must be prepared to react as fast as possible for its survival (Delgado et al., 2006; Phelps, 2006). One of the bodily changes observed in reaction to fear is a speeding-up of the internal clock (Droit-Volet et al., 2010b) because the emotion of fear triggers a “slowing down” of time and causes a state of physical arousal that speeds up our “internal clocks” (Droit-Volet et al., 2011).

Grommet et al. (2019) proposed that fear either serves as an arouser that increases the speed of a hypothetical internal clock, alternatively, that fear increases attention to time, which results in organisms' beginning to time fear-evoking stimuli sooner than they do neutral stimuli. Whatever the mechanism, owners herein consistently overestimated the time their dog explored.

3.1.3.2 Distance

Additionally, I asked owners to estimate the distance their dogs were exploring. I hypothesized that their assessment would exceed the actual exploration distance of their dog. Again, this would be important, because if owners believe their dog explores a long distance they may call their dog more often or keep it on the leash, thereby restricting its exploration and walking behavior, implicating dog welfare (for discussion, see also Part 1 and Part 2).

The ability to encode, judge and assess the location of objects in one's environment – part of spatial cognition - plays a key role in many endeavors like map reading, remembering object locations, navigation, and learning in science, technology, engineering, and mathematics (STEM) (Ariel & Moffa, 2018). In our physical world it is important that we are able to travel to different locations to perform daily tasks, exercise and walk our dog. These tasks require an accurate spatial representation of our environment for proper navigation, like a cognitive map and necessitate a combination of cognitive skills such as object recognition (what), localization (where), and obstacle avoidance (how) (Maguire et al., 1997).

As with time, I hypothesized that emotion would influence the perception of spatial information like distance of the owner.

Both emotion and motivation impact the visual system to detect relevant aspects of the environment by making them easier to see (Veltkamp et al., 2008) and emotional and bodily states appear to regulate visual perception of spatial layout (Zadra & Clore, 2011). Sight is a primary sense that humans use to know not only what is where, but also to know the locations of things in relation to the self and others. One major question in perceptual research is how our visual system is able to create this spatial representation and subsequently perceive distances between ourselves and other objects and it has been proposed that one's personality creates a reference frame, via attentional prioritization, of what is valued, and therefore attended to, in the environment (Proulx et al., 2016). The perceptual system may be highly interconnected, allowing emotional information to influence perceptions that, in turn, influence cognition (Stefanucci et al., 2011). Emotions thus affect how and what we see and provide a strong motivating influence on how the environment is perceived (Zadra & Clore, 2011). Fear, for example, can affect visual processes (Zadra & Clore, 2011) serving as an focus, alternatively, increasing attention to the visual stimuli, which may results in organisms' beginning to expect fear-evoking stimuli and leading to inaccuracies. Stefanucci & Proffitt, (2009) showed that fear heights were overestimated 60 % and a higher fear was related to an increase in height overestimation.

This evidence suggests that emotions may lead owners to attend to different information or cues in the environment, which could then produce changes in their estimates of the layout of the environment. Along this line Stefanucci & Storbeck (2009) showed that feelings of arousal (whether positive or negative) influenced the perception of dangerous environment, suggesting that arousal may be a sufficient cue for altering space and distance perception.

3.2 Material and Methods

I collected GPS data on trials ($n = 3145$) of free ranging, freely exploring domestic pet dogs ($n=30$) of different breeds, size, reproductive status, sex and age (see, **Tables M1.2.1 and M.1.2.2**) while walking with their owners on four consecutive walks in two known and two unknown areas in North Rhine Westphalia, Germany ($n=120$), the average length (median), was 1:17:17h per walk; (median 1:12h) 5:24:53h (median 5:38h) over all walks, for details see **Table M1.2.4**. 51 parameters were recorded for each dog-owner dyad, for an overview see **Table M1.2.5**. The GPS used were a Garmin Astro® 320 and the dog collars DC™ 50, and T5 Mini, Garmin International Inc., Kansas, USA see **M1.2.2**. Seven travelling patterns were differentiated for each run > 20 m, see **Fig. M1.2.2** for pictograms.

Dog-owner teams were acquired through social media like Facebook, networking and personal acquaintances.

3.2.1 Owner questionnaire

Prior to the walks the owner had to complete an owner questionnaire with 33 items and 24 questions, see **Table M3.2.1**. Therein the owner had to answer questions regarding date of birth, breed (in case of mixed breeds the owner description was used), health, whether the dog was neutered/spayed, how long the dog had been living with the owner, whether the dog had any kind of obedience test etc., whether it was used for hunting purposes (in which case the dog was excluded as this would influence the exploration patterns), whether the dog was trained with aversive training methods like negative enforcement, choke collars, halties, tele tact etc., in which case the dog was also excluded. Further the owner had to assess the dogs hunting propensities on a scale from 1-6 (very weak to very strong) and the level of orientation of the dog on the owner. The owner also had to give an assessment on how far the dog would explore on any given walk (maximal distance away from owner), how long the dog would be beyond owners vision (% or minutes), how often the owner thought the dog would explore beyond the range of 20 m (in %); whether the dog would find the owner even if not called; the exploration/orientation strategy the dog would use (star/loop/zickzack/no strategy); whether the dog after an exploration would follow the owner or wait on the path ahead of the owner (anticipation); whether it made a difference if the dog explored in a known or unknown area and if so what difference (walks further/stays closer); how long the owner typically walked the dog (in order to assess similar walking times) and if the dog owner

team always walked the same rounds or different ones; how the owner normally communicated (calling, hand signals, whistling etc.); whether the owner indicated a change of direction to the dog and if so how (signals, calling etc.); how often the owner usually called the dog (often, with every change of direction, if the dog is not seen any more, only in dangerous situations etc.), whether the owner thought the dog would know where he/she was even without visual or acoustic contact; whether owner thought his dog would reliably return even if not called; and whether the dog would behave differently if not called/signaled to during a walk. The questionnaire was given in its German version – for information an English translation is supplied. For all details, see **Table M3.2.1**.

Table M3.2.1: *Owner questionnaire German original and English translation; 33 items; 24 questions.*

Fragebogen	Questionnaire
Datum	Date
Name Halter:	Name owner:
Adresse:	Adress:
Name Hund:	Name dog:
Geb. Datum Hund	Date of birth dog:
Rasse:	Breed:
Geschlecht:	Sex:
Kastriert: Ja Nein	Neutered/spayed: yes no
Wie lange ist der Hund im Besitz:	How long has the dog been with you:
Hat er eine Prüfung: Ja Nein. Welche:	Does the dog have passed an examination: yes no. Which one:
Wird Hund jagdlich geführt: Ja Nein	Is the dog being used as hunting dog: yes no
Ist Hund mit aversiven Trainingsmitteln/methoden trainiert worden: Ja Nein	Has the dog been trained with aversive training methods/ implements: yes no
Bekannte Krankheiten:	Known illnesses:
Hat der Hund Jagdtrieb (1-6: 1= sehr wenig 6=sehr stark):	Does the dog show hunting behavior (1-6: 1= hardly any 6= very strong):
Wie schätzen Sie Ihre Bindung ein (1-6: 1= sehr stark 6=sehr schwach):	How do you assess your bonding/attachment (1-6: 1=very strong 6=weak):
Wie stark orientiert sich der Hund an Ihnen (1-6: 1= sehr stark 6=sehr wenig):	Does the dog use you as orientation (1-6: 1=very strong 6=hardly at all):
Eigene Einschätzung wie weit entfernt sich der Hund maximal? Meter	Your assessment of the maximal distance your dog explores away from you? Meter
Eigene Einschätzung wie lange ist der Hund außerhalb des Sichtbereichs? Minuten/ % eines Spaziergangs.	Your assesment how long is your dog out of sight during a walk? % / minutes of al walk

Fragebogen	Questionnaire
Eigene Einschätzung wie oft ist der Hund während des Spazierganges über 20m entfernt? % eines Spaziergangs	Your assesment how often does your dog explore beyond the 20m range during a walk? % of a walk
Findet Ihr Hund Sie wieder auch wenn er weiter entfernt ist und Sie ihn nicht rufen? a. Ja b. Nein c. Weiß nicht	Will your dog find you if he is further away and you do not call him? a. Yes b. No c. Don't know
Wie orientiert sich/läuft Ihr Hund? a. Er läuft die selbe Spur zurück b. Er läuft einen loop/Kreis c. Er läuft im Zickzack und sucht mit der Nase d. Er hat keine Strategie e. Weiß nicht f. Andere:	How does your dog orient? a. He travels the same track back b. He runs a loop c. He runs zickzack and searches with his nose d. He has no strategy e. Don't know f. Other:
Wenn Ihr Hund sich weiter entfernt hat, folgt er Ihnen oder steht er vor Ihnen auf dem Weg? a. Folgt mir b. Vor mir c. Kommt auf das Gebiet an (bekannt/unbekannt) d. Weiß nicht	If your dog was further away is he afterwards behind you (follows) or ahead of you on the path (waits)? a. Follows b. Ahead c. Depends on the area (known/unknown) d. Don't know
Macht es einen Unterschied, ob Sie in bekannten oder neuen Gebieten sind? Ja Nein a. Ja, er läuft weiter in bekannten Gebieten b. Ja, er läuft weiter in unbekannt Gebieten	Does it make a difference whether you walk in known or unknown areas? Yes no a. Yes he explores further in known areas b. Yes he explores further in unknown areas
Haben Sie eine feste Spaziergangsrunde oder wechseln Sie die Runden regelmäßig? a. Fest b. Wechselnd	Do you walk the same or changing rounds regularly? a. The same b. Changing
Wie lang sind Ihre durchschnittlichen Spaziergänge? a. 30-60 Minuten b. 60-90 Minuten c. Über 90 Minuten	How long is your average dog walk? a. 30-60minutes b. 60-90 minutes c. Longer than 90 minutes
Wie kommunizieren Sie mit Ihrem Hund normalerweise während des Spaziergangs? a. Rufen b. Pfeifen c. Sichtsignale/Handsignale d. Andere:	How do you communicate with your dog during your walk? a. Calling b. Whistling c. Hand signals/other signals d. Other:

Fragebogen	Questionnaire
Zeigen Sie einen Richtungswechsel an? Ja Nein	Do you indicate a change of direction to your dog? Yes no
Wie? a. Rufen b. Pfeifen c. Sichtsignale/Handsignale d. Andere:	How? a. Calling b. Whistling c. Hand signals/other signals d. Other:
Wie oft rufen Sie Ihren Hund auf einem Spaziergang? a. Sehr oft b. Bei jedem externen Reiz (Fahrrad etc.) c. Bei jedem Richtungswechsel d. Sobald ich ihn nicht mehr sehe e. Sobald er sich mehr als 20m entfernt f. Nur in Notsituationen (Auto/Wild) g. Nie h. Weiß nicht	How often do you call your dog during a walk? a. Very often b. At every external stimuli (bike etc.) c. Every change of direction d. As soon as I cannot see him any more e. If he is more than 20m away f. Only in emergency situations (car/game) g. Never h. Don't know
Denken Sie, dass Ihr Hund weiß, wo Sie sich befinden, auch wenn er Sie nicht sieht/hört? Ja Nein	Do you think your dog knows where you are even if he does not see/hear you? Yes no
Halten Sie Ihren Hund für verlässlich/wird er zu Ihnen zurückkommen auch wenn Sie nicht rufen? a. Ja immer b. Nur wenn er nicht abgelenkt ist (andere Hunde/Wild) c. Nein d. Weiß nicht	Do you think your dog will reliably return to you even if you do not call him? a. Yes always b. Only if he is not diverted (other dogs/game) c. No d. Don't know
Wie wird Ihr Hund reagieren, wenn Sie ihn während des Spaziergangs nicht rufen/ansetzen/kommunizieren? a. Es macht keinen Unterschied b. Er wird uns nicht folgen c. Er wird verlorengelassen d. Er wird jagen gehen e. Er wird sich weiter entfernen f. Ich weiß nicht	How will your dog react if during a walk you do not call him/look at him/communicate with him? a. It makes no difference b. He will not follow us c. He will get lost d. He will start hunting e. He will explore further f. I don't know
Bemerkungen:	Comments:

For a number of items regarding owner demographics see **Table M 3.2.2**. The majority of participants were female (90 %), married, had their own house with garden, without children living at home and with more than 1 dog living in the household.

Table M3.2.2: *Owner demographics in percentage with nine variables.*

owner	Variable	N= 30	%
gender	Male	3	10
	female	27	90
Marital status	Single	8	26.7
	Married	16	53.3
	In relationship	2	6.7
	Widowed	2	6.7
	divorced	2	6.7
Grew up with animals	Yes	17	56.7
	no	13	43.3
Has a garden at home	Yes	28	93.3
	no	2	6.7
employment	Full time	27	90
	Part time	2	6.7
	student	1	3.3
Mainly responsible for pet	yes	17	56.7
	no	0	0
	Being shared	13	43.3
Children <18 living in household	Yes	4	13.3
	no	26	86.7
People > 60years living in household	yes	3	10
	no	27	90
More than 1 dog in household	yes	25	83
	no	5	17

Table M 3.2.3: Owner questionnaire overview as applied to LAPS assessment.

Owner	Dog(s)	Attachment 1 (high)- 6 (low)	Orientation on owner; Reliance bonding? 1-6	How will your dog react if you do not call during a walk	Do you think your dog knows where you are if he cannot see /smell/hear you	Difference known unknown area	Judgment maximal distance of dog	Will your dog find you if you do not call	How often do you call	orienta- tion	Hunting behavior	Adopted/ or since puppy
H.M	Amanda	1	1	No difference	yes	no	100m	Don't know	Every external stimuli + emergencies	Don't know	4	P
	Wantje	1	1	No difference	Don't know	no	100m	Don't know	Every external stimuli + emergencies	Don't know	1	p
S.S	Amy	1	1	No difference	yes	Further known	40m	yes	Every external stimuli + emergencies + out of view/20m +	Same track back	3	p
	Nele	1	1	No difference	yes	no	15m	yes	Every external stimuli + emergencies + out of view/20m +	Same track back	3	p
V.B	Arthur	1	1	No difference	yes	Further known	30m	yes	Every external stimuli	Olfaction Same track back	4	p
H.N	Balin	2	2	No difference	Yes	no	100m	Yes	Every external stimuli	Same track back	3	a
C.C.	Balou RR	2	3	Travels further	yes	no	200m	yes	Every external stimuli + emergencies	Same track back	5	a

Owner	Dog(s)	Attachment 1 (high)- 6 (low)	Orientation on owner; Reliance bonding? 1-6	How will your dog react if you do not call during a walk	Do you think your dog knows where you are if he cannot see /smell/hear you	Difference known unknown area	Judgment maximal distance of dog	Will your dog find you if you do not call	How often do you call	orienta- tion	Hunting behavior	Adopted/ or since puppy
	Luna	2	2	Will go hunting	yes	Further known	500m	yes	Every exter- nal stimuli + emergencies	Same track back	4	a
C.B.	Balou_M ix	2	2	No difference	yes	no	100m	yes	Every exter- nal stimuli + out of sight	Same track back	4	a
	Lily	1	1	No difference	yes	Further known	20m	yes	emergencies	Same track back	3	a
S.L	Bill	1	2	Stays closer	yes	Further known	500m	yes	emergencies	Star loop olfaction	2	a
	Kaito	1	3	Stays closer	yes	Further known	500m	yes	emergencies	Same track back loop olfac- tion	4	a
	Lou	4	4	He will stay closer	yes	Further known	400m	yes	emergencies	Same track back loop olfac- tion	4	a
S.M	Dr. Pepper	2	1	No difference	yes	no	500m	yes	Every exter- nal stimuli	Same track back	4	p
	Raiya	3	4	Will travel further	no	Further known	1000m	no	Every exter- nal stimuli	Same track back + olfaction	1	a
E.M	Emma Lea	2	2	If not distracted by prey etc	yes	Further known	100m	Don't know	Every exter- nal stimuli + out of sight	Same track back	3	a

Owner	Dog(s)	Attachment 1 (high)- 6 (low)	Orientation on owner; Reliance bonding? 1-6	How will your dog react if you do not call during a walk	Do you think your dog knows where you are if he cannot see /smell/hear you	Difference known unknown area	Judgment maximal distance of dog	Will your dog find you if you do not call	How often do you call	orienta- tion	Hunting behavior	Adopted/ or since puppy
A.S.	Emma	1	2	No difference	yes	no	20m	yes	Every external stimuli + emergencies	Same track back + olfaction	5	a
	Maloca	1	1	No difference	yes	no	10m	yes	Every external stimuli + emergencies	Don't know	1	a
	Zlata	2	2	No difference	yes	no	30m	yes	Every external stimuli + emergency	Same track back	1	a
N.P.	Freya	2	2	No difference	yes	Further known	50m	yes	Every external stimuli + emergencies	Same track back	2	p
D.S.	Honey	2	2	Dont know-will travel further	Dont know	Further known	100m	Don't know	Every external stimuli + out of sight	Same track back	3	a
M.K.	Kimi	5	4	Will travel further	Dont know	Further known	10m	Don't know	Every external stimuli	Same way back	1	a
	Nina	6	5	Will travel further	Dont know	Further known	20m	Don't know	Every external stimuli	No strategy	6	a
A.U.	Manja	1	1	Could get lost	Dont know	Further known	6m	Don't know	Very often beyond 20m, every stimuli	No strategy	3	a
	Raffaele	1	1	Stays closer	Most of the time	no	50m	yes	Out of sight + emergency	Olfaction zick zack	2	a

Different measures were applied to correlate with the LAPS score, e.g. distance and duration measures, speed and travelling patterns utilized by the dogs. **Table R3.3.9** shows the correlative values between the LAPS categories and LAPS total and attachment; hunting behaviour and reliance on owner values and differences based on the sex of dog **Table R3.3.10**; the reproductive status of dog **Table R3.3.11**; whether purebred or mixed breed **Table R3.3.12**; whether adopted or from a breeder **Table R3.3.13**.

3.2.2 LAPS - Lexington Attachment to Pets Scale

Online and paper-pencil questionnaires were used. LAPS and socio-demographic data were recorded. Subjects were recruited via social media and with the help of other associations.

The Lexington Attachment to Pets Scale (LAPS) by Johnson et al. (1992) is a widely used instrument to measure attachment of owners to their pets (Bagley & Gonsman, 2005; Reevy & Delgado, 2015; Johnson et al., 1992; Stoeckel et al., 2014). The German translation from Hielscher et al. (2019) was used for all owners herein (which also supplies the original English version) **Table M 3.2.4**. The questionnaire contains 23 items overall and measures a total value of owner attachment on a scale of 0 to 69. The LAPS questionnaire consists of three subscales: "General Attachment", "People Substituting" and "Animal Rights / Animal Welfare" which contain 11, 7 and 5 items respectively and the Total LAPS Score. The coding of the items lies between 0 (strongly disagree) and 3 (strongly agree). All items except items H and U show a higher attachment if a higher number is given. In the items H and U a lower coding indicates higher attachment. Consequently, these two items need to be re-coded with the order being reversed. The range of total LAPS score lies between 0 and 69. Within this study each owner (n = 18) filled out the LAPS questionnaire for all of their dogs. Totally n = 30 questionnaires are available. Overall, 11 different dog breeds are represented in this study. The questionnaire was administered as traditional paper format.

Table M 3.2.4: LAPS German translation according to Hielscher et al. (2019).

Bewertung		Name/Datum Hund:
0		Trifft überhaupt nicht zu
1		Trifft eher nicht zu
2		Trifft eher zu
3		Trifft voll zu
A	Mein Haustier bedeutet mir mehr als jeder meiner Freunde.	0 1 2 3
B	Ich vertraue mich meinem Haustier häufig an.	0 1 2 3
C	Ich finde, dass Haustiere dieselben Rechte und Privilegien haben sollten wie andere Familienmitglieder auch.	0 1 2 3
D	Ich finde, dass mein Haustier mein bester Freund/meine beste Freundin ist.	0 1 2 3
E	Meine Gefühle gegenüber Leuten werden häufig davon beeinflusst, wie sich diese meinem Haustier gegenüber verhalten.	0 1 2 3
F	Ich liebe mein Haustier, weil er/sie mir gegenüber loyaler ist, als die meisten Menschen in meinem Leben.	0 1 2 3
G	Ich genieße es anderen Menschen Bilder meines Haustieres zu zeigen.	0 1 2 3
H	Ich finde, mein Haustier ist nur ein Haustier.	0 1 2 3
I	Ich liebe mein Haustier, weil es mich nie verurteilt.	0 1 2 3
J	Mein Haustier weiß es, wenn es mir schlecht geht.	0 1 2 3
K	Ich spreche oft mit anderen Menschen über mein Haustier.	0 1 2 3
L	Mein Haustier versteht mich.	0 1 2 3
M	Ich glaube, dass die Liebe zu meinem Haustier mir hilft gesund zu bleiben.	0 1 2 3
N	Haustiere verdienen genau so viel Respekt wie Menschen.	0 1 2 3
O	Mein Haustier und ich haben eine sehr enge Beziehung.	0 1 2 3
P	Ich würde fast alles tun um gut für mein Haustier zu sorgen.	0 1 2 3
Q	Ich spiele häufig mit meinem Haustier.	0 1 2 3
R	Ich finde, dass mein Haustier ein toller Begleiter ist.	0 1 2 3

Bewertung		Name/Datum Hund:
0		Trifft überhaupt nicht zu
1		Trifft eher nicht zu
2		Trifft eher zu
3		Trifft voll zu
S	Mein Haustier macht mich glücklich.	0 1 2 3
T	Ich finde, dass mein Haustier ein Teil meiner Familie ist.	0 1 2 3
U	Ich bin meinem Haustier nicht sehr verbunden.	0 1 2 3
V	Der Besitz eines Haustieres macht mich glücklicher.	0 1 2 3
W	Für mich ist mein Haustier ein Freund/eine Freundin.	0 1 2 3

3.2.3 Statistical analysis

Continuous variables are presented as mean (MW), standard deviation (SD), median and quartiles (Q25 and Q75). Discrete variables are summarized as absolute and relative frequencies. Boxplots are used for graphical visualization. Spearman correlation coefficients are applied to measure the relationship of two continuous or ordered variables. To compare LAPS between independent groups Mann-Whitney-U Test (p-value) was used. Kruskal-Wallis Test was applied for comparison between three groups. Standard Bonferroni correction was obtained for correction of multiple testing. Level of significance was set to 5 %. All tests are performed two-tailed using SPSS version 25, IBM Inc.

Statistical tools to determine the reliability and validity of the components assessed by multivariate analysis of questionnaire data are in a similar way to their application in canine behavioral testing. In the context of a questionnaire, reliability refers to the internal consistency, the degree to which individual questions associated with a specific construct are correlated and Cronbach alpha coefficient is used as an estimate of internal consistency, where measures greater than 0.7 are generally considered acceptable (Wiener & Haskell, 2016). Hielscher et al. (2019) found in their study an internal consistency for the total LAPS score of Cronbach's $\alpha = .89$ and a test-retest reliability for the total LAPS score of ICC = .95; 95 % CI = .94, .96; $p < .001$.

3.3 Results

3.3.1 Owner Questionnaires/ LAPS Questionnaire results

For all dog-owner teams LAPS total showed a mean of 57.1 (6.55 SD) with a median of 57 and lower and upper quartile of 55 and 61. Considering a range from 0 to 69 the observed values showed high attachment and bonding of all owners and his/her dog(s). All subscales showed high to excellent values: for LAPS general attachment a median of 29 (quartiles: 27 and 31) could be observed, where the theoretically achievable maximum of this subscale was 33. For LAPS substitution the median was 15 (quartiles: 13 and 18) compared to the theoretical maximum of 21. Observed median of subscale LAPS animal right/welfare was 13 (quartiles: 13 and 15) compared with a theoretically achievable maximum of 15 **Table R3.3.1; Fig. R3.3.1**. In comparison, in his study Hielscher et al. 2019 found a slightly lower but comparable owner-dog attachment ($M = 55.49$, $SD = 8.28$) with women ($M = 55.35$, $SD = 8.56$) scoring higher than men ($M = 52.30$, $SD = 8.92$). Herein I did not differentiate between men and women as only two owners were men. Each owner was also asked in a separate questionnaire to assess behavior of his/her dog(s) and a descriptive overview of these questions can be obtained in **Table R3.3.2** and for details see **Table M3.2.1**.

3.3.2.1 Distance measures and correlations

Correlations were analysed to determine whether the distance an owner walks with his/her dog was related to attachment. Further, to see whether the exploration behavior of the dog distancewise was evaluated differently by owners. I expected dogs that stayed closer to their owner to be given a higher owner attachment value. Distance measures and LAPS scores are shown in **Table R3.3.3** and a positive correlation could be demonstrated between the total distance of owner walk and animal welfare ($r = 0.266$; $p = 0.003$, $p^* = 0.072$). Significant correlations were found between total distance of the dog walk and people substitution, animal rights and LAPS total. A significant correlation could also be shown between the total distance of the dog walk and people substitution ($r = 0.414$; $p = <0.001$; $p^* >0.024$), animal rights/welfare ($r = 0.304$; $p = 0.001$; $p^* = >0.024$) and LAPS total ($r = 0.380$; $p = <0.001$ $p^* = >0.024$). Longer walking distances were correlated with a higher outcome of LAPS thus higher owner attachment scores to their dog, **Table R3.3.3**.

3.3.2.2 Duration measures and correlations

Correlations were tested to see whether the duration of the owner walk with the dog was related to attachment and to see whether longer exploration behaviour of the dog was assessed differently by the owner. I expected dogs that explored shorter to be evaluated with a higher owner attachment value. Duration measures are shown in **Table R3.3.4**. Positive correlations could be seen between duration of dogs exploration round and people substitution ($r = 0.227$; $p = 0.013$; $p^* = 0.260$) indicating that the owner attachment correlates with quality time spent with their dog. Also animal welfare ($r = 0.312$; $p = 0.002$; $p^* = 0.020$) and LAPS total ($r = 0.206$; $p = 0.024$; $p^* = 0.480$) were positively correlated, therefore, the longer the total travelling round, the higher the scores of LAPS. Also the duration of owners walking rounds showed these positive correlations indicating that the owner attachment correlates with quality time spent with their dog.

3.3.2.3 Correlations of speed measures and LAPS scores

Speed measures were taken to see whether dogs that explored at the same speed as their owner were given higher attachment values than dogs who travelled at a different (generally higher) speed. Correlations between speed measures and LAPS scores can be seen in **Table R3.3.5**. Positive correlation could be obtained between dog speed and people substitution ($r = 0.243$; $p = 0.007$; $p^* = 0.224$), speed of the total round ($r = 0.239$; $p = 0.010$; $p^* = 0.320$) and negative correlations between speed difference between owner and dog ($r = -0.182$; $p = 0.046$, $p^* > 0.999$) could be shown. Correlations between speed difference and people substitution were also negative, so that higher speed difference was correlated with lower values of people substitution. Thus it is indicated that at similar walking speed the owner attachment to his/her dog is higher compared to the dog travelling at a different speed from owner (implying that they do not walk together and do not display temporal or spatial synchronicity). Correlations of attachment match similar walking speed of the owner-dog team.

3.3.2.4 Correlations between travelling patterns and LAPS scores

Exploration patterns were assessed as I expected owners of dogs displaying easy and controllable patterns like running ahead /following to be evaluated with higher attachment values compared to dogs that used extensive exploration patterns (like Group 3 dogs). Correlations between exploration patterns and LAPS scores can be seen in **Table R3.3.6**. Higher LAPS scores were expected from owners if their dogs used “easy” and

controllable patterns of exploration like runs ahead or follows, which however were negatively correlated. Negative correlations could be seen between runs ahead waits/follows and the subscale animal rights ($r = -0.261$; $p = 0.004$, $p^* = 0.128$) and owner LAPS total ($r = -0.211$; $p = 0.021$; $p^* = 0.672$).

3.3.3.1 Owner-dog scores for each dog and dyads/triads

Table R3.3.4 shows the results of owner LAPS for each dog in each category and in total and **Table R3.3.5** groups the results of owner LAPS by dog-owner dyad/triad for each LAPS category and LAPS total. Results of owner assessment for each dog of one owner are very similar, but not equal, independent of breed, personality or age differences of the dogs. Out of the 30 dogs eight belonged to a single dog household owner, 22 to a two or more dog owner – in this group ten owners accounted for 22 dogs **Tables M1.2.1; M2.2.2**.

3.3.3.2 Owner assessment **Table R3.3.2** and LAPS

I expected a high hunting assessment to correlate negatively with owner attachment as the view on hunting behaviour of pet dogs was in the main negative. **Table R3.3.9** shows the correlative values between the LAPS categories and LAPS total and attachment; hunting behaviour and reliance on owner values. The hunting score was negatively correlated with general attachment, substitution and LAPS total. The hunting behaviour correlation had a high negative correlation with a value of $r = -0.538$ ($p < 0.001$; $p^* = < 0.012$) for general attachment, people substitution ($r = -0.197$; $p = 0.031$; $p^* = < 0.372$), and LAPS total ($r = -0.325$; $p = < 0.001$; $p^* = < 0.012$). Reliance on owner, measured at a 6 step scale was negatively correlated with general attachment ($r = -0.204$; $p = < 0.026$; $p^* = < 0.321$).

3.3.3.3 P-values between the LAPS categories and sex of dog

As sex differences have been proposed with respect to dog behaviour, in particular hunting/exploration behaviour (see discussion Part 2) attachment of owners based on sex of his/her dog was assessed here as well. **Table R3.3.10** shows the correlative values between the LAPS categories and LAPS total and assessment of owners of male versus owners of female dogs. Significant differences between owners of male and owners of female dogs could be seen for the subscales general attachment ($p = 0.010$; $p^* = 0.040$), animal rights/welfare ($p = 0.041$) and LAPS total ($p = 0.025$; $p^* = 0.100$). Owners of male dogs'

displayed higher values in these subscales than owners of female dogs. The differences between owners of male and owners of female dogs were about 1 unit/point for general attachment and animal right/welfare and 3 units/points for LAPS total indicating different levels of attachment based on the sex of the dog **Table R3.3.10** and **Fig. R3.3.2**.

3.3.3.4 P-values between the reproductive status of the dog(s) and LAPS owner

As behavioural differences have been proposed based on the reproductive status of the dog including exploration behaviour (see discussion Part 2) attachment of owners based on the reproductive status of his/her dog was assessed here as well. Furthermore animal welfare issues are often connected with castrating issues. Significant differences of attachment values between owners of intact and owners of neutered dogs could be seen at general attachment ($p = 0.009$; $p^* = 0.036$), people substitution ($p = 0.045$), and at the animal rights level ($p = <0.001$; $p^* = 0.004$) **Table R3.3.11**, **Fig R3.3.3**. Owners of intact dogs show higher values in general attachment (about 1.5 unit/point) and lower values in people substitution (about 1 unit/point) and animal rights (about 1.3 unit/point) than owners of neutered dogs.

3.3.3.5 P-values differences between the LAPS categories and purebred versus mixed breed dog

Differences have been proposed with respect to attachment of owners of purebred versus mixed breed dogs, therefore data was analysed accordingly. Significant differences between the owners of purebred and owners of mixed breed dogs could be seen at the animal rights level ($p = 0.001$; $p^* = 0.004$), difference about 1 unit/point, and LAPS total ($p = 0.015$), difference about 1.5 units/points. Owners of purebred dogs show lower values in these subscales than owners of mixed breed dogs **Table R3.3.12**, **Fig R3.3.4**.

3.3.3.6 P-values differences between the LAPS categories and adopted versus breeder bought dogs.

Differences have been proposed with respect to attachment of owners of adopted dogs versus dogs bought from a breeder (at puppy age), therefore data was analysed accordingly. **Table R3.3.13** shows the correlative values between the LAPS categories and LAPS total and owner assessment of owners of adopted versus owners of breeder bought dogs. Significant differences between owners of adopted and owners of breeder bought dogs could be seen at the animal right/welfare subscale ($p = 0.002$; $p^* = 0.004$).

Owners of adopted dogs show higher values in animal welfare than owners of breeder bought dogs **Fig. R3.3.5**. The attachment value differences between owners of adopted and breeder bought dogs were about 1.5 units/points.

3.3.3.7 Different radius groups (Group 1, 2 and 3) and owner LAPS

As the different radius groups displayed very different exploration behavior I analyzed whether owner attachment differed according to the distance explored by the groups. **Table R3.3.14** shows the different radius groups (Group 1, 2 and 3) and the owners LAPS parameters. Significant differences between owners of dogs of different radius groups could be seen at the people substitution subscale ($p = <0.001$) and LAPS total ($p = 0.001$). LAPS substitution and total score was different for owners of dogs belonging to the radius ≥ 350 m group compared to both other groups. Owner of dogs having a large radius ≥ 350 m (Group 3) have larger scores at people substitution and total LAPS values compared to the other owner groups. No difference was apparent between owners of Group 1 and Group 2 dogs **Fig R3.3.6**.

3.3.4 Comparison self-assessment and measurements of owner and their dogs

Due to the discussion of how far dogs actually explore and whether they engage in hunting behaviour I asked the owners to estimate maximum, median/mean distance of exploration distance of their dogs to compare to the factual distance explored. None of the owner was able to accurately estimate the distance their dogs explored. In **Table R3.3.15** the factual distances recorded during the runs >20 m are listed and compared to the estimation of their owner. As can be seen in **Table R3.3.15** and **Fig. R3.3.7** the inbound or outbound distance of the dogs is generally overestimated by the owners. The maximal distance explored on runs >20 m by the dogs on the other hand was underestimated by all owners except two. Additionally, owners were asked to estimate the duration of their dogs exploration runs >20 m. Owners in general overestimated the duration of exploratory runs >20 m in total as well as on the inbound/outbound scale **Table R3.3.16; Table R3.3.17 and Fig. R3.3.8**.

3.3.1 Owner LAPS scores

Assessment of owner values according to all three LAPS categories and LAPS total: General Attachment; People Substitution; Animal welfare/rights and LAPS total for all questionnaires (n=30) on a scale 0-69 total points.

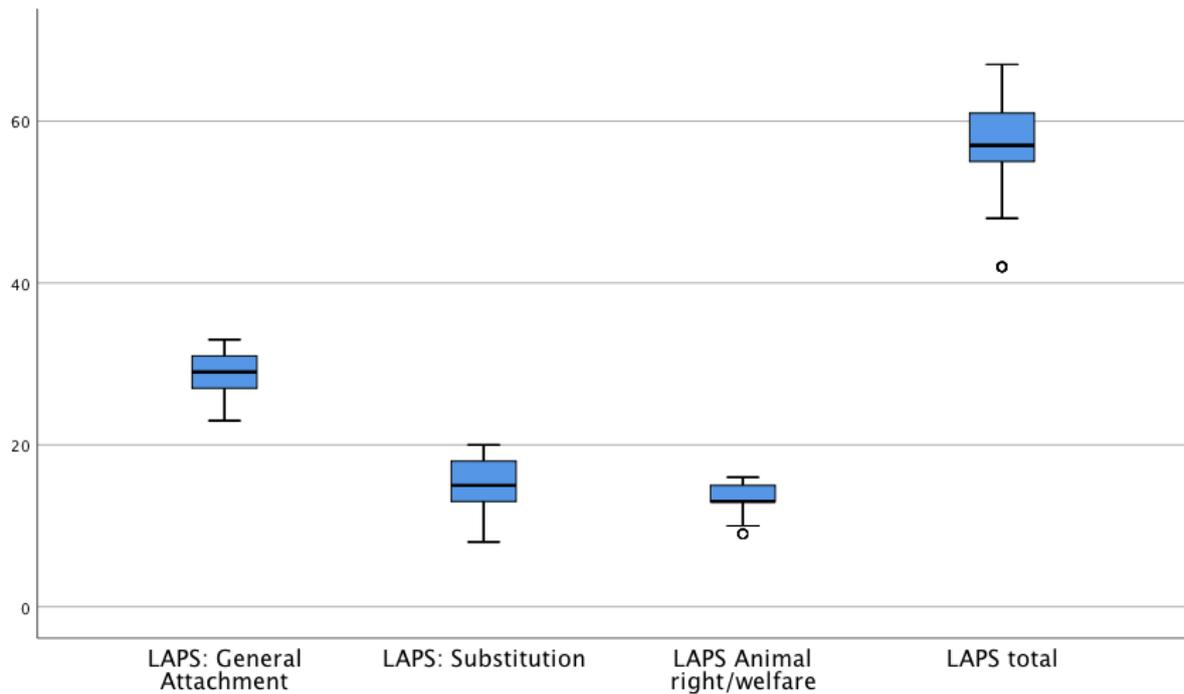


Fig. R3.3.1: Owner LAPS scores General Attachment; People Substitution; Animal welfare/rights and LAPS total for all questionnaires (n=30) on a scale 0-69 total points.

The observed values show high attachment and bonding of all owners towards his/her dog(s) and all subscales show high to excellent values.

Table R3.3.1: Owner LAPS scores General attachment/people substitution/Animal right/welfare/LAPS total for all questionnaires (n=30) mean and median and range.

n = 30	mean	SD	Q25	median	Q75	range
LAPS: general attachment	29.00	2.84	27	29	31	23-33
LAPS: People substitution	14.70	3.57	13	15	18	8-20
LAPS Animal right/welfare	13.40	1.65	13	13	15	9-16
LAPS total	57.10	6.55	55	57	61	42-67

For all dogs the owner LAPS total shows a mean of 57.1 (6.55 SD) with a median of 57 and lower and upper quartile of 55 and 61 and an observed range of 42-67. Considering a range from 0 to 69 the observed values show high attachment and bonding of all owners towards his/her dogs. All subscales show high to excellent values: for LAPS general attachment a median of 29 (quartiles: 27 and 31) can be observed, where the theoretically achievable maximum of this subscale is 33. The range is from 23-33. For LAPS people substitution the median is 15 (quartiles: 13 and 18) compared to the theoretically maximum of 21 and a range of 8-20. Observed median of subscale LAPS animal rights/welfare is 13 (quartiles: 13 and 15) compared with a theoretically achievable maximum of 15 and a range of 9-16.

In comparison Hielscher et al. (2019) found the following values:

	mean	SD	Range
LAPS: general attachment	27.81	3.89	10-33
LAPS: Substitution	14.60	3.98	2-21
LAPS Animal right/welfare	12.64	2.05	5-15
LAPS total	55.07	8.63	20-69

In addition to the LAPS questionnaire several other questions were asked of the owners. Owners had to assess the hunting and bonding/attachment behaviour of each of their dog(s). Also they had to assess whether their dog(s) could remember the position of the owner and how far dogs would explore outside the area of owners influence. A descriptive overview of the questions can be obtained in **Table R3.3.2**.

Table R3.3.2: Owner assessment of his/her dog – overview of questions in %.

		n	%
Reliance on Owner (1 high-6 low)	1	11	36.67 %
	2	12	40.00 %
	3	2	6.67 %
	3.5	1	3.33 %
	4	2	6.67 %
	5	2	6.67 %
Attachment (1 high-6 low)	1	14	46.67 %
	2	12	40.00 %
	3	1	3.33 %
	4	1	3.33 %
	5	1	3.33 %
	6	1	3.33 %
Hunting behaviour (1 low-6 high)	1	6	20.00 %
	2	4	13.33 %
	3	6	20.00 %
	4	6	20.00 %
	5	4	13.33 %
	6	4	13.33 %
How will your dog react if you do not call during a walk	Could get lost	1	3.33 %
	Don't know - will travel further	1	3.33 %
	If not distracted by prey etc.	1	3.33 %
	No difference	16	53.33 %
	Stays closer	4	13.33 %
	Travels further	5	16.67 %
	Will go hunting	1	3.33 %
	Will travel further and go hunting	1	3.33 %
Difference known unknown area	no difference	13	43.33 %
	further known	17	56.67 %
Adopted/since puppy?	puppy	11	36.67 %
	adopted	19	63.33 %
How often do you call	depends	2	6.67 %
	emergencies	6	20.00 %
	Every external stimuli	6	20.00 %
	Every external stimuli + out of sight	3	10.00 %
	Every external stimuli+emergencies+out of view/20m+	1	3.33 %
	Every external stimulus + emergencies	9	30.00 %

		n	%
	Out of sight + emergency	1	3.33 %
	Very often beyond 20m, every stimuli	1	3.33 %
	Whenever out of sight	1	3.33 %
Will your dog find you if you do not call	don't know	8	26.67 %
	no	2	6.67 %
	yes	20	66.67 %
Do you think your dog knows where you are if he cannot see /smell/hear you	don't know	6	20.00 %
	no	2	6.67 %
	yes	21	70.00 %
	most of the time	1	3.33 %

Owner reliance (almost 80 % value 1 and 2) and bonding/attachment (almost 90 % value 1 and 2) values are over all extremely high. Asked how the dog would react if not called during a walk about half of the owners (53 %) said it made no difference. Regarding the difference between known and unknown area a little less than half of the owners answered that it made no difference (43 %) and 57 % said that the dogs would explore further in known areas. More than half (63 %) of the dogs in the study were adopted and had not been bought from a breeder. The calling frequencies varied strongly between the owners, with owners of Group 1 dogs calling their dog more frequently than owners of Group 3 dogs which called their dog only in emergencies. Interestingly, asked if their dog would find them if not called 2/3 of the owners answered yes but 1/3 did not know. On the other hand 70 % answered that their dog would know where the owner was even if he/she could not see /smell/hear the owner. 20 % were not certain whether their dog would know the owner location.

3.3.2 Correlations between hunting score, LAPS and travelling patterns/distance/time dog/s) of one owner.

3.3.2.1 Distance

Correlations of distance measures and owner LAPS scores are assessed in **Table R3.3.3**. Longer walking distances are correlated with higher outcome of LAPS. A significant correlation can be seen between the total distance of the dog walk and people substitution.

Table R3.3.3: Spearman correlation coefficient (r) and corresponding p -value. P^* : Bonferroni correction of p -value. Correction factor for Bonferroni: $4 \times 6 = 24$; only significant uncorrected p -values are affected.

		LAPS: General Attachment	LAPS: People Substitution	LAPS Animal right/welfare	LAPS total
total distance walk owner total in m	r	-0.053	0.110	0.266	0.134
	p	0.568	0.230	0.003	0.143
	p^*			0.072	
total distance dog walk in m	r	0.036	0.414	0.304	0.380
	p	0.696	<0.001	0.001	<0.001
	p^*		<0.024	0.024	<0.024
total runs > 20 m in m	r	-0.081	0.097	-0.117	0.022
	p	0.381	0.294	0.202	0.812
	p^*				
Max distance of run in m	r	-0.012	0.182	-0.088	0.118
	p	0.893	0.047	0.337	0.201
	p^*		>0.999		
Distance outbound in m	r	-0.079	0.162	0.072	0.122
	p	0.439	0.109	0.478	0.229
	p^*				
Distance inbound in m	r	-0.089	0.148	0.092	0.131
	p	0.382	0.143	0.367	0.196
	p^*				

Positive correlations can be seen between the total distance of owner walk and animal welfare ($r = 0.266$; $p = 0.003$, $p^* = 0.072$), but p^* after Bonferroni correction is slightly above 5%. Significant correlations can be seen between the total distance of the dog walk and people substitution, animal right and LAPS total. Maximum distance of runs is positively correlated with people substitution ($r = 0.182$; $p = 0.047$; $p^* = >0.999$), however no significance could be achieved after Bonferroni correction. Longer walking distances are correlated with higher outcome of LAPS. A significant correlation can also be seen between the total distance of the dog walk and people substitution ($r = 0.414^{**}$; $p = <0.001$; $p^* >0.024$), animal rights/welfare $r = 0.304^{**}$; $p = 0.001$; $p^* = >0.024$ and LAPS total $r = 0.380^{**}$; $p = <0.001$ $p^* = >0.024$). Longer walking distances are correlated with a higher outcome of LAPS thus higher owner attachment to their dog.

3.3.2.2 Duration

Correlations of duration measures and owner LAPS scores are assessed in **Table R3.3.4**. Positive correlations can be seen between the duration of the dogs' exploration round and people substitution, animal welfare and LAPS total.

Table R3.3.4: Spearman correlation coefficient (r) and corresponding p -value. P^* : Bonferroni correction of p -value. Correction factor for Bonferroni: $4 \times 5 = 20$; only significant uncorrected p -values are affected.

		LAPS: General Attachment	LAPS: people substitution	LAPS Animal right/welfare	LAPS total
Time_20 m_away	r	-0.094	0.073	-0.105	0.008
	p	0.309	0.429	0.253	0.933
	p^*				
Duration of dogs traveling round in min	r	-0.039	0.227*	0.312**	0.206*
	p	0.673	0.013	0.001	0.024
	p^*		0.260	0.020	0.480
Duration of owners walking round in min.	r	-0.031	0.223*	0.267**	0.191*
	p	0.737	0.015	0.003	0.037
	p^*		0.300	0.060	0.740
Time_inbound	r	-0.063	0.168	0.121	0.144
	p	0.534	0.094	0.229	0.154
	p^*				
Time_outbound	r	-0.122	0.057	0.084	0.026
	p	0.225	0.572	0.406	0.794
	p^*				

The longer the total travelling round, the higher the scores of LAPS. General Attachment shows no positive correlation with duration. Positive correlations can be seen between the duration of the dogs exploration round and people substitution ($r = 0.227$; $p = 0.013$; $p^* = 0.260$) indicating that the owner attachment correlates with quality time spent with their dog. Also animal welfare ($r = 0.312$; $p = 0.002$; $p^* = 0.020$) and LAPS total ($r = 0.206$; $p = 0.024$; $p^* = 0.480$) are positively correlated, therefore, the longer the total travelling round, the higher the scores of LAPS. Time spent with their dog may be an indicator of the owner pet attachment. The duration of the owners walking round also shows these correlations indicating that the owner attachment correlates with quality time spent with their dog: people substitution ($r = 0.223$; $p = 0.015$; $p^* = 0.300$); animal

welfare ($r = 0.267^*$; $p = 0.003$; $p^* = 0.060$) and LAPS total ($r = 0.191^*$; $p = 0.037$; $p^* = 0.740$) were positively correlated but p^* after Bonferroni correction was above 5 %.

3.3.2.3 Speed

Correlations of speed measures and owner LAPS scores are assessed in **Table R3.3.5**. Positive correlation could be obtained between dog speed and people substitution, speed of the total round and negative correlations can be seen between speed differences between owner and dog.

Table R3.3.6: Spearman correlation coefficient (r) and corresponding p -value. P^* : Bonferroni correction of p -value. Correction factor for Bonferroni: $4 \times 8 = 32$; only significant uncorrected p -values are affected.

		LAPS: General Attachment	LAPS: people substitution	LAPS Animal right/welfare	LAPS total
dog average speed in km/h	r	0.012	0.243**	-0.097	0.163
	p	0.899	0.007	0.293	0.076
	p^*		0.224		
owner average walking speed in km/h	r	-0.015	0.112	0.075	0.097
	p	0.871	0.223	0.419	0.294
	p^*				
speed outbound in km/h	r	0.194	0.194	-0.102	0.150
	p	0.054	0.055	0.315	0.139
	p^*				
speed inbound in km/h	r	0.073	0.046	-0.088	0.039
	p	0.471	0.649	0.388	0.702
	p^*				
mean speed total round km/h	r	0.005	0.239**	-0.090	0.164
	p	0.955	0.010	0.334	0.078
	p^*		0.320		
speed maximum km/h	r	-0.005	-0.064	-0.128	-0.037
	p	0.955	0.488	0.165	0.688
	p^*				
speed minimum in km/h	r	0.152	-0.062	0.044	0.078
	p	0.099	0.503	0.637	0.397
	p^*				
Speed_Difference owner-dog	r	-0.014	-0.182*	0.138	-0.103
	p	0.880	0.046	0.132	0.261
	p^*		>0.999		

Positive correlations could be obtained between dog speed and people substitution ($r = 0.243$; $p = 0.007$; $p^* = 0.224$), speed of the total round ($r = 0.239$; $p = 0.010$; $p^* = 0.320$) and negative correlations between speed differences between owner and dog ($r = -0.182$; $p = 0.046$, $p^* > 0.999$) are found, however no significance can be achieved after Bonferroni correction. Correlation values are relatively low. Correlations between speed difference and people substitution are negative, so that a higher speed difference is correlated with lower values of people substitution. Correlations of attachment match similar walking speed of the owner-dog team.

3.3.2.4 Travelling patterns

Correlations between travelling patterns and owner LAPS scores are assessed in **Table R3.3.6**.

Table R3.3.6: Spearman correlation coefficient (r) and corresponding p -value. . P^* : Bonferroni correction of p -value. Correction factor for Bonferroni: $4 \times 8 = 32$; only significant uncorrected p -values are affected.

		LAPS: General Attachment	LAPS: people substitution	LAPS Animal right/welfare	LAPS total
Runs ahead waits/follows	r	-0.143	-0.152	-0.261**	-0.211*
	p	0.120	0.098	0.004	0.021
	p^*			0.128	0.672
Star	r	0.067	0.166	-0.005	0.143
	p	0.467	0.070	0.956	0.120
	p^*				
loop	r	0.048	0.135	0.050	0.125
	p	0.603	0.141	0.585	0.175
	p^*				
Loop+Star	r	0.072	0.071	0.039	0.103
	p	0.434	0.441	0.676	0.262
	p^*				
Mix form runs ahead&loop	r	-0.178	-0.118	-0.060	-0.160
	p	0.051	0.200	0.518	0.080
	p^*				
Mix form runs ahead&star	r	-0.118	-0.093	-0.295**	-0.178
	p	0.200	0.310	0.001	0.052
	p^*			0.032	

		LAPS: Gen- eral Attach- ment	LAPS: people substitution	LAPS Animal right/welfare	LAPS total
runs parallel then meets owner	r	0.057	0.198*	0.127	0.195*
	p	0.538	0.030	0.165	0.033
	p*		0.960		>0.999
number of runs >20m	r	-0.065	0.015	-0.173	-0.052
	p	0.478	0.871	0.058	0.570
	p*				

Negative correlations can be seen between runs ahead waits/follows and animal right ($r = -0.261$; $p = 0.004$, $p^* = 0.128$) and owner LAPS total ($r = -0.211$; $p = 0.021$; $p^* = 0.672$). Also the mixed form of runs ahead and star ($r = -0.295$; $p = 0.001$; $p^* = 0.032$) is significantly negatively correlated with animal rights. The pattern of runs parallel then meets owner and stops is positively correlated with people substitution ($r = 0.198$; $p = 0.030$; $p^* = 0.960$) and LAPS total ($r = 0.195$; $p = 0.033$, $p^* >0.999$). No significance can be achieved after Bonferroni correction.

3.3.3 Owner LAPS for each category and each dog; each dog-owner dyad/triad correlations categories and time/distance/ travelling patterns travelled of dog

Over all values are high in all categories and owner assessed multiple dogs if not identical then without great discrepancies, a range between owner assessment values is observable however. See also **Table R3.3.1** for values of each category.

3.3.3.1 Owner LAPS for each dog

Table R3.3.7: Results of owner LAPS for each dog in each category and in total.

	LAPS: General Attachment	LAPS: people substitution	LAPS Animal right/welfare	LAPS total
Amanda	29	14	12	55
Amy	31	17	13	61
Arthur	33	17	15	65
Balin	33	15	15	63
Balou_Mix	27	8	13	48
Balou_RR	27	9	13	49
Bill	32	20	15	67
Dr. Pepper	32	14	9	55
Emma	30	16	15	61
Freya	32	18	15	65
Honey	25	18	14	57
Kaito	31	20	15	66
Kimi	23	9	10	42
Lea/Emma	31	14	14	59
Lili	29	10	16	55
Lou	31	20	15	66
Luna	27	9	13	49
Mala	30	15	15	60
Manja	29	18	13	60
Marley	29	18	13	60
Molly	30	14	13	57
Nele	26	17	13	56
Nina	23	9	10	42
Odin	27	12	14	53
Raffaele	31	19	13	63
Raya	32	13	12	57
Tamina	29	15	13	57
Thorin	23	13	14	50
Wantje	29	14	12	55
Zlata	29	16	15	60
Total	29	14.7	13.4	57.1

Table R3.3.8 shows the values attached by owners of multiple dogs to the respective dog. Values are similar but not always identical. See also differences based on sex or adoption status below.

Table R3.3.8: *Results of owner LAPS by dog-owner dyad/triad for each LAPS category and LAPS total.*

		LAPS: General Attachment	LAPS: people substitution	LAPS Animal right/welfare	LAPS total
1	Amanda	29	14	12	55
	Wanda	29	14	12	55
2	Balou	27	8	13	48
	Lilli	29	10	16	55
3	Balou_RR	27	9	13	49
	Luna	27	9	13	49
4	Amy	31	17	13	61
	Nele	26	17	13	56
5	Dr. Pepper	32	14	9	55
	Raiya	32	13	12	57
6	Kimi	23	9	10	42
	Nina	23	9	10	42
7	Manja	29	18	13	60
	Raffaele	31	19	13	63
8	Marley	29	18	13	60
	Tamina	29	15	13	57
9	Bill	32	20	15	67
	Kaito	31	20	15	66
	Lou	31	20	15	66
10	Emma	30	16	15	61
	Zlata	29	16	15	60
	Mala	30	15	15	60

Results of dogs from one owner are very similar, sometime even equal (e.g. Amanda and Wanda, Balou_RR and Luna, Kimi and Nina) thus the owner often assessed his/her dogs similarly independent of breed, age, personality or other differences.

3.3.3.2 Owner LAPS and attachment, hunting behaviour and reliance on owner

Table R3.3.9 shows the correlative values between the owner LAPS categories, LAPS total and attachment; hunting behaviour and reliance on owner values. Significant negative correlations can be seen between attachment (as assessed in questionnaire from 1-6) and all subscales of owner LAPS. Furthermore, the hunting score is negatively correlated with general attachment, substitution and LAPS total.

Table R3.3.9: Spearman correlation coefficient (r) and corresponding p -value. P^* : Bonferroni correction of p -value. Correction factor for Bonferroni: $4 \times 3 = 12$; only significant uncorrected p -values are affected.

		LAPS: General Attachment	LAPS: people substitution	LAPS Animal right/welfare	LAPS total
Attachment	r	-0.246**	-0.438**	-0.228*	-0.403**
	p	0.007	<0.001	0.012	<0.001
	p^*	0.084	<0.012	0.144	<0.012
Hunting behaviour	r	-0.538**	-0.197*	-0.055	-0.325**
	p	<0.001	0.031	0.551	<0.001
	p^*	<0.012	0.372		<0.012
Reliance on owner	r	-0.204*	-0.166	-0.022	-0.125
	p	0.026	0.070	0.814	0.172
	p^*	0.312			

Taking the values of **Table R3.3.2** the second owner questionnaire, significant negative correlations can be seen between attachment (as assessed in questionnaire from 1-6) and all subscales of owner LAPS. Also the hunting score is negatively correlated with general attachment, substitution and LAPS total. The hunting behaviour assessment has a negative correlation with a value of $r = -0.538$ ($p < 0.001$; $p^* = < 0.012$) for general attachment and LAPS total ($r = -0.325$; $p = < 0.001$; $p^* = < 0.012$). Reliance on owner, measured at a 6 step scale is negatively correlated with general attachment $r = -0.204$; $p = < 0.026$; $p^* = < 0.321$.

3.3.3.3 Owner LAPS and sex of dog(s)

Table R3.3.10 shows the p-values between the owner LAPS categories and owner LAPS total and owners of male versus owners of female dogs and **Fig. R3.3.2** shows a comparison between owners of female versus owners of male dog assessment value for all LAPS categories and LAPS total. Male dogs were assessed higher than female dogs by their owners for general attachment, animal rights/welfare and LAPS total.

Table R3.3.10: LAPS Comparison owner of male versus owner of female dogs. *P**: Bonferroni correction of p-value. Correction factor for Bonferroni: 4; only significant uncorrected p-values are affected.

	Female dog					Male dog					p-value Mann Whitney U Test	p*
	Mean	SD	Median	Q25	Q75	Mean	SD	Median	Q25	Q75		
LAPS: General Attachment	28.56	2.67	29	27	30	29.67	2.98	31	27	32	0.010	0.040
LAPS: people substitution	14.22	3.07	14.5	13	17	15.42	4.14	16	12.5	19.5	0.064	0.164
LAPS Animal right/welfare	13.22	1.63	13	12	15	13.67	1.67	14	13	15	0.041	
LAPS total	56	5.99	57	55	60	58.75	7.05	61.5	51.5	65.5	0.025	0.100

As sex differences have been proposed with respect to dog behaviour including exploration/hunting behaviour (see discussion Part 2) attachment of owner based on sex of his/her dog was assessed. Significant differences between owners of male and owners of female dogs can be seen for general attachment ($p = 0.010$; $p^* = 0.040$), animal right/welfare ($p = 0.041$) and LAPS total ($p = 0.025$; $p^* = 0.100$). Animal right and LAPS total show large differences that are not significant after Bonferroni correction. Owners of male dogs show higher values in the subscales than owners of female dogs. The differences between owners of male and owners of female dogs are about 1 unit/point for general attachment and animal right/welfare and 3 units/points for LAPS total.

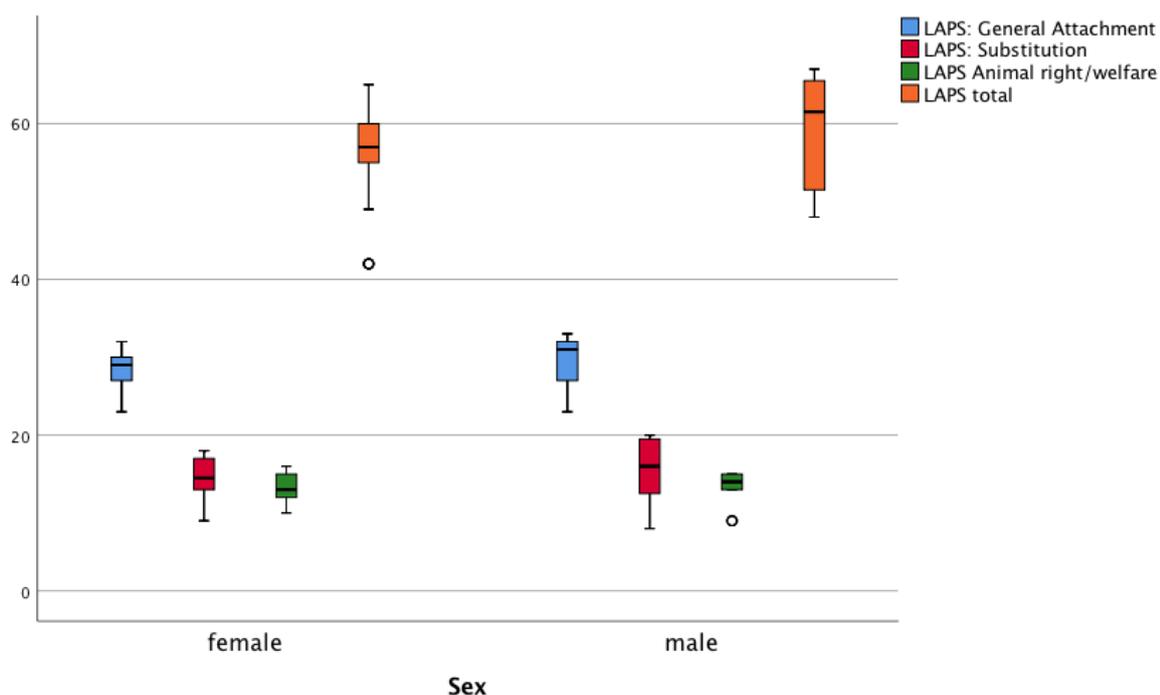


Fig. R3.3.3: Comparison owners of female versus owners of male dog assessment value for all LAPS categories and LAPS total. Males were assessed higher than females by their owners in all categories.

Male dogs were assessed higher than female dogs by their owners for general attachment, animal rights/welfare and LAPS total.

3.3.3.4 LAPS and difference of owner of neutered/spayed versus owner of intact dogs

Table R3.3.11 shows the p-values between the owner LAPS categories, owner LAPS total and owners of intact versus owners of neutered/spayed dogs. **Fig. R3.3.3** compares owners of intact versus neutered/spayed dog assessment values for all LAPS categories and LAPS total. Owners of Intact dogs show higher values in general attachment and lower values in people substitution and animal rights than owners of neutered dogs.

Table R3.3.11: Comparison of assessment of owners of intact versus owner of neutered/spayed dogs and all LAPS parameter. *P**: Bonferroni correction of *p*-value. Correction factor for Bonferroni: 4; only significant uncorrected *p*-values are affected.

	Intact dogs					Neutered dogs					p-value	p*
	Mean	SD	Median	Q25	Q75	Mean	SD	Median	Q25	Q75		
LAPS: General Attachment	30.25	1.95	30	29	32	28.55	2.98	29	27	31	0.009	0.036
LAPS: people substitution	14	2.83	14	13.5	15.5	14.95	3.78	15.5	12	18	0.045	0.180
LAPS Animal right/welfare	12.5	1.68	12.5	12	13.5	13.73	1.52	14	13	15	<0.001	<0.004
LAPS total	56.75	4.68	56	55	59.5	57.23	7.12	58.5	53	63	0.155	

As behavioural differences have been proposed based on the reproductive status of the dog including exploration behaviour (see discussion Part 2) attachment of owner based on reproductive status of his/her dog was assessed here as well. Furthermore animal welfare issues are often connected with castrating issues. Significant differences (Mann Whitney U test) of attachment values between owners of intact and owners of neutered dogs can be seen at general attachment ($p = 0.009$; $p^* = 0.036$), people substitution ($p = 0.045$), and at the animal rights level ($p = <0.001$; $p^* = 0.004$). Owners of intact dogs show higher values in general attachment (about 1.5 unit/point) and lower values in people substitution (about 1 unit/point) and animal rights (about 1.3 unit/point) than owners of neutered dogs. Overall the general assessment of the dogs of one owner shows little variance (see above) and dogs, independent of reproductive status were often evaluated similarly by their owner. However comparing intact and neutered/spayed dogs results differed.

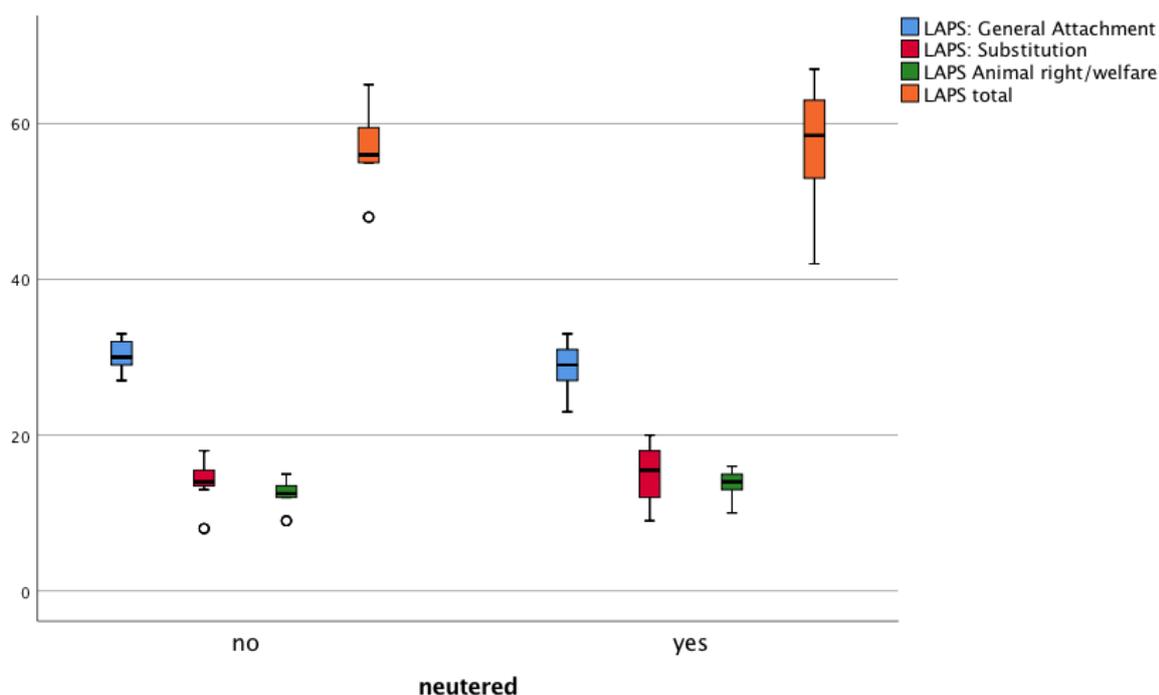


Fig. R3.3.4: Comparison owners of intact versus neutered/spayed dog assessment value for all LAPS categories and LAPS total.

Owners of intact dogs show higher values in general attachment and lower values in people substitution and animal rights than owners of neutered dogs.

3.3.3.5 LAPS and difference of owner of pure breed dogs versus owner of mixed breed dogs

Table R3.3.12 shows the p-values between the owner LAPS categories, owner LAPS total and owners of pure breed versus mixed breed dogs. **Fig. R3.3.4** compares owners of purebred versus mixed breed dog assessment values for all LAPS categories and LAPS total. Significant differences between the owners of purebred and owners of mixed breed dogs can be seen at the animal rights level and LAPS total. Owners of purebred dogs show lower values in these subscales than owners of mixed breed dogs.

Table R3.3.12: Comparison of assessment owner of purebred dog and owner of mixed breed dogs and all LAPS parameters. P*: Bonferroni correction of p-value. Correction factor for Bonferroni: 4; only significant uncorrected p-values are affected.

	Mixed breed dog					Pure breed dog					p-value	p*
	Mean	SD	Median	Q25	Q75	Mean	SD	Median	Q25	Q75		
LAPS: General Attachment	29.4	2.73	29.5	29	31	28.8	2.89	29	27	31	0.304	
LAPS: people substitution	15.1	4.47	15.5	10	20	14.5	3.03	14	13	17	0.118	
LAPS Animal right/welfare	14	1.69	15	13	15	13.1	1.56	13	12.5	14	0.001	0.004
LAPS total	58.5	7.91	60.5	55	66	56.4	5.67	57	54	60	0.015	0.060

Differences have been proposed with respect to attachment of owners of purebred versus mixed breed dogs therefore data was analysed accordingly. Significant differences (Mann Whitney U test) between the owners of purebred and owners of mixed breed dogs can be seen at the animal rights level ($p = 0.001$; $p^* = 0.004$), difference about 1 unit/point, and LAPS total ($p = 0.015$) difference about 1.5 units/points. Owners of purebred dogs show lower values in these subscales than owners of mixed breed dogs.

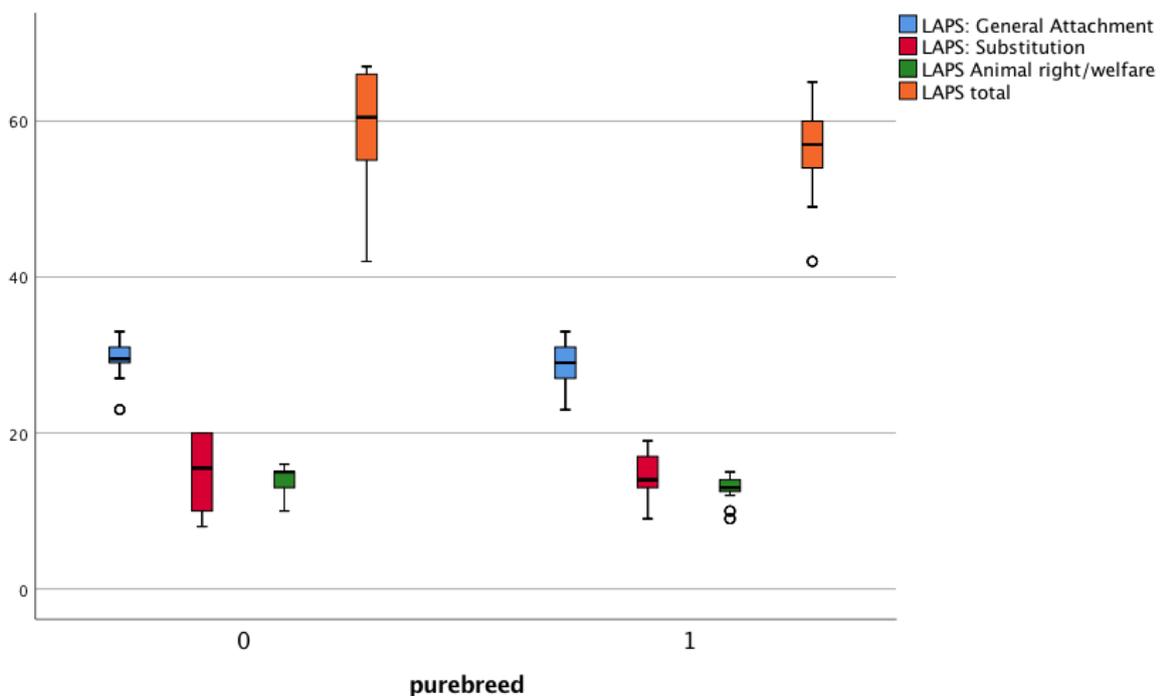


Fig. R3.3.5: Comparison owner of purebred versus mixed breed dog assessment value for all LAPS categories and LAPS total.

Owners of purebred dogs show lower values at the animal rights level difference about 1 unit/point, and LAPS total subscales than owners of mixed breed dogs.

3.3.3.6 LAPS and difference of owner of adopted dog versus owner of breeder bought dogs

Table R3.3.13 shows the p-values between the owner LAPS categories, owner LAPS total and owner of adopted versus not adopted (breeder bought) dogs. **Fig. R3.3.5** shows a comparison of owners of adopted and breeder bought dog assessment values for all LAPS categories and LAPS total. Significant differences between owners of adopted and owners of breeder bought dogs can be seen at the animal rights/welfare subscale. Owners of adopted dogs show higher values in animal welfare than owner of breeder bought dogs.

Table R3.3.13: Comparison of owner assessment of owners with adopted and not adopted dogs and all LAPS parameters. P*: Bonferroni correction of p-value. Correction factor for Bonferroni: 4; only significant uncorrected p-values are affected.

	puppy					Adopted dog						
	Mean	SD	Median	Q25	Q75	Mean	SD	Median	Q25	Q75	p-value	p*
LAPS: General Attachment	29.73	2.07	29	29	32	28.58	3.14	29	27	31	0.148	
LAPS: people substitution	15.45	1.95	15	14	17	14.26	4.18	15	9	18	0.277	
LAPS Animal right/welfare	12.91	1.58	13	12	14	13.68	1.63	14	13	15	0.002	0.008
LAPS total	58.09	3.96	57	55	61	56.53	7.62	59	49	63	0.935	

Differences have been proposed with respect to attachment of owners of adopted versus breeder bought dogs therefore data were analysed accordingly. Significant differences (Mann Whitney U test) between owners of adopted and owners of breeder bought dogs can be seen at the animal rights/welfare subscale ($p = 0.002$; $p^* = 0.004$). Owners of adopted dogs show higher values in animal welfare than owner of breeder bought dogs. The attachment value differences between owner of adopted and breeder dogs are about 1.5 units/points.

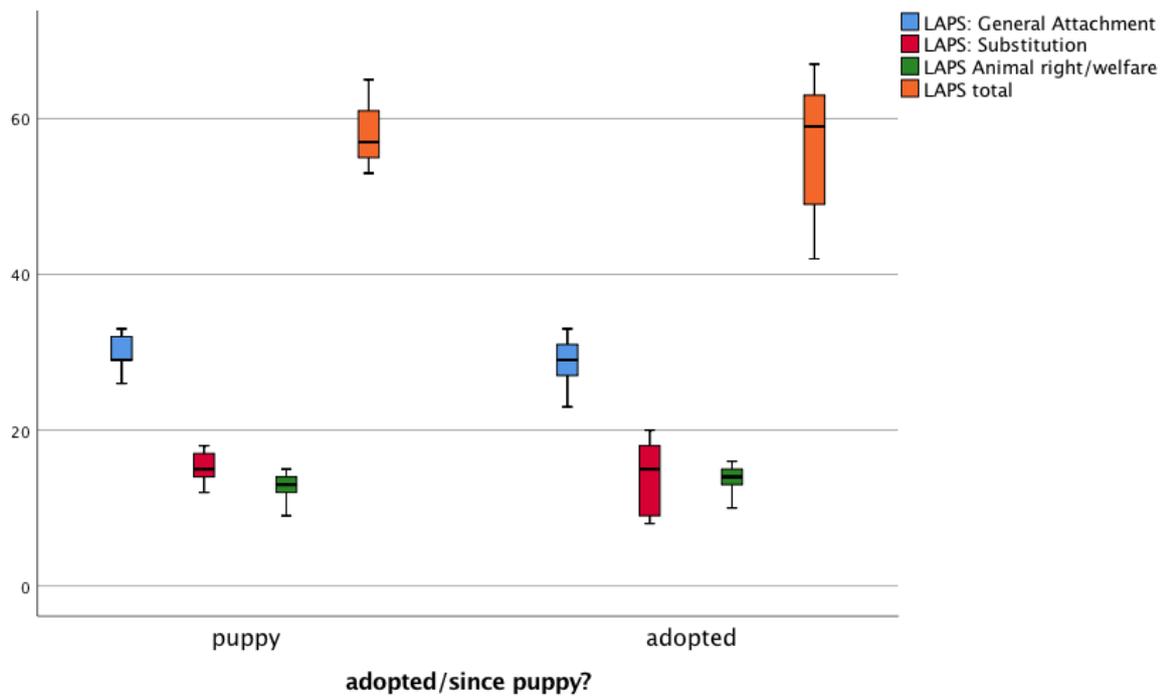


Fig. R3.3.6: Comparison of owner of adopted and not adopted dog assessment value for all LAPS categories and LAPS total.

Differences can be seen at the animal rights/welfare subscale. Owners of adopted dogs show higher values in animal welfare than owner of breeder bought dogs.

3.3.3.7 Owner LAPS and radius of exploration (3 Groups)

Table R3.3.14 shows the different radius groups (Group 1, 2 and 3) of the dogs and the owner LAPS parameters. **Fig. R3.3.6** shows a comparison between owners of dogs of different radius groups all LAPS categories and LAPS total. Significant differences between owners of dogs of different radius groups can be seen at the people substitution subscale and LAPS total. Owners of dogs having a large radius ≥ 350 m (Group 3) have larger scores at people substitution and total LAPS compared to the other owner groups.

Table R3.3.14: Comparison of owners of dogs with different radius (Group 1, 2 and 3) groups and owner LAPS parameter.

	Radius <150 m Group 1					150m <= Radius<350 m Group 2					Radius >= 350m Group 3					p-values			
	Mean	SD	Me- dian	Q 25	Q 75	Mean	SD	Me- dian	Q25	Q75	Mean	SD	Me- dian	Q 25	Q 75	KW-Test	2vs 3	1 vs 3	1vs2
LAPS: General Attach- ment	29.46	2	29	29	30	27.5	3.9	28	23	31	29.67	2.29	31	29	31	0.054	0.021	0.455	0.063
LAPS: people substitu- tion	14.31	2.67	14	14	16	13	3.41	13.5	9	16.5	16.78	3.91	18	15	20	<0.001	<0.001	<0.001	0.075
LAPS Animal right/ welfare	13.46	1.8	13	13	15	13	1.9	13.5	11.5	14.5	13.67	1.07	13	13	15	0.670	0.214	0.895	0.457
LAPS total	57.23	4.25	56	55	60	53.5	8.49	54.5	45.5	60.5	60.11	5.86	60	57	66	0.001	0.002	0.001	0.122

As the different radius groups displayed very diverse exploration behavior I analyzed whether owner attachment varied according to the distance groups. Significant differences (Mann Whitney U test) between owners of dogs of different radius groups can be seen at the people substitution subscale ($p = <0.001$) and LAPS total ($p = 0.001$). LAPS substitution and total score is different for owners of dogs belonging to radius ≥ 350 m (Group 3) and both other groups. Owner of dogs having a large radius ≥ 350 m have larger scores at people substitution and total LAPS compared to the other owner groups. No difference is apparent between owners of Group 1 and Group 2 dogs. Therefore a higher attachment of owners of far ranging Group 3 dogs is indicated.

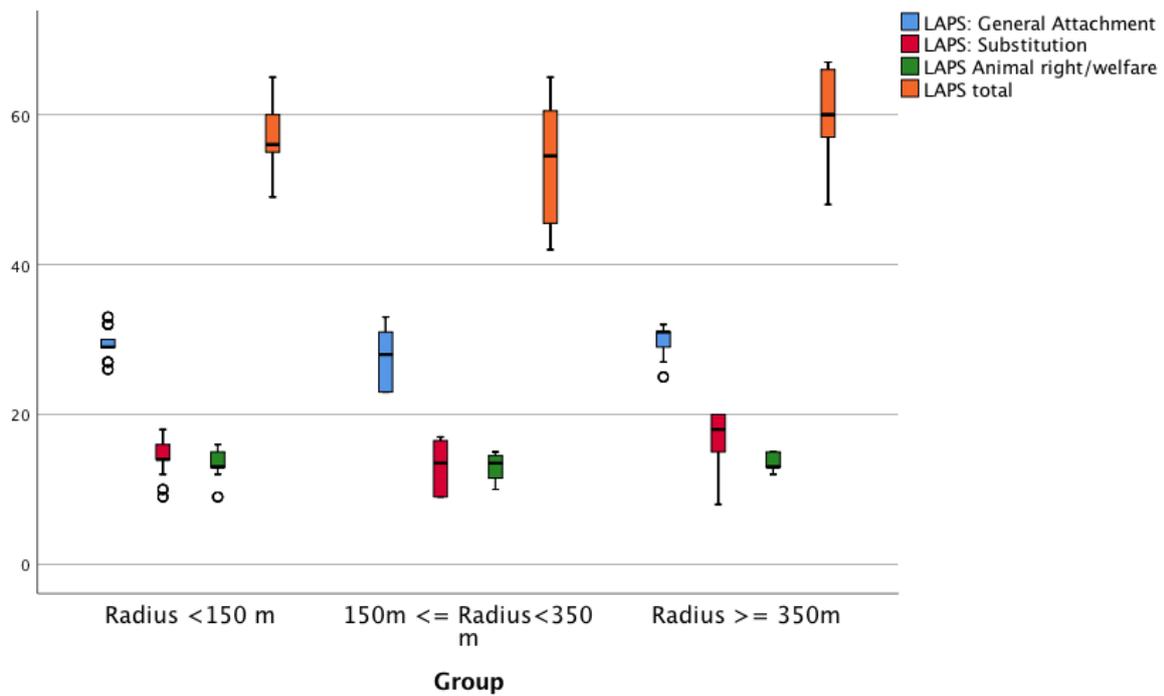


Fig. R3.3.7: Comparison owners of dogs of different radius group (Group 1, 2 and 3) and all LAPS categories and LAPS total.

Significant differences between owners of dogs of different radius groups can be seen at people substitution subscale and LAPS total. Owner of dogs having a large radius ≥ 350 m (Group 3 dogs) have higher scores at people substitution and total LAPS compared to the other owner groups.

3.3.4 Comparison between self-assessment and measurements

Within a separate initial owner questionnaire each owner was asked to judge the distance their dog(s) would explore. In **Table R3.3.15** the factual distances recorded during the runs >20 m are listed and compared to the estimation of their owner. **Fig. R3.3.7** shows the differences between owner assessment of distance explored by their dog and factual distance in meter of runs >20 m. Exploration distance of runs >20 m is generally overestimated by the owners. **Table R3.3.16** and **Fig. R3.3.8** show the difference of time measures. Again, duration of runs >20 m is greatly overestimated by the owners.

Table R3.3.7: Comparison self-assessment of owner in questionnaire and factual distance measures of dog runs >20 m on all walks

	Judgment maximal distance of dog in m	mean distance out-bound in m					mean distance inbound in m					Max distance of run in m				
	Mean/Median	Mean	SD	Median	Q25	Q75	Mean	SD	Median	Q25	Q75	Mean	SD	Median	Q25	Q75
Amanda	100	30	5	30	27	33	42	15	42	31	52	128	38	125	99	157
Amy	100	43	10	40	35	51	47	6	44	43	50	229	68	223	171	286
Arthur	30	36	5	37	33	40	53	9	56	47	59	188	39	182	161	215
Balin	100	49	18	49	37	62	46	32	46	23	68	139	54	146	95	183
Balou_Mix	100	83	16	85	72	94	73	26	72	51	95	513	234	457	351	675
Balou_RR	200	51	13	51	42	61	41	2	41	40	42	154	63	129	114	194
Bill	500	86	10	85	80	93	84	12	84	75	93	586	52	588	548	624
Dr. Pepper	500	74	54	44	41	136	28	15	23	17	45	154	170	80	59	249
Emma	20	69	.	69	69	69	34	.	34	34	34	69	44	65	39	99
Freya	50	28	.	28	28	28	27	.	27	27	27	117	52	99	86	149
Honey	100	89	27	90	66	112	60	36	46	37	83	368	144	417	276	459
Kaito	500	100	27	106	82	119	94	28	89	77	111	710	325	795	492	928
Kimi	10	72	20	71	56	89	66	31	65	41	91	384	248	333	189	580
Lea/Emma	100	58	16	58	44	72	27	16	33	16	39	245	120	242	159	332
Lili	20	39	11	35	32	45	41	12	41	31	51	123	35	113	99	146
Lou	400	122	44	115	88	157	116	23	119	100	132	560	316	495	368	752
Luna	500	45	10	47	37	53	50	17	46	37	63	297	65	285	244	350
Mala	10	.	.	.	.	.	.	.	.	.	.	57	74	35	0	113
Manja	6	.	.	.	.	.	.	.	.	.	.	134	155	92	31	238
Marley	1000	115	46	111	85	145	117	32	116	97	138	1469	837	1600	837	2100
Molly	4	21	.	21	21	21	27	.	27	27	27	106	15	104	93	118
Nele	100	42	1	42	41	42	56	5	56	52	59	139	60	134	100	178
Nina	20	66	27	73	37	90	68	28	81	36	87	352	211	334	184	521
Odin	50	.	.	.	.	.	.	.	.	.	.	58	10	58	50	66
Raffaele	50	68	12	70	58	78	56	21	53	40	72	376	228	365	208	544
Raya	1000	93	20	93	78	107	83	30	78	59	106	519	267	445	318	721
Tamina	1000	92	39	91	65	118	109	50	108	68	151	1277	673	1400	753	1800
Thorin	200	74	20	78	52	91	69	10	73	58	77	220	79	218	152	287
Wantje	100	.	.	.	.	.	.	.	.	.	.	121	34	119	92	150
Zlata	30	106	6	106	102	110	95	12	95	87	104	233	74	211	183	283

As can be seen in **Table R3.3.15** and **Fig. R3.3.7** the inbound or outbound distance (blue and red bars) of the dogs is generally overestimated by the owners. Owners of Kimi and Nina, Zlata and Emma, Lilly and Molly underestimate the difference their dogs explore

during runs >20 m. The maximal distance of the distance explored on runs >20 m by the dogs is underestimated by all owners except the owners of Luna and Dr. Pepper.

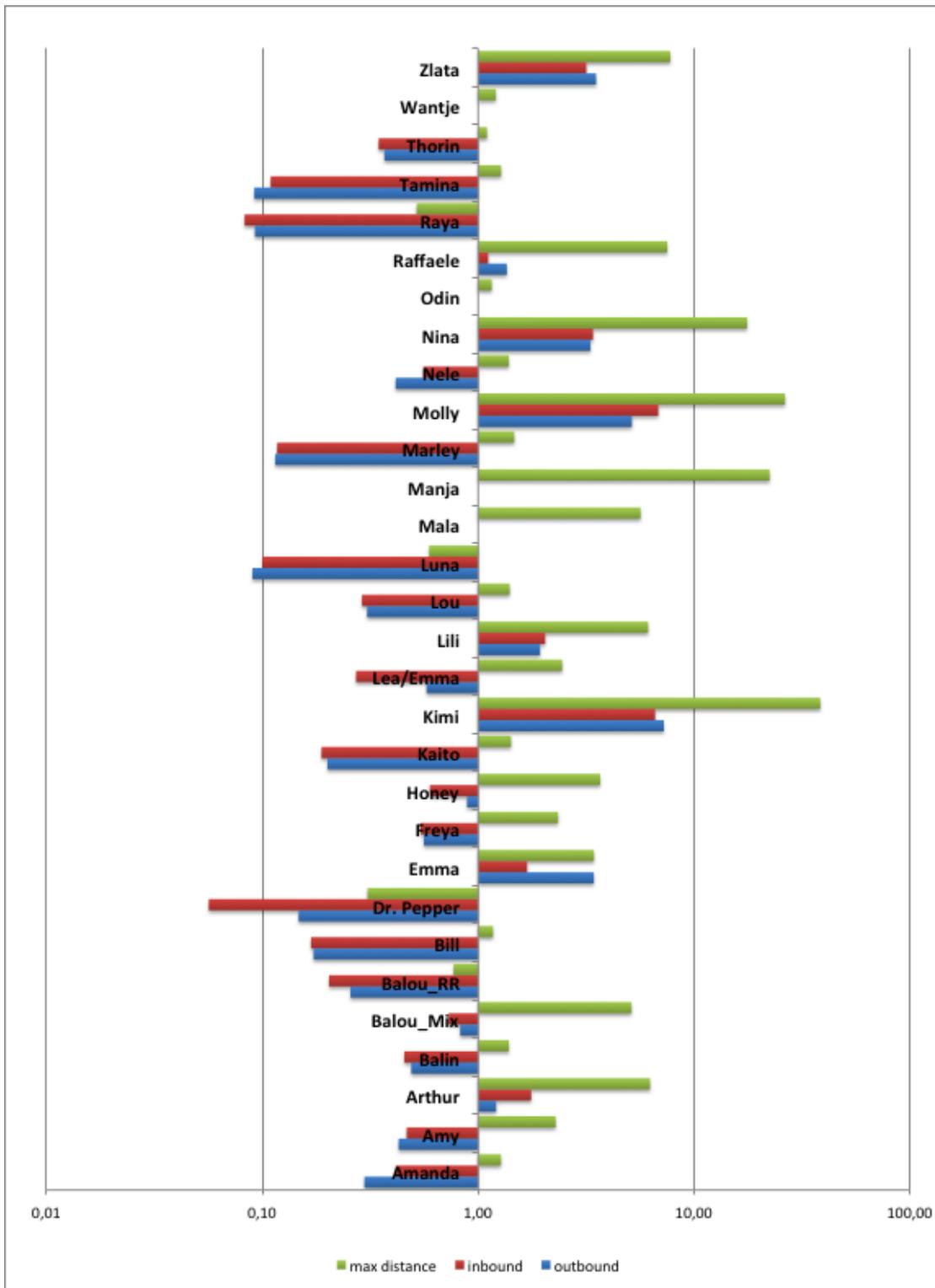


Fig. R3.3.8: Differences between owner assessment of distance explored by their dog and factual distance in meter of runs >20 . If line at 1 = identical values/correct assessment. Line left of middle: overestimation of owner of distance explored by their dog. Line to the right of middle: underestimation of the owner of distance explored of their dog. Green: maximum distance explored by the dog on runs >20 m. Red: inbound distance travelled, blue: outbound distance travelled.

Table R3.3.8: Comparison self-assessment of owner in questionnaire and factual time measures of dog runs >20 m on all walks

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog – owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Amanda	Mean 48.2m	100m	60 % of walk	Walk 1: 1414m/4700m= 30 % Walk 2: 1929m/4700m= 41 % Walk 3: 2204m/5300m= 41.6 % Walk 4: 2615m/5300m= 49.3 % grand mean =35.8 %	00:02:00	mean runs <20m 00:16:14 average 00:00:19 each run
Amy	mean 58.5m	40m	10 % of walk	Walk 1: 2879m/4900m= 60.78 % Walk 2:3179m/5300m= 59.98 % Walk 3:3544m/4300m= 82.42 % Walk 4:2664m/5100m= 52.24 % grand mean =63.86 %	00:01:30	Mean runs <20m 00:22:27 Average 00:00:26 each run
Arthur	mean 72.1m	30m	3 % of walk	Walk 1: 2974m/5600m= 53.1 % Walk 2: 3330m/4800m= 69.4 % Walk 3: 3280m/6600m= 49.7 % Walk 4: 2951m/5200m = 56.8 % grand mean =56.5 %	00:02:30	mean runs <20m 00:23:06 Average 00:00:33 each run
Balin	Mean 82.1m	100m	5 % of walk	Walk 1: 276m/6500m =4.3 % Walk 2: 328m/6200m =5.3 % Walk 3: 273m/ 6400m= 4.3 % Walk 4: 287m/6100m= 4.7 % grand mean =4.6 %	00:02:00	Mean runs <20m mean 00:02:52 average 00:00:51 each run

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog - owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Balou RR	mean 54.4m	200m	40 % of walk	Walk 1: 1294m/6000m= 21.6 % Walk 2: 2351m/5600m= 42 % Walk 3: 2488m/5900m= 42.2 % Walk 4: 1305m/6600m= 19.8 % grand mean =30.9 %	00:04:00	Mean runs <20m mean 00:15:46. Average 00:00:27 each run
Balou_Mix	Mean 236.3m	100m	80 % of walk	Walk 1: 9690m/56000m= 173 % Walk 2: 4434m/5000m= 88.7 % Walk 3: 4566m/5000m= 91.3 % Walk 4: 4775m/5000m= 95.5 % grand mean =113.9 %	00:05:00	mean runs <20m 00:34:43 average 00:00:49 each run
Bill	Mean 122.3m	500m	70 % of walk	Walk 1: 5806m/5900m= 98.4 % Walk 2: 5233m/5200m= 100.6 % Walk 3: 7129m/4200m= 169.7 % Walk 4: 9157m/5500m= 166.5 % grand mean =131.4 %	00:06:00	mean runs <20m 00:36:31 average 00:00:40 each run
Dr.Pepper	mean 51.8m	500m	5 % of walk	Walk 1: 127m/5100m= 2.5 % Walk 2: 167m/5800m=2.9 % Walk 3: 1864m/4000m= 46.6 % Walk 4: 115m/4500m= 2.6 % grand mean =10.7 %	00:04:00	mean runs <20m 00:03:26 average 00:00:18 each run

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog - owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Emma Lea	Mean 61.3m	100m	5 % of walk	Walk 1: 2684m/4200m= 63.9 % Walk 2: 3257m/4500m= 72.4 % Walk 3: 2548m/5200m= 49 % Walk 4: 831m/5300m= 15.7 % grand mean =48.5 %	00:02:00	mean runs <20m 00:15:11 average 00:00:24 each run
Emma	Mean 79.5m	20m	1 % of walk	Walk 1: 0 % Walk 2: 72m/10200m= 0.7 % Walk 3: 308m/5400m= 5.7 % Walk 4: 97m/4700m= 2 % grand mean =1.6 %	00:01:00	mean runs <20m 00:01:04 average 00:00:33 each run
Freya	mean 117.3m	100m	5 % of walk	Walk 1: 110m/6600m= 1.7 % Walk 2: 193m/5100m= 3.8 % Walk 3: 162m/6000m= 2.7 % Walk 4: 297m/5000m= 5.9 % grand mean =3.4 %	00:02:00	mean runs <20m 1:06:50 average 00:00:46 each run
Honey	mean 159.8m	100m	70 % of walk	Walk 1: 3288m/3400m= 96.7 % Walk 2: 2132m/4100m= 52 % Walk 3: 2127m/8500m= 25 % Walk 4: 1389m/12200m= 11.4 % grand mean =20.7 %	00:06:00	mean runs <20m 00:12:50. average 00:00:55 each run

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog - owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Kaito	mean 144.9m	500m	80 % of walk	Walk 1: 4659m/5300m= 87.9 % Walk 2: 4322m/5900m= 73.3 % Walk 3: 6594m/4200m= 157 % Walk 4: 5451m/4200m= 128.8 % grand mean = 107.3 %	00:06:00	mean runs <20m 00:40:50 average 00:01:07 each run
Kimi	mean 102m	10m	10 % of walk	Walk 1: 4084m/5000m= 81.7 % Walk 2: 3364m/4100m= 82 % Walk 3: 1782m/5900m= 30.2 % Walk 4: 1022m/5400m= 18.9 % grand mean =39 %	00:01:00	mean runs <20m 00:17:31. average 00:00:43 each run
Lili	mean 61.9m	20m	1 % of walk	Walk 1: 1913m/5600m= 34.2 % Walk 2: 891m/5000m= 17.8 % Walk 3: 1016m/4700m= 21.6 % Walk 4: 746m/5000m= 14.9 % grand mean =22.5 %	00:00:30	mean runs <20m 00:07:25. average 00:00:23 each run
Lou	mean 137m	400m	30 % of walk	Walk 1: 8172m/5600m= 145.9 % Walk 2: 5592m/5500m= 101.7 % Walk 3: 5966m/4200m= 142 % Walk 4: 3330m/7400m= 45 % grand mean = 101.6 %	00:05:00	mean runs <20m 00:41:13 average 00:00:59 each run

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog - owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Luna	mean 77.2m	500m	50 % of walk	Walk 1: 3974m/6500m= 61.1 % Walk 2: 3279m/5700m= 57.5 % Walk 3: 2742m/5900m= 46.5 % Walk 4: 1424m/6600m= 21.6 % grand mean =46.2 %	00:03:00	mean runs <20m 00:19:54 average 00:00:33 each run
Mala	No mean	10m	0 %	Walk 1: 0 % Walk 2: 0 % Walk 3: 69m/9800m= 0.7 % Walk 4: 157m/8100m= 1.9 % grand mean =0.6 %	00:00:00	00:02:18 mean 00:01:09 each run
Manja	average 179m	40m	1 % of walk	Walk 1: 225m/8500m= 2.7 % Walk 2: 0 % Walk 3: 61m/4300m= 1.4 % Walk 4: 219m/10000m= 2.2 % grand mean =2.3 %	00:01:00	mean runs <20m 00:02:30 Average 00:01:30 each run
Marley	mean 177.5m	1000m	15 % of walk	Walk 1: 4590m/6200m= 74 % Walk 2: 8073m/5100m= 158.3 % Walk 3: 7938m/6200m= 128 % Walk 4: 7648m/5300m= 144.3 % grand mean =123.9 %	00:05:00	mean runs <20m 00:33:07 average 00:00:50 each run
Molly	mean 77m	4m	0 %	Walk 1: 213m/5400m= 3.9 % Walk 2: 195m/6200m= 3.2 % Walk 3: 235m/6000m= 3.9 % Walk 4: 305m/5000m= 6.1 % grand mean =4.3 %	00:00:20	mean runs <20m 00:01:32 average 00:00:30 each run

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog - owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Nele	mean 45.5m	15m	5 % of walk	Walk 1: 1991m/4900m= 40.6 % Walk 2: 2345m/5300m= 44.3 % Walk 3: 2493m/4300m= 58 % Walk 4: 22318m/5100m= 45.5 % grand mean=46.7 %	00:03:00	mean runs <20m 00:17:07 average 00:00:21 each run
Nina	mean 102.9m	20m	10 % of walk	Walk 1: 4889m/5000m= 97.8 % Walk 2: 4242m/4100m= 103.5 % Walk 3: 1202m/5900m= 20.4 % Walk 4: 1997m/5400m= 18.5 % grand mean =43.6 %	00:00:04	mean runs <20m 00:19:09 average 00:00:42 each run
Odin	mean 40m	50m	80 % of walk	Walk 1: 4493m/4400m= 11.2 % Walk 2: 435m/4700m= 9.3 % Walk 3: 572m/5000m= 11.4 % Walk 4: 842m/5000m= 16.8 % grand mean =12.3 %	00:02:00	mean runs <20m 00:05:14 average 00:00:22 each run
Raffaele	mean 133.3m	50m	3 % of walk	Walk 1: 3290m/3900m= 84.4 % Walk 2: 2305m/8500m= 27.1 % Walk 3: 949m/12200m= 7.8 % Walk 4: 341m/5400m= 6.3 % grand mean =23 %	00:01:00	mean runs <20m 00:09:21 average 00:00:46 each run

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog - owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Raiya	mean 139.5m	1000m	70 % of walk	Walk 1: 2320m/3700m= 62.7 % Walk 2: 3360m/2200m= 152.7 % Walk 3: 4890m/4200m= 118.6 % Walk 4: 2563m/4700m= 54.5 % grand mean =76 %	00:06:00	mean runs <20m 00:15:14 average 00:00:39 each run
Tamina	mean 165.8m	1000m	30 % of walk	Walk 1: 3298m/6200m= 53.2 % Walk 2: 7842m/5100m= 153.8 % Walk 3: 6040m/6200m= 97.4 % Walk 4: 7435m/5300m= 140.3 % grand mean =108 %	00:05:00	mean runs <20m 00:35:05 average 00:00:57 each run
Thorin	mean 85.1m	200m	15 % of walk	Walk 1: 3022m/7200m= 42 % Walk 2: 3649m/7100m= 51.4 % Walk 3: 2499m/5300m= 47.2 % Walk 4: 1290m/8500m= 15.2 % grand mean =37.2 %	00:02:00	mean runs <20m 00:18:51 average 00:00:37 each run
Wantje	mean 48.2m	100m	60 % of walk	Walk 1: 909m/4700m=1 9.3 % Walk 2: 1479m/4700m= 31.5 % Walk 3: 1585m/5300m= 29.9 % Walk 4: 21901m/5300m= 35.9 % grand mean =27.6 %	00:02:00	mean runs <20m 00:12:35 average 00:00:25 each run

dog	Mean maximum distance all runs data m	Owner maximum distance runs estimate m	How often does the dog travel <20 m owner	Data Difference dog - owner distance each walk in %	Time runs >20 m per run owner estimate	Data mean runs >20 m
Zlata	mean 161.3m	30m	3 % of walk	Walk 1: 579m/8200m=7 % Walk 2: 852m/12200m= 7 % Walk 3: 293m/9800m=3 % Walk 4: 171m/8100m=2 % grand mean =5 %	00:01:00	mean runs <20m 00:03:35 average 00:01:23 each run

As can be perceived some great discrepancies existed between owner judgement and data with respect to distance and/or time explored as well as the percentage the dog explores beyond owner walked distance.

Table R3.3.17: Comparison self-assessment of owner in questionnaire and factual time measures of dog runs >20 m inbound and outbound.

dog	owner estimate total time in min.	Owner estimate time away per run (inbound & outbound)	number of inbound/outbound runs	Time inbound in min.					Time outbound in min.				
				MW	SD	Med	Q25	Q 75	MW	SD	Med	Q25	Q 75
Amanda	10	2	5	0	0	0	0	0	0	0	0	0	0
Amy	35	1.5	23	1	1	1	1	2	1	1	1	1	2
Arthur	100	2-3	50	4	3	4	2	7	3	3	4	2	5
Balin	10	2	5	0	1	0	0	1	0	1	0	0	1
Balou_Mix	290	5	58	6	4	6	4	9	21	20	11	10	32
Balou_RR	16	3-5	4	0	0	0	0	0	1	1	1	0	1
Bill	564	5-7	94	9	5	8	5	12	11	4	10	9	14
Dr. Pepper	28	3.5	8	0	1	0	0	1	1	1	1	0	2
Emma	4	1	4	0	0	0	0	0	1	1	1	0	1
Freya	8	2	4	0	0	0	0	0	0	0	0	0	0
Honey	258	5-7	43	3	2	3	2	5	5	1	6	4	6
Kaito	294	6	49	8	3	9	6	10	10	3	10	8	13
Kimi	42	1	42	4	4	4	1	7	7	5	6	2	11
Lea/Emma	62	2	31	1	1	2	1	2	2	1	2	1	2
Lili	10	0.5	19	1	1	1	0	2	16	29	2	1	31
Lou	180	5	36	7	3	8	5	9	8	3	9	6	10
Luna	135	3	45	3	2	3	2	4	4	1	4	3	5
Mala	0	0.33	0	.	.	.	.	.	.	.	.	.	.
Manja	3	1	3	0	0	0	0	0	0	0	0	0	0
Marley	285	5	57	7	1	7	6	8	8	2	8	6	10
Molly	2	0.33	5	0	0	0	0	0	0	0	0	0	0
Nele	69	3	23	0	1	0	0	1	0	1	0	0	1
Nina	160	4	40	5	5	5	1	9	6	7	5	1	11
Odin	0	2	0	.	.	.	.	.	.	.	.	.	.
Raffaele	30	1	30	2	2	1	1	3	2	2	2	1	4
Raya	186	5-7	31	2	2	3	1	4	4	1	4	3	5
Tamina	265	5	53	7	4	6	5	10	8	6	7	3	13
Thorin	34	2	17	1	1	2	1	2	3	3	4	1	6
Wantje	2	2	1	0	.	0	0	0	0	.	0	0	0
Zlata	7	1	7	2	1	1	1	3	1	2	1	0	3

Table R3.3.17 shows for each dog the owner estimate of duration per run >20 m in minutes and the number of inbound/outbound runs of each dog. The column owner estimate total time in minutes shows the result minutes per run multiplied by the number of inbound/outbound travels (ergo each run). As can be seen the estimate is not realistically presentably anymore (e.g. Bill 564 minutes). It does show the discrepancy however between actual duration of the runs >20 m and the estimated time of the owner.

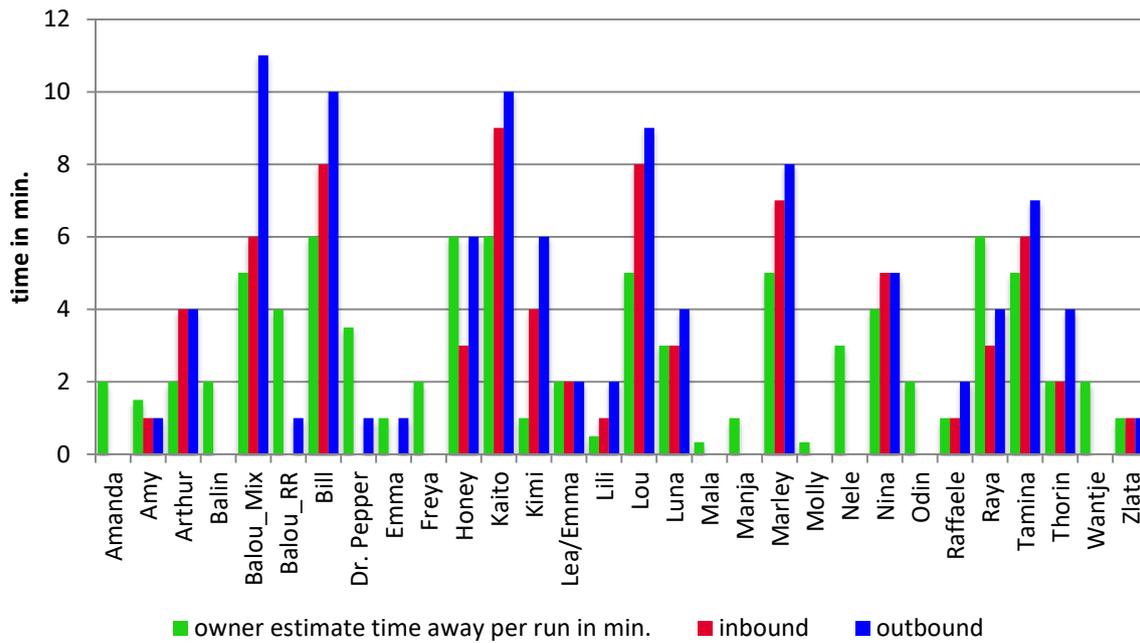


Fig. R3.3.8: Differences between owner assessment of time explored by their dog (green: estimate of duration per run in minutes) and factual duration in minutes of all runs >20 m, inbound (red) and outbound (blue).

3.4 Discussion

3.4.1 Introduction

Attachment to dogs is a widespread phenomenon and has been shown to impact on dog owners' quality of life. Dog ownership is often associated with physical, mental and psychosocial health benefits, like greater levels of physical activity compared to non-owners (Westgarth et al., 2013; Serpell 1991), improved cardiovascular functioning (Levine et al., 2013) and mental wellbeing by decreasing stress and benefits to human psychosocial health (Polheber & Matchock, 2014). Dogs may provide comfort in distressing moments by serving as a safe haven with attachment function (Barker et al., 2016; Barker et al., 2015) or act as a secure base (Bowlby, 1969; Green & Campbell, 2000).

For all dog owners LAPS total displayed a mean of 57.1 (6.55 SD) with a median of 57 and lower and upper quartile of 55 and 61. Considering a range from 0 to 69 the observed values showed high attachment and bonding of all owners to his/her dogs. All subscales indicated high to excellent values: for LAPS general attachment a median of 29 (quartiles: 27 and 31) could be observed, where the theoretically achievable maximum of this subscale was 33. For LAPS Substitution the median was 15 (quartiles: 13 and 18) compared to the theoretically maximum of 21. Observed median of subscale LAPS Animal right/welfare was 13 (quartiles: 13 and 15) compared with a theoretically achievable maximum of 15 **Table 3.3.1; Fig. 3.3.1**. In their study Hielscher et al. (2019) found a slightly lower German owner-dog attachment ($M = 55.49$, $SD = 8.28$) with women ($M = 55.35$, $SD = 8.56$) scoring higher than men ($M = 52.30$, $SD = 8.92$), see Table in **Section 3.3.3.1**. Herein we did not differentiate between men and women as only two dog owners were men. This of course may have skewed results as female dog owners generally score higher than men (Hielscher et al., 2019; Reevy & Delgado, 2014).

Hielscher et al. (2019) also found a significant negative correlation between the age of the subject and total LAPS score. Further, significant correlations were found based on owner educational level, but no significant differences were found between owners of purebred and owners of mixed breed dogs. In this study significant differences between the owners of purebred and owners of mixed breed dogs could be established at the animal rights level and LAPS total. Owners of purebred dogs showed lower values in these subscales than owners of mixed breed dogs, see **Table R3.3.12; Fig. R3.3.4**.

Reevy & Delgado (2014) using LAPS postulated that several variables were related to the level of affection for one's pet. Higher levels of conscientiousness and neuroticism significantly correlated with an increased LAPS score, as did gender (being female). They also proposed that high levels of neuroticism were associated with a high level of affection toward a pet and with high anxious attachment, suggesting that an owner's neuroticism may be beneficial for the pet's welfare and neuroticism contributed to affection independently of the contribution of conscientiousness. In human relationships, anxious attachment may manifest in "clingy" behavior or overprotective parenting and a lack of support for a child's autonomy (see also discussion Part 1). Zilcha-Mano et al. (2011) also found that neuroticism was associated with increased anxious attachment, but only extraversion (and not conscientiousness or openness) was associated with reduced avoidant attachment in their study.

While owner reports are arguably effective, interobserver reliability has been shown to vary depending on the particular trait being rated (Ley et al., 2009; Rooney et al., 2007). Additionally, physical traits such as ear shape and coat colour have been reported to affect ratings of dog behavior and personality (Fratkin & Baker, 2013). Furthermore, as previously discussed, there is ample evidence that owners may misinterpret their dog's behavior and cognitive capacity. Taken together, this suggests that owner reports alone may not be a sufficient measure of dog-human relationships. Also such approaches may be overly simplistic, as attachment dimensions alone may fail to capture the influence of specific human behaviors, such as affiliation, and perceptions on the dog-human relationship. Furthermore, as we are defining the human-animal bond as a symbiotic relationship, affective benefits to the dog, through attachment or otherwise, should be considered (Payne et al., 2015). Therefore the LAPS is only one part and aspect of this thesis.

3.4.2 LAPS

Attachment has been shown to correlate with physical activity and motivation to go on dog walks in dog owners (Cutt et al., 2008; Westgarth et al., 2016; Westgarth et al., 2013) however, attachment to animals appears also to be culturally determined. Overall, average LAPS values in this study are higher than in the studies of Hayama et al. (2016 – used exclusively male owners), Johnson et al., (1992), Shore et al., (2005) and Weiss & Gramann (2009). The studies of Reevy & Delgado (2015) and Stephens et al. (2012) found similar values, while Kruger et al. (2014) found higher scores in their examina-

tion. Singer et al. (1995) found mixed results with an overall score that was higher than the values in this study. All the above-mentioned studies that used the LAPS were conducted in the USA. Hielscher et al. (2019) conducted their LAPS study (cats and dogs) also in Germany, with results comparable to the ones found herein.

I used only a small sample size (30 LAPS total), which makes the LAPS values less reliable because of a lack of statistical power.

3.4.3 Owner Attachment

An attachment bond is a close, emotional relationship between two individuals (Bowlby 1958), providing a sense of security and reducing feelings of stress and anxiety (Carter 1998). Some attachment scholars (e.g., Fraley & Davis, 1997; Zeifman & Hazan, 2008) propose that attachment theory is a valid model for understanding relationships if four criteria are met: (a) proximity maintenance, that means desiring proximity to the attachment figure, especially when distressed; (b) viewing and utilizing the attachment figure as a safe haven, i.e. someone who will provide emotional support, reassurance and encouragement; (c) viewing and using the attachment figure as a secure base who enhances one's feelings of security, thereby allowing for exploration and self-growth; and (d) suffering separation distress when separated from the attachment figure, either physically or emotionally.

Zilcha-Mano et al. (2012) examined each of these criteria in regard to the owner-dog attachment and concluded that dogs may act as attachment figures for humans. Dogs may serve attachment functions (i.e., secure base, etc.), even if, at the same time, the relationship between owner and dog resembles a parent-child relationship (Payne et al., 2015; Topál et al., 1998). Parallels between infant/mother and dog/owner attachment have gained further support from the finding that ownership styles are similar to human parenting behavior (Herwijnen et al., 2018), suggesting that owners largely use their parenting repertoire when interacting with their dogs (Cimarelli et al., 2017; Herwijnen et al., 2018).

The physiological and emotional benefits that ensue from a positive dog-human relationship extend to both members of the dyad, having similar qualities as interpersonal relationships in that both parties can be significant attachment figures for one another (Ryneerson, 1978). Owners may see their dog as accepting, affectionate, honest and loyal, which are qualities that can satisfy a person's basic need for self-worth (Nebbe, 2001). According to attachment theory (Bowlby 1958), the attached individual

shows a preference for the attachment figure and gets distressed when involuntarily separated from it, which may be one reason why most of the owners were stressed on the walks when they could not see their dog anymore.

Green et al. (2018) found that attachment dimensions were associated with attachment-related behaviors for instance feeling less emotionally secure without one's pet or turning to one's pet as a replacement for human companionship. Attachment theory therefore can illuminate individual differences in relationship dynamics within a dog – owner relationship (Green et al., 2018).

Ainsworth et al., (1978) originally described three attachment styles: secure (individuals use the attachment figure as a secure base and voluntarily moves away to engage in exploration; reunion behaviour is smooth and positive), ambivalent/resistant (individual is distressed when separated from the attachment figure, but resists comfort when reunited) and avoidant (individual shows no signs of distress when separated from the attachment figure and explores regardless of whether the attachment figure is present or not) see also Section **1.4.3 Attachment**.

Analogous to children it is likely that dogs have different attachment styles towards their owners and vice versa and increased knowledge about these attachment styles could shed light on the factors influencing the success of particular dog-human relationships. That would also account for the different behaviour of the dogs belonging to one owner or between dogs of different owners in this study: besides genetic, breed or learning differences owner may treat the second/third dog differently, based on increased knowledge/experience or because they have a changed attachment structure based on an altered personal requirement.

Another factor influencing attachment may be oxytocin. Similarly to the finding that polymorphism in the OXTR gene is related to security/insecurity of mother-infant attachment in humans (Chen et al., 2011), it is likely that oxytocin plays an important role in the relationships between dogs and their owners, with higher oxytocin levels being associated with a more positive relationship from perspective of the owner (Thielke & Udell, 2015). Owners kissing their dogs have higher oxytocin concentrations, as do their dogs, than owners who do not (Handlin et al., 2012) and oxytocin has a role in bond formation (Carter et al., 1997), so frequent affiliative interactions between dog and owner strengthen attachment. This may be a physiological explanation of why the amount of time that dogs and owners spend together is reported to have a critical influence on both dogmanship (Lefebvre et al., 2007) and functional dog-human relationships (Kortschral

et al., 2009) and may be reflected in the LAPS duration measures, **Table R3.3.4**: Positive correlations were found between duration of dogs exploration and LAPS total signifying that time spent with their dog may be indicative of owner attachment. Also the duration of owners walking rounds showed these positive correlations demonstrating that the owner attachment correlates with quality time spent with their dog.

Studies have reported associations between attachment styles of human infants and polymorphisms in their dopamine D4 receptor, serotonin transporter, and oxytocin receptor (OXTR) genes (Kovács et al., 2018; Chen et al., 2011; Spangler, 2011), suggesting that genetic polymorphisms could moderate the links between parental behavior, environmental effects and infant attachment. Thus, attachment styles are shaped by a combination of genetic factors and social experiences (Fonagy, 2001; Herwijnen et al., 2018). Kovács et al. (2018) provided evidence that genetic variations in dogs' OXTR gene are associated with attachment behavior to their owners. The behavioral aspects measured (Attachment, Anxiety, and Acceptance) showed significant association with all three dog OXTR SNPs investigated. Kovács et al. (2018) argued that the owner's genetic background may have an influence on their parenting style that, in turn, affects the dogs' attachment behavior or the effects of the dogs' own OXTR genotype on it. Another important finding of the study is that both dog and owner OXT genetic variation shapes the dog-owner attachment in an interactive manner. Earlier research has also shown a mutual effect of both dogs and their owners on the peripheral oxytocin levels of both parties (Nagasawa et al., 2015).

3.4.3.1 Satisfaction

Attachment strength is related to owner satisfaction regarding his dog (Serpell, 1996). Different dog-related characteristics impact on owner satisfaction, consequently the attachment level. Satisfaction is based on different behavioral traits displayed by the dogs and owners' descriptions of their ideal dog included obedience, physical closeness and affection (Diverio et al., 2016) with an owner preference of having a dog that is calm, compliant, faithful, and nonaggressive (King et al., 2009). Problematic or unwanted behaviour, like hunting behaviour, has negative effects on the dog-owner relationship and attachment (Bennett & Rohlf, 2007) whereas obedient behaviour has a positive effect on owner attachment (Clark & Boyer, 1993). Therefore, I expected owner with dogs that stayed close to be more satisfied thus giving a higher attachment score.

3.4.3.2 Distance, duration and speed measures of dog(s) and correlations of LAPS

Correlations were tested to see whether the distance an owner walked with his dog was related to attachment and to analyse whether exploration behaviour of the dog was assessed differently as I expected dogs that stayed closer to the owner to receive higher owner attachment scores. Distance measures and LAPS scores were analysed in **Table R3.3.3** and a (low) positive correlation could be demonstrated between the distance of owner walk and animal welfare. Significant correlation could be established between the total distance of the dog walk and people substitution, animal rights and LAPS total. Since this was a correlation study, cause and effect are difficult to distinguish. However, it seems plausible that longer walking distances are correlated with a higher outcome of LAPS and that owner attachment correlated with longer walking distances with their dogs, **Table R3.3.3**. For these owners attachment includes animal welfare values and is associated with taking their dogs out for (longer) walks. Olsen (2008) found a correlation between walking length/frequency and unrestricted walks in that the longer or more frequent the daily walks, the less restricted the dogs and the more often they were off the leash.

Positive correlations could be shown between walking duration and animal welfare as well as LAPS total furthermore indicating that the owner attachment correlates with quality time spent with their dog, **Table R3.3.4**. Positive correlations could be seen between duration of dogs exploration round and people substitution indicating that the owner attachment correlates with quality time spent with their dog (as a person substitute). Also animal welfare and LAPS total were positively correlated, therefore, the longer the total travelling round, the higher the scores of LAPS. Spending more quality time with their dog and thus having a closer bonding/higher attachment value is in accordance with findings of Kotrschral et al. (2009) and Miklósi (2014). Quality time spent with the dog is associated with experiencing the relationship with the dog as close (Lago et al., 1983) and could result in fewer behavioural problems (Bennett & Rohlf, 2007).

Along these lines were also the negative correlations between speed difference between owner and dog **Table R3.3.5** indicating that a similar walking speed of owner and dog implies higher owner attachment scores to his/her dog(s). One reason being for instance temporal and spatial synchronicity (see discussion Part 1). Affiliation between partners is associated with a high level of behavioral synchronization (Duranton et al., 2019). Thus temporal, activity and location synchrony increases social cohesion (Duranton & Gaunet, 2018) which may be reflected in higher attachment scores. Correlations of

attachment thus match similar walking speed of the owner-dog dyad. Furthermore between the three Groups with ascending radius speed differences increased exponentially, see **Fig. R1.3.2**. Therefore Group 1 dogs stayed close and adapted their speed to that of the owner; whereas Group 3 dogs explored at their own, significantly higher speed – away from the owner. Of course attachment issues are also influenced by the owner's personality. For example, extroverted (active, outgoing) owners may prefer longer or more frequent walks with their dogs.

3.4.3.3 Correlations between travelling patterns, radius groups and LAPS scores

Exploration patterns were assessed as I expected owners of dogs displaying easy and controllable patterns like running ahead /following to be evaluated with higher attachment scores compared to dogs that used extensive exploration patterns (like Group 3 dogs). Correlations between exploration patterns and LAPS scores can be seen in **Table R3.3.6**. Higher LAPS scores were expected from owners if their dogs used “easy” and controllable patterns of exploration, which however were negatively correlated. Negative correlations could be seen between runs ahead waits/follows and the subscale animal rights and owner LAPS total. Outcomes were surprising as one would expect reliable and “easy” patterns to be positively correlated to higher attachment values of owner. On the other hand it might be argued that an independent dog has higher attachment values (see discussion part 1). In accordance are the findings of the different radius groups displayed. **Table R3.3.14** shows the different radius groups (Group 1, 2 and 3) and the owners LAPS parameters. Significant differences between owners of dogs of different radius groups could be determined. LAPS substitution and total score was different for owner of dogs belonging to the radius ≥ 350 m group compared to both other groups. Owner of dogs having a large radius ≥ 350 m (Group 3) had higher scores of total LAPS values compared to the other owner groups. No difference was apparent between owners of Group 1 and Group 2 dogs **Fig R3.3.6**. Therefore, a higher attachment of owners of far ranging, possibly more independent dogs may be argued for.

The long ranging dogs may actually have a different type of owner: they have a higher score on people substituting indicating a higher value of the dog(s) as compared to people. Links between owner attachment style and dog behavior implies that dogs developed different strategies to handle particular situations, based on the type of support they got from their owner and by experience from their previous interaction history (Rehn et al., 2017; Dodman et al., 2018) in the past in challenging or new situations. It

has been shown that owners with a secure attachment style have dogs that show a behavioral response similar to that of securely attached children (Siniscalchi et al., 2013), whereas dogs who received less social support from their insecure owners became overly dependent on them, i.e. stayed closer to the owner and explored less. High attachment values in Group 3 dog owners may reflect secure owners supporting the dog's attempts to independently deal with problems or threats, leading to a more confident dog that explores longer distances.

3.4.3.4 Owner-dog scores for each dog and dyads/triads

Table R3.3.9 shows the results of owner LAPS for each dog in each category and in total and **Table R3.3.10** groups the results of owner LAPS by dog-owner dyad/triad for each LAPS category and LAPS total. Results of owner assessment for each dog of their dogs were similar, but not identical.

The presence of more than one dog in the household may affect the attachment values between the owner and dog. Studies propose that single dogs show the highest similarity to the owner, and in the case of a multi-dog household, the second/third dogs' similarity patterns may complement each other (Turcsán et al., 2012). Therefore the dogs may have different social roles (e.g., one is emotionally more close to the owner, while the other is more suitable for outdoor activities) thus, the owners' choice of the second dog may reflect their need to fill the similarity gap left by their first dog and reflect a different kind of attachment. However, more than one dog in the household may also decrease attachment to the individual dog(s) (Marinelli et al., 2007).

3.4.3.5 Owner assessment dog characteristics and LAPS

I expected a high hunting score to correlate negatively with owner attachment as the view on hunting behaviour of pet dogs was in the main negative and associated with owner stress and anxiety. **Table R3.3.9** shows the correlative values between the LAPS categories and LAPS total and attachment; hunting behaviour and reliance on owner values. Negative correlations can be seen between attachment and all scales of owner LAPS. Also the hunting score was negatively correlated with general attachment, substitution and LAPS total. Reliance on owner, measured at a 6 step scale was negatively correlated with general attachment. Thus perceived negative, problematic or unwanted behaviour in the dog has clearly negative effects on the dog-owner relationship and attachment value (see also Bennett & Rohlf, 2007).

Attachment (LAPS) and sex of dog

As sex differences have been proposed with respect to dog behaviour in particular hunting/exploration behaviour (Mongillo et al., 2017; Scandurra et al., 2018 and see discussion Part 2) attachment of owners based on sex of his/her dog was assessed. **Table R3.3.10** shows the correlative values between the LAPS categories and LAPS total and assessment of owners of male versus owners of female dogs. Significant differences between owners of male and owners of female dogs could be seen for the subscales general attachment, animal rights/welfare and LAPS total. Owners of male dogs' displayed higher values in these subscales than owners of female dogs. The differences between owners of male and owners of female dogs were about 1 unit/point for general attachment and animal right/welfare and 3 units/points for LAPS total indicating different levels of attachment based on sex of the dog **Table R3.3.10** and **Fig. R3.3.2**.

This result is interesting as it has been argued that male dogs tend to be more independent and show less-appreciated aspects such as intermale aggression, sexual problems, and straying tendencies (Wells & Hepper, 2000). Mondelli et al. (2016) along this line found that significantly more female dogs were adopted and significantly more males returned to the shelter. Mongillo et al. (2016) demonstrated that females of different pure and mixed breeds displayed more gazing behavior toward the owners than males indicating a higher interactive value. D'Aniello et al. (2015) showed that female dogs were more likely to interact with humans (see also Persson et al., 2015), which would have led to the expectation that female dog would receive higher attachment scores. However, as 90% of the owners were women this finding is in line with Kotrschal et al., (2008). They found that attachment behaviour differed depending on the gender of the owner and the sex of their dog.

Attachment (LAPS) and reproductive status of dog

Behavioural differences have also been proposed based on the reproductive status of the dog including exploration behaviour (Scandurra et al., 2018 and see discussion Part 2). Therefore attachment of owners based on the reproductive status of his/her dog was assessed. Furthermore animal welfare issues are often connected with castrating issues. Significant differences of attachment values between owners of intact and owners of neutered dogs could be seen at general attachment, people substitution, and at the animal rights level **Table R3.3.11**, **Fig R3.3.3**. Owners of intact dogs showed higher values in general attachment (about 1.5 unit/point) and lower values in people substitution

(about 1 unit/point) and animal rights (about 1.3 unit/point) than owners of neutered dogs.

Perhaps general attachment was slightly higher for owners of intact dogs because many intact dogs are bought from breeders and have been with their owner from an early age whereas adopted dogs often come to their owner later in life. With respect to welfare issues the same holds true: Breeder dogs will often not be castrated whereas adopted dogs are usually castrated for greater welfare purposes like decreasing the dog population and the awareness in owners of adopted dogs is thus different placing a higher value on castration i.e. the reproductive status of their dog.

Attachment (LAPS) and purebred versus mixed breed dogs

Differences have been proposed with respect to attachment of owners of purebred versus mixed bred dogs (Holland, 2019; Marinelli et al., 2007) therefore data were analysed accordingly. Significant differences between the owners of purebred and owners of mixed breed dogs could be established at the animal rights level, difference about 1 unit/point, and LAPS total, difference about 1.5 units/points. Owners of purebred dogs showed lower values in these subscales than owners of mixed breed dogs **Table R3.3.12, Fig R3.3.4**. 33 % (n=10) of the dogs herein were mixed breeds and 67 % (n=20) of the dogs were pure breeds **Table M1.2.2**. Owners of mixed bred dogs had higher values in the animal right/welfare subscale and the overall LAPS score. It has been proposed that owners who are extrinsically motivated display behavior that earns external rewards and social acknowledgment (i.e., status) and tend to acquire a dog as part of a personal identity, owning “designer” and purebred dogs (Holland, 2019). Owners with an intrinsic motivation towards dog ownership are often more likely to own a mixed breed dog and may be more concerned with their dog’s innate qualities than their appearance or breed (Holland, 2019). Studies have also proposed that purebred dogs have owners with stronger dog companionship experience (Dotson & Hyatt, 2008) and receive more care from their owners (Marinelli et al., 2007) than mixed breed dogs. Hielscher et al. (2019) in their study found no significant differences in owner attachment to purebred dogs compared to mixed breed dogs.

Attachment (LAPS) and adopted versus breeder bought/puppy dogs

Table R3.3.13 shows the correlative values between the LAPS categories and LAPS total and owner assessment of owners of adopted versus owners of breeder bought dogs.

Significant differences between owners of adopted and owners of breeder bought dogs could be seen at the animal right/welfare subscale. Owners of adopted dogs showed higher values in animal welfare than owners of breeder bought dogs **Fig. R3.3.5**. The attachment value differences between owner of adopted and breeder bought dogs were about 1.5 units/points. Thus attachment subscale animal welfare is higher in owners of adopted dogs than owners of breeder bought dogs. 19 dogs herein were adopted **Table M 3.2.3**. Bir et al. (2017) found that in the USA women were more inclined to favor adoption and rescue a dog compared to men, with a significantly higher percentage of women (40 %) than men (32 %) agreeing that the only responsible way to acquire a dog is through a shelter/rescue (see also Reese et al., 2017). An additional factor regarding owner demographics is the educational level. In Bir et al. (2017) respondents with at least a college degree were more likely to adopt from a shelter than those without college degrees, which is in line with the findings of Reese et al. (2017). Bir et al. (2017) also identified age as an important demographic characteristic. In particular, the beliefs of older respondents (aged 55–88 years) were frequently significantly different to the younger age categories (18–34 and 35–54 years). Those in the older category were more inclined than younger people to believe that the acquisition of purebred dogs is acceptable. This finding is in line with the study by Woodhead et al. (2018) that explored how beliefs about dog-breeding and acquisition varied among a sample of Australian adults (n= 986). One of the factors found to distinguish members of the “exclusive adoption” group was their age; they were significantly younger than the members of the other two groups.

Another characteristic related to owner satisfaction appears to be the dog’s age. Diverio et al. (2016) found a strong inclination towards acquiring a dog as a puppy. However, a survey showed that 40 % of dog owners spent less than a week getting information prior to purchasing a puppy (RSPCA: London, UK, 2012). Other research indicated that around one fifth of prospective dog owners do not carry out any research at all before taking on a dog (Kuhl, 2017). In this study 11 dogs had been with the owners since puppyhood **Table M 3.2.3 and** the attachment value was about 1.5 units/points higher for owners of adopted (grown dogs) than breeder bought (puppy) dogs.

Along these lines the physical appearance of the dog clearly influences owner satisfaction, thus attachment. Sandoe et al. (2017) reported that for some dog owners, the dog’s appearance may be considered more important than its health. The preference for human-like attributes like blue eyes or “smile” has been described as anthropomorphic

selection—‘selection in favor of physical and behavioral traits that facilitate the attribution of human mental states to nonhumans’ (Serpell, 2003).

Sandoe et al. (2017) suggested that the lesser importance placed upon health compared to appearance among owners of some breeds with intrinsic health problems might not be a paradox, in that the increased levels of caregiving behavior required to care for dogs with health problems might be an explanation for why owners of specific physically distinctive dog breeds rePORt strong attachment ties to them. Thus, it is possible that health (including poor health), as a trait, is potentially important in some owners’ acquisition motivations. A person’s choice of dog may also be a representation of the owner’s self (Savishinsky, 1983) and owners might project their self-identity onto their dogs (Hirschman, 1994). Veevers (1985) suggested that people keep pets as an expression of owner personality. Tesfom & Birch (2013) also reported an association between how dog owners’ define themselves and their dog breed choice; overall, those who perceived their personal behavior and race as important in defining their sense of self rated the dog’s breed as an important feature in their acquisition choice (see also Holland, 2019). Studies also suggest that the decision to acquire a specific dog might be influenced by the degree of similarity between the physical appearance and personality of dog and owner (Payne & Jaffe, 2005), concluding that the psychological mechanisms guiding dog choice resemble those guiding human mate choice: namely, assortative mating.

3.4.4 Distance and time assessment

3.4.4.1 Distance

Within a separate owner questionnaire each owner was asked to judge the distance their dog(s) would explore. In **Table R3.3.15** the factual distances recorded during the runs >20 m are listed and compared to the estimation of their owner, see also **Fig. R3.3.7**. Exploration distance of runs >20 m outbound and inbound was generally overestimated by the owners. Overall, owners were not able to assess the exploration distances of their dog(s) correctly. As can be seen in **Table R3.3.15** and **Fig. R3.3.7** distance explored was generally misjudged by the owners. This is important because if owners believe their dog explores long distances, thereby decreasing owner control and increasing risk to the dog, they arguably call their dog more often. Even worse, the owner may decide to keep the dog on the leash, thereby restricting its exploration and walking behavior, implicating dog welfare (for discussion see also Part 1 and Part 2). A survey in the UK found that one in four owners never let the dog off the leash because they

feel it's too dangerous (<https://www.harringtonspetfood.com/dogventures> 2017). Data obtained herein reflects the explorative behavior of the dogs whilst off leash: All dogs travelled significantly longer distances than their owners ($p < 0.001$), see **Table R1.2.1**. Therefore it is of paramount importance to offer the dogs the opportunity to explore off leash and point out that the majority of owners misjudge their dogs walking distance. Dogs stay closer and explore shorter distances than assumed by their owner. The importance here is moreover that the owner, thus the closest person to the dog is not able to judge distance correctly. Third parties, like legislators, may arguably be even less in a position to evaluate exploration distance.

What are possible mechanisms of owner's misperception? Visual perception and distance estimation may be influenced by numerous factors. Moods for instance affect visual perceptions (Riener et al., 2011). A downcast mood leads to systematically overestimating e.g. hill slant (Proffitt et al., 1995) and perception varies with the perceiver's capacity and biases.

Emotional reactions such as fear have been shown to influence perception of distance (Stefanucci & Proffitt, 2009). From an evolutionary perspective, emotions have evolved to regulate behavior, helping the individual to evaluate the presence of threats and to avoid them (Lang et al., 1997). Thus, the owner may emotionally perceive a threat in the environment (there was no actual danger to be seen) and the adaptive answer was that the dog was perceived as being farther away than it actually was (a zone of danger). Owing to their intrinsic evolutionary relevance, emotional stimuli are processed not only when they are task relevant but also under competing task demands (Codispoti et al., 2006b). Emotional responses are produced by stimuli that are highly significant, and engage motivational systems that developed throughout evolution. Several responses are influenced by the emotional value of a visual stimulus, and the emotion is in turn enhanced by contextual factors (Codispoti et al., 2006b). Therefore with the expectation of the owner of potential danger and uncontrollability the dog in owner's estimation moved further away. The feeling of protection was only afforded when the dog could be called to stay in a visual circle of security.

Studies have shown that objects in the environment with emotional and motivational relevance draw attention and may become more easily detected by appearing larger (Zadra et al., 2011). Therefore emotions affect how and what we see and probably expect to see and provide a strong motivating influence on how the environment is perceived (Zadra & Clore, 2011). Fear can affect visual processes by increasing the perception of potential threats (Zadra & Clore, 2011). If the adaptive function of fear is to pro-

tect an organism from threat, then it could be expected that cues relevant to threat would be inaccurate: Stefanucci & Proffitt (2009) demonstrated that fear heights were overestimated 60 % and a higher fear was related to an increase in height overestimation. This evidence suggests that emotion may lead owners to attend to different sources of information or cues in the environment, which could then produce changes in their estimates of the layout of the environment. Along this line Stefanucci & Storbeck (2009) postulated that feelings of arousal (whether positive or negative) influenced the perception of dangerous environment, suggesting that arousal may be a sufficient cue for altering space and distance perception as well, which is in accordance with the findings herein.

It has been proposed that inaccurate performance may be age related. Proulx et al. (2016) found that older adults displayed poorer performance and lower confidence in their spatial cognitive abilities. However, for most spatial domains there was no age difference in either the absolute or relative accuracy of metacognitive judgments. Older adults typically prefer using egocentric strategies during navigation that are person centred (e.g., turn left, then right), younger adults prefer allocentric strategies which use a cognitive map to reference different locations in the environment for navigation (Proulx et al., 2016). Herein no age difference became apparent in the (incorrect) distance estimation.

Furthermore Yuan et al. (2019) found gender differences with results indicating that the reason why females performed not so well in large-scale spatial ability was that they were more susceptible to emotions and females performed not so well in small-scale spatial ability because they mostly adopted an egocentric strategy. As most of the owners herein were women this may also have an implication on distance judgment **Table R3.3.11, Fig. R3.3.7**.

3.4.4.2 Duration

Within the questionnaire each owner was also asked to judge the duration their dog(s) would explore. **Table R3.3.16** and **Fig. R3.3.8** shows the difference of time measures. Again, the duration of runs >20 m was greatly overestimated by the owners. The same as above in **3.4.4.1** applies: If owner perceive their dogs as being out of sight for too long they may resort to keeping the dog on a leash, restricting its exploration behaviour.

Time perception is a distinct area of study with its own psychophysical methods designed for assessing the perceived duration of a temporal interval. Time perception is also prone to distortions and illusions based on emotional factors (Grommet et al., 2019). Research has shown that perceived durations of emotionally arousing events are

usually inaccurate according to valence when compared to neutral events (Angrilli et al., 1997). Generally, as arousal increases with the presentation of emotional stimuli, time estimations also increase. Negative valence like fear or discomfort, but not positive valence, is generally correlated with time overestimations (Grommet et al., 2019).

Owners were feeling worried or afraid whenever their dog was out of sight or if they expected it could or would be out of sight (because it was not called back). Threatening, negative, or fearful stimuli tend to give rise to a feeling that time is slowing down or expanding (Bar-Haim et al., 2010; Droit-Volet & Gil 2016), and this effect is commonly referred to as time dilation and has been demonstrated for angry faces (Gil et al., 2007) and fear cuing pictures (Grommet et al 2011). One previously proposed mechanism for time dilation is through changes in psychophysiological response. Models of time perception share an element of scalar expectancy theory known as the internal clock, containing mechanisms by which the brain is able to experience time passing and function effectively. A debate exists about whether to treat factors that influence these internal clock mechanisms (e.g., emotion, personality and related neurophysiological components) as arousal- or attentional-based factors (Lehockey et al., 2018). However, time perception is affected by both arousal and attention and emotions influence both of these variables (Ohman et al., 2001). From an arousal perspective, emotional stimuli may lead to overestimations in time perception. Recent research on the effects of fear on timing has focused on two accounts proposed by Scalar Expectancy Theory for why the durations of fear stimuli are overestimated in comparison to the durations of neutral stimuli: One possibility is that fear serves as an arouser that increases the speed of a hypothetical internal clock. The other possibility is that fear increases attention to time, which results in organisms' beginning to time fear-evoking stimuli sooner than they do neutral stimuli (Grommet et al., 2019).

Although time can be measured using standard units, the relationship between an individual's experience of perceived time and a standard unit is highly sensitive to context. Stressful and threatening stimuli have been previously shown to produce time distortion effects, such that individuals perceive the stimuli as lasting for different amounts of time as compared to a standard unit (van Hedger et al., 2017). Grommet et al., (2019) proposed that fear either serves as an arouser that increases the speed of a hypothetical internal clock, alternatively, that fear increases attention to time, which results in organisms' beginning to time fear-evoking stimuli sooner than they do neutral stimuli.

Whatever the mechanism, owners herein consistently overestimated the duration their dog explored, see **Table R3.3.12** and **Table R3.3.7**.

3.5 Conclusion

Human factors, including personality and attitudes, clearly influence the owner-dog relationship and attachment values. In this study different attachment scores could be found for the owner-dog dyads/triads as hypothesized. Over all attachment scores had high to excellent values. Significant correlations were found between distance measures and attachment scores demonstrating high attachment values of owners taking their dog out for longer walks. High perceived hunting scores were negatively correlated with attachment scores. Also owners of male dogs' displayed higher attachment values than owners of female dogs and owners of intact dogs showed higher values in general attachment and lower attachment scores in animal rights than owners of neutered dogs. Owners of mixed bred dogs had higher values in the animal right/welfare overall LAPS score than owners of purebred dogs.

As hypothesized the owner evaluation of time and distance their dog(s) explored exceeded the factual data. Therefore arguably human perception in expected behaviour (like hunting) clearly influences judgment and potential prejudices, even though not founded in fact as can be seen in the time and distance perception estimates of the owners. Inherent may be the danger of owners restricting their dogs' exploration behaviour based on inaccurate judgments.

In summary positive attitudes and affiliative behaviour clearly contribute to a strong owner-dog attachment and vice versa, illustrating the benefits that can ensue for both parties from a successful and satisfying owner-dog relationships and should inspire the cultivation of such. In contrast, negative attitudes, insecure attachment, and misunderstanding of dog behaviour have the potential to disrupt these relationships and impact the dyadic functionality negatively for both partners.

4 General summary

“All animals are equal. But some animals are more equal than others.”
George Orwell’s *Animal Farm* (1987, p.90)

The process of domestication has brought millions of pet dogs to live alongside humans in our communities and thus share our environment. Dogs are a controversial subject in the urban environment, being simultaneously a benefit to many, while being a nuisance to some, and all the while require our concern for their welfare.

Very often their natural needs are subsumed by the communal requirements as their use of the public realm becomes increasingly contested (Lee et al., 2009) often leading to conflict, resulting in increasingly stringent legislation minimizing dogs rights (in Germany, for instance, *Landeshundegesetz NRW*) prohibiting e.g. off leash walks. The dog (as companion animal) relationship is generally a one-sided affair: humans choose particular individuals thereby determining their further living conditions, which often begs the question of whether domesticated animals would be better off outside of the companion relationship, instead of behaving in a way that conforms to the owner (and community) expectations. Even regulations promoting the dogs’ welfare have humans decide which freedoms a dog is allowed and how these freedoms are to be defined (Srinivasan, 2013) thereby describing an anthropocentrism in how we admit dogs into ‘our’ urban habitat. Regulating dogs in public open space typically focuses on the dog and the dog owner, ignoring any reference to responsibilities of others in the community (Instone & Mee, 2011).

In terms of dogs interacting within the public, a number of studies focus upon the effect which dogs have on the natural environment, suggesting narrow confines within that context, based on (often unsubstantiated) fears of potential misbehavior like hunting or aggression. In the context of regulating dogs in public open space, Weston et al. (2014) postulated an absence of studies which explore the effectiveness of these regulations and how human (or cultural) values influence those regulations. To afford some base of welfare and responsibility for dogs is to provide them with freedoms and opportunities to flourish and realize their capabilities, including the freedom for a dog to integrate and interact with the community and to express themselves through activities like exploration, barking, marking territory, play and socialization. These actions in turn im-

prove a dog's chance of living an authentic life and opportunities for realizing its capabilities thereby also decreasing problematic or pathological behaviors.

With the effects of increased urbanization and industrialization, and a general estrangement from the natural world, perhaps a previously existent ability to understand animals has been lost from much of the population. It is a paradox then, that although human beings have been living in close proximity with dogs for perhaps 30,000 years (Thalmann et al., 2013), claiming co-evolution (Miklósi et al., 2016); "enculturation" (Call & Tomasello, 1996); social skills of dogs in cooperative–communicative tasks (Hare & Tomasello, 2005a; Miklósi et al., 2016) and skills shared with humans (Hare et al., 2002; Miklósi & Topál, 2013), our interpretations and responses to their communication are often badly flawed (Kuhne 2016; Firnkes et al., 2017; Mariti et al., 2017; Mariti et al., 2012; Meints et al., 2018).

As dog-keeping faces growing pressures from increased urban living density many dog owners (and trainers) are still unfamiliar with basic dogmanship requirements (Howell et al., 2016) as well as their physiological and behavioral needs (McGreevy & Bennett, 2010). The public profile of dogs as companions is threatened with every news story about a dog bite and, typically, legislative responses increasingly restricting dogs' freedoms (McGreevy et al., 2017). Society is making dogs less welcome and increasingly dense living situations make it harder for responsible owners to do the right thing, not least by reducing areas available for exercise (Instone & Sweeney, 2014). In a descending spiral, the more dogs are restricted in public, and the more their owners become aware of how an incident with a member of the public may result in unacceptable levels of restriction for the dog, like being constantly walked on a leash, the greater the likelihood of dogs showing unwelcome behaviors due to inadequate socialization or related issues (Corrieri et al., 2018). This, in turn, increases the tension between dog owners and others and ultimately, dog welfare suffers.

As always, education is key to the solution. Education in how to interpret dog behavior and how to behave around dogs is likely to both improve communication between dogs and human beings, and reduce the frequency of conflict and aggression by giving people the tools to de-escalate situations with dogs through their own behavior. Unsurprisingly, there is a mass of information in the public domain on dog behavior and training; unfortunately, this is not matched by objective data on the behavior and mindset of human beings who interact with dogs (Kerswell et al., 2009: Owner not noticing dogs' stress signalling or misinterpreting dogs' attempts to signal; also, Mariti et al.,

2012; Bloom, 2013: misinterpreting dogs signals; also Meints et al., 2010; Tami et al., 2009: dog ownership does not predict correct understanding of dogs' behavior and Wan et al., 2012; Kuhne 2016: over all very little knowledge regarding dog behavior; also Firnkes et al., 2017; Mariti et al., 2017; McGreevy et al., 2012; Meints et al., 2018; Reisner & Shofer 2008; including stress and appeasement signals; Mariti et al., 2012; Meints et al., 2018). This is a critical missing link in enhancing communication within the dog-human dyad and guaranteeing dogs a better future in the human domain.

Ethical and ethological welfare problems with respect to dogs have also been voiced in Germany (Döring et al., 2008) as pertains to off-leash restrictions. Independent of exact times a dog should have the opportunity to run free, there is agreement on the basic need of exploration on cognitive and behavioral skills. Feddersen-Petersen (1997) stated that a dog on a leash is not able to explore, engage in social interactions or chose its physiological walking speed, as they are always restricted by the owner and behavioral problems result (see also, Hallgren 1997). Döring et al., (2008) as well as Kluge (2002), come to the conclusion that the legal restrictions (in Germany) imposing on-leash walking rules are welfare relevant in that they fundamentally restrict and impact on the dog physical and psychological welfare and violate § 1 Sentence 2 Tierschutzgesetz (animal rights legislation). The Tierärztliche Arbeitsgemeinschaft Hundehaltung der Bundestierärztekammer (2003) is also of the opinion that leash restrictions compromise dogs' welfare and can lead to behavioral problems.

One option to offer exploration opportunities are 'dog parks', however, what is key in defining a 'dog park' is the purposeful nature of its construction for dogs (perhaps to the exclusion of others as in Tissot (2011)). In saying this however, not all dogs have the capacity to experience a dog park in a harmonious way; indeed, in their inclusiveness towards all dogs, the dog parks themselves exclude vulnerable and less confident dogs, the larger and more boisterous dogs causing their own form of regulated nuisance towards others of their kind (Jackson, 2012), based of course on owners inappropriate behavior by not being mindful and considerate. Further problems include that many dog parks are not fenced in, are too small, offer no appropriate stimuli (Döring et al., 2008) or based on the density of dogs therein are hot-spots for transferring diseases (Ferreira et al., 2017) with high levels of aggression or mobbing (Döring et al., 2008). Therefore it is important to establish appropriate areas in which dogs may explore off-leash. The main arguments against freely exploring dogs have been in the foremost their ecological

impact on wild life and potential aggression against humans or conspecifics despite studies stating otherwise.

The use of a leash has been shown to increase aggression between conspecifics (Sediva et al., 2017; Feddersen-Petersen 1997; Rezac et al., 2011; Bekoff & Meaney, 1997; Olsen, 2008). Rezác et al. (2011) found that threat appeared twice as often between dogs on a leash as between dogs off leash and the use of a leash had a marked effect on dyadic interactions between dogs on walks with their owners. The occurrence of play between dogs was more than two times higher when both dogs were off leash than when one or both dogs were on a leash (Rezac et al., 2011). Similarly, the study of Bekoff & Meaney (1997) suggests that leashed dogs are less friendly than unleashed dogs. Canine social play includes behaviors such as chasing and play-fighting games (Ward et al., 2008). In other words, play between dogs enhances their physical activity that can improve the health and quality of life. Longer daily periods of off-leash activity are associated with a healthier status of dogs (Wallis et al., 2018). The use of a leash has a reducing effect on the amount of interactions between dogs (Westgarth et al., 2010). Furthermore the study of Bekoff & Meaney (1997) in accordance with this study showed that unleashed dogs generally stay fairly close to their owners in public places. In a spatial study, Soto & Palomares (2015) in agreement found that domestic dogs rarely strayed far from boundaries adjacent to human settlements.

While freely exploring, the dogs utilize different senses and cognitive skills. Mental maps are established when the dog is allowed to explore its environment (Tenzin-Dolma, 2012) and walking should not merely be the act of providing physical movement; pausing for calm quiet sniffing expands the mental horizons of the dog and provides it with information of incidents that have occurred recently in that particular environment. An exercise regime that provides an appropriate combination of walking and sniffing time will result in a happy, well stimulated dog (TenzinDolma, 2012). Behaviorists acknowledge that a daily exercise regime that is strictly for physical exercise is meaningless and of little benefit to the dog's psychological well-being (Fishburn, 2014; Fisher, 2014; McDevitt, 2007; Reusche, 2012; Rugaas 2005; Scholz & Von Reinhardt, 2006; Steinker, 2012; Tenzin-Dolma, 2012).

For practical reasons dog owners should vary the area they walk in, first to offer new learning opportunities to their dog(s) and secondly because dogs do tend to explore shorter distances and duration in new areas, which may decrease owner worries. Dogs must be given the option to explore off the leash at their own pace and have opportuni-

ties for problem-solving (and as monitored by a GPS, see Part 1). This will enable dogs to develop their personality, to become a stable, competent, self-reliant and secure individual, making interactions with other individuals safer and more pleasant.

Attachment and bonding issues between owner and dog are of paramount importance. Arguably in this study the securely attached dogs showed little distress independent of area or surrounding; they explored further, but displayed reliable and cognitive highly developed exploration strategies and great flexibility in attention shifts, demonstrating the secure base effect: regulation via feeling of security and social support. Dogs belonging to anxious owners were “clinging” to their owner during the walks, looking more toward the owner and unwilling (or cognitively unable) to explore (being normally always being called back), like Group 1 dogs. These dogs may get less social support and in turn become overly dependent. Using the analog of the parent – child relationship it has been established that two parenting dimensions i.e. overprotection and anxious rearing have been associated with the development of anxiety (e.g., Wood et al., 2003). Dog owners displaying these behaviors may thereby elicit anxiety symptoms in their dogs combined with less explorative behavior, behavioral inhibition (Van Brakel et al., 2006) and inhibited temperament (Rubin et al., 1999).

Therefore further research is needed to elucidate the interaction between owner and spatial orientation strategies utilized by domestic dogs, as they are clearly able to orient beyond purely homing. As indicated by this study, domestic free-ranging, exploring dogs possess spatial orientation abilities, despite the majority of current literature postulating otherwise, in that they arguably used multiple clues not only to assess their own spatial position, but additionally the ability to incorporate the varying, unknown location of their owner into their “map”. This may be based on the close interaction, due to domesticity, between owner and dog, which may enable the dog to anticipate the owner movement and project their own spatial movement to incorporate the owner’s movement and position. The options for the development of the dog personality rest in large parts in owner’s hand, together with the responsibility to ensure the dogs’ physical and psychological welfare.

Literature

- Ainsworth MD, Blehar MC, Waters E, Wall S. Measures and methods of attachment. In: Ainsworth MDS, Wall S, editors. *Patterns of attachment: Psychological study of the strange situation*. Hillsdale, New Jersey: L. Eerbaum Ass. Inc. 1978; 45–64.
- Akos Z, Beck R, Nagy M, Vicsek T, Kubinyi E. Leadership and Path Characteristics during Walks Are Linked to Dominance Order and Individual Traits in Dogs. *PLoS Comput Biol* 2014; 10(1): e1003446.
- Albuquerque N, Guo K, Wilkinson A, Savalli C, Otta E, Mills D. Dogs recognize dog and human emotions. *Biol Lett* 2016; 12:1 20150883.
- Albuquerque N, Guo K, Wilkinson A, Resende B, Mills DS. Mouth-licking by dogs as a response to emotional stimuli. *Behav Proc* 2018; 146, 42–45.
- Alcaro A, Huber R, Panksepp J. Behavioral functions of the mesolimbic dopaminergic system: an affective neuroethological perspective. *Brain Res Rev* 2007; 12; 56(2):283-321.
- Anderson DJ, Adolphs R. A framework for studying emotions across species. *Cell* 2014; 157: 187–193.
- Andics A, Gácsi M, Faragó T, Kis A, Miklósi A. Voice-sensitive regions in the dog and human brain are revealed by comparative fMRI. *Curr Biol* 2014; 24, 574–578.
- Andics A, Miklósi Á. Neural processes of vocal social perception: Dog-human comparative fMRI studies. *Neurosci Biobehav Rev* 2018; 85, 54–64.
- Andics A, Gábor A, Gácsi M, Faragó T, Szabó D, Miklósi Á. Neural mechanisms for lexical processing in dogs. *Science* 2016; 9(2); 353(6303):1030-1032.
- Andics A, Gácsi M, Faragó T, Kis A, Miklósi Á. Voice-sensitive regions in the dog and human brain are revealed by comparative fMRI. *Curr Biol* 2014; 24: 574–578.
- Angrilli A, Cherubini P, Pavese A, Mantredini S. The influence of affective factors on time perception. *Percept Psychophys* 1997; 8; 59(6):972-82.
- Archer J, Ireland JL. The development and factor structure of a questionnaire measure of the strength of attachment to pet dogs. *Anthrozoos* 2011; 24(3):249–261.
- Archer J. Why do people love their pets? *Evol Hum Behav* 1997; 18: 237–259.
- Arhant C, Bubna-Littitz H, Bartels A, Futschik A, Troxler J. Behaviour of smaller and larger dogs: effects of training methods, inconsistency of owner behaviour and level of engagement in activities with the dog. *Appl Anim Behav Sci* 2010; 123(3–4): 131–142.
- Ariel R, Moffa S. Age-related Similarities and Differences in Monitoring Spatial Cognition. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn.* 2018; 5; 25(3): 351–377.

- Asensio N, Brockelman WY, Malaivijitnond S, Reichard UH. Gibbon travel paths are goal oriented. *Anim Cogn* 2011; 14(3), 395–405.
- Asher L, Blythe S, Roberts R, Toothill L, Craigon PJ, Evans KM, et al. A standardized behavior test for potential guide dog puppies: Methods and association with subsequent success in guide dog training. *J Vet Behav* 2013; 8(6): 431–438.
- Asp, HE, Fikse WF, Nilsson K, Strandberg E. Breed differences in everyday behaviour of dogs. *Appl Anim Behav Sci* 2015; 169: 69–77.
- Atickem A, Bekele A, William SD: Competition between domestic dogs and Ethiopian wolf (*Canis simensis*) in the Bale Mountains National Park, Ethiopia. *Afr J Ecol* 2009; 48:401- 407.
- Axelsson E, Ratnakumar A, Arendt ML, Maqbool K, Webster MT, Perloski M: The genomic signature of dog domestication reveals adaptation to a starch-rich diet. *Nature* 2013; 495:360-364
- Baddeley AD. The psychology of memory. In: *The Essential Handbook of Memory Disorders for Clinicians* (eds Baddeley, A.D., Kopelman, M.D. & Wilson, B.A.). J. Wiley, New York, 2004: 1–12.
- Bagley DK, Gonsman VL. Pet attachment and personality type. *Anthrozoos* 2005; 18: 28–42.
- Bailey I, Myatt JP, Wilson AM. Group hunting within the Carnivora: physiological, cognitive and environmental influences on strategy and cooperation. *Behav Ecol Sociobiol* 2013; 67:1–17.
- Bar-Haim Y, Kerem A, Lamy D, Zakay D. When time slows down: The influence of threat on time perception in anxiety. *Cogn & Emot.* 2010; 24(2):255–263.
- Barker SB, Barker RT, McCain NL, Schubert CM. A randomized cross-over exploratory study of the effect of visiting therapy dogs on college student stress before final exams. *Anthrozoös* 2016; 29: 35–46.
- Barker SB, Wolen AR. The benefits of human-companion animal interaction: a review. *J Vet Med Educ* 2008; 35(4):487–495.
- Barnard S, Wells DL, Milligan ADS, Arnott G, Hepper PG. Personality traits affecting judgement bias task performance in dogs (*Canis familiaris*). *Sci Rep* 2018; 4(27); 8(1):6660.
- Bauer EB, Smuts BB. Cooperation and competition during dyadic play in domestic dogs, *Canis familiaris*. *Anim Behav* 2007; 73(3): 489 – 499.
- Bauman AE, Russell SJ, Furber SE, Dobsonm AJ. The epidemiology of dog walking: an unmet need for human and canine health. *Med J Aust* 2001; 175(11 – 12): 632 – 634.

- Baumrind D. Authoritative parenting revisited: history and current status In: Larzelere RE, Sheffield Morris A, Harrist AW, editors. *Authoritative Parenting. Synthesizing Nurturance and Discipline for Optimal Child Development*. Washington: American Psychological Association; 2013: 11–34.
- Baumrind D, Lazelere RE, Owens EB. Effects of preschool parents' power assertive patterns and practices on adolescent development. *Parent Sci Pract* 2010; 10:157–201.
- Beck L, Madresh EA. Romantic partners and four-legged friends: An extension of attachment theory to relationships with pets. *Anthrozoos* 2008; 21: 43–56.
- Bekoff, M. Observations of scent-marking and discriminating self from others by a domestic dog (*Canis familiaris*): Tales of displaced yellow snow. *Behav Proc* 2001; 55, 75–79.
- Bekoff M. Social play behavior: cooperation, fairness, trust, and the evolution of morality. *J Conscious Stud* 2001; 8(2): 81 – 90.
- Bekoff M 2000. *Animal Emotions: Exploring Passionate Natures*, <http://bioscience.oxfordjournals.org/content/50/10/861.full>
- Bekoff M, Ickes RW. Behavioral interactions and conflict among domestic dogs, black-tailed prairie dogs, and people in Boulder, Colorado. *Anthrozoös* 1999; 12(2), 105-110.
- Bekoff M. Intentional communication and social play: how and why animals negotiate and agree to play. In: Bekoff, M., Byers, J.A. (Eds.), *Animal Play. Evolutionary, Comparative, and Ecological Perspectives*. Cambridge University Press, New York, NY 1998: 97–113.
- Bekoff M, Meaney CA. Interactions among dogs, people, and the environment in Boulder, Colorado: A case study. *Anthrozoös* 1997; 10(1), 23-31.
- Belyayev DK, Trut LN. Behaviour and reproductive function of animals. II. Correlated changes under breeding for tameness. *Bulletin of the Moscow Society of Naturalists Biological Series (in Russian)* 1964; 69(5): 5-14.
- Ben-Aderet T, Gallego-Abenza M, Reby D, Mathevon N. Dog-directed speech: why do we use it and do dogs pay attention to it? *Proc Biol Sci* 2017; 284 (1846):20162429.
- Bennett PC, Rohlf VI. Owner-companion dog interactions: relationships between demographic variables, potentially problematic behaviours, training engagement and shared activities. *Appl Anim Behav Sci* 2007; 102: 65e84.
- Bennett PC, Cooper N, Rohlf VI, Mornement K. Factors influencing satisfaction with companion-dog-training facilities. *J Appl Anim Welf Sci* 2007; 10: 217e241.
- Berns GS, Brooks AM, Spivak M. Scent of the familiar: An fMRI study of canine brain responses to familiar and unfamiliar human and dog odors. *Behav Proc* 2015; 110, 37–46.

- Bingman VP, Cheng K. Mechanisms of animal global navigation: comparative perspectives and enduring challenges. *Ethol Ecol Evol* 2005; 17, 295–318.
- Bir C, Widmar NJO, Croney CC. Stated preferences for dog characteristics and sources of acquisition. *Anim* 2017; 7: 59.
- Bischof N. Untersuchungen zur Systemanalyse der sozialen Motivation I: Die Regulation der sozialen Distanz – Von der Feldtheorie zur Systemtheorie [On the regulation of social distance – from field theory to systems theory]. In: *Zeitsch Psychol* 1993; 201: 5–43.
- Bischof N: A systems approach toward the functional connections of attachment and fear. *Child Develop* 1975; 46: 801–817.
- Blackwell EJ, Bradshaw JWS, Casey RA. Fear responses to noises in domestic dogs: prevalence, risk factors and co-occurrence with other fear related behavior. *Appl Anim Behav Sci* 2013; 145: 15–25.
- Bloom T, Friedman H. Classifying dogs' (*Canis familiaris*) facial expressions from photographs. *Behav Proc* 2013; 96, 1–10.
- Blouin DD. Are dogs children, companions, or just animals? Understanding variations in people's orientations toward animals. *Anthrozoos*. 2013; 26(2):279–294.
- Bognár Z, Iotchev IB, Kubinyi E. Sex, skull length, breed, and age predict how dogs look at faces of humans and conspecifics. *Anim Cogn* 2018; 21(4):447–456.
- Bollen KS, Horowitz J. Behavioral evaluation and demographic information in the assessment of aggressiveness in shelter dogs. *Appl Anim Behav Sci* 2008; 112(1): 120–135.
- Bonanni R, Cafazzo S. The social organization of a population of free-ranging dogs in a suburban area of Rome: a reassessment of the effects of domestication on dog behaviour. In Kaminski J, Marshall-Pescini S editors. *The social dog: behaviour and cognition*. Elsevier Inc. 2014: 65–104.
- Bonanni R, Cafazzo S, Valsecchi P, Natoli E. Effect of affiliative and agonistic relationships on leadership behaviour in freeranging dogs. *Anim Behav* 2010; 79, 981–991.
- Bonanni R, Natoli E, Cafazzo S, Valsecchi P. Free-ranging dogs assess the quantity of opponents in intergroup conflicts. *Anim Cogn* 2010b; 14(1):103–115.
- Bonanni R, Valsecchi P, Natoli E. Pattern of individual participation and cheating in conflicts between groups of free-ranging dogs. *Anim Behav* 2010c; 79:957–968.
- Bouton ME. Context, time, and memory retrieval in the interference paradigms of Pavlovian learning. *Psychol Bull* 1993; 114(1): 80–98.
- Bowlby J (1969). *Attachment: Attachment and loss* (Vol. 1). London, England: Hogarth.
- Bowlby J. The nature of the child's tie to his mother. *Int J Psychoanal* 1958; 39(5):350–373.
- Bradshaw JW, Blackwell EJ, Casey RA. Dominance in domestic dogs useful construct or bad habit? *J Vet Behav* 2009; 4(3):135–144.

- Bradshaw JW, Rooney N. Dog social behavior and communication. In *The Domestic Dog*; Serpell J, Ed.; Cambridge University Press: Cambridge, UK, 2016: 133–159.
- Bräuer J, Call J. The magic cup: Great apes and domestic dogs (*Canis familiaris*) individuate objects according to their properties. *J Comp Psych* 2011; 125, 353–361.
- Bräuer J, Kaminski J, Riedel J, Call J, Tomasello M. Making inferences about the location of hidden food: Social dog–causal ape. *J Comp Psychol* 2006; 120:38–47.
- Brodbeck DR, Tanninen SE (2012) Place Learning and Spatial Navigation. In: Seel N.M. (eds) *Encyclopedia of the Sciences of Learning*. Springer, Boston, MA.
- Brucks D, Marshall-Pescini S, Range F. Dogs and wolves do not differ in their inhibitory control abilities in a non-social test battery. *Anim Cogn* 2019; 22:1–15.
- Bruno EA, Guthrie JW, Ellwood SA, Mellanby RJ, Clements DN. Global positioning system derived performance measures are responsive indicators of physical activity, disease and the success of clinical treatments in domestic dogs. *PLoS One* 2015;10(2):e0117094.
- Bryce CM, Wilmers C, Williams TM (2017). Energetics and evasion dynamics of large predators and prey: pumas vs. hounds *PeerJ*, DOI10.7717/peerj.3701
- Buckley NJ. Spatial concentration effects and the importance of local enhancement in the evolution of colonial breeding in seabirds. *Am Nat* 1997; 149(6): 1091–1112.
- Burns JG, Foucaud J, Mery F. Costs of memory: lessons from ‘mini’ brains. *Proc Biol Sci* 2011; 278(1707): 923–929.
- Butterworth G. Pointing is the royal road to language for babies. In: Kita S (Ed.). *Pointing: where language, culture, and cognition meet*. Hillsdale: Erlbaum; 2003: 9–33.
- Buttner AP, Thompson B, Strasser R, Santo J. Evidence for a synchronization of hormonal states between humans and dogs during competition. *Physiol Behav* 2015; 147: 54–62.
- Buttner AP. Neurobiological underpinnings of dogs’ human-like social competence: How interactions between stress response systems and oxytocin mediate dogs’ social skills. *Neurosci Biobehav Rev* 2016; 71: 198–214.
- Buxton DF, Goodman DC. Motor function and the corticospinal tracts in the dog and raccoon. *J Comp Neurol* 1967; 129: 341–360.
- Cafazzo S, Valsecchi P, Bonanni R, Natoli E. Dominance in relation to age, sex, and competitive contexts in a group of free-ranging domestic dogs. *Behav Ecol* 2010; 21:443–455.
- Cafazzo S, Natoli E, Valsecchi P. Scent-marking behaviour in a pack of free-ranging domestic dogs. *Ethol* 2012; 118: 10.
- Cafazzo S, Bonanni R, Valsecchi P, Natoli E. Social variables affecting mate preferences, copulation and reproductive outcome in a pack of free-ranging dogs. *PLoS One* 2014; 9(6):e98594.

- Cagan A, Blass T. Identification of genomic variants putatively targeted by selection during dog domestication. *BMC Evol Biol* 2016; 16:10.
- Call J, Tomasello M. "The effect of humans on the cognitive development of apes," in *Reaching into Thought*, eds A.E.Russon, K.A.Bard, and S.T. Parker (New York, NY: Cambridge University Press), 1996: 371–403.
- Campos JJ, Anderson DI, Barbu-Roth MA, Hubbard EM, Hertenstein MJ, Witherington D. Travel broadens the mind. *Infancy* 2000; 1(2), 149–219.
- Carleton RN. Fear of the unknown: One fear to rule them all? *J Anxiety Disord* 2016; 41(6):5-21.
- Carr BJ, Canapp SO Jr, Zink MC. Quantitative Comparison of the Walk and Trot of Border Collies and Labrador Retrievers Breeds with Different Performance Requirements. *PLoS One* 2015; 10(12):e0145396.
- Carrier LO, Cyr A, Anderson RE, Walsh CJ (2013), Exploring the dog park: Relationships between social behaviours, personality and cortisol in companion dogs, http://dogsbody.psych.mun.ca/cru/CRU_Summer_2014/Publications_files/
- Carter CS. Neuroendocrine perspectives on social attachment and love. *Psychoneuroendocrinol* 1998; 23: 779–818.
- Carter CS, DeVries AC, Taymans SE, Roberts RL, Williams JR, Getz LL. Peptides, Steroids, and Pair Bonding. *Ann N Y Acad Sci* 1997; 807:260–272.
- Carter SB. 'Establishing a framework to understand the regulation and control of dogs in urban environments: a case study of Melbourne, Australia', *SpringerPlus* 2016; 5 (1190):1-13.
- Caston J, Chianale C, Delhay-Bouchaud N, Mariani J. Role of the cerebellum in exploration behavior. *Brain Res.* 1998; 10(19); 808(2):232-7.
- Catala A, Mang B, Wallis L, Huber L. Dogs demonstrate perspective taking based on geometrical gaze following in a Guesser-Knower task. *Anim Cogn* 2017; 7;20(4):581-589.
- Cavanaugh LA, Leonard HA, Scammon DL. A tail of two personalities: how canine companions shape relationships and well-being. *J Bus Res* 2008; 61(5):469–479.
- Cattet J, Etienne AS. Blindfolded dogs relocate a target through path integration. *Anim Behav* 2004; 68: 203–212.
- Charan J, Biswas T. How to calculate sample size for different study designs in medical research? *Indian J Psychol Med* 2013; 35: 121–126.
- Charnetski CJ, Riggers S, Brennan FX. Effect of petting a dog on immune system function. *Psychol Rep* 2004; 12; 95:1087-91.
- Charlton BD, Swaisgood RR, Zhihe Z, Snyder RJ. Giant pandas attend to androgen-related variation in male bleats. *Behav Ecol Sociobiol* 2012; 66:969–974.
- Chartrand TL, Bargh JA. The Chameleon effect: the perception-behavior link and social interaction. *J. Personal Soc Psychol* 1999; 76(6): 893–910.

- Chen FS, Barth ME, Johnson, SL, Gotlib IH, Johnson SC. Oxytocin receptor (OXTR) polymorphisms and attachment in human infants. *Front Psychol* 2011; 2:200.
- Chen M, Daly M, Williams N, Williams S, Williams C, Williams G. Non-invasive detection of hypoglycaemia using a novel, fully biocompatible and patient friendly alarm system. *BMJ* 2000; 321: 1565–1566.
- Cheng K. More psychophysics of the pigeons use of landmarks. *J Comp Phys A* 1990; 166: 857–863.
- Cheng K. The determination of direction in landmark-based spatial search in pigeons—a further test of the vector summodel. *Anim Learn Behav* 1994; 22: 291–301.
- Cheng K, Spetch ML. Mechanisms of landmark use in mammals and birds. In: Healy S. (Ed.), *Spatial Representation in Animals*. Oxford University Press, Oxford, England, 1998: 1–17.
- Cheng K, Spetch ML, Kelly D, Bingman VP. Small-scale spatial cognition in pigeons. *Behav Proc* 2006; 72: 115–127.
- Cheung A, Zhang S, Stricker C, Srinivasan MV. Animal navigation: general properties of directed walks. *Biol Cybern* 2008; 99: 197–217.
- Christian HE, Westgarth C, Bauman A, Richards EA, Rhodes RE, Evenson KR, Mayer JA, Thorpe RJ Jr. Dog ownership and physical activity: a review of the evidence. *J Phys Act Health* 2013; 7; 10(5):750–9.
- Cimarelli G, Marshall-Pescini S, Range F, Virányi Z. Pet dogs' relationships vary rather individually than according to partner's species. *Sci Rep*. 2019; 9(1):3437.
- Cimarelli G, Virányi Z, Turcsán B, Rónai Z, Sasvári-Székely M, Bánlaki Z. Social Behavior of Pet Dogs Is Associated with Peripheral OXTR Methylation. *Front Psychol*. 2017; 8:549.
- Cimarelli G, Turcsán B, Range F, Virányi Z. The Other End of the Leash: An Experimental Test to Analyze How Owners Interact with Their Pet Dogs. *J Vis Exp* 2017; (128):56233.
- Cimarelli G, Turcsán B, Bánlaki Z, Range F, Virányi Z. Dog Owners' Interaction Styles: Their Components and Associations with Reactions of Pet Dogs to a Social Threat. *Front Psychol* 2016; 7:1979.
- Clark GI, Boyer WN. The effects of dog obedience training and behavioural counseling upon the human-canine relationship. *Appl Anim Behav Sci* 1993; 37:147e159.
- Clearfield MW, Osborne CN, Mullen M. Learning by looking: infants' social looking behavior across the transition from crawling to walking. *J Exp Child Psychol* 2008; 100: 297–307.
- Clutton-Brock J. Origins of the dog: The archaeological evidence. In J. Serpell (Ed.), *The Domestic Dog: Its Evolution, Behavior and Interactions with People* 2016: 7–21. Cambridge: Cambridge University Press.

- Clutton-Brock J. Origins of the dog: domestication and early history. In: Serpell J (ed) *The domestic dog its evolution behaviour and interactions with people*. Cambridge University Press, Cambridge, 1995: 7–20.
- Clutton-Brock J: *A Natural History of Domesticated Animals*. Cambridge, UK: Cambridge Univ Press; 1999.
- Clutton-Brock J. Dog, in I.L. Mason (ed.) *Evolution of domesticated animals*. London: Longman 1984.
- Codispoti M, Ferrari V, De Cesarei A, Cardinale R. Implicit and explicit categorization of natural scenes. *Prog Brain Res* 2006b; 156: 57 – 69.
- Coe JB, Young I, Lambert K, Dysart L, Nogueira Borden L, Rajić A. A Scoping Review of Published Research on the Relinquishment of Companion Animals, *J App Anim Welfare Scie* 2014; 17:3: 253-273.
- Cohen JA, Fox MW. Vocalizations in wild canids and possible effects of domestication. *Behav Proc* 1976; 1:77–92.
- Cohn J. How wild wolves became domestic dogs. *BioScience* 1997; 47: 725 B728.
- Colbert-White EN, Tullis A, Andresen DR, Parker KM, Patterson KE. Can dogs use vocal intonation as a social referencing cue in an object choice task? *Anim Cogn* 2018; 21:253–265.
- Collett TS, Graham P. Animal navigation: Path integration, visual landmarks and cognitive maps. *Curr Biol* 2004; 14:475–477.
- Collett TS, Cartwright BA, Smith BA. Landmark learning and visuospatial memories in gerbils. *J Comp Phys A* 1986; 158: 835–851.
- Collier-Baker E, Davis JM, Suddendorf T. Do dogs (*Canis familiaris*) understand invisible displacement? *J Comp Psych* 2004; 118:421–433.
- Cook A, Arter J, Jacobs LF. My owner, right or wrong: the effect of familiarity on the domestic dog's behavior in a food-choice task. *Anim Cogn* 2014; 17(2):461-70.
- Coppinger R, Coppinger L (2016). *What is a dog?* Chicago, IL: University of Chicago Press.
- Coppinger R, Coppinger L (2001). *Dogs: A startling new understanding of canine origin, behavior & evolution*. 1st edn. New York: Scribner.
- Coppinger R, Coppinger L, Skillings E. Observations on assistance dog training and use. *J Appl Anim Welfa Sci* 1998; 1:133–144.
- Corrieri L, Adda M, Miklósi Á, Kubinyi E. Companion and free-ranging Bali dogs: Environmental links with personality traits in an endemic dog population of South East Asia. *PLoS ONE* 2018; 13(6): e0197354.
- Corriveau KH, Harris PL, Meins E, Fernyhough C, Arnott B, Elliott L, Liddle B, Hearn A, Vittorini L, de Rosnay M. Young children's trust in their mother's claims: longitudinal links with attachment security in infancy. *Child Dev* 2009; 80:750–761.

- Coull JT, Cheng RK, Meck WH. Neuroanatomical and neurochemical substrates of timing. *Neuropsychopharma* 2011; 36: 3–25.
- Craig M, Rand J, Mesch R, Shyan-Norwalt M, Morton J, Flickinger E. Domestic dogs (*Canis familiaris*) and the radial arm maze: spatial memory and serial position effects. *J Comp Psychol* 2012; 126: 233–242.
- Craik FIM, Lockhart RS. Levels of processing: a framework for memory research. *J Verbal Behav* 1972; 11: 671–684.
- Creel S, Creel NM. Communal hunting and pack size in African wild dogs, *Lycaon pictus*. *Anim Behav* 1995; 50: 1325–1339.
- Cuaya LV, Hernández-Pérez R, Concha L. Our Faces in the Dog's Brain: Functional Imaging Reveals Temporal Cortex Activation during Perception of Human Faces. *PLoS ONE* 2016; 11(3): e0149431.
- Curb LA, Abramson CI, Grice JW, Kennison SM. The relationship between personality match and pet satisfaction among dog owners. *Anthrozoos* 2013; 26(3):395–404.
- D'Aniello B, Scandurra A, Alterisio A, Valsecchi P, Prato-Previde E The importance of gestural communication: a study of human-dog communication using incongruent information. *Anim Cogn* 2016; 11; 19(6):1231–1235.
- D'Aniello B, Scandurra A, Prato-Previde E, Valsecchi P. Gazing toward humans: A study on water rescue dogs using the impossible task paradigm. *Behav Proc* 2015; 110:68–73.
- D'Aniello B, Scandurra A. Ontogenetic effects on gazing behaviour: A case study of kennel dogs (Labrador Retrievers) in the impossible task paradigm. *Anim Cogn* 2016; 19:565–570.
- D'Aniello B, Alterisio A, Scandurra A, Petremolo E, Iommelli MR, Aria M What's the point? Golden and Labrador retrievers living in kennels do not understand human pointing gestures. *Anim Cogn* 2017; 7; 20(4):777–787.
- D'Aniello B, Semin GR, Alterisio A, Aria M, Scandurra A. Interspecies transmission of emotional information via chemosignals: from humans to dogs (*Canis lupus familiaris*) *Anim Cogn* 2018; 1; 21(1):67–78.
- Dall PM, Ellis SL, Ellis BM, Grant PM, Colyer A, Gee NR, Granat MH, Mills DS. The influence of dog ownership on objective measures of free-living physical activity and sedentary behaviour in community-dwelling older adults: a longitudinal case-controlled study. *BMC Public Health* 2017; 17:496.
- Dall SRX, Giraldeau L, Olsson O, McNamara JM, Stephens DW. Information and its use by animals in evolutionary ecology. *Trend Ecol & Evol* 2005; 20(4): 187–193.
- Dalziel BD, Morales JM, Fryxell JM. Fitting probability distributions to animal movement trajectories: using artificial neural networks to link distance, resources, and memory. *Am Nat* 2008; 172(2), 248–258.

- Davidson RJ. Well-being and affective style: Neural substrates and biobehavioural correlates. *Phil Trans R Soc Lond B* 2004; 359: 1395–1411.
- Day JEL, Kyriazakis I, Rogers PJ. Food choice and intake: towards a unifying framework of learning and feeding motivation. *Nutrit Res Rev* 1998; 11: 25-43.
- Day RL, Coe RL, Kendal JR, Laland KN. Neophilia, innovation and social learning: a study of intergeneric differences in callitrichid monkeys. *Anim Behav* 2003; 65: 559-571.
- De Bruijn GJ, de Groot R, van den Putte B, Rhodes R. Conscientiousness, extraversion, and action control: comparing moderate and vigorous physical activity. *J SPORT Exerc Psychol* 2009; 31(6):724–742.
- DEFRA, 2006, Code of practice for the welfare of dogs, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69390/pb13333-cop-dogs-091204.pdf
- Deldalle S, Gaunet F. Effects of 2 training methods on stress-related behaviors of the dog (*Canis familiaris*) and on the dog-owner relationship. *J Vet Behav* 2014; 9(2):58–65.
- Delgado MR, Olsson A, Phelps EA. Extending animal models of fear conditioning to humans. *Biol Psycho* 2006; 73: 39–48.
- Deldalle S, Gaunet F. Effects of 2 training methods on stress-related behaviors of the dog (*Canis familiaris*) and on the dog-owner relationship. *J Vet Behav* 2014; 9(2):58–65.
- De Keuster T, Lamoureux J, Kahn A. Epidemiology of dog bites: A Belgian experience of canine behaviour and public health concerns. *Vet J* 2006; 173: 482–487.
- Denny MW. Limits to running speed in dogs, horses and humans. *J Experiml Biol* 2008; 211: 3836-3849.
- Depue RA, Collins PF. Neurobiology of the structure of personality: dopamine facilitation of incentive motivation and extraversion. *Behav Brain Sci* 1999; 22:491–569.
- Diamond LM. Contributions of psychophysiology to research on adult attachment: review and recommendations. *Pers Soc Psychol Rev* 2001; 5: 276–295.
- Diverio S; Boccini B; Menchetti L; Bennett PC. The Italian perception of the ideal companion dog. *J Vet Behav* 2016; 12: 27–35.
- Dodman NH, Brown DC, Serpell JA. Associations between owner personality and psychological status and the prevalence of canine behavior problems. *PLoS One* 2018;13(2):e0192846.
- Döring D, Mittmann A, Schneider BM, Erhard MH. Genereller Leinenzwang für Hunde – ein Tierschutzproblem? Über den Zwiespalt zwischen Gefahrenabwehr und tiergerechter Haltung. *Deutsches Tierärzteblatt* 2008; 12:1606-1613.

- Donaldson J. The Culture Clash. A Revolutionary New Way of Understanding the Relationship between Humans and Domestic Dogs; James & Kenneth Publishers: Berkeley, CA, USA, 1996.
- Doré FY, Fiset S, Goulet S, Dumas MC, Gagnon S. Search behavior in cats and dogs: Interspecific differences in working memory and spatial cognition. *Anim Learn Behav* 1996; 24, 142–149.
- Doréy NR, Udell MAR, Wynne CDL. Breed differences in dogs sensitivity to human points: A meta-analysis. *Behav Proc* 2009; 81: 409–415.
- Dotson MJ, Hyatt EM. Understanding dog–human companionship. *J Bus Res* 2008; 61:457–466.
- Droit-Volet S, Gil S. The emotional body and time perception. *Cogn Emot* 2016; 30(4):687-99.
- Droit-Volet S, Fayolle SL, Gil S. Emotion and time perception: effects of film-induced mood. *Frontiers in integrative neuroscience*, 5 PMID2011: 21886610.
- Droit-Volet S, Mermillod M, Cocenas-Silva R, Gil S. The effect of expectancy of a threatening event on time perception in human adults. 2010b *Emotion* 10: 908–914.
- Droit-Volet S, Gil S. The time-emotion paradox. *J Philos Trans R Soc Lond B Biol Sci* 2009; 364: 1943–1953.
- Droit-Volet S, Wearden JH. Speeding up an internal clock in children? Effects of visual flicker on subjective duration. *Q J Exp Psychol* 2002; 55B: 193–211.
- Dukas R. Learning mechanisms, ecology, and evolution. In *Cognitive Ecology II* 2009: 7–26. (eds Dukas, R., Ratcliffe, J.M.). University of Chicago Press.
- Durantón C, Bedossa T, Gaunet F. Pet dogs exhibit social preference for people who synchronize with them: what does it tell us about the evolution of behavioral synchronization? *Anim Cogn* 2019; 3; 22(2):243-250.
- Durantón C, Bedossa T, Gaunet F. When walking in an outside area, shelter dogs (*Canis familiaris*) synchronize activity with their caregivers but do not remain as close to them as do pet dogs. *J Comp Psychol* 2019; 8; 133(3):397-405.
- Durantón C, Bedossa T, Gaunet F. (2018b). Shelter dogs present activity synchrony but only mere location synchrony with their caregivers when walking in an outside area. Manuscript submitted for publication.
- Durantón C, Bedossa T, Gaunet F. Pet dogs synchronize their walking pace with that of their owners in open outdoor areas. *Anim Cogn* 2018a; 3; 21(2):219-226.
- Durantón C, Gaunet F. Behavioral synchronization and affiliation: Dogs exhibit human-like skills. *Learn Behav* 2018; 12(46): 364–373.
- Durantón C, Friederike R, Zsófia V. Do pet dogs (*Canis Familiaris*) follow ostensive and non-ostensive human gaze to distant space and to objects? *R Soc Open Sci* 2017; 4(7):170349.

- Durantón C, Bedossa T, Gaunet F. Interspecific behavioural synchronization: Dogs present locomotor synchrony with humans. *Scient Rep* 2017a; 7: 12384.
- Durantón C, Bedossa T, Gaunet F. Do shelter dogs engage in social referencing with their caregiver in an approach paradigm? An exploratory study. *Appl Anim Behav Sci* 2017b; 189: 57–65.
- Durantón C, Jeannin S, Bedossa T, Gaunet F. Studying episodic memory: dogs as a biological model? *Med Sci (Paris)*. 2017; 33(12):1089-1095.
- Durantón C, Bedossa T, Gaunet F. When facing an unfamiliar person, pet dogs present social referencing based on their owners' direction of movement alone. *Anim Behav* 2016; 113:147–156.
- Durantón C, Gaunet F. Behavioural synchronization from an ethological perspective: short overview of its adaptive values. *Adapt Behav* 2016; 24(3):181–191.
- Durantón C, Gaunet F. Effects of shelter housing on dogs' sensitivity to human social cues. *J Vet Behav: Clin Appl Res* 2016; 14: 20–27.
- Durantón C, Gaunet F. *Canis sensitivus*: Affiliation and dogs' sensitivity to others' behavior as the basis for synchronization with humans? *J Vet Behav Clin Appl Res* 2015; 10: 513–524.
- Dürr S, Ward MP. Roaming behaviour and home range estimation of domestic dogs in Aboriginal and Torres Strait Islander communities in Northern Australia using four different methods. *Prev Vet Med* 2014; 117: 340–357.
- Dürr S, Dhand N, Bombara C., Molloy S, Ward M. What influences the home range size of free-roaming domestic dogs? *Epidem Infect* 2017; 145(7): 1339-1350.
- Dwyer F, Bennett PC, Coleman GJ. Development of the Monash Dog Owner Relationship Scale (MDORS). *Anthrozoos* 2006; 19(3):243–256.
- Ecuyer-Dab I, Robert M. Have sex differences in spatial ability evolved from male competition for mating and female concern for survival? *Cogn* 2004; 91, 221–257.
- Elgier AM, Jakovcevic A, Barrer G, Mustaca AE, Bentosela M. Communication between domestic dogs (*Canis familiaris*) and humans: Dogs are good learners. *Behav Proc* 2009; 81: 402–408.
- Elgier AM, Jakovcevic A, Mustaca AE, Bentosela M. Learning and owner–stranger effects on interspecific communication in domestic dogs (*Canis familiaris*). *Behav Proc* 2009; 81: 44–49.
- Ellingsen K, Zanella AJ, Bjerkås E, Indrebø A. The relationship between empathy, perception of pain and attitudes toward pets among Norwegian dog owners. *Anthrozoos* 2010; 23(3):231–243.
- Engel J, Lamprecht J. Doing What Everybody Does? A Procedure for Investigating Behavioural Synchronization. *J Theor Biol* 1997;(3)21; 185(2):255-62.
- Erickson KI, Voss MW, Prakash RS, et al. Exercise training increases size of hippocampus and improves memory. *Proc Natl Acad Sci U S A*. 2011; 108(7):3017–3022.

- Eriksson T, Germundsjö L, Åström E, Rönnlund M. Mindful Self-Compassion Training Reduces Stress and Burnout Symptoms Among Practicing Psychologists: A Randomized Controlled Trial of a Brief Web-Based Intervention. *Front Psychol* 2018; 11;9:2340.
- Etienne AS, Jeffery KJ. Path integration in mammals. *Hippocamp* 2004; 14: 180–192.
- Etienne AS, Maurer R, Boulens V, Levy A, Rowe T. Resetting the path integrator: a basic condition for route-based navigation. *J Exp Biol* 2004; 207: 1491–1508.
- Etienne AS, Maurer R, Georgakopoulos J, Griffin A. Dead reckoning (path integration), landmarks, and representation of space in a comparative perspective. In R.G. Golledge (Ed.), *Wayfinding behavior: Cognitive mapping and other spatial processes* 1999: 197–228. Baltimore, MD: Johns Hopkins University Press.
- Etienne AS, Maurer R, Seguinot V. Path integration in mammals and its interaction with visual landmarks. *J Exp Biol* 1996; 199: 201–209.
- Evans MJ, Rittenhouse TAG, Hawley JE, Rego PW, Eggert LS. Spatial genetic patterns indicate mechanism and consequences of large carnivore cohabitation within development. *Ecol Evol* 2018; 4;8(10):4815-4829.
- Fabrigoule C. Cue selection with the dog in a double “T” maze has multiple solutions. *Année Psychologique* 1976;23: 59–381.
- Fabrigoule C, Sagave I (1992). Reorganization of cues and path organisation in dogs. *Behav Proc* 1992; 28(1/2): 65–79.
- Fagan WF, Lewis MA, Auger-Méthé M, Avgar T, Benhamou S, Breed G, LaDage L, Schlägel U, Tang W, Papastamatiou Y, Forester J, Mueller T. Spatial memory and animal movement. *Ecol Lett* 2013; DOI: 10.1111/ele.12165.
- Fallani G, Prato Previde E, Valsecchi P. Behavioral and physiological responses of guide dogs to a situation of emotional distress. *Physiol & Behav* 2007; 90: 648–655.
- Faragó T, Pongrácz P, Range F, Virányi Z, Miklósi Á “The bone is mine’: Affective and referential aspects of dog growls. *Anim Behav* 2010; 79: 917–925.
- Faragó T, Pongrácz P, Miklósi Á, Huber L, Virányi Z, Range F Dogs’ expectation about signalers’ body size by virtue of their growls. *PLoS ONE* 2010; 5: e15175.
- Faragó T, Takács N, Miklósi Á, Pongrácz P Dog growls express various contextual and affective content for human listeners. *R Soc Open Sci* 2017; 4: 170134.
- Faragó T, Andics A, Devecseri V, Kis A, Gácsi M, Miklósi Á Humans rely on the same rules to assess emotional valence and intensity in conspecific and dog vocalizations. *Biol Lett* 2014; 10: 20130926.
- Faragó T, Townsend S, Range F. The Information Content of Wolf (and Dog) Social Communication. G. Witzany (ed.), *Biocommunication of Animals* 2014.
- Faragó T, Takács N, Miklósi Á, Pongrácz P. (in prep) Assessment of inner state and context recognition from growls by human listeners 2019.

- Farrell MJ, Robertson IH. Mental rotation and automatic updating of body-centered spatial relationships. *J Exp Psychol Learn Mem Cogn* 1998; 4: 227–233.
- Fearon P, Shmueli-Goetz Y, Viding E, Fonagy P, Plomin R. Genetic and environmental influences on adolescent attachment. *J Child Psychol Psychiatr Allied Discip* 2014; 55: 1033–1041.
- Feddersen-Petersen D. Social behaviour of dogs and related canids. In *The Behavioural Biology of Dogs*. Edited by Jensen P. Trowbridge, UK: Cromwell Press; 2007:105–119.
- Feddersen-Petersen D. *Hunde psychologie: Sozialverhalten und Wesen, Emotionen und Individualität*. Stuttgart: Kosmos Verlag; 2004.
- Feddersen-Petersen DU Vocalization of European wolves (*Canis lupus lupus L.*) and various dog breeds (*Canis lupus f. fam.*) *Arch. Tierz.*, 2000; 4: 387–397.
- Feddersen-Petersen D. Hund. In: Sambraus HH, Steiger A (Hrsg.), *Das Buch vom Tier-schutz*. Ferdinand Enke Verlag, Stuttgart, 1997:245–296.
- Feddersen-Petersen D. The ontogeny of social play and agonistic behaviour in selected canid species. *Bonner Zoologische Beiträge* 1991; 42:97–114.
- Ferreira A, Alho AM, Otero D, et al. Urban Dog Parks as Sources of Canine Parasites: Contamination Rates and Pet Owner Behaviours in Lisbon, PORTugal. *J Environ Public Health* 2017;2017:5984086.
- Fleming PJS, Nolan H, Jackson SM, Ballard G-A, Bengsen A, Brown WY, Meek PD, Mifsud G, Pal SK, Sparkes J. Roles for the Canidae in food webs reviewed: where do they fit? *Food Webs* 2017; 12:14–34.
- Firnkes A, Bartels A, Bidoli E, Erhard M. Appeasment signals used by dogs during dog-human communication. *J Vet Sci* 2017; 19:35–44.
- Fischer J, Hammerschmidt K, Cheney DL, Seyfarth RM. Acoustic features of male baboon loud calls: influences of context, age, and individuality. *J Acoust Soc Am* 2002; 111:1465.
- Fischer J, Kitchen DM, Seyfarth RM, Cheney DL. Baboon loud calls advertise male quality: acoustic features and their relation to rank, age, and exhaustion. *Behav Ecol Sociobiol* 2004; 56:140–148.
- Fischer J, Hammerschmidt K, Cheney DL, Seyfarth RM. Acoustic features of male baboon loud calls: influences of context, age, and individuality. *J Acoust Soc Am* 2002; 111:1465.
- Fiset S, Malenfant N. Encoding of local and global cues in domestic dogs' spatial working memory. *OJAS* 2013; 3, 3A: 1–11.
- Fiset S, Plourde V. Object permanence in domestic dogs (*Canis lupus familiaris*) and gray wolves (*Canis lupus*). *J Comp Psych* 2013; 127:115–127.
- Fiset S. Evidence for averaging of distance from landmarks in the domestic dog. *Behav Proc* 2009; 81: 429–438.

- Fiset S, LeBlanc V. Invisible displacement understanding in domestic dogs (*Canis familiaris*): The role of visual cues in search behavior. *Anim Cogn* 2007; 10: 211–224.
- Fiset S, Beaulieu C, LeBlanc V, Dubé L. Spatial memory of domestic dogs (*Canis familiaris*) for hidden objects in a detour task. *J Exp Psychol Anim* 2007; B 33: 497–508.
- Fiset S. Landmark-based search memory in the domestic dog (*Canis familiaris*). *J Comp Psychol* 2007; 121: 345–353.
- Fiset S, Landry, Ouellette M. Egocentric search for disappearing objects in domestic dogs: Evidence for a geometric hypothesis of direction. *Anim Cogn* 2006; 9: 1–12.
- Fiset S, Beaulieu C, Landry F. Duration of dogs' (*Canis Familiaris*) working memory in search for disappearing objects. *Anim Cogn* 2003; 6: 1–10.
- Fiset S, Gagnon S, Beaulieu C. Spatial encoding of hidden objects in dogs (*Canis familiaris*). *J Comp Psychol* 2000; 114: 315–324.
- Fitch WT, Huber L, Bugnyar T. Social cognition and the evolution of language: constructing cognitive phylogenies. *Neuron* 2010; 65, 795–814.
- Fitch WT, Neubauer J, Herzel H. Calls out of chaos: the adaptive significance of nonlinear phenomena in mammalian vocal production. *Anim Behav* 2002; 63:407–418.
- Flack A, Pettit B, Freeman R, Guilford T, Biro D. What are leaders made of? The role of individual experience in determining leader e follower relations in homing pigeons. *Anim Behav* 2012; 83: 703–709.
- Foltin S . Masterthesis, University Dusiburg-Essen 2016.
- Fonagy P. The human genome and the representational world: the role of early mother-infant interaction in creating an interpersonal interpretive mechanism. *Bull Menninger Clin* 2001; 65: 427–448.
- Foyer P, Wilsson E, Jensen P. Levels of maternal care in dogs affect adult offspring temperament. *Sci Rep* 2016; 6:19253.
- Frank H, Frank MG. Comparison of problem-solving performance in six-week old wolves and dogs. *Anim Behav* 1982; 30, 95–98.
- Frank H, Frank MG. On the effects of domestication on canine social development and behavior. *Appl Anim Ethol* 1982; 8(6), 507–525.
- Frantz L A F, Laurent AF; Mullin VE, Pionnier-CapitanM, Ollivier M, Perri A, Linderholm A, Mattiangeli V et al. Genomic and archaeological evidence suggests a dual origin of domestic dogs. *Science* 2016; 352(6290): 1228–1231.
- Fratkin JL, Baker SC. The role of coat color and ear shape on the perception of personality in dogs. *Anthrozoos* 2013; 26(1):125–133.
- Fronhofer EA, Pasurka H, Poitrineau K, Mitesser O, Poethke HJ. Risk sensitivity revisited: from individuals to populations. *Anim Behav* 2011; 82: 875–883.
- Fugazza C, Mongillo P, Marinelli L Sex differences in dogs' social learning of spatial information. *Anim Cogn* 2017; 20:789–794.

- Fugazza C, Pogány Á, Miklósi Á. Recall of Others' Actions after Incidental Encoding Reveals Episodic-like Memory in Dogs. *Curr Biol* 2016; 12; 26(23):3209-3213.
- Fugazza C, Pogány Á, Miklósi Á. Do as I . . . Did! Long term memory of imitative actions in dogs (*Canis familiaris*). *Anim Cogn* 2016a; 19(2): 263–269.
- Fugazza C, Pogány Á, Miklósi Á. Spatial generalization of imitation in dogs (*Canis familiaris*). *J Comp Psychol* 2016b; 130(3): 249–253.
- Fugazza C, Miklósi Á. Deferred imitation and declarative memory in domestic dogs. *Anim Cogn* 2014; 17(2): 237–247.
- Gácsi M, Maros K, Sernkvist S, Faragó T, Miklósi A. Human analogue safe haven effect of the owner: behavioural and heart rate response to stressful social stimuli in dogs. *PLoS One* 2013; 1; 8(3):e58475.
- Gácsi M, Vas J, Topál J, Miklósi A. Wolves do not join the dance: sophisticated aggression control by adjusting to human social signals in dogs. *Appl Anim Behav Sci* 2013; 145 (3–4):109–122.
- Gácsi M, Gyoöri B, Virányi Z, Kubinyi E, Range ., Belényi B, Miklósi Á Explaining dog wolf differences in utilizing human pointing gestures: Selection for synergistic shifts in the development of some social skills. *PLoS ONE* 2009; 4:e6584.
- Gácsi M, Kara E, Belenyi B, Topál J, Miklósi A. The effect of development and individual differences in pointing comprehension of dogs. *Anim Cogn* 2009a; 12: 471–479.
- Gácsi M, McGreevy PD, Kara E, Miklósi Á. Effects of selection for cooperation and attention in dogs. *Behav Brain Funct* 2009b; 5:31.
- Gácsi M, Miklósi Á, Varga O, Topál J, Csányi V Are readers of our face readers of our minds? Dogs (*Canis familiaris*) show situation-dependent recognition of human's attention. *Anim Cogn* 2004; 7: 144–153.
- Gagnon S, Doré FY. Search behavior in various breeds of adult dogs (*Canis familiaris*): Object permanence and olfactory cues. *J Comp Psychol* 1992;106: 58–68.
- Gagnon S, Doré FY. Search behavior of dogs (*Canis familiaris*) in invisible displacement tasks. *Anim Learn Behav* 1993; 21: 246–254.
- Gagnon S, Doré FY. Cross-sectional study of object permanence in domestic puppies (*Canis familiaris*). *J Comp Psychol* 1994; 108: 220–232.
- Gallistel CR (1990). *The organization of learning*. Cambridge, MA: Bradford Books/MIT Press.
- Gaunet F, Besse S. Guide dogs' navigation after a single journey: A descriptive study of path reproduction, homing, shortcut and detour. *PLoS ONE* 2019; 14(7):e0219816.
- Gaunet F, Pari-Perrin E, Bernardin G. Description of dogs and owners in outdoor built-up areas and their more-than-human issues. *Environmen Manag* 2014; 54(3): 383–401.

- Gaunet F, Deldalle S. Effects of 2 training methods on stress-related behaviors of the dog (*Canis familiaris*) and on the dog-owner relationship. *J Vet Behav: Clin Appl Re*. 2014; 9: 58–65.
- Gaunet F. Sensitivity and adjustments of domestic dog to social agents: knowledge from the scientific field. *J Vet Behav: Clin Appl Res* 2012; 7(6): e6.
- Gaunet F, Deputte BL. Functionally referential and intentional communication in the domestic dog: Effects of spatial and social contexts. *Anim Cogn* 2011; 14: 849–860.
- Gaunet F. How do guide dogs and pet dogs (*Canis familiaris*) ask their owners for their toy and for playing? *Anim Cogn* 2010; 13: 311–323.
- Germonpré M, Lázníčková-Galetová M, Sablin MV. Palaeolithic dog skulls at the Gravettian Předmostí site, the Czech Republic. *J Archaeol Sci* 2012; 39(1):184–202.
- Gershman AK, Sacks JJ, Wright C. Which dogs bite? A case-control study of risk factors. *Pediatr* 1994; 93:913–917.
- Gibbs RB, Johnson DA. Sex-specific effects of gonadectomy and hormone treatment on acquisition of a 12-arm radial maze task by Sprague Dawley rats. *Endocrinol* 2008; 6;149(6):3176-83.
- Gil S, Niedenthal PM, Droit-Volet S. Anger and time perception in children *Emotion* 2007; 2; 7(1):219-25.
- Gillath O, Bunge SA, Shaver PR, Wendelken C, Mikulince M. Attachment-style differences in the ability to suppress negative thoughts: exploring the neural correlates. *Neuroim* 2005; 28: 835–847
- Gladwell M. 2006. *Troublemakers*. The New Yorker.
- Goddard ME, Beilharz RG. The relationship of fearfulness to, and the effects of, sex, age and experience on exploration and activity in dogs. *Appl Anim Behav Sci* 1984;12:267–278.
- Gogoleva SS, Volodin JA, Volodina EV, Trut LN. To bark or not to bark: vocalizations by red foxes selected for tameness or aggressiveness toward humans. *Bioacoust* 2012; 18: 99–132.
- Goldberg S. Recent developments in attachment theory and research. *Can J Psychia* 1991; 36: 393–400.
- Goodale E, Beauchamp G, Magrath RD, Nieh JC, Ruxton GD Interspecific information transfer influences animal community structure. *Trends Ecol Evol* 2010; 25(6): 354–361.
- Gorny JH, Gorny B, Wallace DG, Whishaw IQ. Fimbria-fornix lesions disrupt the dead reckoning (homing) component of exploratory behavior in mice. *Learn Mem* 2002; 9:387-394.
- Gosling SD. From mice to men: what can we learn about personality from animal research? *Psychol Bull* 2001; 127(1):45–86.

- Gottman JM, Katz LF, Hooven C. Parental meta-emotion philosophy and the emotional life of families: theoretical models and preliminary data. *J Fam Psychol* 1996; 10:243–268.
- Gould-Beierle KL, Kamil AC. The effect of proximity on landmark use in Clark's nutcrackers. *Anim Behav* 1999; 58: 477–488.
- Green JD, Campbell WK. Attachment and exploration: Chronic and contextual accessibility. *Pers Soc Psychol Bull* 2000; 26: 452–461.
- Grommet EK, Droit-Volet S, Gil S, Hemmes NS, Baker AH, Brown BL. Behav Processes. Time estimation of fear cues in human observers 2011; 1; 86(1):88–93.
- Grommet EK, Hemmes NS, Brown BL. The Role of Clock and Memory Processes in the Timing of Fear Cues by Humans in the Temporal Bisection Task. *Behav Proc* 2019; 7;164:217–229.
- Gruber T, Grandjean D. A comparative neurological approach to emotional expressions in primate vocalizations. *Neurosci Biobehav Rev* 2017; 73: 182–190.
- Grüner K, Muris P, Merckelbach H. The relationship between anxious rearing behaviours and anxiety disorders symptomatology in normal children. *J Behav Ther Exp Psychiat* 1999; 3; 30(1):27–35.
- Guéguen N, Jacob C, Martin A. Mimicry in social interaction: its effect on human judgment and behavior. *Europ J Soc Sci* 2009; 8(2): 253–259.
- Hagstrom JT. Atmospheric propagation modeling indicates homing pigeons use loft-specific infrasonic 'map' cues. *J Exp. Biol* 2013; 216: 687–699.
- Hallgren A 1997. Hundeprobleme – Problemhunde. Verlagshaus Oertel und Spörer, Reutlingen.
- Halpern DF. Sex differences in cognitive abilities. 3rd ed. Lawrence Erlbaum Associates; London, UK: 2000.
- Handelman B. Canine Behavior: A Photo Illustrated Handbook; Dogwise Publishing: Wenatchee, WA, USA, 2012.
- Handlin L, Nilsson A, Ejdebäck M, Hydbring-Sandberg E, Uvnäs-Moberg K. Associations between the psychological characteristics of the human-dog relationship and oxytocin and cortisol levels. *Anthrozoos* 2012; 25(2):215–228.
- Haraway D 2008. When Species Meet. University of Minnesota Press.
- Hare B. Survival of the friendliest: Homo sapiens evolved via selection for prosociality. *Ann Rev Psychol* 2017; 68: 155–186.
- Hare B, Wobber V, Wrangham R. The self-domestication hypothesis: evolution of bonobo psychology is due to selection against aggression. *Anim Behav* 2012; 83:573–585.
- Hare B. From nonhuman to human mind: what changed and why? *Curr Dir Psychol Sci* 2007; 16:60–64.

- Hare B, Plyusnina I, Ignacio N, Schepina O, Stepika A, Wrangham R, Trut L. Social cognitive evolution in captive foxes is a correlated by-product of experimental domestication. *Curr Biol* 2005;15:226–30.
- Hare B, Tomasello M. The emotional reactivity hypothesis and cognitive evolution. *Trends Cogn Sci* 2005a; 9:464–465.
- Hare B, Tomasello M. Human-like social skills in dogs? *Trends Cogn Sci* 2005b; 9:439–444.
- Hare B, Brown M, Williamson C, Tomasello M. The domestication of social cognition in dogs. *Science* 2002; 11; 298(5598):1634-6.
- Hare B, Tomasello M. Domestic dogs (*Canis familiaris*) use human and conspecific social cues to locate hidden food. *J Comp Psychol* 1999; 113:173-7.
- Hart V, Nováková P, Malkemper EP, Begall S, Hanzal V, Ježek M, Kušta T, Němcová V, Adámková J, Benediktová K, Červený J, Burda H. Dogs are sensitive to small variations of the Earth's magnetic field. *Front Zool* 2013; 10: 80.
- Hart LY. Dogs as human companions: a review of the relationship. In: Serpell, J. *The domestic dog: its evolution, behaviour and interactions with people*. Cambridge: Cambridge University Press, 1995: 161–178.
- Hawley WR, Grissom EM, Barratt HE, Conrad TS, Dohanich GP. The effects of biological sex and gonadal hormones on learning strategy in adult rats. *Physiol Behav* 2012; 105: 1014–1020.
- Hayama S, Chang L, Gumus K, King GR, Ernst T. Neural correlates for perception of companion animal photographs. *Neuropsychol* 2016; 85: 278–495.
- Head E, Milgram NW, Cotman CW. Neurobiological models of aging in the dog and other vertebrate species. *Funct Neurobiol Aging* 2001;5: 457–468.
- Hecht J, Horowitz A. Introduction to dog behaviour. *Anim Behav for Shelter Vet and Staff*, 1st ed.; Weiss, E., Mohan-Gibbons, H., Zawistowski, S., Eds.; Wiley-Blackwell: London, UK, 2015: 5–30.
- Helton WS. Cephalic index and perceived dog trainability. *Behav Proc* 2009; 82:355–358.
- Helton WS, Helton ND. Physical size matters in the domestic dog's (*Canis lupus familiaris*) ability to use human pointing cues. *Behav Proc* 2010; 85: 77–79.
- Herman RA, Wallen K. Cognitive performance in rhesus monkeys varies by sex and prenatal androgen exposure. *Horm Behav* 2007; 51:496–507.
- Herwijnen IRV, van der Borg JAM, Naguib M, Beerda B. The existence of parenting styles in the owner-dog relationship. *PLoS One* 2018; 13(2):e0193471.
- HibyEF, RooneyNJ, Bradshaw JWS. Dog training methods: their use, effectiveness and interaction with behaviour and welfare. *Anim Welf* 2004; 13:63–69.
- Hinde RA. Control of movement patterns in animals. *Q J Exp Psychol* 1969; 21: 105–126.

- Hirschman EC. Consumers and their animal companions. *J Consum Res* 1994; 20: 616–632.
- Holcomb R, Williams RC, Richards PS. The elements of attachment: Relationship maintenance and intimacy. *J Delta Soc* 1985; 2(1): 28–34.
- Holland KE. Review Acquiring a Pet Dog: A Review of Factors Affecting the Decision-Making of Prospective Dog Owners. *Anim* 2019; 9: 124.
- Horn L, Huber L, Range F. The Importance of the secure base effect for domestic dogs – Evidence from a manipulative problem-solving task. *PLoS ONE* 2013; 8(5): e65296.
- Horn L, Range F, Huber L. Dogs' attention towards humans depends on their relationship, not only on social familiarity. *Anim Cogn* 2013; 16: 435–443.
- Horn L, Virányi Z, Miklósi Á, Huber L, Range F. Domestic dogs (*Canis familiaris*) flexibly adjust their human directed behavior to the actions of their human partners in a problem situation. *Anim Cogn* 2015; 15(1): 57–71.
- Horowitz A. Smelling themselves: Dogs investigate their own odours longer when modified in an “olfactory mirror” test. *Behav Proc* 2017; 143: 17–24.
- Horowitz A. Attention to attention in domestic dog (*Canis familiaris*) dyadic play. *Anim Cogn* 2009; 12: 107–118.
- Horowitz A. Disambiguating the “guilty look”: Salient prompts to a familiar dog behaviour. *Behav Proc* 2009; 81(3):447–452.
- Horváth Z, Doka A, Miklósi A. Affiliative and disciplinary behavior of human handlers during play with their dog affects cortisol concentrations in opposite directions. *Horm Behav* 2008; 54(1):107–114.
- Horváth Z, Igyártó BZ, Magyar A, Miklósi Á. Three different coping styles in police dogs exposed to a short-term challenge. *Horm Behav* 2007; 2:621–630.
- Hovestadt T, Poethke HJ. From random walks to informed movement. *Oikos* 2013; 122: 857–866.
- Howell P. Between the muzzle and the leash: dog-walking, discipline and the modern city. In: Atkins P (ed) *Animal cities: beastly urban histories*. Ashgate, Abingdon, 2012: 221–241.
- Howse MS, Anderson RE, Walsh CJ. Social behaviour of domestic dogs (*Canis familiaris*) in a public off-leash dog park. *Behav Proc* 2018; 3:13.
- Hsu YY, Serpell JA. Development and validation of a questionnaire for measuring behavior and temperament traits in pet dogs. *J Am Vet Med Assoc* 2003; 223: 1293–1300.
- Huber L, Popovová N, Riener S, Salobir K, Cimarelli G. Would dogs copy irrelevant actions from their human caregiver? *Learn & Behav* 2018; 46:387–397.

- Huber A, Barber ALA, Faragó T, Müller CA, Huber L. Investigating emotional contagion in dogs (*Canis familiaris*) to emotional sounds of humans and conspecifics. *Anim Cogn* 2017; 20(4):703–715.
- Huber L, Racca A, Scaf B, Virányi Z, Range F. Discrimination of familiar faces in dogs (*Canis familiaris*) *Learn Motiv* 2013; 44:258–69.
- Huber L, Range F, Voelkl B, Szucsich A, Virányi Z, Miklósi Á. The evolution of imitation: What do the capacities of nonhuman animals tell us about the mechanisms of imitation? *Phil Trans R Soc London B: Biol Sci* 2009; 64: 2299–2309.
- Hudson EG, Brookes VJ, Dürr S, Ward MP. Domestic dog roaming patterns in remote northern Australian indigenous communities and implications for disease modeling. *Prev Vet Med* 2017; 10(1);146:52-60.
- Hudson EG, Brookes VJ, Ward MP, Dürr S. Using roaming behaviours of dogs to estimate contact rates: the predicted effect on rabies spread. *Epidemiol Infect* 2019; 147:e135.
- Hughes J, Macdonald DW. A review of the interactions between free-roaming domestic dogs and wildlife. *Biol Conserv* 2013; 157: 341–351.
- Hughes RN. Neotic preferences in laboratory rodents: issues, assessment and substrates. *Neurosci Biobehav Rev* 2007; 31(3):441-64.
- Hunt MG, Otto CM, Serpell JA, Alvarez J. Interactions between handler well-being and canine health and behavior in search and rescue teams. *Anthrozoös* 2012; 25: 323–335.
- Instone L, Mee K. Companion acts and companion species: boundary transgressions and the place of dogs in urban public space. In: Bull J (ed) *Animal movements—moving animals: essays on direction, velocity and agency in humanimal encounters*. Crossroads of Knowledge Series at the Centre for Gender Research, University Printers, Uppsala, 2011: 229–250.
- Isgor C, Sengelaub DR. Prenatal gonadal steroids affect adult spatial behavior, CA1 and CA3 pyramidal cell morphology in rats. *Horm Behav* 1998; 10; 34(2):183-98.
- Ishikawa Y, Mills D, Willmott A, Mullineaux D, Guo K. Sociability modifies dogs' sensitivity to biological motion of different social relevance. *Anim Cogn* 2018; 3;21(2):245-252.
- Janik VM, Sayigh LS, Wells RS. Signature whistle shape conveys identity information to bottlenose dolphins. *Proc Natl Acad Sci USA* 2006; 103:8293–8297.
- Johansson EE. *Human-Animal Bonding: An Investigation of Attributes* [doctoral thesis]. Edmonton, AB: University of Alberta; 1999.
- Johnson TP, Garrity TF, Stallones L. Psychometric evaluation of the Lexington Attachment to Pets Scale (LAPS). *Anthrozoös* 1992; 5(3): 160–175.

- Johnson-Ulrich L, Johnson-Ulrich Z, Holekamp K. Proactive behavior, but not inhibitory control, predicts repeated innovation by spotted hyenas tested with a multi-access box. *Anim Cogn* 2018; 21(3):379–392.
- Johnson TP, Garrity TF, Stallones L. Psychometric evaluation of the Lexington Attachment to Pets Scale (LAPS). *Anthrozoos* 1992; 5: 160–175.
- Julius H, Beetz A, Kotrschal K, Turner D, Uvnäs-Moberg K. *Attachment to Pets*. Göttingen: Hogrefe Publishing, 2013: 192.
- Kamil AC, Cheng K. Way-finding and landmarks: the multiple-bearings hypothesis. *J Exp Biol* 2001; 204: 103–113.
- Kamil AC, Jones JE. The seed-storing corvid clark's nutcracker learns geometric relationships among landmarks. *Nature* 1997; 390: 276–279.
- Kaminski J, Hynds J, Morris P, Waller BM. Human attention affects facial expressions in domestic dogs. *Sci Rep* 2017; 7: 12914.
- Kaminski J, Marshall-Pescini S. *The Social Dog: Behavior and Cognition*. Burlington, VT: Elsevier Science; 2014.
- Kaminski J, Pitsch A, Tomasello M. Dogs steal in the dark. *Anim Cogn* 2013; 5(3):385-94.
- Kaminski J, Nitzschner M. Do dogs get the point? A review of dog–human communication ability. *Learn Motiv* 2013; 44: 294–302.
- Kaminski J, Schulz L, Tomasello M. How dogs know when communication is intended for them. *Dev Sci* 2012;3; 15(2):222-32.
- Kaminski J, Templemann S, Call J, Tomasello M. Domestic dogs comprehend human communication with ironic signs. *Dev Sci* 2012; 12:831–7.
- Kaminski J, Neumann M, Bräuer J, Call J, Tomasello M. Dogs, *Canis familiaris*, communicate with humans to request but not to inform. *Anim Behav* 2011; 82: 651–658.
- Kaminski J, Call J, Fischer J. Word learning in a domestic dog: evidence for “fast mapping”. *Sci* 2004; 6; 304(5677):1682-3.
- Kamler JF, Gray MM, Oh A, Macdonald DW. Genetic structure, spatial organization, and dispersal in two populations of bat-eared foxes. *Ecol Evol* 2013; 3(9):2892–2902.
- Kanat-Maymon Y, Antebi A, Zilcha-Mano S. Basic psychological need fulfilment in human-pet relationships and well-being. *Pers Individ Dif* 2016; 92:69–73.
- Kasparson AA, Badridze J, Maximov VV. Colour cues proved to be more informative for dogs than brightness. *Proc Biol Sci* 2013; 280: 20131356.
- Kaulfuß P, Mills DS. Neophilia in domestic dogs (*Canis familiaris*) and its implication for studies of dog cognition. *Anim Cogn* 2008; 11: 553-556.
- Keller H. Attachment – past and present. But what about the future? *Integr Psychol Behav Sci* 2008; 42: 406–415.

- Kelley AE, Cador M, Stinus L. Exploration and its measurement: a psychopharmacological perspective. In: Boulton AA, Baker GB, eds. Psychopharmacology: Neuromethods. Vol. 13 Humana Press: Clifton; 1989.
- Kerepesi A, Dóka A, Miklósi Á. Dogs and their human companions: the effect of familiarity on dog–human interactions. Behav Proc 2015; 110: 27–36.
- Kerswell KJ, Bennett PJ, Butler KL, Hemsworth PH. Self-reported comprehension ratings of dog behaviour by puppy owners. Anthrozoös 2009; 22:183–93.
- Kertes DA, Liu J, Hall NJ, Hadad NA, Wynne CDL, Bhatt SS. Effect of Pet Dogs on Children's Perceived Stress and Cortisol Stress Response. Soc Dev 2017; 5; 26(2):382-401.
- Kidd AH, Kidd RM, George CC. Successful and unsuccessful pet adoptions. Psychol Rep 1992; 70 (2):547–561.
- Kim HS, Sherman DK, Sasaki JY, Xu J, Chu TQ, Ryu C, et al. Culture, distress, and oxytocin receptor polymorphism (OXTR) interact to influence emotional support seeking. Proc Natl Acad Sci U.S.A. 2010; 107: 15717–15721.
- Kimchi T, Etienne AS, Terkel J. A subterranean mammal uses the magnetic compass for path integration. PNAS 2004; 101(4): 1105–1109.
- King T, Marston LC, Bennett PC. Describing the ideal Australian companion dog. Appl Anim Behav Sci, 2009; 120(1):84–93
- King AJ, Williams LJ, Mettke-Hofmann C. The effects of social conformity on Gouldian finch personality. Anim Behav 2015; 99: 25-31.
- Kis A, Hernádi A, Miklósi B, Kanizsár O and Topál J. The Way Dogs (*Canis familiaris*) Look at Human Emotional Faces Is Modulated by Oxytocin. An Eye-Tracking Study. Front Behav Neurosci 2017;11:210.
- Kis A, Hernádi A, Kanizsár O, Gácsi M, Topál J. Oxytocin induces positive expectations about ambivalent stimuli (cognitive bias) in dogs. Horm Behav 2015; 69:1–7.
- Kis A, Bence M, Lakatos G, Pergel E, Turcsán B, Pluijmakers J, et al. Oxytocin receptor gene polymorphisms are associated with human directed social behavior in dogs (*Canis familiaris*). PLoS ONE 2014;9:e83993
- Kis A, Topál J, Gácsi M, Range F, Huber L, Miklósi Á, Virányi Z. Does the A-not-B error in adult pet dogs indicate sensitivity to human communication? Anim Cogn 2012; 15(4):737–743.
- Kis A, Turcsán B, Gácsi M. The effect of the owner's personality on the behaviour of owner-dog dyads. Interact Stud 2012; 13(3):373–385.
- Kiss R. (2018) Biomechanical analysis of the kinematics of different dog harnesses - Research rePORT - Cooperation Research Center for Biomechanics Budapest University of Technology and Economics.

- Kita S. Pointing: A foundational building block of human communication. In: Kita S (Ed.). Pointing: where language, culture, and cognition meet. Hillsdale: Erlbaum; 2003: 1-8.
- Kiyokawa Y, Honda A, Takeuchi Y, Mori Y. A familiar conspecific is more effective than an unfamiliar conspecific for social buffering of conditioned fear responses in male rats. *Behav Brain Res* 2014; 267:189-193.
- Kobak RR, Sceery A. Attachment in late adolescence: working models, affect regulation, and representations of self and others. *Child Dev* 1988;59: 135–146.
- Konno A, Romero T, Inoue-Murayama M, Saito A, Hasegawa T. Dog Breed Differences in Visual Communication with Humans. *PLoS One* 2016; 11(10): e0164760.
- Konok V, Kosztolányi A, Rainer W, Mutschler B, Halsband U, Miklósi Á. Influence of owner attachment style and personality on their dogs' separation-related disorder. *PLOS ONE* 2015; 10:e0118375.
- Koolhaas JM, Korte SM, De Boer SF, Van Der Vegt BJ, Van Reenen CG, Hopster H, De Jong IC, Ruis MAW, Blokhuis HJ. Coping styles in animals: Current status in behavior and stress-physiology. *Neurosci Biobehav Rev* 1999; 23: 925–935.
- Kostarczyk E, Fonberg E. Heart rate mechanisms in instrumental conditioning reinforced by petting in dogs. *Physiol Behav* 1981; 28: 27–30.
- Koster JM, Tankersley KB. Heterogeneity of hunting ability and nutritional status among domestic dogs in lowland Nicaragua. *PNAS* 2012;109 (8): E463–E470.
- Kotrschal K, Schöberl I, Bauer B, Thibeaut AM, Wedl M. Dyadic relationships and operational performance of male and female owners and their male dogs. *Behav Process* 2009; 81: 383-391.
- Kovács K, Virányi Z, Kis A, et al. Dog-Owner Attachment Is Associated With Oxytocin Receptor Gene Polymorphisms in Both Parties. A Comparative Study on Austrian and Hungarian Border Collies. *Front Psychol* 2018; 9:435.
- Kovács K, Kis A, Kanizsár O, Hernádi A, Gácsi M, Topál J. The effect of oxytocin on biological motion perception in dogs (*Canis familiaris*). *Anim Cogn* 2016a; 19:513–522.
- Kovács K, Kis A, Pogány Á, Koller D, Topál J. Differential effects of oxytocin on social sensitivity in two distinct breeds of dogs (*Canis familiaris*). *Psychoneuroendocrinol* 2016b; 74: 212–220.
- Kramer G. Wird die Sonnenhöhe bei der Heimfindeorientierung verwertet? *J Ornithol* 1953; 94: 201–19.
- Krause J, Hoare D, Krause S, Hemelrijk CK, Rubenstein DI. Leadership in fish shoals. *Fish Fish* 2000; 1: 82–89.
- Krause J, James R, Croft DP. Personality in the context of social networks. *Phil Trans R Soc* 2010; 365: 4099–4106.

- Krauze-Gryz D, Gryz J. Free-ranging domestic dogs (*Canis familiaris*) in central Poland: Density, penetration range and diet composition. *Polish J Ecol* 2014; 62, 183 – 193.
- Krebs RM, Schott BH, Schütze H, Düzel E. The novelty exploration bonus and its attentional modulation. *Neuropsychol* 2009; 9; 47(11):2272-81.
- Kubinyi E, Bence M, Koller D, et al. Oxytocin and Opioid Receptor Gene Polymorphisms Associated with Greeting Behavior in Dogs. *Front Psychol* 2017; 8:1520.
- Kubinyi E, Pongrácz P, Miklósi A. Dog as a model for studying conspecific and heterospecific social learning. *J Vet Behav* 2009; 4(1): 31–41.
- Kubinyi E., Turcsán B., Miklósi Á. Dog and owner demographic characteristics and dog personality trait associations. *Behav Proc* 2009; 81:392–401.
- Kubinyi E, Miklósi A, Topál J, Csányi V. Social mimetic behaviour and social anticipation in dogs: preliminary results. *Anim Cogn* 2003; 3:6(1):57-63.
- Kuhl CA. An Investigation of Pedigree Dog Breeding and Ownership in the UK: Experiences and Opinions of Veterinary Surgeons, Pedigree Dog Breeders and Dog Owners. Ph.D.Thesis. The University of Nottingham, Nottingham, UK, 2017.
- Kuhne F, Hoessler JC, Struwe R. Affective behavioural responses by dogs to tactile human-dog interactions. *Berl Munch Tierarztl Wochenschr* 2012; 125: 371–378.
- Kuhne F. Behavioural responses of dogs to dog-human social conflict situations. *Appl Anim Behav Sci* 2016; 182:38–43.
- Kukekova AV, Johnson JL, Xiang X, Feng S, Liu S, Rando HM, Kharlamova AV, Herbeck Y, Serdyukova NA, Xiong Z, Beklemischeva V, Koepfli K-P, Gulevich RG, Vladimirova AV, Hekman JP, Perelman PL, Graphodatsky AS, O'Brien SJ, Wang X, Clark AG, Acland GM, Trut LN, Zhang G. Red fox genome assembly identifies genomic regions associated with tame and aggressive behaviours. *Nat Ecol Evol* 2018.
- Ladha C, O'Sullivan J, Belshaw Z, Asher L. GaitKeeper: A System for Measuring Canine Gait. *Sensors* 2017; 17: 309.
- LaFollette MR, Rodriguez KE, Ogata N, O'Haire ME. Military Veterans and Their PTSD Service Dogs: Associations between Training Methods, PTSD Severity, Dog Behavior, and the Human-Animal Bond. *Front Vet Sci* 2019; 6:23.
- Lago DJ, Knight B, Connell C. Relationships with companion animals among the rural elderly. In: Katcher, A.H., Beck, A.M. (Eds.), *New Perspectives on Our Lives with Companion Animals*. University of Pennsylvania Press, Philadelphia, PA, 1983: 329e340.
- Lakatos G. Evolutionary approach to communication between humans and dogs. *Ann Ist Super Sanità* 2011; 47(4): 373-377.
- Lakin JL, Jefferis VE, Cheng CM, Chartrand TL. The chameleon effect as social glue: Evidence for the evolutionary significance of nonconscious mimicry. *J Nonverb Behav* 2003; 7: 145–162.

- Landsberg GM, Hunthausen WL, Ackerman LJ. Handbook of Behavior Problems of the Dog and Cat. 2nd ed. Philadelphia, PA: Elsevier Health Sciences; 2003.
- Lang J. Ja, wo laufen sie denn? Ein Beitrag zur Räuber-Beute-Beziehung zwischen Wild und Hund. Beiträge zur Jagd- und Wildforschung 2014; 39: 337-345.
- Lang PJ, Bradley MM, Cuthbert BN. Motivated attention: affect, activation, and action. In: Attention and Orienting, P.J. Lang, R.F. Simons, and M. Balaban, eds. (Mahwah, NJ: Erlbaum) 1997: 97 – 135.
- Larson G, Fuller DQ. The Evolution of Animal Domestication. Ann Rev Ecol Evol Syst 2014; 45:1: 115-136.
- Lazzaroni M, Range F, Bernasconi L, et al. The role of life experience in affecting persistence: A comparative study between free-ranging dogs, pet dogs and captive pack dogs. PLoS One. 2019; 14(4):e0214806.
- Lea SEG, Osthaus B. In what sense are dogs special? Canine cognition in comparative context. Learn Behav 2018; 46: 335.
- Lee HS, Shepley M, Huang CS. Evaluation of off-leash dog parks in Texas and Florida: a study of use patterns, user satisfaction, and perception. Landsc Urban Plan 2009; 92:314–324.
- Lefebvre D, Diederich C, Delcourt M, Giffroy JM. The quality of the relation between handler and military dogs influences efficiency and welfare of dogs. Appl Anim Behav Sci 2007;104(1-2):49–60.
- Lehockey KA, Winters AR, Nicoletta AJ, Zurlinden TE, Everhart DE. The effects of emotional states and traits on time perception. Brain Inform 2018; 5(2):9.
- Ley JM, Bennett PC, Coleman GJ. A refinement and validation of the Monash Canine Personality Questionnaire (MCPQ). Appl Anim Behav Sci 2009; 116(2-4):220–227.
- Lisberg AE, Snowdon CT. The effects of sex, gonadectomy and status on investigation patterns of unfamiliar conspecific urine in domestic dogs, *Canis familiaris*. Anim Behav 2009; 77: 1147–1154.
- Locklear MN, Kritzer MF. Assessment of the effects of sex and sex hormones on spatial cognition in adult rats using the Barnes maze. Horm Behav 2014;7;66(2):298-308.
- Lord K, Schneider R, Coppinger R. Evolution of working dogs. In J. Serpell (Ed.), The Domestic Dog: Its Evolution, Behavior and Interactions with People 2016: 42-66. Cambridge: Cambridge University Press.
- Lord K, Feinstein M, Smith B, Coppinger R. Variation in reproductive traits of members of the genus *Canis* with special attention to the domestic dog (*Canis familiaris*). BehavProc 2013; 92: 131–142.
- Lord K, Feinstein M, Coppinger R. Barking and mobbing. Behav Proc 2009; 7; 81(3):358-68.

- Lorenz KP, Kolkmeier CA, Gansloßer U. Comparison of the Social Behaviour of Intact and Neutered Female Domestic Dogs (*Canis Lupus Familiaris*): Questionnaires and Case Studies. *Dairy and Vet Sci J* 2019; 12(2): 555835.
- Lorenz K (1981). *The foundations of ethology*. Springer Verlag, Wien, Austria.
- Luescher AU, Reisner IR. Canine aggression toward familiar people: A new look at an old problem. *Vet Clin N Am Small Anim Prac* 2008; 38: 1107–1130.
- Maaswinkel H, Whishaw IQ. Homing with locale, taxon, and dead reckoning strategies by foraging rats: sensory hierarchy in spatial navigation. *Behav Brain Res* 1999; 99: 143–52.
- Macdonald DW, Johnson DDP: Patchwork planet. The resource dispersion hypothesis, society, and the ecology of life. *J Zool* 2015; 295:75-107.
- MacLean EL, Snyder-Mackler N, vonHoldt BM, Serpell JA. Highly heritable and functionally relevant breed differences in dog behavior *Proc R Soc B* 2019; 10;286(1912):20190716.
- MacLean EL, Herrmann E, Suchindra S, Hare B. Individual differences in cooperative communicative skills are more similar between dogs and humans than chimpanzees. *Anim Behav* 2017; 126: 41–51.
- Macpherson K, Roberts WA. Spatial memory in dogs (*Canis familiaris*) on a radial maze. *J Comp Psychol* 2010; 124, 1: 47–56.
- McCrae RR, Martin TA, Hrebickova M, Urbanek T, Boomsma DI, Willemsen G, Costa PT. Personality trait similarity between spouses in four cultures. *J Pers* 2008; 76: 1137–1164.
- McNicholas J, Collis GM. Dogs as catalysts for social interactions: robustness of the effect. *Br J Psychol* 2000; 2; 91:61-70.
- Maes LD, Herbin M, Hackert R, Bels VL, Abourachid A. Steady locomotion in dogs: temporal and associated spatial coordination patterns and the effect of speed. *J Exp Biol* 2008; 211: 138–149.
- Maglio SJ, Polman E. Spatial orientation shrinks and expands psychological distance. *Psychol Sci* 2014; 25(7): 1345-52.
- Maguire EA, Frackowiak RSJ, Frith CD. Recalling routes around London: activation of the right hippocampus in taxi drivers. *J Neurosci* 1997; 17: 7103–7110.
- Mancini C, van der Linden J, Bryan J, Stuart A. Exploring interspecies sensemaking: dog tracking semiotics and multispecies ethnography. In: *Ubicomp 2012*, Pittsburgh, USA.
- Manteuffel G, Puppe B, Schön PC. Vocalization of farm animals as a measure of welfare. *Appl Anim Behav Sci* 2004; 88:163–182.
- Marder A, Duxbury MM. Review Obtaining a pet: realistic expectations. *Vet Clin North Am Small Anim Pract* 2008; 9; 38(5):1145-62, viii.

- Mariette MM, Griffith SC. Nest visit synchrony is high and correlates with reproductive success in the wild zebra finch *Taeniopygia guttata*. *J Av Biol* 2012; 43: 131–140.
- Marinelli L, Adamelli S, Normando S, Bono G. Quality of life of the pet dog: influence of owner and dog's characteristics. *Appl Anim Behav Sci* 2007; 108: 143e156.
- Mariti C, Falaschi C., Zilocchi M, Fatjó J, Sighieri C, Ogi A, et al. Analysis of the intraspecific visual communication in the domestic dog (*Canis familiaris*): a pilot study on the case of calming signals. *J Vet Behav* 2017; 18:49–55.
- Mariti C, Carlone B, Ricci E, Sighieri C, Gazzano A. Intraspecific attachment in adult domestic dogs (*Canis familiaris*): preliminary results. *Appl Anim Behav Sci* 2014; 152: 64–72.
- Mariti C, Gazzano A, Moore JL. Dog attachment to man: a comparison between pet and working dogs. *J Vet Behav: Clin Appl Res* 2013; 8: 135–145.
- Mariti C, Gazzano A, Moore JL, Baragli P, Chelli L, Sighieri C. Perception of dogs' stress by their owners. *J Vet Behav* 2012; 7:213–9.
- Marshall-Pescini S, Cafazzo S, Virányi Z, Range F. Integrating social ecology in explanations of wolf–dog behavioral differences. *Curr Opin Behav Scien* 2017, 16:80–86.
- Marshall-Pescini S, Rao A, Virányi Z, Range F. The role of domestication and experience in 'looking back' towards humans in an unsolvable task. *Sci Rep* 2017; 7: 46636.
- Marshall-Pescini S, Passalacqua C, Barnard S, Valsecchi P, Prato-Previde E. Agility and search and rescue training differently affects pet dogs' behaviour in socio-cognitive tasks. *Behav Proc* 2009; 81:416–422.
- McComb K, Reby D. Communication in terrestrial animals. *Communication*. Elsevier Academic, Oxford 2009: 1167–1171.
- McConnell PB. *For the Love of a Dog*, Ballantine Books, New York, 2006: xxviii,139-141, 196.
- McDevitt L. *Control Unleashed*, Clean Run Productions, USA 2007: 31-68 Mackinnon, P. 20014, Scentwork.
- McGreevy P, Starling M, Payne E, Bennett P. Defining and measuring dogmanship: A new multidisciplinary science to improve understanding of human–dog interactions. *Vet J* 2017; 229(11): 1-5.
- McGreevy PD, Starling M, Branson NJ, Cobb ML, Calnon D. An overview of the dog-human dyad and ethograms within it. *J Vet Beh Clin App Res* 2012; 7:103–17.
- McGreevy P, Grassi TD, Harman AM. A strong correlation exists between the distribution of retinal ganglion cells and nose length in the dog. *Brain Behav Evol* 2004; 63:13–22.
- Mehrkam LR, Wynne CDL. Behavioral differences among breeds of domestic dogs (*Canis lupus familiaris*): Current status of the science. *Appl Anim Behav Sci* 2014; 155: 12–27.

- Meints K, Brelsford V, De Keuster T. Teaching Children and Parents to Understand Dog Signaling. *Front Vet Sci* 2018; 5:257.
- Meints K, Racca A, Hickey N. How to prevent dog bite injuries? Children misinterpret dogs' facial expressions. *Inj Prevent* 2010; 16:A68.
- Merola I, Prato-Previde E, Lazzaroni M, Marshall-Pescini S. Dogs' comprehension of referential emotional expressions: Familiar people and familiar emotions are easier. *Anim Cogn* 2014; 17: 373–385.
- Merola I, Prato-Previde E, Marshall-Pescini S. Social referencing in dog-owner dyads? *Anim Cogn* 2012a; 15 (2): 175–185.
- Merola I, Prato-Previde E, Marshall-Pescini S. Dogs' social referencing towards owners and strangers. *PLoS ONE* 2012b; 7:e47653.
- Mersmann D, Tomasello M, Call J, Kaminski J, Taborsky M. Simple mechanisms can explain social learning in domestic dogs (*Canis familiaris*). *Ethol* 2011; 117: 1–16.
- Meyer I, Forkman B. Dog and owner characteristics affecting dog owner relationship. *J Vet Behav* 2014; 9: 143-150.
- Miklósi A (2016). *Dog behaviour, evolution and cognition*. 2nd ed. Oxford, England: Oxford University Press.
- Miklósi Á. Dogs in anthropogenic environments: Society and family. In *Dog Behaviour, Evolution, and Cognition*, 2nd ed.; Miklósi, Á., Ed.; University Press: Oxford, UK, 2016: 47–66.
- Miklósi A, Kubinyi E. Current Trends in Canine Problem-Solving and Cognition. *Curr Dir Psychol Sci* 2016; 10; 25(5): 300–306.
- Miklósi A, Turcsán B, Kubinyi E. The Personality of Dogs. In: *The Social Dog*. 2014; 7: 191-222.
- Miklósi Á, Topál J. What does it take to become 'best friends'? Evolutionary changes in canine social competence. *Trends CognSci* 2013; 17: 287–294.
- Miklósi A (2007). *Dog behaviour, evolution, and cognition*. Oxford, England: Oxford University Press.
- Miklósi Á, Soproni K. A comparative analysis of animals' understanding of the human pointing gesture. *Anim Cogn* 2006; 9: 81–93.
- Miklósi Á, Pongrácz P, Lakatos G, Topál J, Csányi V. A comparative study of the use of visual communicative signals in interactions between dogs (*Canis familiaris*) and humans and cats (*Felis catus*) and humans. *J Comp Psychol* 2005; 119:179-86.
- Miklósi Á, Topál J, Csányi V. Comparative social cognition: what can dogs teach us? *Anim Behav* 2004; 67(6):995–1004.
- Miklósi Á, Kubinyi E, Topál J, Gácsi M, Virányi Z, Csányi V. A simple reason for a big difference: wolves do not look back at humans, but dogs do. *Curr Biol* 2003; 13: 763–766.

- Miklósi Á, Polgárdi R, Topál J, Csányi V. Intentional behaviour in dog–human communication: An experimental analysis of ‘showing’ behaviour in the dog. *Anim Cogn* 2000; 3: 159–166.
- Miklósi Á, Polgárdi R, Topál J, Csányi V. Use of experimenter-given cues in dogs. *Anim Cogn* 1998; 1:113–21.
- Miller H, Gipson C, Vaughan A, Rayburn-Reeves R, Zentall TR. Object permanence in dogs: invisible displacement in a rotation task. *Psychon B Rev* 2009; 16(1): 150–155.
- Miller HC, Rayburn-Reeves R, Zentall TR. Imitation and emulation by dogs using a bidirectional control procedure. *Behav Proc* 2009; 80:109–114.
- Miller M, Lago D. Observed pet–owner in-home interactions: Species differences and association with the Pet Relationship Scale. *Anthrozoos* 1990; 4: 49–54.
- Mills DS. What’s in a word? A review of the attributes of a command affecting the performance of pet dogs. *Anthrozoös* 2005; 18:208–221.
- Minetti AE. “The three modes of terrestrial locomotion”. In Benno Maurus Nigg, Brian R. MacIntosh, Joachim Mester (eds.). *Biomechanics and Biology of Movement. Human Kinetics*. 2000: 67–78.
- Mittelstaedt H, Mittelstaedt ML. Homing by path integration. In: Papi F., Wallraff H.G., editors. *Avian navigation*. New York: Springer.1982: 290–297
- Molnár CS, Pongrácz P, Miklósi Á. Seeing with ears: Sightless humans’ perception of dog bark provides a test for structural rules in vocal communication. *Q J Exp Psychol* 2010; 63: 1004–1013.
- Molnár CS; Kaplan F, Roy P, Pachet F, Pongrácz P, Dóka A, Miklósi Á. Classification of dog barks: A machine learning approach. *Anim Cogn* 2008; 11: 389–400.
- Molnár C, Pongrácz P, Faragó T, Dóka A, Miklósi Á. Dogs discriminate between barks: The effect of context and identity of the caller. *Behav Proc* 2009; 82: 198–201.
- Molnár C, Pongrácz P, Dóka A, Miklósi Á. Can humans discriminate between dogs on the base of the acoustic parameters of barks? *Behav Proc* 2006; 73:76–83.
- Mondelli F, Prato Previde E, Verga M, Levi D, Magistrelli S, Valsecchi P. The Bond That Never Developed: Adoption and Relinquishment of Dogs in a Rescue Shelter. *J App Anim Welf Sci* 2016; 7(4): 253–266.
- Mongillo P, Scandurra A, D’Aniello B, Marinelli L. Effect of sex and gonadectomy on dogs’ spatial performance. *Appl Anim Behav Sci* 2017; 191:84–89.
- Mongillo P, Pitteri E, Candaten M, Marinelli L. Can attention be taught? Interspecific attention by dogs (*Canis familiaris*) performing obedience tasks. *Appl Anim Behav Sci* 2016; 182:30–37.
- Mongillo P, Adamelli S, Pitteri E, Marinelli L. Reciprocal attention of dogs and owners in urban contexts. *J Vet Behav: Clin Appl Res* 2014; 9(4): 158–163.

- Mongillo P, Bono, G, Regolin L, Marinelli L. Selective attention to humans in companion dogs, *Canis familiaris*. *Anim Behav* 2010; 80: 1057e1063.
- Moretti L, Hentrup M, Kotrschal K, Range F. The influence of relationships on neophobia and exploration in wolves and dogs. *Anim Behav* 2015; 9 (107): 159-173.
- Müller CA, Riemer S, Virányi Z, Huber L, Range F. Inhibitory control, but not prolonged object-related experience appears to affect physical problem-solving performance of pet dogs. *PLOS One* 2016; 11: e147753.
- Müller CA, Schmitt K, Barber AL, Huber L. Dogs can discriminate emotional expressions of human faces. *Curr Biol* 2015; 25: 601–605.
- Müller, CA, Riemer S, Range F, Huber L. Dogs' use of the solidity principle: revisited. *Anim Cogn* 2014a; 17(3): 821–825.
- Müller CA, Riemer S., Range F, Huber L. The use of a displacement device negatively affects the performance of dogs (*Canis familiaris*) in visible object displacement tasks. *J Comp Psychol* 2014b; 128: 240–250.
- Müller CA, Riemer S, Virányi Z, Huber L, Range F. Dogs learn to solve the support problem based on perceptual cues. *Anim Cogn* 2014; 17: 1071 –1080.
- Müller CA, Mayer C, Dörrenberg S, Huber L, Range F. Female but not male dogs respond to a size constancy violation. *Biol Lett* 2011; 7:689–691.
- Müller M, Wehner R. Path integration in desert ants, *Cataglyphis fortis*, *PNAS* 1988; 85: 5287-5290.
- Muhly TB, Semeniuk C, Massolo A, Hickman L, Musiani M. Human activity helps prey win the predator-prey space race. *PLoS ONE* 2011; 6 (3): e17050.
- Muir M. 2012, Stress in Dogs: Recognising the causes and how to deal with them, [www.action4dogs.co.uk/stress in dogs.html](http://www.action4dogs.co.uk/stress%20in%20dogs.html) (Accessed 15.9.19).
- Muris P, van Brakel AM, Arntz A, Schouten E. Behavioral Inhibition as a Risk Factor for the Development of Childhood Anxiety Disorders: A Longitudinal Study. *J Child Fam Stud* 2011; 20(2):157–170.
- Naderi S, Miklósi Á, Dóka A, Csányi V. Co-operative interactions between blind persons and their dogs. *Appl Anim Behav Sci* 2001; 74: 59–80.
- Nagasawa M, Ogawa M, Mogi K, Kikusui T. Intranasal Oxytocin Treatment Increases Eye-Gaze Behavior toward the Owner in Ancient Japanese Dog Breeds. *Front Psychol* 2017; 8():1624.
- Nagasawa M, Mitsui S, En S, Ohtani N, Ohta M, Sakuma Y, Onaka T, Mogi K, Kikusui T. Oxytocin-gaze positive loop and the coevolution of human-dog bonds. *Scie* 2015; 348: 333–336.
- Nagasawa M, Murai K, Mogi K, Kikusui T. Dogs can discriminate human smiling faces from blank expressions. *Anim Cogn* 2011; 14: 525–533.

- Nathan R, Getz WM, Revilla E, Holyoak M, Kadmon R, Saltz D et al. A movement ecology paradigm for unifying organismal movement research. *Proc Natl Acad Sci USA*, 2008; 105: 19052–19059.
- Nebbe L (2001). The elementary school counselor and the HCAB. In P. Salloto (Ed.), *Pet Assisted Therapy: A Loving Intervention and an Emerging Profession*.
- Netting FE, Wilson CC, Goodie JL, Stephens MB, Byers CG, Olsen CH. Attachment, social support, and perceived mental health of adult dog walkers: what does age have to do with it? *J Sociol Soc Welf* 2013; 40:261–283.
- Netto WJ, Planta DJU. Behavioural testing for aggression in the domestic dog. *Appl Anim Behav Sci* 1997; 52: 243–263.
- O'Farrell V. Owner attitudes and dog behavior problems. *Appl Anim Behav Sci* 1997; 52: 205–213.
- O'Heare J. *Dominance Theory and Dogs* (2008). DogPsych Publishing; 2nd ed. New York.
- O'Keefe J, Nadel (1978). *The hippocampus as a cognitive map*. London, England: Clarendon press.
- Obleser P, Hart V, Begall S, Malkemper EP, Holá M, Painter MS, Červený J, Burda H. Compass-controlled escape behavior in roe deer. *Behav Ecol Sociobiol* 2015; 70: 1345–1355.
- Ohala JJ. Ethological theory and the expression of emotion in the voice. In: *Proceedings of the fourth international conference on spoken language, ICSLP 1996*; 96: 1812–1815.
- Ohman A, Lundqvist D, Esteves F. The face in the crowd revisited: a threat advantage with schematic stimuli. *J Pers Soc Psychol* 2001; 80:381–396.
- Oláh K, Topál J, Kovács K, et al. Gaze-Following and Reaction to an Aversive Social Interaction Have Corresponding Associations with Variation in the OXTR Gene in Dogs but Not in Human Infants. *Front Psychol* 2017; 8:2156.
- Olsen U. Zusammenhänge zwischen Hundeverhalten und unterschiedlicher Einschränkung des Hundes durch die Leine. Berlin, Freie Univ., Diss., 2008.
- Osthaus B, Lea SEG, Slater AM. Dogs (*Canis lupus familiaris*) fail to show understanding of means-end connections in a string-pulling task. *Anim Cogn* 2005; 8: 37–47.
- Ostojić L, Clayton NS. Behavioural coordination of dogs in a cooperative problem-solving task with a conspecific and a human partner. *Anim Cogn* 2014; 3; 17(2):445–59.
- Oudeyer PY, Gottlieb J, Lopes M. Intrinsic motivation, curiosity, and learning: Theory and applications in educational technologies. *Prog Brain Res* 2016; 229:257–284.
- Oullier O, Scott Kelso JA. Coordination from the perspective of social coordination dynamics. In *The Encyclopedia of Complexity and Systems Science*, ed R. A. Meyer (Heidelberg; Springer) 2009: 8198–8213.
- Oullier O, de Guzman GC, Jantzen KJ, Lagarde J, Scott Kelso JA. Social coordination dynamics: Measuring human bonding. *Soc Neurosci* 2008; 3(2): 178–192.

- Otmakhova N, Duzel E, Deutch AY, Lisman J. The hippocampal-VTA loop: the role of novelty and motivation in controlling the entry of information into long-term memory In: *Intrinsically Motivated Learning in Natural and Artificial Systems*. Springer; 2013: 235–54.
- Ovodov ND, Crockford SJ, Kuzmin YV, Higham TF, Hodgins GW, van der Plicht J. A 33,000-year-old incipient dog from the Altai Mountains of Siberia: evidence of the earliest domestication disrupted by the Last Glacial Maximum. *PLoS One* 2011; 6(7):e22821.
- Owren MJ, Seyfarth RM, Cheney DL. The acoustic features of vowel-like grunt calls in chacma baboons (*Papio cyncephalus ursinus*): implications for production processes and functions. *J Acoust Soc Am* 1997; 101:2951–2963.
- Pal SK. Mating System of Free-Ranging Dogs (*Canis familiaris*). *Int J Zool* 2011; 59:314216.
- Pal SK. Parental care in free-ranging dogs, *Canis familiaris*. *Appl Anim Behav Sci* 2005; 90:31-47.
- Pal SK, Ghosh B, Roy S. Dispersal behaviour of free-ranging dogs (*Canis familiaris*) in relation to age, sex, season and dispersal distance. *Appl Anim Behav Sci* 1998; 61:123–132.
- Palagi E, Nicotra V, Cordoni G. Rapid mimicry and emotional contagion in domestic dogs. *R Soc open sci* 2015; 2: 150505.
- Paldanius M, Kärkkäinen T, Väänänen-Vainio-Mattila K, Juhlin O, Häkkinen J. Communication Technology for Human-Dog Interaction: Exploration of Dog Owners' Experiences and Expectations. *Proc CHI'11*. ACM Press 2011: 2631-2640.
- Palmer R, Custance D. A counterbalanced version of Ainsworth's Strange Situation Procedure reveals secure-base effects in dog-human relationships. *Appl Anim Behav Sci* 2008; 109: 306–319.
- Papastamatiou YP, Cartamil DP, Lowe CG, Meyer CG, Wetherbee BM, Holland KN. Scales of orientation, directed walks and movement path structure in sharks. *J Anim Ecol* 2011; 80: 864–874.
- Parker HG, Dreger DL, Rimbault M, Davis BW, Mullen AB, Carpintero-Ramirez G, Ostrander EA. Genomic analyses reveal the influence of geographic origin, migration, and hybridization on modern dog breed development. *Cell Rep* 2017; 19: 697–708.
- Parker HG, Kukekova AV, Akey D, Goldstein O, Kirkness EF, Baysac K, Mosher DS, Sutter NB, Aguirre GD, Acland GM, Ostrander EA. Breed relationships facilitate fine mapping studies: A 7.8kb deletion segregates with collie eye anomaly across multiple dog breeds. *Genome Res* 2007; 19: 697–708.
- Parker HG, Kim LV, Sutter NB, Carlson S, Lorentzen TD, Malek TB, Johnson GS, DeFrance HB, Ostrander EA, Kruglyak L. Genetic structure of the purebred domestic dog. *Scien* 2004; 304: 1160–1164.

- Pattison KF, Laude JR, Zentall TR. The case of the magic bones: Dogs' memory of the physical properties of objects. *Learn Motiv* 2013; 44:252–257.
- Paul M, Sen S, Sau S, Nandi AK, Bhadra A. High early life mortality in free- ranging dogs is largely influenced by humans. *Sci Rep* 2016; 6:19641.
- Paul M, Sen Majumder S, Bhadra A. Grandmotherly care: a case study in Indian free-ranging dogs. *J Ethol* 2014a; 32:75-82.
- Paul M, Sen Majumder S, Bhadra A. Selfish mothers? An empirical test of parent-offspring conflict over extended parental care. *Behav Proc* 2014b; 103:17-22.
- Pauli AM, Bentley E, Diehl KA, Miller PE. Effects of the application of neck pressure by a collar or harness on intraocular pressure in dogs. *J Am Anim Hosp Assoc* 2006; 5;42(3):207-11.
- Pause, BM. Processing of body odor signals by the human brain. *Chemosens Percept* 2012; 5: 55–63.
- Payne E, DeAraugo J, Bennett P, McGreevy P. Exploring the existence and potential underpinnings of dog-human and horse-human attachment bonds. *Behav Proc* 2016; 4 (125):114-21.
- Payne, C, Jaffe K. Self seeks like: Many humans choose their dog-pets following rules used for assortative mating. *J Ethol* 2005; 23: 15–18
- Pays O, Dubot AL, Jarman PJ, Loisel P, Goldizen AW. Vigilance and its complex synchrony in the red-necked pademelon, *Thylogale thetis*. *Behavior Ecol* 2008; 20: 22–29.
- Peham C, Limbeck S., Galla K, Bockstahler B. Pressure distribution under three different types of harnesses used for guide dogs. *Vet J* 2013; 198: e93–e98.
- Penn DJ, Oberzauche E, Grammer K, Fischer G, Soini HA, Wiesler D, Novotny MV, Dixon SJ, Xu Y, Brereton RG. Individual and gender fingerprints in human body odor. *J R Soc Interface* 2007; 4: 331–340.
- Perri A. A wolf in dog's clothing: initial dog domestication and Pleistocene wolf variation. *J Archaeol Sci* 2016; 68:1–4.
- Persson ME, Roth LS, Johnsson M, Wright D, Jensen P. Human-directed social behaviour in dogs shows significant heritability. *Genes Brain Behav* 2015; 14(4):337-44.
- Pettersson H, Kaminski J, Herrmann E, Tomasello M. Understanding of human communicative motives in domestic dogs. *Appl Anim Behav Sci* 2011; 133: 235–245.
- Phelps EA. Emotion and cognition: insights from studies of the human amygdala. *Ann Rev Psychol* 2006; 57: 27–53.
- Phillips JB, Muheim R, Jorge PE. A behavioral perspective on the biophysics of the light-dependent magnetic compass: a link between directional and spatial perception? *J Exp Biol* 2010;213: 3247–3255.
- Phillips JB, Schmidt-Koenig K, Muheim R (2006). True navigation: Sensory bases of gradient maps. In: Brown M.F. & Cook R.G. (Eds.), *Animal Spatial Cognition: Comparative, Neural, and Computational Approaches*.

- Piaget J (1954). The construction of reality in the child. New York: Basic Books.
- Pinc L, Bartoš L, Reslova A, Kotrba R. Dogs discriminate identical twins. PLoS ONE 2011; 6: e20704.
- Plutchik R. Individual and breed differences in approach and withdrawal in dogs. Behav 1971; 40: 302–311.
- Polgár Z, Miklósi Á & Gácsi M. Strategies used by pet dogs for solving olfaction-based problems at various distances. PLoS ONE 2015; 10(7): e0131610.
- Polheber JP, Matchock RL. The presence of a dog attenuates cortisol and heart rate in the Trier Social Stress Test compared to human friends. J Behav Med 2014; 10; 37(5):860-7.
- Pongrácz P, Szabó É, Kis A, Péter A, Miklósi Á. More than noise?—Field investigations of intraspecific acoustic communication in dogs (*Canis familiaris*). Appl Anim Behav Sci 2014; 159: 62–68.
- Pongrácz P, Molnár C, Miklósi Á. Barking in family dogs: An ethological approach. Vet J 2010; 183:141–147.
- Pongrácz P, Molnár C, Miklósi Á. Acoustic parameters of dog barks carry emotional information for humans. Appl Anim Behav Sci 2006; 100:228–240.
- Pongrácz, P, Miklósi Á, Vida V, Csányi V. The pet dogs' ability for learning from a human demonstrator in a detour task is independent from the breed and age. App Anim Behav Sci 2005; 90: 309–323.
- Pongrácz P, Molnár C, Miklósi Á, Csányi V. Human listeners are able to classify dog (*Canis familiaris*) barks recorded in different situations. J Comp Psychol 2005; 119:136–144.
- Pongrácz P, Miklósi Á, Kubinyi E, Topál J, Csányi V. Interaction between individual experience and social learning in dogs. Anim Behav 2003; 65(3): 595–603.
- Pongrácz P, Miklósi Á, Kubinyi E, Gurobi K, Topál J, Csányi V. Social learning in dogs: The effect of a human demonstrator on the performance of dogs in a detour task. Anim Behav 2001; 62: 1109–1117.
- Poresky RH, Hendrix C, Hosier JE, Samuelson ML. The Companion Animal Bonding Scale: Internal reliability and construct validity. Psychol Rep 1987; 60: 743–746.
- Powell L, Chia D, McGreevy P, Podberscek AL, Edwards KM et al. Expectations for dog ownership: Perceived physical, mental and psychosocial health consequences among prospective adopters. PLOS ONE 2018; 13(7): e0200276.
- Power T 2000. Play and exploration in children and animals. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Prato-Previde E, Valsecchi P. The immaterial cord: The dog– human attachment bond. In J. Kaminski & S. Marshall-Pescini (Eds.), The social dog 2014: 165–189. San Diego, CA: Academic Press.

- Prato-Previde E, Fallani G, Valsecchi P. Gender differences in owners interacting with pet dogs: an observational study. *Ethol* 2006; 112: 63–73.
- Prato-Previde E, Custance DM, Spiezio C, Sabatini F. Is the dog-human relationship an attachment bond? An observational study using Ainsworth's strange situation. *Behav* 2003; 140: 225–254.
- Prichard A, Cook PF, Spivak M, Chhibber R, Berns GS. Awake fMRI Reveals Brain Regions for Novel Word Detection in Dogs. *Front Neurosci* 2018; 12:737.
- Price EO. *Animal Domestication and Behavior*. CABI; Wallingford, UK: 2002.
- Price EO. Behavioural aspects of domestication. *Quart Rev of Biol* 1984; 59: 1:32.
- Proulx MJ, Todorov OS, Taylor Aiken A, de Sousa AA. Where am I? Who am I? The Relation between Spatial Cognition, Social Cognition and Individual Differences in the Built. *Front Psychol* 2016; 7:64.
- Proffitt DR, Bhalla M, Gossweiler R, Midgett J. Perceiving geographical slant. *Psychon Bull Rev* 1995; 12; 2(4):409-28.
- Puurunen J, Tiira K, Vapalahti K, Lehtonen M, Hanhineva K, Lohi H. Fearful dogs have increased plasma glutamine and γ -glutamyl glutamine. *Sci Rep* 2018; 8(1):15976.
- Quaranta A, Siniscalchi M, Vallortigara G. Asymmetric tail wagging responses by dogs to different emotive stimuli. *Curr Biol* 2007; 17: R199–R201.
- Quervel-Chaumette M, Mainix G, Range F, Marshall-Pescini S. Dogs do not show pro-social preferences towards humans. *Front Psych* 2016b; 7: 1416.
- Racca A, Guo K, Meints K, Mills DS. Reading faces: differential lateral gaze bias in processing canine and human facial expressions in dogs and 4-year-old children. *PLoS ONE* 2012; 7: e36076.
- Racca A, Amadei E, Ligout S, Guo K, Meints K, Mills DS. Discrimination of human and dog faces and inversion responses in domestic dogs (*Canis Familiaris*). *Anim Cogn* 2010; 13:525–33.
- Rammsayer T. Dopaminergic and serotonergic influence on duration discrimination and vigilance. *Pharmacopsychiatry* 1989; 22: 39–43.
- Rammsayer T. Effects of pharmacologically induced dopamine-receptor stimulation on human temporal information processing. *Neuroquantol* 2009; 7: 103–113.
- Reevy GM, Delgado MM. Are Emotionally Attached Companion Animal Caregivers Conscientious and Neurotic? *J Appl Anim Welf Sci* 2015;18(3):239-58.
- Range F, Marshall-Pescini S, Kratz C, Virányi Z. Wolves lead and dogs follow, but they both cooperate with humans. *Sci Rep* 2019; 3(7); 9(1):3796.
- Range F, Virányi Z. Tracking the evolutionary origins of dog-human cooperation: the “Canine Cooperation Hypothesis”. *Front Psychol* 2015; 5:1582.
- Range F, Virányi, Z. Wolves are better imitators of conspecifics than dogs. *PLoS ONE* 2014; 9: e86559.

- Range F, Virányi Z. Tracking the evolutionary origins of dog human cooperation: the canine cooperation hypothesis. *Front Psychol* 2014; 5: 1582.
- Range F, Virányi Z. Social learning from humans or conspecifics: differences and similarities between wolves and dogs. *Front Psychol* 2013; 4:868.
- Range F, Huber L, Heyes C. Automatic imitation in dogs. *Proc R Soc B Biol Sci* 2011; 278: 211–217.
- Range F, Horn L, Virányi Z, Huber L. The absence of reward induces inequity aversion in dogs. *Proc Natl Acad Sci U.S.A.* 2009b; 106: 340–345.
- Range F, Horn L, Bugnyar T, Gajdon GK, Huber L. Social attention in keas, dogs, and human children. *Anim Cog* 2009; 12: 181e192.
- Range F, Huber L. Attention in common marmosets: implications for social-learning experiments. *Anim Behav* 2007; 73: 1033–1041.
- Rapee RM, Schniering CA, Hudson JL. Anxiety disorders during childhood and adolescence: origins and treatment. *Annu Rev Clin Psychol* 2009; 5:311–41.
- Reese LA, Skidmore M, Dyar W, Rosebrook E. No dog left behind: A hedonic pricing model for animal shelters. *J Appl Animal Welf Sci* 2017; 20: 52–64.
- Reevy GM, Delgado MM. Are Emotionally Attached Companion Animal Caregivers Conscientious and Neurotic? Factors That Affect the Human–Companion Animal Relationship. *J Appl Anim Welf Sci* 2015; 18(3):239–58.
- Rehn T, Beetz A, Keeling LJ. Links between an Owners’s Adult Attachment Style and the Support-Seeking Behavior of Their Dog. *Front Psychol* 2017; 8:2059.
- Rehn T, Lindholm U, Keeling L, Forkman B. I like my dog, does my dog like me? *Appl Anim Behav Sci* 2014; 150:65–73.
- Rehn T, Handlin L, Uvnäs-Moberg K, Keeling LJ. Dogs’ endocrine and behavioural responses at reunion are affected by how the human initiates contact. *Physiol Behav* 2014; 124:45–53.
- Rehn T, McGowan RTS, Keeling LJ. Evaluating the Strange Situation Procedure (SSP) to Assess the Bond between Dogs and Humans. *PLoS ONE* 2013; 8(2): e56938.
- Rendell L, Fogarty L, Hoppitt WJE, Morgan TJH, Webster MM, Laland KN. Cognitive culture: theoretical and empirical insights into social learning strategies. *Trends Cogn Sci* 2011; 15:68–76.
- Reid PJ. Adapting to the human world: dogs’ responsiveness to our social cues. *Behav Proc* 2009; 80(3):325–333.
- Reisner IR, Shofer FS. Effects of gender and parental status on knowledge and attitudes of dog owners regarding dog aggression toward children. *J Am Vet Med Assoc* 2008; 233:1412–9.
- Rendall D, Rodman PS, Emond RE. Vocal recognition of individuals and kin in free-ranging rhesus monkeys. *Anim Behav* 1996; 51:1007–1015.

- Reusche S (2012) .Chronic Stress in Dogs, <https://paws4udogs.wordpress.com/2012/01/06/chronic-stress-in-dogs> (Accessed 19.2.19).
- Reusche S (2011). Exercising your dog, paws4udogs.wordpress.com/2011/12/30/exercise (Accessed 19.2.19).
- Reusche S (2012). Too Much of a Good Thing: Overexcitement in exercise, <https://paws4udogs.wordpress.com/2012/01/06/too-much-of-a-good-thing> (Accessed 19.2.19).
- Rezáč P, Viziová P, Dobesová M, Havlíček Z, Pospíšilová. Factors affecting dog-dog interactions on walks with their owners. *Appl Anim Behav Sci* 2011;134: 170e176.
- Richardson MJ, Marsh KL, Schmidt RC. Effects of visual and verbal interaction on unintentional interpersonal coordination. *J Exp Psychol: Hum Percep & Perf* 2005; 31(1): 62–79.
- Richardson MJ, Marsh KL, Isenhower RW, Goodman JRL, Schmidt RC. Rocking together: dynamics of intentional and unintentional interpersonal coordination. *Hum Mov Sci* 2007; 26: 867–891.
- Richardson EH. The homing instinct in dogs. *Psyche* 2 (new series) 1921: 52–56.
- Riemer S, Muller C, Virányi Z, Huber L, Range F. The predictive value of early behavioural assessments in pet dogs—a longitudinal study from neonates to adults. *PLoS ONE* 2014; 9(7): e101237.
- Riener CR, Stefanucci JK, Proffitt DR, Clore G. An effect of mood on the perception of geographical slant. *Cogn Emot* 2011;25(1):174–182.
- Rigterink A, Houpt K, Cho M, Eze O. Genetics of canine behavior: A review. *World J Med Genet* 2014; 4(3):46–57.
- Rohlf VI, Bennett PC, Toukhsati S, Coleman G. Beliefs underlying dogowners' health care behaviors: results from a large, self-selected, internet sample. *Anthrozoös* 2012; 25: 171e185.
- Rohlf VI, Bennett PC, Toukhsati S, Coleman G. Why do even committed dog owners fail to comply with some responsible ownership practices? *Anthrozoös* 2010; 23:143–155.
- Roll A, Unshelm J. Aggressive conflicts amongst dogs and factors affecting them. *Appl Anim Behav Sci* 1997; 52:229–242.
- Romero T, Nagasawa M, Mogi K, Hasegawa T, Kikusui T. Intranasal administration of oxytocin promotes social play in domestic dogs. *Comm. Int Biol* 2015; 8: e1017157.
- Romero T, Nagasawa M, Mogi K, Hasegawa T, Kikusui T. Oxytocin promotes social bonding in dogs. *Proc Natl Acad Sci USA* 2014; 111: 9085–9090.
- Romero T, Konno A, Hasegawa T. Familiarity bias and physiological responses in contagious yawning by dogs support link to empathy. *PLoS ONE* 2013; 8: e71365.

- Rooijackers EF, Kaminski J, Call J. Comparing dogs and great apes in their ability to visually track object transpositions. *Anim Cogn* 2009; 12:789–796.
- Rooney NJ, Gaines SA, Bradshaw JW, Penman S. Validation of a method for assessing the ability of trainee specialist search dogs. *Appl Anim Behav Sci* 2007; 103(1–2):90–104.
- Rooney NJ, Bradshaw JW, Robinson IH. Do dogs respond to play signals given by humans? *Anim Behav* 2001; 61: 715–722.
- Rooney NJ, Bradshaw JW, Robinson IH. A comparison of dog-dog and dog-human play behaviour. *Appl Anim Behav Sci*. 2000; 66(3):235–248.
- Roy MM, Christenfeld NJS. Do dogs resemble their owners? *Psychol Sci* 2004; 15(5): 361–363.
- Royal Society for the Prevention of Cruelty to Animals (RSPCA). Do Puppies Have Secret Powers: Understanding the Irrational Behavior of the Puppy Buying Publics; RSPCA: London, UK, 2012.
- Rubin KH, Nelson LJ, Hastings P, Asendorpf J. The transaction between parents' perceptions of their children's shyness and their parenting styles. *Internatl J Behav Devel* 1999; 23:937–957.
- Ruefenacht S, Gebhardt-Henrich S, Miyake T, Gaillard C. A behaviour test on German Shepherd dogs: heritability of seven different traits. *Appl Anim Behav Sci* 2002; 79: 113–132.
- Rugaas T. On Talking Terms with Dogs: Calming Signals, Qanuk, England 2005: 57.
- Ruiz-Izaguirre E, van Woersem A, Eilers KCHAM, van Wieren SE, Bosch G, van der Zijpp AJ, de Boer IJM: Roaming characteristics and feeding practices of village dogs scavenging sea-turtle nests. *Anim Conserv* 2014:146-156.
- Rynearson E. Humans and pet attachment. *Psychiat* 1978; 133: 550-555
- Salman MD, New JG, Scarlett JM, Kass PH, Ruch-Gallie R, Hetts S. Human and animal factors related to the relinquishment of dogs and cats in 12 selected shelters in the United States. *J Appl Anim Welf* 1998; 1: 207–226.
- Sakai M, Morisaka T, Kogi K, Hishii T, Kohshima S. Fine-scale analysis of synchronous breathing in wild Indo-Pacific bottlenose dolphins (*Tursiops aduncus*). *Behav Proc* 2010; 83: 48–53.
- Sandoe P, Kondrup SV, Bennett PC, Forkman B, Meyer I, Proschowsky HF, Serpell JA, Lund TB. Why do people buy dogs with potential welfare problems related to extreme conformation and inherited disease? A representative study of Danish owners of four small dog breeds. *PLoS ONE* 2017; 12: e0172091.
- Sarviaho R, Hakosalo O, Tiira K, Sulkama S, Salmela E, Hytönen MK et al. Two novel genomic regions associated with fearfulness in dogs overlap human neuropsychiatric loci. *Translation Psychiat* 2019; 9:18.

- Savalli C, Resende B, Gaunet F. Eye contact is crucial for referential communication in pet dogs. *PLoS ONE* 2016; 11: e0162161.
- Savishinsky JS. Pet ideas: The domestication of animals, human behavior and human emotions. In *New Perspectives in Our Lives with Companion Animals*; Aaron, K., Beck, A., Eds.; University of Pennsylvania Press: Philadelphia, PA, USA, 1983: 112–131.
- Savolainen P, Zhang YP, Luo J, Lundeberg J, Leitner T. Genetic evidence for an East Asian origin of domestic dogs. *Science* 2002; 11 (22); 298(5598):1610-3.
- Scandurra A, Alterisio A, Di Cosmo A, D'Ambrosio A, D'Aniello B. Ovariectomy Impairs Socio-Cognitive Functions in Dogs. *Animals* 2019; 9: 58.
- Scandurra A, Alterisio A, Di Cosmo A, D'Aniello B. Behavioral and Perceptual Differences between Sexes in Dogs: An Overview. *Animals*. 2018; 8(9):151.
- Scandurra A, Marinelli L, Lööke M, D'Aniello B, Mongillo P. The effect of age, sex and gonadectomy on dogs' use of spatial navigation strategies. *Appl Anim Behav Sci* 2018; 9 (205): 89-97.
- Scandurra A, Alterisio A, Aria M, Vernese R, D'Aniello B. Should I fetch one or the other? A study on dogs on the object choice in the bimodal contrasting paradigm. *Anim Cogn* 2018; 21: 119–126.
- Scandurra A, Alterisio A, Marinelli L, Mongillo P, Semin GR, D'Aniello B. Effectiveness of verbal and gestural signals and familiarity with signal-senders on the performance of working dogs. *Appl Anim Behav Sci* 2017; 191:78–83.
- Scandurra A, Mongillo P, Marinelli L, Aria M, D'Aniello B. Conspecific observational learning by adult dogs in a training context. *Appl Anim Behav Sci* 2016; 174: 116–120.
- Scandurra A, Alterisio A, D'Aniello B. Behavioural effects of training on water rescue dogs in the Strange Situation Test. *Appl Anim Behav Sci* 2016; 174: 121–127.
- Scandurra A, Prato-Previde E, Valsecchi P, Aria M, D'Aniello B. Guide dogs as a model for investigating the effect of life experience and training on gazing behaviour. *Anim Cogn* 2015; 18:937–944.
- Scarlett JM, Salman MD, New JG, Kass PH. Reasons for relinquishment of companion animals in U.S. animal shelters: Selected health and personal issues. *J Appl Anim Welfa Sci* 1999; 2: 41–57.
- Schilder MB, Vinke CM, van der Borg JA. Dominance in domestic dogs revisited: useful habit and useful construct? *J Vet Behav* 2014; 9(4): 184–191.
- Schöberl I, Wedl M, Beetz A, Kotrschal K. Psychobiological Factors Affecting Cortisol Variability in Human-Dog Dyads. *PLoS One* 2017; 12(2):e0170707.
- Schöberl I, Beetz A, Solomon J, Wedl M, Gee N, Kotrschal K. Social factors influencing cortisol modulation in dogs during a strange situation procedure. *J Vet Behav* 2016; 11:77–85.

- Schöberl I, Wedl M, Bauer B, Day J, Moestl E, Kotrschal K. Effects of owner-dog relationship and owner personality on cortisol modulation in human-dog dyads. *Anthrozoos* 2012; 25(2):199–214.
- Scholz M, Von Reinhardt C. 2007 *Stress in dogs* Dogwise Publishing, Washington, USA.
- Schwab C, Huber L. Obey or not obey? Dogs (*Canis familiaris*) behave differently in response to attentional states of their owners. *J Comp Psychol* 2006; 8; 120(3):169–75.
- Scott JP, McGray C. Allelomimetic behavior in dogs: negative effects of competition on social facilitation. *J Comp Physiol* 1967; 63, 316–319.
- Scott JP, Fuller JL. *Genetics and the social behavior of the dog*. The University of Chicago Press, Chicago and London (1965).
- Scott JP, Marston MV. Social facilitation and allelomimetic behavior in dogs. I. Social facilitation in a non-competitive situation. *Behav* 1950; 2: 121–134.
- Sediva M, Holcova K, Pillerova L, Koru E, Rezac P. Factors Influencing Off-leash Dog Walking in Public Places. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 2017; 65(5): 1761–1766.
- Seguinot V, Cattet J, Benhamou S. Path integration in dogs. *Anim Behav* 1998; 55: 787–799.
- Sen Majumder S, Pual M, Sau S, Bhadra A. Denning habits of free-ranging dogs reveal preference for human proximity. *Sci Rep* 2016; 6:32014.
- Sen Majumder S, Bhadra A, Ghosh A, Mitra S, Bhattacharjee D, Chatterjee J, Nandi AK, Bhadra A. To be or not to be social: foraging associations of free-ranging dogs in an urban ecosystem. *Acta Ethol* 2014; 17:1-8.
- Serpell JA. Anthropomorphism and anthropomorphic selection: Beyond the “cute response”. *Soc Animal* 2003; 11: 83–100.
- Serpell JA. Evidence for an association between pet behavior and owner attachment levels. *Appl Anim Behav Sci* 1996; 47(1–2):49–60.
- Serpell J. Beneficial effects of pet ownership on some aspects of human health and behaviour. *J R Soc Med* 1991; 12; 84(12):717–20.
- Shah DS, Prados J, Gamble J, De Lillo C, Gibson CL. Sex differences in spatial memory using serial and search tasks. *Behav Brain Res* 2013; 257: 90–99.
- Sheppard G, Mills DS. Development of a psychometric scale for the evaluation of the emotional predispositions of pet dogs. *Int J Comp Psychol* 2002; 15:201–222.
- Shin CW, Kim GA, Park WJ, et al. Learning, memory and exploratory similarities in genetically identical cloned dogs. *J Vet Sci* 2016; 17(4):563–567.
- Sibbald AM, Shellard LJF, Smart TS. Effects of space allowance on the grazing behaviour and spacing of sheep. *Appl Anim Behav Sci* 2000; 70: 49–62.

- Sih A, Del Giudice M Linking behavioural syndromes and cognition: a behavioural ecology perspective *Philos Trans R Soc Lond B Biol Sci* 2012; 10; 367(1603):2762-72.
- Silva K, de Sousa L. '*Canis empathicus*'? A proposal on dogs' capacity to empathize with humans. *Biol Lett* 2011; 7: 489-492.
- Silva-Rodríguez EA, Sieving KE: Domestic dogs shape the landscape-scale distribution of a threatened forest ungulate. *Biol Conserv* 2012; 150:103-110.
- Silva-Rodríguez EA, Sieving KE. Influence of care of domestic carnivores on their predation on vertebrates. *Conserv Biol* 2011; 25:808-815.
- Siniscalchi M, d'Ingeo S, Fornelli S, Quaranta A. Lateralized behavior and cardiac activity of dogs in response to human emotional vocalizations. *Sci Rep* 2018; 8: 77.
- Siniscalchi M, d'Ingeo S, Quaranta A. Orienting asymmetries and physiological reactivity in dogs' response to human emotional faces. *Learn Behav* 2018; 12; 46(4):574-585.
- Siniscalchi M, d'Ingeo S, Quaranta A. The dog nose "KNOWS" fear: Asymmetric nostril use during sniffing at canine and human emotional stimuli. *Behav Brain Res* 2016; 304:34-41.
- Siniscalchi M. Olfaction and the Canine Brain. In *Canine Olfaction Science and Law*; Jezierski, T., Ensminger, J., Papet, L.E., Eds.; CRC Press: Boca Raton, FL, USA, 2016: 31-37.
- Siniscalchi M, Lusito R, Vallortigara G, Quaranta A. Seeing left-or right-asymmetric tail wagging produces different emotional responses in dogs. *Curr Biol* 2013; 23: 2279-2282.
- Siniscalchi M, Stipo C, Quaranta A. "Like owner, like dog": correlation between the owner's attachment profile and the owner-dog bond. *PLOS ONE* 2013; 8:e78455.
- Siniscalchi M, Lusito R, Sasso R, Quaranta A. Are temporal features crucial acoustic cues in dog vocal recognition? *Anim Cogn* 2012; 15: 815-821.
- Siniscalchi, M, Sasso R, Pepe AM, Dimatteo S, Vallortigara G, Quaranta A. Sniffing with the right nostril: Lateralization of response to odour stimuli by dogs. *Anim Behav* 2011; 82: 399-404.
- Siniscalchi M, Quaranta A, Rogers LJ. Hemispheric specialization in dogs for processing different acoustic stimuli. *PLoS ONE* 2008; 3: e3349.
- Slaa EJ, Wassenberg J, Biesmeijer JC. The use of field-base social information in eusocial foragers: local enhancement among nestmates and heterospecifics in stingless bees. *Ecol Entomol* 2003; 28: 369-379.
- Slessor G, Phillips LH, Bull R. Age-related declines in basic social perception: evidence from tasks assessing eye-gaze processing. *Psychol Aging* 2008; 23:812-822.
- Sluka CM, Stanko K, Campbell A, Cáceres J, Panoz-Brown D, Wheeler A, Bradley J, Allen C. Incidental spatial memory in the domestic dog (*Canis familiaris*). *Learn Behav* 2018; 12; 46(4):513-521.

- Smith AF, Semeniuk CA, Rock MJ, Massolo A. Reported off-leash frequency and perception of risk for gastrointestinal parasitism are not associated in owners of urban park-attending dogs: A multifactorial investigation. *Prev Vet Med* 2015; 7(1);120(3-4):336-48.
- Sneider JT, Hamilton DA, Cohen-Gilbert JE, Crowley DJ, Rosso IM, Silveri MM. Sex differences in spatial navigation and perception in human adolescents and emerging adults. *Behav Proc* 2015; 111:42–50.
- Somppi S, Törnqvist H, Kujala MV, Hänninen L, Krause CM, Vainio O. Dogs Evaluate Threatening Facial Expressions by Their Biological Validity—Evidence from Gazing Patterns. *PLoS ONE* 2016; 11(1):e0143047.
- Somppi S, Törnqvist H, Hänninen L, Krause CM, Vainio O. How dogs scan familiar and inverted faces: An eye movement study. *Anim Cogn* 2014; 17: 793–803.
- Soproni K, Miklósi Á, Topál J, Csányi V. Comprehension of human communicative signs in pet dogs (*Canis familiaris*). *J Comp Psychol* 2001; 115: 122–126.
- Soproni K, Miklósi Á, Topál J, Csányi V. Dogs' (*Canis familiaris*) responsiveness to human pointing gestures. *J CompPsychol* 2002; 116:27-34.
- Soto CA, Palomares F. Human-related factors regulate the presence of domestic dogs in protected areas. *Oryx* 2015; 49:254–260.
- Srinivasan K. The biopolitics of animal being and welfare: dog control and care in the UK and India. *Trans Inst Br Geogr* 2013; 38:106–119.
- Spady TC, Ostrander EA. Canine behavioral genetics: pointing out the phenotypes and herding up the genes. *Am J Hum Genet* 2008; 1(82):10–8.
- Sparkes J, Kortner G, Ballard G, Fleming PJS, Brown WY. Effects of Sex and Reproductive State on Interactions between Free Roaming Domestic Dogs. *PLoS ONE* 2014; 9(12): e116053
- Spetch ML, Kelly D. Comparative spatial cognition: processes in landmark and surface-based place finding. In: Wasserman E.A. & Zentall, T.R. (Eds.), *Comparative Cognition: Experimental Explorations of Animal Intelligence*. Oxford University Press, Oxford, England 2006: 210–228.
- Spokas M, Heimberg RG. Overprotective parenting, social anxiety, and external locus of control: cross-sectional and longitudinal relationships. *Cognit Ther Res* 2009; 33:543–551.
- Stahl PW. Early dogs and endemic South American canids of the Spanish Main. *J Anthropol Res* 2013; 69:515-533.
- Starling MJ, Branson N, Thomson PC, McGreevy PD “Boldness” in the domestic dog differs among breeds and breed groups. *Behav Proc* 2013; 7(97):53-62.
- Starling MJ, Branson N, Thomson PC, McGreevy PD. Age, sex and reproductive status affect boldness in dogs. *Vet J* 2013; 197 (3): 868–872.

- Stefanucci JK, Gagnon KT, Lessard DA. Follow your heart: Emotion adaptively influences perception. *Soc Pers Psychol Compass* 2011; 5(6): 296–308.
- Stefanucci JK, Proffitt DR, Clore GL, Parekh N. Skating down a steeper slope: fear influences the perception of geographical slant. *Percept* 2008; 37(2):321-3.
- Stefanucci JK, Storbeck J. Don't look down: Emotional arousal elevates height perception. *J Experim Psychol: General*. 2009; 138:131–145.
- Stilwell V (2014b), Dog Enrichment, [Online], <https://positively.com/dogwellness/dog-enrichment>(Accessed 18.10.19).
- Stilwell V (2014c), Scent work, [Online], <https://positively.com/dog-behavior/trickssPORTs/dog-sPORTs/scent-work>(Accessed 10.9.19).
- Stöwe M, Bugnyar T, Heinrich B, Kotrschal K. Effects of group size on approach to novel objects in ravens (*Corvus corax*). *Ethol* 2006; 112: 1079-1088.
- Stöwe M, Bugnyar T, Loretto MC, Schloegl C, Range F, Kotrschal K. Novel object exploration in ravens (*Corvus corax*): effects of social relationships. *Behav Proc* 2006; 7;73(1):68-75.
- Strandberg E, Jacobsson J, Saetre P. Direct genetic, maternal and litter effects on behaviour in German shepherd dogs in Sweden. *Livest Prod Sci* 2005; 93:33–42.
- Stronen AV, Navid EL, Quinn MS, Paquet PC, Bryan HM, Darimont CT: Population genetic structure of gray wolves (*Canis lupus*) in a marine archipelago suggests island-mainland differentiation consistent with dietary niche. *BMC Ecol* 2014; 14:11.
- Stoeckel LE, Palley LS, Gollub RL, Niemi SM, Evins AE. Patterns of brain activation when mothers view their own child and dog: An fMRI study. *PLoS ONE* 2014; 9:10.
- Sullivan S, Ruffman T, Hutton SB. Age differences in emotion recognition skills and the visual scanning of emotion faces. *J Gerontol B Psychol Sci Soc Sci* 2007; 62: P53–P60.
- Sundman AS, Persson ME, Grozelier A, Halldén LL, Jensen P, Roth LSV. Understanding of human referential gestures is not correlated to human-directed social behaviour in Labrador retrievers and German shepherd dogs. *Appl Anim Behav Sci* 2018; 201:46–53.
- Sung SY, Choi JN. Do Big Five personality factors affect individual creativity? The moderating role of extrinsic motivation. *Soc Behav Pers* 2009; 37(7):941–956.
- Svartberg K. Individual differences in dog behavior/dog personality. In: Jensen, P. (Ed.), *The Behavioural Biology of Dogs*. CABI, Oxfordshire, England, 2007: 182e206.
- Svartberg K. A comparison of behaviour in test and in everyday life: Evidence of three consistent boldness-related personality traits in dogs. *Appl Anim Behav Sci* 2005; 91:103–128.
- Svartberg K, Tapper I, Temrin H, Radesäter T, Thorman S. Consistency of personality traits in dogs. *Anim Behav* 2005; 69: 283e291.

- Svartberg K, Forkman B. Personality traits in the domestic dog (*Canis familiaris*) Appl Anim Behav Sci 2002; 79:133–155.
- Svartberg K. Shyness–boldness predicts performance in working dogs. Appl Anim Behav Sci 2002; 79:157–174.
- Svobodova I, Valpenı P, Pinc L, Bartos L. Testing German shepherd puppies to assess their chances of certification. Appl Anim Behav Sci 2008; 113(1–3): 139–149.
- Swaney W, Kendal J, Capon H, Brown C, Laland KN. Familiarity facilitates social learning of foraging behaviour in the guppy. Anim Behav 2001; 62:591–598.
- Szetei V, Miklósi Á, Topál J & Csányi V. When dogs seem to lose their nose: an investigation on the use of visual and olfactory cues in communicative context between dog and owner. Appl Anim Behav Sci 2003; 83(2): 141–52.
- <https://www.statista.com/statistics/414956/dog-population-european-union-eu-by-country/> accessed 26.11.2018
- Tami G, Gallagher A. Description of the behavior of domestic dog (*Canis familiaris*) by experienced and inexperienced people. Appl Animal Behav Sci 2009; 120:159–69.
- Taniguchi Y, Seino S, Nishi M, Tomine Y, Tanaka I, Yokoyama Y, Amano H, Kitamura A, Shinkai S. Physical, social, and psychological characteristics of community-dwelling elderly Japanese dog and cat owners. PLoS ONE 2018; 13(11): e0206399.
- Taylor AM, Reby D, McComb K. Context-related variation in the vocal growling behaviour of the domestic dog (*Canis familiaris*). Ethol 2009; 115: 905–915.
- Taylor AM, Reby D, McComb K. Human listeners attend to size information in domestic dog growls. J Acoust Soc Am 2008; 123: 2903–2909.
- Taylor AM, Reby D, McComb K. Why do large dogs sound more aggressive to human listeners: Acoustic bases of motivational misattributions. Ethol 2010; 116: 1155–1162.
- Taylor AM, Reby D, McComb K. Size communication in domestic dog, *Canis familiaris*, growls. Anim Behav 2010b; 79:205–210.
- Téglás E, Gergely A, Kupán K, Miklósi Á, Topál, J. Dogs' gaze following is tuned to human communicative signals. Curr Biol 2012; 22: 209–212.
- Temesi A, Turcsán B, Miklósi A. Measuring fear in dogs by questionnaires: an exploratory study toward a standardized inventory. Appl Anim Behav Sci 2014; 161: 121–130.
- Tenzin-Dolma L. The Heartbeat at Your Feet. Need2Know Books, Plymouth, 2012:8, 23, 68.
- Tesfom G, Birch N. Does definition of self-predict adopter dog breed choice? Int Rev Public Nonprofit Mark 2013; 10: 103–127.

- Thalmann O, Shapiro B, Cui P, Schuenemann VJ, Sawyer SK, Grennfield DL, Germonpré MB, Sablin MV, López-Giráldez F, Domingo-Roura X. Complete mitochondrial genomes of ancient canids suggest a European origin of domestic dogs. *Science* 2013; 342(6160):871–874.
- Thesen A, Steen JB, Døving KB. Behaviour of dogs during olfactory tracking. *J Exp Biol* 1993; 180, 247-251.
- Thielke LE, Udell MA. The role of oxytocin in relationships between dogs and humans and potential applications for the treatment of separation anxiety in dogs. *Biol Rev* 2015; 92: 378–388.
- Tiira K, Sulkama S, Lohi H. Prevalence, comorbidity, and behavioral variation in canine anxiety. *J Vet Behav Clin Appl Res* 2016; 16: 36 –44.
- Tiira K, Lohi H. Reliability and validity of a questionnaire survey in canine anxiety research. *Appl Anim Behav Sci* 2014; 155: 82-92.
- Tinbergen N. On aims and methods of ethology. *Zeitschrift für Tierpsychologie* 1963; 20:410-33.
- Topál J, Kis A, Oláh K. Dogs' sensitivity to human ostensive cues: A unique adaptation? In *The Social Dog*, 1st ed.; Kaminski, J., Marshall-Pescini, S., Eds.; Academic Press: Cambridge, MA, USA, 2014: 329.
- Topál J, Gácsi M. Lessons we should learn from our unique relationship with dogs: an ethological approach. In: Birke L. & Hockenhull J. (Eds.), *Crossing Boundaries: Creating Knowledge about Ourselves with Other Animals*, 2012: 163–188.
- Topál J, Miklósi A, Gácsi M, Dóka A, Pongrácz P, Kubinyi E, et al. The dog as a model for understanding human social behavior, in *Advances in the Study of Behavior*, Vol. 39, eds Brockmann H. J., Roper T. J., Naguib M., Wynne-Edwards K. E., Mitani J. C., Simmons L. W., editors. (Burlington: Academic Press), 2009: 71–116.
- Topál J, Gergely G, Erdőhegyi Á, Csibra G, Miklósi Á. Differential sensitivity to human communication in dogs, wolves, and human infants. *Science* 2009; 325:1269–1272.
- Topál J, Byrne RW, Miklósi A, Csányi V. Reproducing human actions and action sequences: “Do as I Do!” in a dog. *Anim Cogn* 2006; 10; 9(4):355-67.
- Topál J, Gácsi M, Miklósi A, Virányi Z, Kubinyi E. The effect of domestication and socialization on attachment to human: a comparative study on hand reared wolves and differently socialized dog puppies. *Anim Behav* 2005; 70: 1367–1375.
- Topál J, Miklósi A, Csányi V, Doka A. Attachment behavior in dogs (*Canis familiaris*): a new application of Ainsworth's (1969) Strange Situation Test. *J Comp Psychol* 1998; 112(3): 219-29.
- Tops M, Huijbregts SCJ, Buisman-Pijlman FTA. Commentary: Intranasal Oxytocin Treatment Increases Eye-Gaze Behavior toward the Owner in Ancient Japanese Dog Breeds. *Front Psychol* 2018; 9:1473.

- Törnqvist H, Somppi S, Koskela A, Krause CM, Vainio O, Kujala, MV. Comparison of dogs and humans in visual scanning of social interaction. *R Soc Open Sci* 2015; 2: 150341.
- Trivers RL. The evolution of reciprocal altruism. *Q Rev Biol* 1971; 46:35–57.
- Trut LN, Oskina I, Kharlamova A. Animal evolution during domestication: the domesticated fox as a model. *BioEssays* 2009; 31:349–60.
- Tuber DS, Sanders S, Hennessy MB, Miller JA. Behavioral and glucocorticoid responses of adult domestic dogs (*Canis familiaris*) to companionship and social separation. *J Compar Psychol* 1996; 110(1): 103–108.
- Tukey JW. *Exploratory data analysis*. Addison-Wesley 1977, see also SPSS manual.
- Turcsán B, Wallis L, Virányi Z, Range F, Müller CA, Huber L, Riemer S. Personality traits in companion dogs-Results from the VIDOPET. *PLoS One*. 2018; 13(4):e0195448.
- Turcsán B. Context and individual characteristics modulate the association between oxytocin receptor gene polymorphism and social behavior in border collies. *Front Psychol* 2017; 8:2232.
- Turcsán B, Range F, Virányi Z, Miklósi A, Kubinyi E. Birds of a feather flock together? Perceived personality matching in owner-dog dyads. *Appl Anim Behav Sci* 2012; 140: 154-160.
- Turcsán B., Kubinyi E., Miklósi Á. Trainability and boldness traits differ between dog breed clusters based on conventional breed categories and genetic relatedness. *Appl Anim Behav Sci* 2011; 132:61–70.
- Trut L, Oskina I, Kharlamova A. Animal evolution during domestication: the domesticated fox as a model. *Bioessays* 2009; 31:349-360.
- Twining H, Arluke A, Patronek G. Managing the stigma of outlaw breeds: A case study of pit bull owners. *Soc & Anim* 2000; 8: 25–52.
- Udell MA. When dogs look back: inhibition of independent problem-solving behaviour in domestic dogs (*Canis lupus familiaris*) compared with wolves (*Canis lupus*). *Biol Lett* 2015; 11(9): 20150489.
- Udell MAR, Ewald M, Doréy NR, Wynne CDL. Exploring breed differences in dogs (*Canis familiaris*): Does exaggeration or inhibition of predatory response predict performance on humanguided tasks? *Anim Behav* 2014; 89:99–105.
- Udell MAR, Doréy NR, Wynne CDL. Interspecies social learning in dogs: The inextricable roles of phylogeny and ontogeny. In T. R. Zentall & E. A. Wasserman (Eds.), *The Oxford handbook of comparative cognition* (2nd ed., 2012: 819–831). New York, NY: Oxford University Press
- Udell MA, Morey NR, Wynne CDL. What did domestication do to dogs? A new account of dogs' sensitivity to human actions. *Biol Rev* 2010; 85: 327–345.
- Udell MA, Wynne CD. Ontogeny and phylogeny: Both are essential to human-sensitive behaviour in the genus *Canis*. *Anim Behav* 2010;79:e9–e14.

- Udell MA, Doréy NR, Wynne CD. What did domestication do to dogs? A new account of dogs' sensitivity to human actions. *Biol Rev* 2010; 85: 327–345.
- Udell MAR, Doréy NR, Wynne CDL. What did domestication do to dogs? A new account of dogs' sensitivity to human actions. *Biol Rev Camb Philos Soc* 2009; 85:327–345.
- Udell MAR, Giglio RF, Wynne CDL. Domestic dogs (*Canis familiaris*) use human gestures but not nonhuman tokens to find hidden food. *J Comp Psychol* 2008; 122: 84–93.
- Urbanik J, Morgan M. A tale of tails: the place of dog parks in the urban imaginary. *Geoforum* 2013; 44:292–302.
- Valone TJ, Templeton JJ. Public information for the assessment of quality: a widespread social phenomenon. *Philos Trans R Soc London B* 2002; 357: 1549-1557.
- Vanak AT, Gompper ME: Dogs *Canis familiaris* as carnivores: their role and function in intraguild competition. *Mamm Rev* 2009, 39:265-283.
- Van Brakel AML, Muris P, Bögels SM, Thomassen C. A multifactorial model for the etiology of anxiety in non-clinical adolescents: Main and interactive effects of behavioral inhibition, attachment, and parental rearing. *J Child & Fam Stud* 2006; 15:568–578.
- Van Gerven DJ, Ferguson T, Skelton RW. Acute stress switches spatial navigation strategy from egocentric to allocentric in a virtual Morris water maze. *Neurobiol Learn and Mem* 2016; 132: 29–39.
- Van Hedger K, Necka EA, Barakzai AK, Norman GJ. The influence of social stress on time perception and psychophysiological reactivity. *Psychophysiol* 2017; 54(5):706–712.
- Van Kesteren F, Mastin A, Mytynova B, et al. Dog ownership, dog behaviour and transmission of *Echinococcus spp.* in the Alay Valley, southern Kyrgyzstan. *Parasitol* 2013; 140(13):1674–1684.
- Van Moorter B, Visscher, D, Benhamou S, Borger L, Boyce MS, Gaillard JM. Memory keeps you at home: a mechanistic model for home range emergence. *Oikos* 2009; 118(5), 641–652.
- Van Rooy D, Haase B, McGreevy PD, Thomson PC, Wade CM. Evaluating candidate genes *oprm1*, *drd2*, *avpr1a*, and *oxtr* in golden retrievers with separation-related behaviors. *J Vet Behav Clin Appl Res* 2015; 16: 22–27.
- VanUden CJT, Besser MP. Test-retest reliability of temporal and spatial gait characteristics measured with an instrumented walkway system (GAITRite). *BMC Musculoskelet Disord* 2004; 5: 13
- Van Ulzen NR, Lamothe CJC, Daffertshoffer A, Semin GR, Beek PJ. Characteristics of instructed and uninstructed interpersonal coordination while walking side-by-side. *Neurosci Lett* 2008; 432: 88–93.
- Van Wassenhove V, Wittmann M, Craig AD, Paulus MP. Psychological and neural mechanisms of subjective time dilation. *Front Neurosci* 2011; 5:56.

- Vas J, Topál J, Gyóri B, Miklósi Á. Consistency of dogs' reactions to threatening cues of an unfamiliar person. *Appl Anim Behav Sci* 2008; 112: 331–344.
- Vas J, Topál J, Gácsi M, Miklósi Á, Csányi V. A friend or an enemy? Dogs' reaction to an unfamiliar person showing behavioural cues of threat and friendliness at different times. *Appl Anim Behav Sci* 2005; 94: 99–115.
- Veevers J. The social meaning of pets. *Marriage Fam Rev* 1985; 8: 11–30.
- Veit A, Wondrak M, Huber L. Object movement reenactment in free-ranging Kune piglets. *Anim Behav* 2017; 132: 49–59.
- Veltkamp M, Aarts H, Custers R. Perception in the Service of Goal Pursuit: Motivation to Attain Goals Enhances the Perceived Size of Goal-Instrumental Objects. *Soc Cogn* 2008; 26:720–736.
- Virányi Z, Gácsi M, Kubinyi E, Topál J, Belényi B, Ujfalussy D, Miklósi A. Comprehension of human pointing gestures in young human-reared wolves (*Canis lupus*) and dogs (*Canis familiaris*). *Anim Cogn* 2008; 7; 11(3):373-87.
- VonHoldt BM, Shuldiner E, Koch IJ, Kartzinel RY, Hogan A, Brubaker L, Wanser S, Stahler D, Wynne CDL, Ostrander EA, Sinsheimer JS, Udell MAR. Structural variants in genes associated with human Williams-Beuren syndrome underlie stereotypical hypersociability in domestic dogs. *Sci Adv* 2017; 3(7):e1700398.
- Voss K, Galeandro L, Wiestner T, Haessif M, Montavon PM. Relationships of body weight, body size, subject velocity, and vertical ground reaction forces in trotting dogs. *Vet Surg* 2010; 39(7): 863–869.
- Wallace DG, Choudhry S, Martin MM. Comparative analysis of movement characteristics during dead-reckoning-based navigation in humans and rats. *J Comp Psychol* 2006; 120 (4): 331–344.
- Wallace DG, Hines DJ, Whishaw IQ. Quantification of a single exploratory trip reveals hippocampal formation mediated dead reckoning. *J Neurosci Meth* 2002a; 113: 131–145.
- Wallace DG, Hines DJ, Gorny JH, Whishaw IQ (2002b). A role for the hippocampus in dead reckoning: An ethological analysis using natural exploratory and food carrying tasks. In: Jeffery K. (Ed.), *Biological basis of navigation*. Oxford University Press, New York, NY.
- Waller D, Lippa Y. Landmarks as beacons and associative cues: their role in route learning. *Mem Cognit* 2007; 7; 35(5):910-24.
- Wallis LJ, Szabó D, Erdélyi-Belle B, Kubinyi E. Demographic Change Across the Lifespan of Pet Dogs and Their Impact on Health Status. *Front Vet Sci* 2018; 5:200.
- Wallis LJ, Range F, Müller CA, Serisier S, Huber L, Virányi Z. Training for eye contact modulates gaze following in dogs. *Anim Behav* 2015; 106(8):27-35.
- Wallraff HG, Andreae MO. Spatial gradients in ratios of atmospheric trace gases: a study stimulated by experiments on bird navigation. *Tellus* 2000; B 52: 1138–57.

- Wan M, Bolger N, Champagne FA. Human perception of fear in dogs varies according to experience with dogs. *PLoS ONE* 2012; 7:e51775.
- Wan M, Kubinyi E, Miklósi A, Champagne F. A cross-cultural comparison of reports by German Shepherd owners in Hungary and the United States of America. *Appl Anim Behav Sci* 2009; 121: 206-213.
- Wang, RF. Building a Cognitive Map by Assembling Multiple Path Integration Systems. *Psychon Bull & Rev* 2016; 23(3): 692–702.
- Wang RF, Crowell JA, Simons DJ, Irwin DE, Kramer AF, Ambinder MS, Thomas LE, Gosney JL, Levinthal BR, Hsieh BB. Spatial updating relies on an egocentric representation of space: effects of the number of objects. *Psychon Bull Rev* 2006; 4; 13(2):281-6.
- Wang X, Pipes L, Trut LN, Herbeck Y, Vladimirova AV, Gulevich RG, Kharlamova AV, Johnson JL, Acland GM, Kukekova AV, Clark AG. Genomic responses to selection for tame/aggressive behaviors in the silver fox (*Vulpes vulpes*). *Proc Natl Acad Sci USA* 2018;115:10398–403.
- Ward C, Bauer EB, Smuts BB. Partner preferences and asymmetries in social play among domestic dog, *Canis lupus familiaris*, littermates. *Anim Behav* 2008; 76(4): 1187 – 1199.
- Way BM, Taylor SE. Social influences on health: is serotonin a critical mediator? *Psychosom Med* 2010; 72: 107–112.
- Wayne RK, Ostrander EA. Lessons learned from the dog genome. *Trends Genet* 2007;11(23):557–67.
- Wayne RK, vonHoldt BM. Evolutionary genomics of dog domestication *Mamm Genome* 2012; 2; 23(1-2):3-18.
- Wedl M, Schöberl I, Bauer B, Day J, Kotrschal K. Relational factors affecting dog social attraction to human partners. *Interact Stud* 2010; 11: 482-503.
- Wehner R, Srinivasan MV. Searching behavior of desert ants, genus *Cataglyphis* (*Formicidae, Hymenoptera*). *J Comp Physiol Psychol* 1981; 142: 315-338.
- Weilenmann A, Juhlin O. Understanding people and animals: the use of a positioning system in ordinary human canine interaction. *Proc. CHI'11.ACM Press*, 2011: 2631-2640.
- Wells DL. Behaviour of Dogs. In *The Ethology of Domestic Animals: An Introductory Text*, 3rd ed.; Jensen, P., Ed.; CABI: Oxford, UK, 2017: 228–238.
- Wells DL, Hepper PG. Directional tracking in the domestic dog, *Canis familiaris*. *Appl Anim Behav Sci* 2003; 84: 297–305.
- Wells DL, Hepper PG. Prevalence of behavior problems reported by owners of dogs purchased from an animal rescue shelter. *Appl Anim Behav Sci* 2000; 69: 55–65.
- Wells DL, Hepper PG. The behavior of dogs in a rescue shelter. *Anim Welf* 1992; 1: 171–186.

- Werhahn G, Virányi Z, Barrera G, Sommese A, Range F. "Wolves (*Canis lupus*) and dogs (*Canis familiaris*) differ in following human gaze into distant space but respond similar to their packmates' gaze": Correction to Werhahn et al. (2016). *J Comp Psychol* 2017; 131(1): 49.
- Westgarth C, Christley RM, Pinchbeck GL, Gaskell RM, Dawson S, Bradshaw JWS. Dog behavior on walks and the effect of use of the leash. *Appl Anim Behav Sci* 2010; 125: 38–46.
- Westgarth C. Dog behavior on walks and the effect of use of the leash. *Appl Anim Behav Sci* 2010; 125(1):38-46.
- Westgarth C, Pinchbeck GL, Bradshaw JW, Dawson S, Gaskell RM, Christley RM. Dog–human and dog–dog interactions of 260 dog-owning households in a community in Cheshire. *Vet Rec* 2008;162:436–442.
- Westgarth C, Christley RM, Christian HE. How might we increase physical activity through dog walking?: A comprehensive review of dog walking correlates. *Int J Behav Nutr Phys Act* 2014;11:83.
- Weston MA, Fitzsimons JA, Wescott G, Miller KK, Ekanayake KB, Schneider T. Bark in the park: a review of domestic dogs in parks. *Environ Manag* 2014; 54:373–382.
- Wiener P, Haskell MJ (2016). Use of questionnaire-based data to assess dog personality. *J Vet Behav* Vol 2016;16: 81-85
- Whishaw IQ, Hines DJ, Wallace DG. Dead reckoning (path integration) requires the hippocampal formation: Evidence from spontaneous exploration and spatial learning tasks in light (allothetic) and dark (idiothetic tests). *Behav Brain Res* 2001; 127: 49–69.
- Wilshin S, Haynes GC, PORteous J, Koditschek D, Revzen S, Spence AJ. Morphology and the gradient of a symmetric potential predict gait transitions of dogs. *Biol Cybern* 2017; 111(3-4):269–277.
- Wiltschko W, Wiltschko R. Magnetic orientation and magnetoreception in birds and other animals. *J Comp Physiol A* 2005; 191: 675–693.
- Wiltschko R, Wiltschko W. Avian magnetic compass: Its functional properties and physical basis. *Curr Zool* 2010; 56: 265–276.
- Wing Chan T, Koo A. Parenting style and youth outcomes in the UK. *Eur Sociol Rev* 2011; 27(3):385–399.
- Wittlinger M, Wehner R, Wolf H. The ant odometer: stepping on stilts and stumps. *Science* 2006; 312: 1965-1967.
- Wobber C, Hare B, Koler-Matznick J, et al. Breed Differences in Domestic Dogs' (*Canis familiaris*) Comprehension of Human Communicative Signals. *Interact Stud* 2009; 10:206–224.

- Wood JJ, McLeod BD, Sigman M, Hwang WC, Chu BC. Parenting and childhood anxiety: theory, empirical findings, and future directions. *J Child Psychol Psychiat* 2003; 44(1):134-51.
- Woodhead JK, Feng LC, Howell TJ, Ruby MB, Bennett PC. Perceptions of dog breeding practices, breeding of dog welfare and companion dog acquisition in a self-selected sample of Australian adults. *Anim Welf* 2018; 27: 357-368.
- Wolf M, Frair J, Merrill E, Turchin P. The attraction of the known: the importance of spatial familiarity in habitat selection in wapiti *Cervus elaphus*. *Ecography* 2009; 32: 401-410.
- Worsley HK, O'Hara SJ. Cross-species referential signalling events in domestic dogs (*Canis familiaris*). *Anim Cogn* 2018; 21: 457-465.
- Wyatt TD. How animals communicate via pheromones. *Am Sci* 2015; 103: 114.
- Wynne CDL. What is special about dog cognition? *Curr Dir Psychol Sci* 2016; 25(5): 345-350.
- Wynne CD, Udell MA, Lord KA. Ontogeny's impacts on human-dog communication. *Anim Behav* 2008;76:e1-e4.
- Wynne CDL, Udell MAR. *Animal Cognition*. 2nd eds. Edition Palgrave Macmillan, England (2013).
- Yeon SC. The vocal communication of canines. *J Vet Behav* 2007; 2: 141-144.
- Yin S, McCowan B. Barking in domestic dogs: Context specificity and individual identification. *Anim Behav* 2004; 68: 343-355.
- Yuan L, Kong F, Luo Y, Zeng S, Lan J and You X. Gender Differences in Large-Scale and Small-Scale Spatial Ability: A Systematic Review Based on Behavioral and Neuroimaging Research. *Front Behav Neurosci* 2019;13:128.
- Zapata I, Serpell JA, Alvarez CE. Genetic mapping of canine fear and aggression. *BMC Genom* 2016; 17: 572.
- Zadra JR, Clore GL. Emotion and perception: the role of affective information. *Wiley Interdiscip Rev Cogn Sci* 2011; 2(6):676-685.
- Zeifman D, Hazan C. Pair bonds as attachments: Reevaluating the evidence. In J. Cassidy & P. R. Shaver (Eds.), *Handbook of attachment: Theory, research, and clinical applications* (2nd ed., 2008: 436-455). New York, NY: Guilford
- Zeigler-Hill V, Highfill L. Applying the interpersonal circumplex to the behavioral styles of dogs and cats. *Appl Anim Behav Sci* 2010; 124(3):104-112.
- Zentall TR, Pattison KF. Now you see it, now you don't: Object permanence in dogs. *Curr Direct Psychol Sci* 2016; 25:357-362.
- Zilcha-Mano S, Mikulincer M, Shaver PR. Pets as safe havens and secure bases: The moderating role of pet attachment orientations. *J Res Pers* 2012; 46: 571-580.

Zilcha-Mano S, Mikulincer M, Shaver PR. An attachment perspective on human-pet relationships: conceptualization and assessment of pet attachment orientations. *J Res Pers* 2011; 45(4):345–357.

Zivotofsky AZ, Hausdorff JM. The sensory feedback mechanisms enabling couples to walk synchronously: an initial investigation. *J Neuroengin Rehab* 2007; 4: 28.

Appendix Part 1 results

Appendix Part 1.1 Duration of walk: Dog(s) and owner traveling time

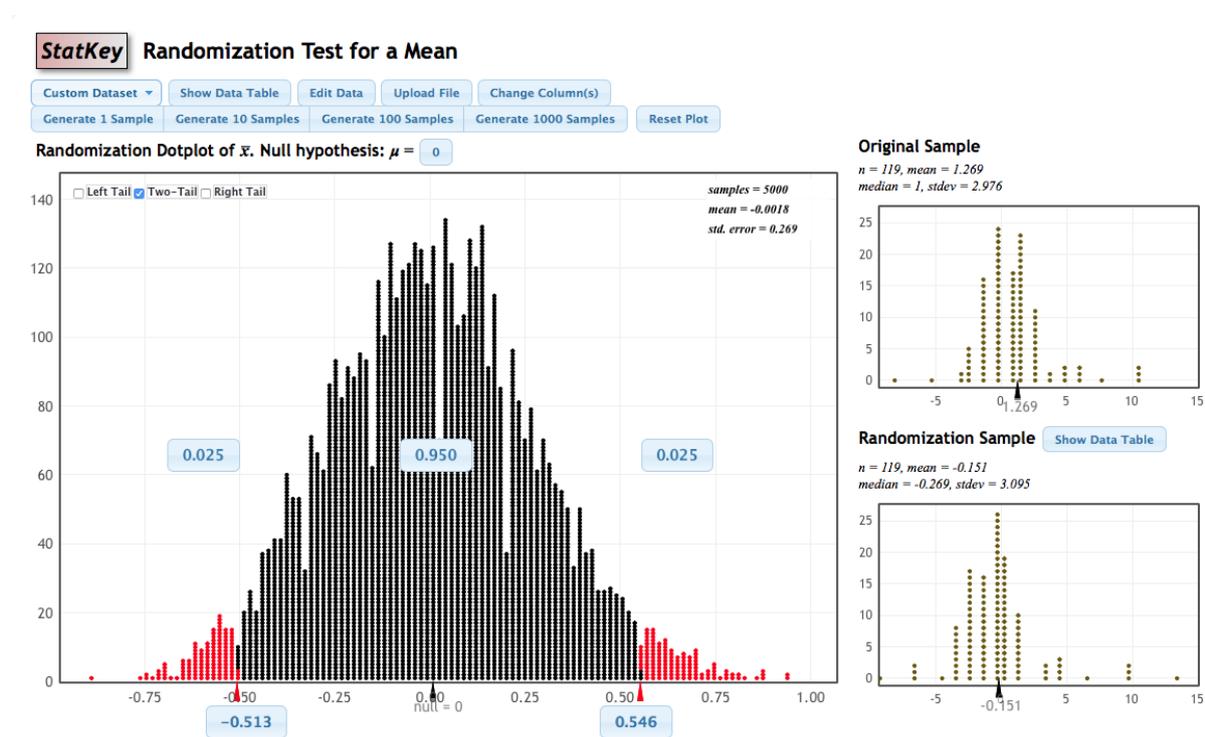
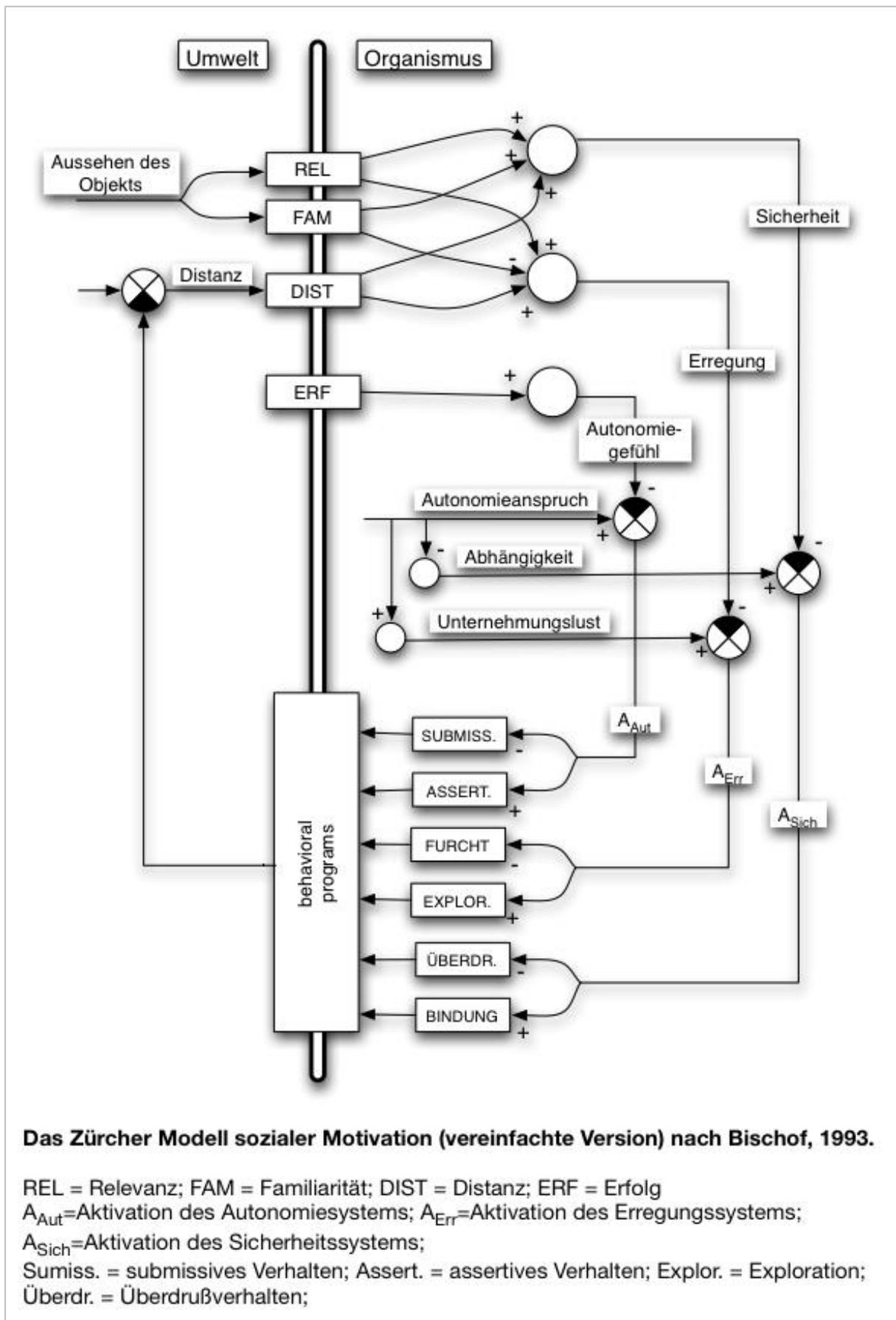


Fig. R1.1.1: Randomization test for one mean difference: difference in walking time between dog and owner.

Results of the randomization test applied to the difference in walking time in minutes shows that the observed difference of -00:01:27h is statistically significant ($p < 0,001$). Drawing 5000 random samples with mean 0 (H_0 : no difference in walking time between owner and dog) a mean of -00:01:27 minutes could never be observed by chance. Thus one can conclude, that the observed difference of -00:01:27h is not derived from a distribution with zero mean.



Quelle: https://de.wikipedia.org/wiki/Z%C3%BCrcher_Modell_der_sozialen_Motivation#/media/Datei:ZM_Schema_deutsch.png

Appendix Part 2 Material and Methods

Table M2.2.4.1: Assessment sheet data each individual dog for each and all walks, including travelling patterns.

Dog	Sex	Neutered	Breed	Age	Owner
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Walk 1, 0x.0x.1x known: travelling patterns x run >20m

- Of the entire walk how many runs >20m and what kind of travelling patterns have these runs

Runs ahead waits/follows	Star	loop	Loop+star	Mix forms runs ahead & loops	Mix forms runs ahead & star	Runs parallel then meets owner
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Pausing times walk 1

- Of these runs >20m how often and how long did the dog pause within the measured 2sec/5sec segments

Run	Pause	Total	Outbound/inbound
1	00:00:xx	00:0x:xx	Outbound
Total run 1 pause	00:0x:xx	Entire walk pause	inbound
Time total walking		00:xx:xx	No POR
0x:0x:xx/00:0x:xx=x%			

Walk 2, 0x.0x.1x new: travelling patterns x runs >20m

Runs ahead waits/follows	Star	loop	Loop+star	Mix forms runs ahead & loops	Mix forms runs ahead & star	Runs parallel then meets owner
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Pausing times walk 2

Run	Pause	Total	Outbound/inbound
2	00:00:xx	00:0x:xx	Outbound 00:00:xx inbound 00:00:xx
Total run 2 pause	00:0x:xx	Entire walk pause	No POR
Time total walking		00:xx:xx	
0x:xx:xx/00:0x:xx=x%			

Then walk 3 and 4 accordingly

Total - all walks= xx runs

Runs ahead waits/ follows	Star	loop	Loop+star	Mix forms runs ahead & loops	Mix forms runs ahead & star	Runs parallel then meets owner
Walk 1-4	Total all walks	Walk 1 03.08.16 known area	Walk 2 08.07.16 new area	Walk 3 31.10.17 known area	Walk 4 01.11.17 new area	
Time walk dog	Total time of all walks (1-4) dog and mean thereof	02:01:11	02:40:32	02:12:13	02:37:16	
Owner average walking speed kmh	Total average 4,6kmh	4,4kmh	4,6kmh	4,8kmh	4,5kmh	
Dog average walking speed kmh	Total average 5,4kmh	5,2kmh	6,2kmh	5,2kmh	4,9kmh	
total distance walk owner m	total 38300m mean 9575m	8200m	12200m	9800m	8100m	
total distance walk dog m	total 40200m mean 10050m	8700m	13100m	10100m	8300m	
distance differ- ence own- er/dog walk m	total 1900m mean 475m 1900m/38300 m= 5 % 1900m/40200 =4,7 %	500m 500m/8200m =6,1 % 500m/8700m =5,8 %	900m 900m/12200m =7,4 % 900m/13100m =6,9 %	300m 300m/9800m =3 % 300/10100m =3 %	200m 200m/8100m =2,5 % 200m/8300m =2,4 %	
Runs > 20m	N=11 total 1895m mean 473,8m average 161,3m 1895m/38300 m=5 %	N=4 runs total 579m mean 144,8m 579m/8200m=7 %	N= 4 runs total 852m mean 213m 852m/12200m =7 %	N=2 runs total 293m mean 146,5m 293m/9800m =3 %	N=1 runs total 171m 171m/8100m =2 %	
Time moving dog min	total 7:51:58 mean 1:57:59 total average 00:14:22 mean 00:03:35 00:14:22/ 7:51:58=3 %	Total 01:40:33 Runs > 20m 00:03:30 mean 00:00:53 00:03:30/ 01:40:33=3,5 %	Total 02:07:28 Runs > 20m total 00:06:43 mean 00:01:41 00:06:43/ 02:07:28=5,3 %	Total 01:55:10 Runs > 20m total 00:02:19 mean 00:01:10 00:02:19/ 1:55:10=2 %	Total 02:08:47 Runs > 20m total 00:01:50 00:01:50/ 02:08:47=1,4 %	
Speed mean Speed max/ min of dog	Grand mean 7,6kmh. 35kmh max/0kmh min.	35/0,1kmh Average 9,9kmh	21/0kmh Average 7,7kmh	26/0,1kmh Average 7kmh	30/0kmh Average 5,6kmh	

Time entire run (incl.pauses) Min-> of entire run how much time is dog >20m away in %	Grand mean total 9:31:12 mean 02:22:48 runs <20m 00:14:22 mean 00:03:35 average 00:01:23 00:14:22/9:31:12=2,5 %	Total 02:01:11 Runs > 20m total 00:03:30 average 00:00:53 00:03:30/02:01:11=2,9 %	Total 02:40:32 Runs > 20m total 00:06:43 average 00:01:41 00:06:34/02:40:32=4 %	Total 02:12:13 Runs > 20m total 00:02:19 average 00:01:10 00:02:19/02:12:13=1,8 %	Total 02:37:16 Runs > 20m total 00:01:50 00:01:50/02:37:16=1,2 %
Max distance of run m	Grand mean 473,8m (total distance all runs 1895m) Average 161,3m	195m (total 579m average 144,8m)	338m (total 852m average 213m)	227m (total 293m average 146,5m)	171m
Known area runs Distance m Time min	Total 872m average 145,7m total 00:05:49 mean 00:02:55 average 00:01:01	total 579m average 144,8m total 00:03:30 average 00:00:53.		total 293m average 146,5m total 00:02:19 average 00:01:10	
New Area runs Distance m Time min	Total 1023m average 192m total 00:08:33 mean 00:04:16 average 00:01:46		total 852m average 213m total 00:06:43 average 00:01:41		total 171m total 00:01:50
Difference known/ new area time/ distance	872m/ 1023m=17,3 % increase Distance new area; 00:05:49/ 00:08:33 = 32 % increase time travelled new area				

Distance out-bound / in-bound (only applies with POR)	Total n=7/11 total outbound 729m mean 243m Total inbound 726m mean 242m Difference 729m/726m =0,4 %	N=2/4 total outbound 203m, mean 101,5m total inbound 173m mean 86,5m difference =17,3 % decrease	N=4/4 total outbound 438m, mean 109,5m total inbound 414m mean 103,5m difference =5,8 % decrease	N=1/2 Total outbound 88m Total inbound 139m difference =58 % increase	N=0/1
Time out-bound/ inbound	total n=7/11 total outbound 00:05:29 mean 00:00:47 total inbound 00:06:00 mean 00:00:45 difference 8,6 %	N=2/4 total outbound total 00:1:12 mean 00:00:36 total inbound total 00:01:03 mean 00:00:32 difference 12,5 %	N=4/4 total outbound 00:03:47 mean 00:00:57 total inbound 00:03:52 mean 00:00:58 difference 2,2 %	N=1/2 total outbound total 00:00:30 total inbound total 00:01:05 difference 53,8 %	N=0/1
Speed out-bound/ inbound	Grand Mean outbound 9,5kmh, in- bound 9,9kmh Difference 4,2 % increase	Mean outbound 10,4kmh, inbound 14kmh Difference 34,6 % increase	Mean outbound 7,7kmh, inbound 7,9kmh Difference 2,6 % increase	Mean outbound 10,5kmh, inbound 7,7kmh Difference 36,4 % decrease	
Are the travelling patterns similar in known vs unknown areas	Travelling pattern loop etc	1 /4 parallel; 3/4 loop	3/4 loops; 1/ 4 loop+star	1/2 Star; 1/2 loop	1/1 parallel
2 dogs run together Distance/time/ speed/ travelling pat- terns differences	Yes see dog # Or no				

Appendix Part 2 results

Appendix Part 2.1 Runs >20m: Distance of dogs travelled in known areas compared to unknown areas

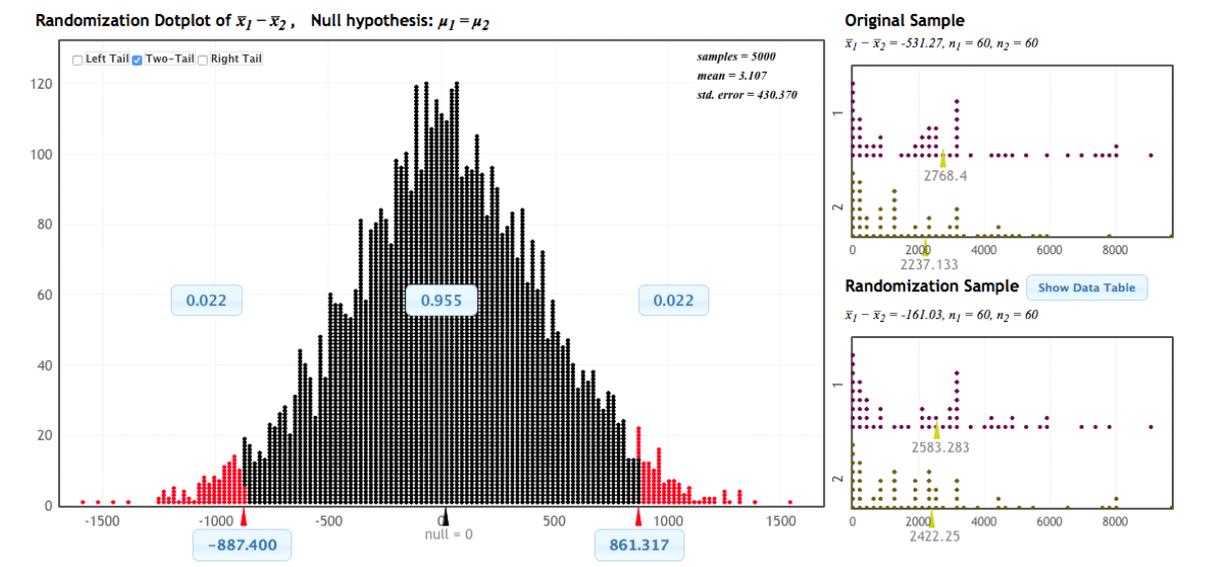


Fig. R2.1.3 Randomization test for one mean difference of all runs >20m known versus unknown area of all dogs.

Between known and unknown area a difference of -531 m was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -887,4 and 861,317. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between known and unknown area could be shown.

Appendix Part 2.2 Differences between known and unknown areas in relation to maximal median difference from the owner Group 1; Group 2; Group 3

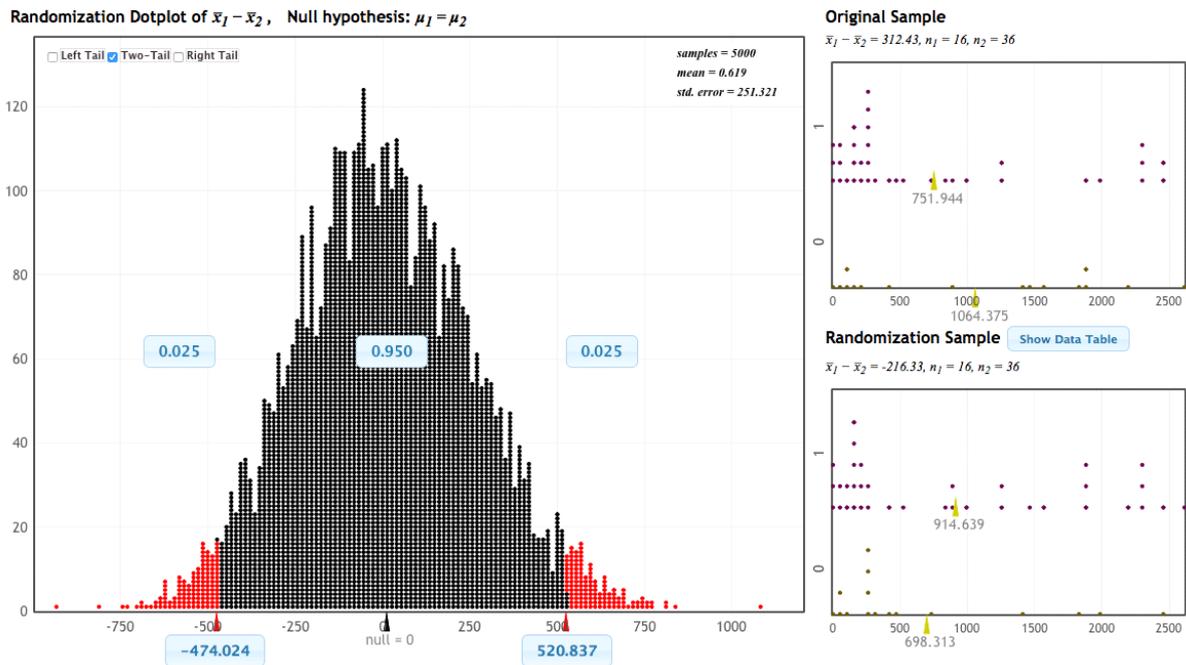


Fig. R2.3.4: Randomization test for one mean difference. Difference between known and unknown area runs >20m for Group 1.

For Group 1 a difference between known and unknown area a difference of -312 m was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -474 and 520. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between known and unknown area of runs >20m could be demonstrated for Group 1.

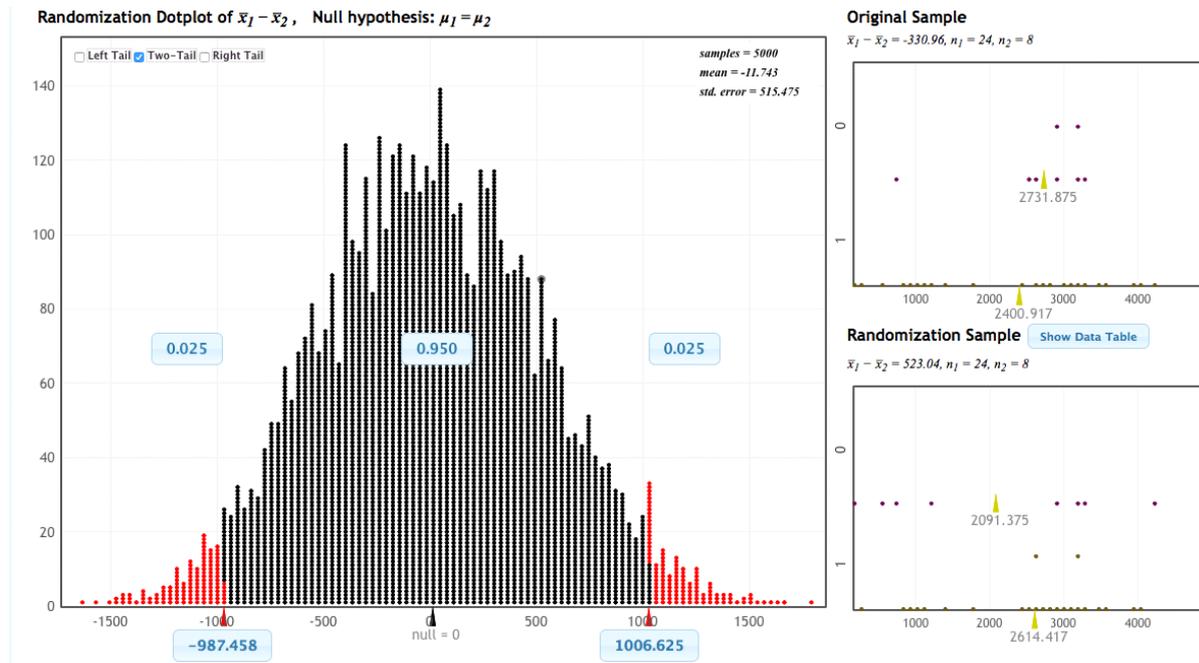


Fig. R2.3.5: Randomization test for one mean difference. Difference between known and unknown area runs >20m for Group 2.

For Group 2 a difference between known and unknown area a difference of 331 m was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -987 and 1007. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between known and unknown area runs >20m could be shown for Group 2.

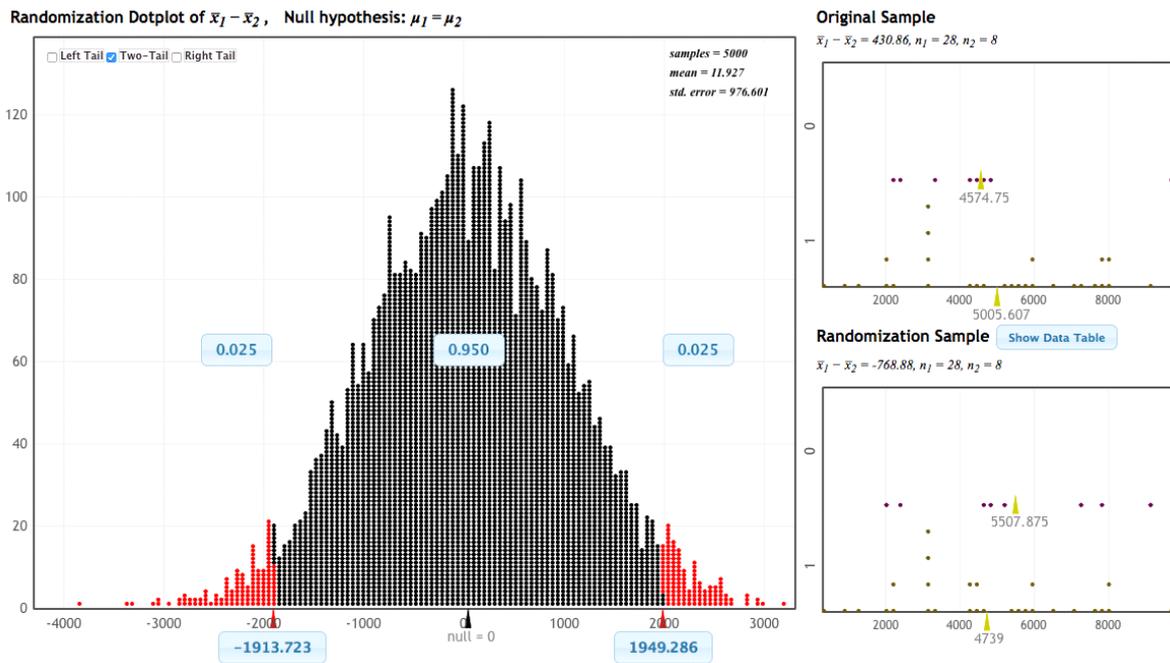


Fig. R2.3.6: Randomization test for one mean difference. Difference between known and unknown area runs >20m for Group 3.

For Group 3 a difference between known and unknown area a difference of 431 m was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -1914 and 1949. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between known and unknown area runs >20m could be demonstrated for Group 3.

Appendix Part 2.3 Runs >20m: Time travelled by the dogs in known areas compared to unknown areas

Table R2.4.1: Individual dogs: time away from the owner in minutes; known vs. unknown area.

Time away in min.	Area											
	Known area						Unknown area					
	n of runs	mean	median	Q25	Q75	sd	n of runs	mean	median	Q25	Q75	sd
Amanda	107	18	18	16	20	3	97	13	13	10	16	4
Amy	100	21	21	19	22	2	108	22	22	20	24	3
Arthur	80	24	24	23	24	1	97	20	20	20	20	0
Balin	6	30	3	3	3	0	9	2	2	2	2	0
Balou_Mix	96	30	30	30	30	0	78	39	39	24	53	21
Balou_RR	90	21	21	20	22	1	48	10	10	9	10	1
Bill	121	43	43	39	46	5	100	30	30	27	33	4
Dr. Pepper	39	6	6	0	11	8	5	0	0	0	0	0
Emma	1	0	0	0	0	0	5	1	1	0	1	1
Freya	6	1	1	1	1	0	3	1	1	0	1	1
Honey	34	12	12	11	13	1	24	13	13	10	16	4
Kaito	71	45	45	41	48	5	77	36	36	33	39	4
Kimi	38	15	15	9	21	8	58	19	19	12	26	10
Lea/Emma	85	19	19	15	22	5	60	11	11	5	17	8
Lili	34	6	6	4	7	2	40	9	9	5	12	5
Lou	78	51	51	44	58	10	104	31	31	22	39	12
Luna	69	23	23	21	24	2	80	16	16	9	23	10
Mala	1	0	0	0	0	0	1	1	1	0	1	1
Manja	1	0	0	0	0	0	4	3	3	1	5	3
Marley	76	36	36	35	37	1	83	29	29	23	35	8
Molly	7	1	1	1	1	0	6	1	1	1	1	0
Nele	103	17	17	17	17	0	98	17	17	15	18	2
Nina	43	17	17	7	27	14	60	21	21	7	34	19
Odin	33	6	6	5	7	1	25	4	4	3	4	1
Raffaele	35	14	14	11	17	4	12	4	4	1	6	4
Raya	73	17	17	13	20	5	33	63	63	13	113	71
Tamina	81	45	45	41	48	5	66	25	25	19	30	8
Thorin	62	25	25	22	28	4	60	12	12	8	16	6
Wantje	72	15	15	13	16	2	51	10	10	7	13	4
Zlata	6	3	3	2	3	1	5	4	4	1	6	4
Total	1648	18	17	4	24	15	1497	15	11	3	23	18

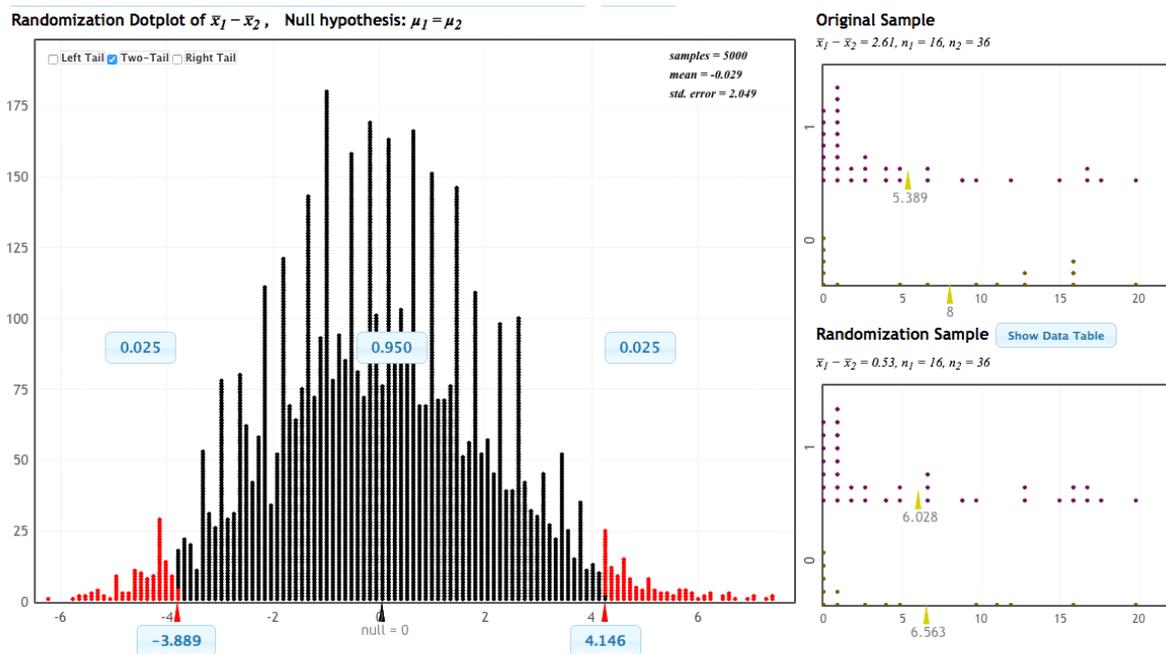


Fig. R2.4.5: Randomization test for one mean difference. Difference between known and unknown area travelling time of runs > 20m for Group 1.

For Group 1 a difference between known and unknown area of time travelled of runs > 20m a difference of 2.61 min was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -3.89 and 4.15 min. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between known and unknown area of time travelled of runs > 20m could be shown for Group 1.

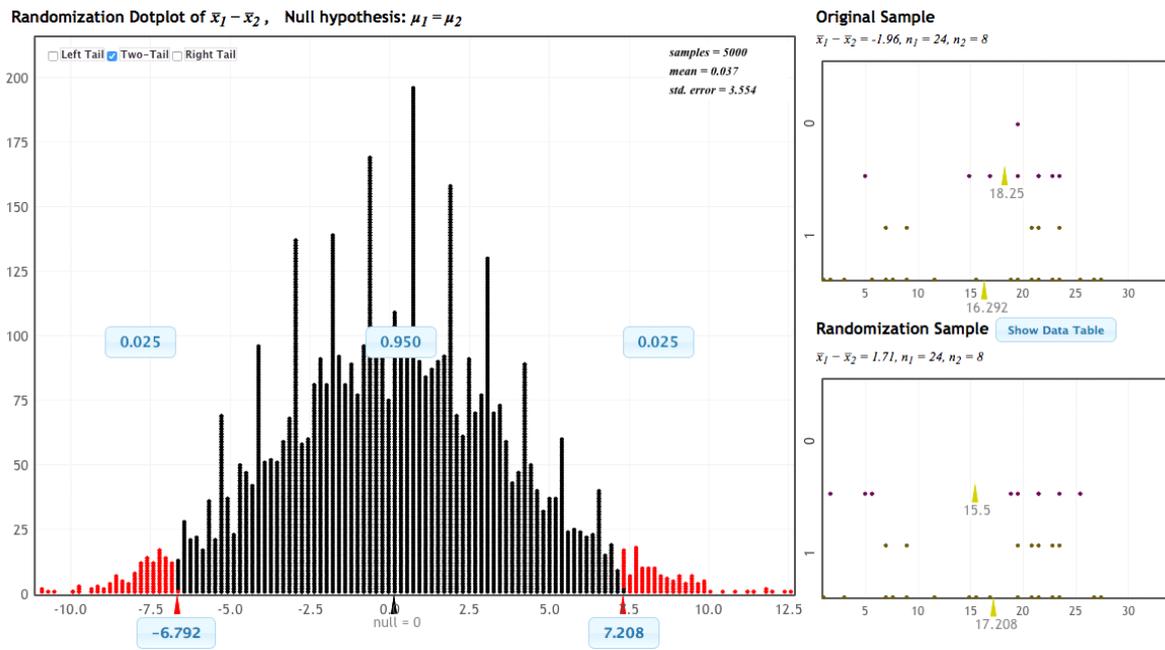


Fig. R2.4.6: Randomization test for one mean difference. Difference between known and unknown area travelling of time runs > 20m for Group 2.

For Group 2 a difference between known and unknown area time travelled of runs >20m a difference of 1.96 min was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -6.79 and 7.21 min. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between known and unknown area of time travelled of runs >20m could be shown for Group 2.

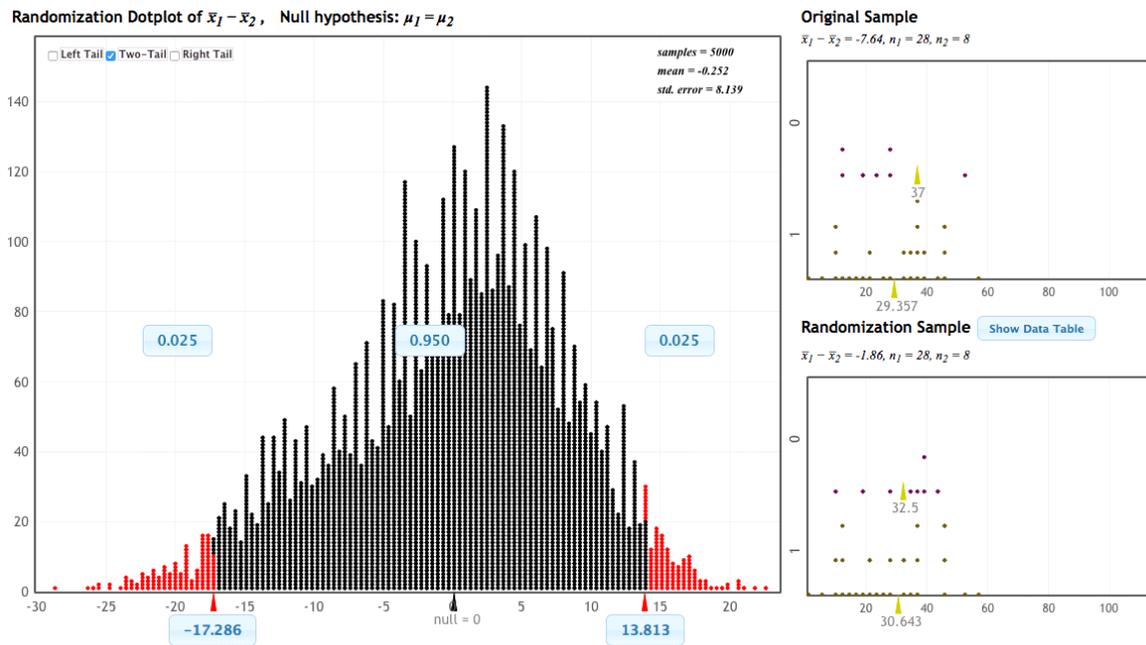


Fig. R2.4.7: Randomization test for one mean difference. Difference between known and unknown area travelling time of runs > 20m for Group 3.

For Group 3 a difference between known and unknown area of time travelled of runs >20m a difference of -7.64 min was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -17.29 and 13.81 min. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between known and unknown area of time travelled of runs >20m could be shown for Group 3.

Appendix Part 2.4 Distance outbound versus inbound (runs>20m) travelled by the dogs

Table R2.5.1: Distance outbound vs. inbound travelling round >20m each dog in meter.

N=30 Dog nnn- nnn=n=30	N point of return (POR)	Distance outbound in m					Distance inbound in m				
		mean	medi- an	Q25	Q75	sd	mean	median	Q25	Q75	sd
Amanda	5	51,67	53,0	36	66	15,04	64,00	62,0	26	104	39,04
Amy	23	235,00	202,0	139	331	141,73	259,00	175,0	170,5	347,5	172,71
Arthur	50	466,00	495,5	272	660	286,97	606,75	593,5	308	905,5	382,38
Balin	5	71,33	73,0	18	123	52,52	79,00	55,0	46	136	49,57
Balou_Mix	59	1257,00	1270,5	883	1631	523,24	1114,50	1039,5	692,5	1536,5	594,66
Balou_RR	4	102,50	102,5	84	121	26,16	81,50	81,5	79	84	3,54
Bill	94	1984,50	1647,0	1437	2532	857,65	2003,75	1768,0	1326	2681,5	1054,43
Dr. Pepper	8	86,00	85,0	57,5	114,5	44,17	34,50	39,5	23	46	16,05
Emma	4	120,00	120,0	34	206	121,62	69,50	69,5	38	101	44,55
Freya	5	57,50	48,0	37,5	77,5	29,08	63,75	56,0	51	76,5	21,23
Honey	43	904,25	948,0	778,5	1030	194,20	625,75	551,5	372	879,5	364,37
Kaito	49	1220,50	1200,0	795,5	1645,5	508,05	1138,75	1168,5	763	1514,5	453,15
Kimi	42	848,75	775,5	278,5	1419	681,34	807,75	768,5	195	1420,5	711,18
Lea/Emma	31	448,50	486,0	323	574	194,93	331,75	337,0	185	478,5	186,74
Lili	19	171,50	128,5	116	227	98,86	213,00	153,5	91	335	184,02
Lou	36	1092,25	1234,0	811,5	1373	473,22	1063,25	1168,0	706	1420,5	475,62
Luna	45	481,25	439,5	396,5	566	143,89	540,25	578,5	395	685,5	198,58
Mala	0	.	.	.	.	.	.	.	.	.	.
Manja	3	36,33	32,0	29	48	10,21	46,33	52,0	32	55	12,50
Marley	57	1564,25	1668,0	1250	1878,5	420,63	1619,50	1688,5	1455,5	1783,5	245,57
Molly	5	42,67	34,0	32	62	16,77	71,00	82,0	39	92	28,16
Nele	7	101,33	84,0	56	164	56,05	111,67	84,0	54	197	75,41
Nina	40	761,50	654,0	90	1433	807,63	790,00	720,0	104	1476	806,31
Odin	0	.	.	.	.	.	.	.	.	.	.
Raffaele	30	558,00	510,5	179	937	462,83	452,00	259,0	151	753	487,82
Raya	32	703,50	788,0	526	881	249,90	675,50	696,0	379,5	971,5	381,33
Tamina	50	1303,00	1023,5	551,5	2054,5	998,13	1371,50	1076,5	847	1896	856,05
Thorin	17	322,00	350,5	99	545	261,67	281,50	312,5	129	434	191,77
Wantje	1	65,00	65,0	65	65	.	91,00	91,0	91	91	.
Zlata	7	243,00	203,0	88	438	178,40	242,00	173,0	139	414	149,92
Total	771	606,16	407,0	88	971	650,74	587,94	274,0	91	987	655,67

Appendix Part 2.5 Time and speed outbound versus inbound (runs>20m) travelled by the dogs

Table R2.6.1: Time outbound versus inbound travelling round >20m each dog in minutes, mean and median.

Dog N=30	Time_outbound in min.					Time_inbound in min.				
	mean	median	Q25	Q75	SD	mean	median	Q25	Q75	SD
Amanda	0	0	0	0	0	0	0	0	0	0
Amy	1	1	1	2	1	1	1	1	2	1
Arthur	3	4	2	5	3	4	4	2	7	3
Balin	0	0	0	1	1	0	0	0	1	1
Balou_Mix	21	11	10	32	20	6	6	4	9	4
Balou_RR	1	1	0	1	1	0	0	0	0	0
Bill	11	10	9	14	4	9	8	5	12	5
Dr. Pepper	1	1	0	2	1	0	0	0	1	1
Emma	1	1	0	1	1	0	0	0	0	0
Freya	0	0	0	0	0	0	0	0	0	0
Honey	5	6	4	6	1	3	3	2	5	2
Kaito	10	10	8	13	3	8	9	6	10	3
Kimi	7	6	2	11	5	4	4	1	7	4
Lea/Emma	2	2	1	2	1	1	2	1	2	1
Lili	16	2	1	31	29	1	1	0	2	1
Lou	8	9	6	10	3	7	8	5	5	3
Luna	4	4	3	5	1	3	3	2	4	2
Mala	0	.	.	.	0	0	.	.	.	0
Manja	0	0	0	0	0	0	0	0	0	0
Marley	8	8	6	10	2	7	7	6	8	1
Molly	0	0	0	0	0	0	0	0	0	0
Nele	0	0	0	1	1	0	0	0	1	1
Nina	6	5	1	11	7	5	5	1	9	5
Odin	.	.	.	.	.	.	.	.	.	.
Raffaele	2	2	1	4	2	2	1	1	3	2
Raya	4	4	3	5	2	2	3	1	4	2
Tamina	8	7	3	13	6	7	6	5	10	4
Thorin	3	4	1	6	3	1	2	1	2	1
Wantje	0	0	0	0	0	0	0	0	0	0
Zlata	1	1	0	3	2	2	1	1	3	1
Total	5	2	0	7	8	3	1	0	5	3

Table R2.6.3: Speed outbound vs. inbound travelling round >20m each dog in km/h.

	group	number of runs >20m	N point of return (poi)	speed outbound in km/h					speed inbound in km/h				
				mean	median	Q25	Q75	sd	mean	median	Q25	Q75	sd
Amanda	1	204	5	8,33	8,3	8,0	8,7	0,35	9,60	9,7	8,6	10,5	0,95
Amy	2	208	23	8,63	8,4	8,1	9,2	0,97	10,88	11,2	9,9	11,9	1,58
Arthur	2	177	50	7,78	8,3	7,1	8,5	1,19	8,93	8,9	8,8	9,1	0,26
Balin	1	15	5	5,67	4,7	4,7	7,6	1,67	8,10	7,7	4,9	11,7	3,42
Balou_Mix	3	174	59	9,30	9,2	8,4	10,2	1,14	9,95	9,9	8,4	11,5	1,85
Balou_RR	1	138	4	6,15	6,2	5,7	6,6	0,64	8,65	8,7	6,9	10,4	2,47
Bill	3	221	94	10,98	11,2	10,4	11,6	0,85	14,83	14,9	14,5	15,2	0,43
Dr. Pepper	1	44	8	11,65	12,2	9,7	13,6	2,50	10,43	11,0	8,3	12,6	3,33
Emma	1	6	4	8,15	8,2	5,0	11,3	4,45	7,85	7,9	6,8	8,9	1,48
Freya	1	9	5	8,98	9,3	7,9	10,1	1,58	8,68	7,3	6,8	10,6	3,25
Honey	3	58	43	10,58	10,5	10,1	11,1	0,76	11,42	10,8	9,5	13,4	2,64
Kaito	3	148	49	7,08	7,1	6,4	7,8	0,84	9,35	9,3	8,6	10,1	1,15
Kimi	2	96	42	8,18	8,1	6,9	9,5	1,94	10,15	10,1	8,9	11,5	1,54
Lea/Emma	2	145	31	12,75	12,8	11,8	13,8	1,18	12,08	11,9	11,2	13,0	1,44
Lili	1	74	19	8,08	7,6	7,3	8,9	1,31	10,58	10,7	9,0	12,2	2,42
Lou	3	182	36	8,75	8,8	8,5	9,1	0,45	11,35	11,1	10,3	12,5	1,60
Luna	2	149	45	7,85	7,5	5,8	9,9	2,48	10,95	10,7	10,1	11,8	1,10
Mala	1	2	0	.	.	.	.	.	.	.	.	.	.
Manja	1	5	3	8,03	7,3	5,2	11,6	3,26	6,57	6,6	4,7	8,4	1,85
Marley	3	159	57	11,85	12,1	11,4	12,4	0,73	14,03	14,1	13,8	14,3	0,33
Molly	1	13	5	6,90	6,8	6,7	7,2	0,26	10,67	11,0	9,2	11,8	1,33
Nele	1	201	7	7,20	6,6	6,6	8,4	1,04	10,03	9,4	9,0	11,7	1,46
Nina	2	103	40	7,25	8,0	5,7	8,9	2,41	10,08	10,3	9,4	10,8	0,96
Odin	1	58	0	.	.	.	.	.	.	.	.	.	.
Raffaele	3	47	30	11,58	11,7	11,0	12,2	0,85	10,05	9,8	8,5	11,7	2,09
Raya	3	106	32	12,68	10,8	10,2	15,2	4,25	15,33	15,5	12,7	18,0	3,10
Tamina	3	147	50	9,45	9,1	8,2	10,8	1,69	10,35	10,1	9,9	10,8	0,66
Thorin	2	122	17	7,65	8,0	6,3	9,0	1,66	10,00	10,4	9,2	10,8	1,26
Wantje	1	123	1	5,60	5,6	5,6	5,6	.	8,80	8,8	8,8	8,8	.
Zlata	2	11	7	9,53	10,4	7,7	10,5	1,59	9,87	7,9	7,7	14,0	3,58
Total		3145	771	9,04	8,7	7,5	10,7	2,47	10,54	10,5	8,8	11,9	2,55

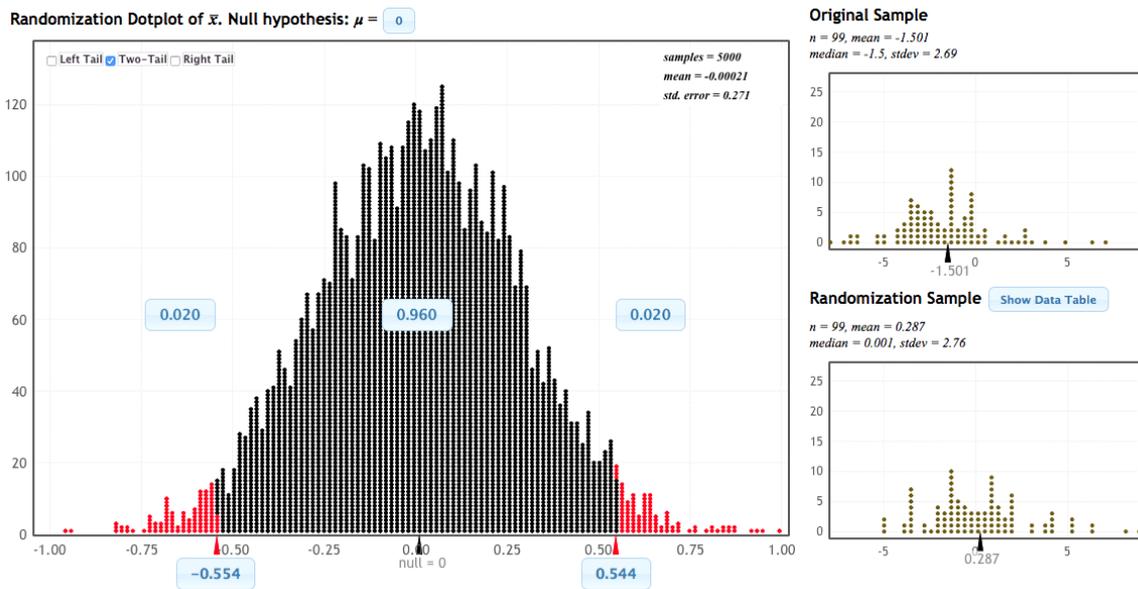


Fig. R2.6.10: Randomization test for one mean difference: Speed inbound versus outbound travel of runs >20m.

Between inbound and outbound a speed difference of -1,5 km/h was observed. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -0,55 and 0,54. The observed value is outside these limits, therefore $p < 0.05$, the Nullhypothesis could be rejected. A difference between outbound and inbound speed could be shown. Dogs travel significantly faster inbound, back to their owner, see also **Table R2.6.3 Appendix**.

Appendix Part 2.6 Distance travelled male versus female dogs (runs>20m)

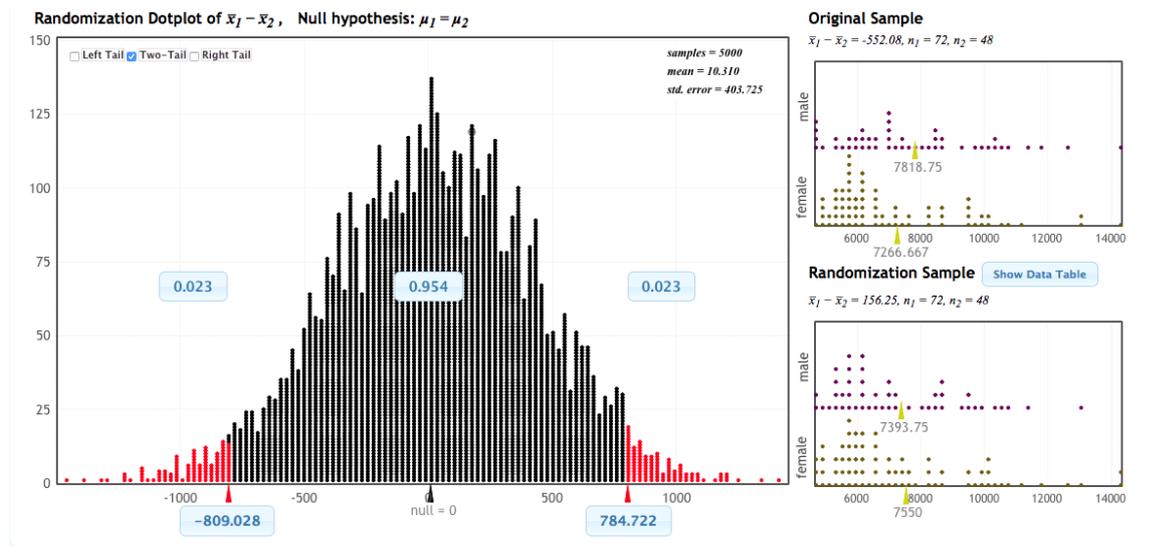


Fig. R2.7.4: Randomization test for one mean difference. Total distance of dog walks in *m* female vs. male dogs.

Total distance travelled males versus female dogs. Between male and female dogs difference between the distances of dog walks of 552 m was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -809 and 784. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between male and female dogs could be demonstrated on the total distance of all walks.

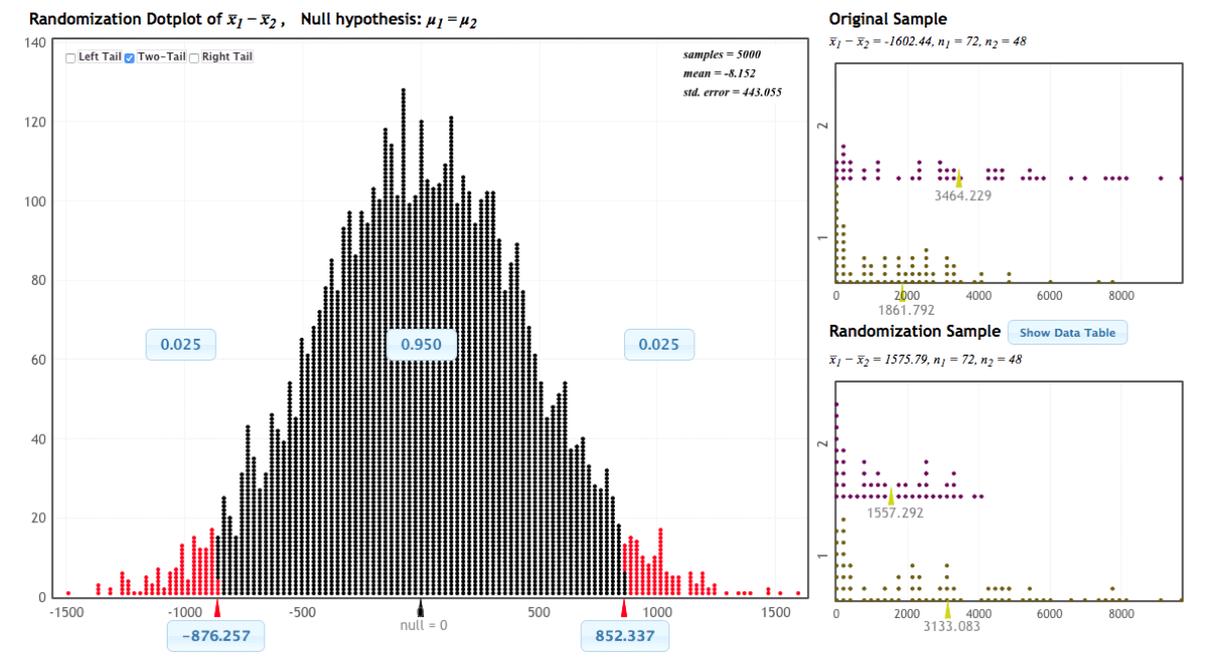


Fig. R2.7.5: Randomization test for one mean difference. Total runs >20m in m female vs. male dogs.

Between male and female dogs difference between total runs >20 m of 1602m was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -876 and 852. The observed value is outside these limits, therefore $p < 0.05$, the Nullhypothesis could be rejected. A significant difference between male and female dogs could be shown: Male dogs have longer runs > 20m than female dogs.

Appendix Part 2.7 Time travelled male versus female dogs (runs>20m)

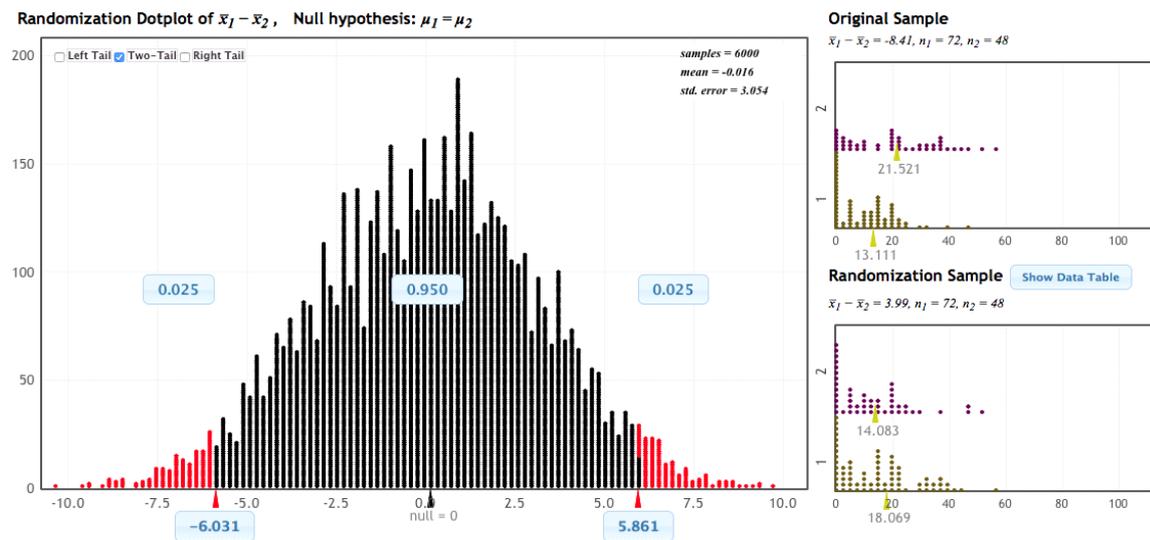


Fig. R2.8.3: Randomization test of one mean difference. Difference male versus female dogs, duration of runs >20m.

Between male and female dogs difference between the duration of runs (Time >20m_away) of -8 min. was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -6 and 6 min. The observed value is outside these limits, therefore $p < 0.05$, the Nullhypothesis could be rejected. A difference between male and female dogs could be shown. Male dogs are significantly longer >20m away from their owner than female dogs.

Appendix Part 2.8 Distance travelled neutered versus intact dogs (runs>20m)

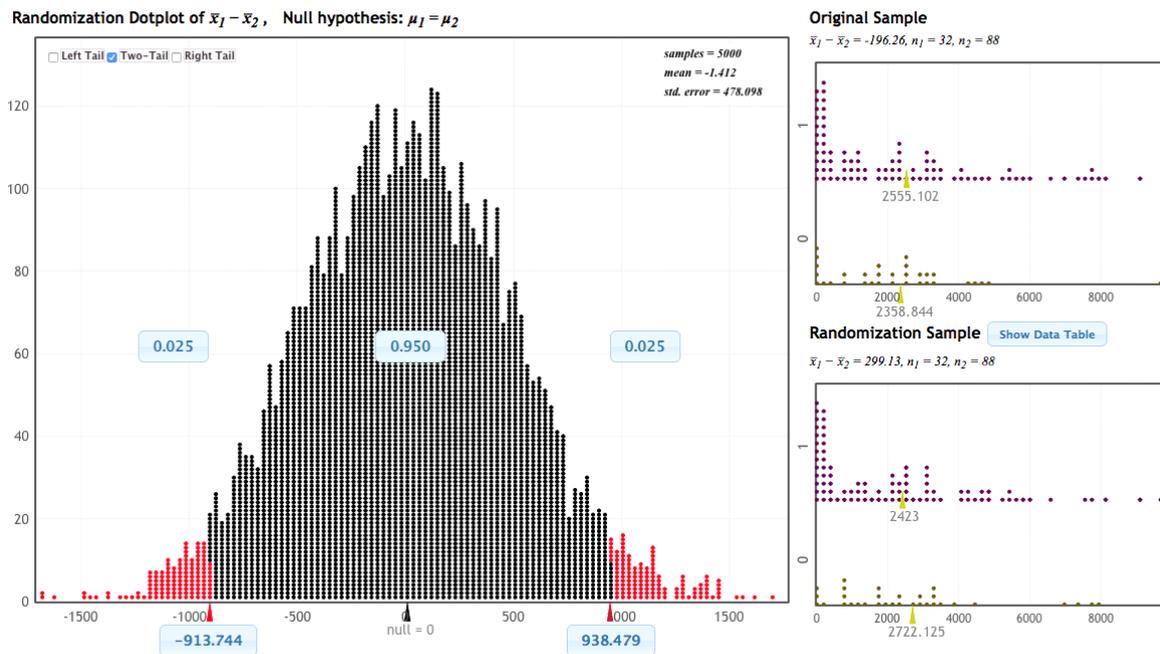


Fig. R2.9.5 Randomization test of one mean difference. All runs >20m total distance travelled between all neutered versus all intact dogs.

Appendix Part 2.9 Time travelled neutered versus intact dogs (runs>20m)

Between all intact and all neutered dogs difference between the distances of runs of 196 m was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -913 and 938. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between all neutered and all intact dogs of runs > 20m distance could be demonstrated.

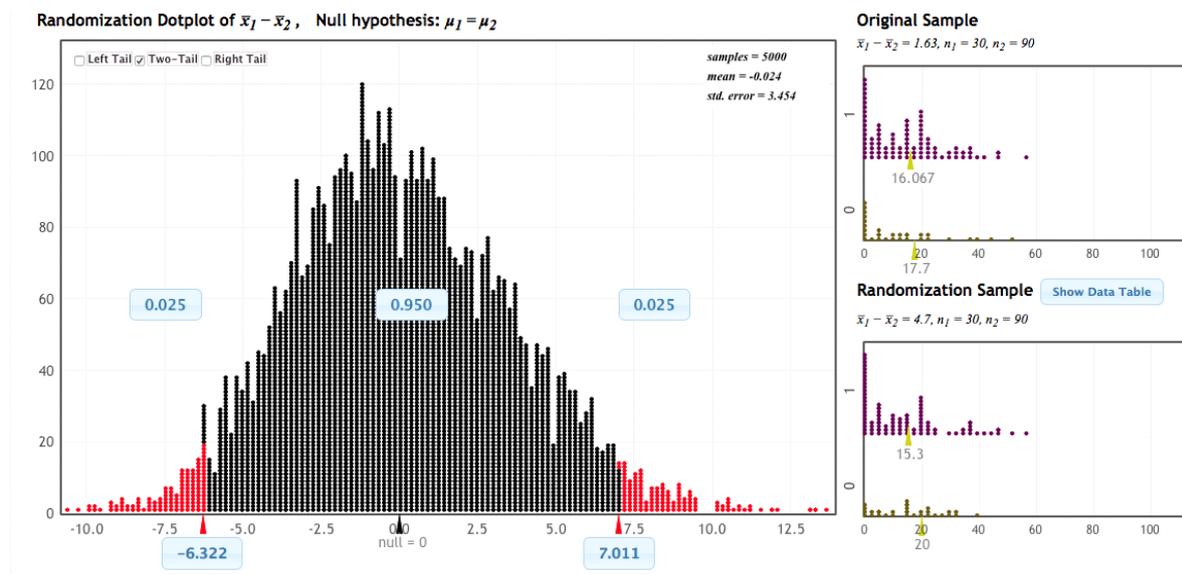


Fig. R2.10.5: Randomization Test for one mean difference: Time runs >20m all neutered versus all intact dogs in minutes.

Between all intact and all neutered dogs difference between the duration of runs > 20m (Time_20m_away) of 2 min was observed from the dataset. Simulating 5000 samples of identical distributed datasets, critical values to reject the Nullhypothesis of no effect are -6 and 7. The observed value is within these limits, therefore $p > 0.05$, the Nullhypothesis could not be rejected. No difference between neutered and intact dogs could be shown.

Appendix Part 2.10 Differences in over all speed between the dogs and overall dogs

Table R2.13.1: Individual dogs speed mean and median in km/h.

	dog average speed in km/h				
	mean	Sd	Q25	Median	Q75
,	5,13	0,22	4,95	5,10	5,30
Amy	6,08	0,31	5,85	6,00	6,30
Arthur	6,20	0,24	6,05	6,20	6,35
Balin	4,75	0,33	4,50	4,85	5,00
Balou_Mix	7,75	1,18	6,80	7,60	8,70
Balou_RR	5,23	0,24	5,05	5,30	5,40
Bill	7,77	0,80	7,30	7,60	8,25
Dr. Pepper	5,03	0,19	4,90	4,95	5,15
Emma	5,13	0,32	4,95	5,00	5,30
Freya	5,77	0,38	5,50	5,65	6,05
Honey	6,85	0,82	6,35	6,80	7,35
Kaito	6,07	0,46	5,70	6,05	6,45
Kimi	6,07	0,80	5,40	6,15	6,75
Lea/Emma	5,93	0,51	5,55	5,95	6,30
Lili	5,03	0,34	4,75	5,10	5,30
Lou	6,18	0,74	5,70	6,25	6,65
Luna	5,70	0,58	5,30	5,70	6,10
Mala	4,95	0,21	4,80	4,95	5,10
Manja	5,55	0,70	5,10	5,45	6,00
Marley	9,35	0,70	8,95	9,65	9,75
Molly	5,58	0,48	5,20	5,45	5,95
Nele	5,57	0,17	5,45	5,55	5,70
Nina	6,20	0,83	5,50	6,25	6,90
Odin	4,55	0,24	4,35	4,55	4,75
Raffaele	6,45	1,14	5,55	6,40	7,35
Raya	7,40	1,04	6,65	7,45	8,15
Tamina	7,93	0,68	7,55	8,25	8,30
Thorin	5,85	0,37	5,55	5,80	6,15
Wantje	4,85	0,17	4,75	4,80	4,95
Zlata	5,38	0,57	5,05	5,20	5,70
total	6,01	1,21	5,20	5,65	6,55

Appendix Part 2.11 Classification of dogs according to their travelling patterns

Table R2.14.1: Travelling patterns of all dogs individually, runs > 20m.

Dog Runs >20m	Runs ahead waits/ follows	Star	loop	Loop+star	Mix forms runs ahead & loops	Mix forms runs ahead & star	Runs parallel then meets owner
1.Amanda n=204runs	172	5	0	0	0	25	2
2.Amy n=208 runs	155	28	14	0	0	0	11
3.Arthur n=177 runs	109	40	18	1	3	0	6
4.Balin n=15 runs	6	2	1	0	0	0	6
5.Balou RR n=138 runs	129	2	2	0	2	0	3
6. Balou n=174 runs	77	34	31	4	15	1	12
7. Bill n=221 runs	88	66	46	4	0	0	17
8. Dr.Pepper n=44 runs	34	4	6	0	0	0	0
9. Emma Lea n=145 runs	103	39	1	1	0	0	1
10. Emma n=6 runs	3	2	1	0	0	0	0
11. Freya n=9 runs	2	4	3	0	0	0	0
12. Honey n=58 runs	5	34	7	0	4	5	3
13. Kaito n=148 runs	60	38	26	3	0	0	21
14. Kimi n=96 runs	53	27	15	1	0	0	0
15. Lily n=74 runs	48	18	4	0	0	0	4
16. Lou n=182 runs	97	33	16	3	0	0	33
17. Luna n=149runs	75	31	19	1	10	3	10
18. Mala n=2 runs	0	0	0	0	0	0	2
19. Manja n=5 runs	0	3	0	0	0	0	2

Dog Runs >20m	Runs ahead waits/ follows	Star	loop	Loop+star	Mix forms runs ahead & loops	Mix forms runs ahead & star	Runs parallel then meets owner
20. Marley n=159 runs	87	38	12	0	6	5	11
21. Molly n=13 runs	6	2	3	0	1	0	1
22. Nele n=201 runs	187	6	1	0	0	0	7
23. Nina n=103 runs	50	31	14	1	0	0	7
24. Odin n=58 runs	58	0	0	0	0	0	0
25. Raffaele n=47 runs	8	27	9	1	0	0	2
26. Raiya n=106 runs	55	30	9	3	1	3	5
27. Tamina n=147 runs	71	31	18	4	2	6	15
28. Thorin n=122 runs	93	12	8	0	1	0	8
29. Wantje n=123 runs	119	1	0	0	0	2	1
30. Zlata n=11 runs	0	1	7	1	0	0	2

Table R2.14.2: Results of the clustering algorithm. Walks are allocated to groups according to their patterns. Distance is a measure of how far the walk is away from the clustering center. Lower values indicate “typical” walks of the group.

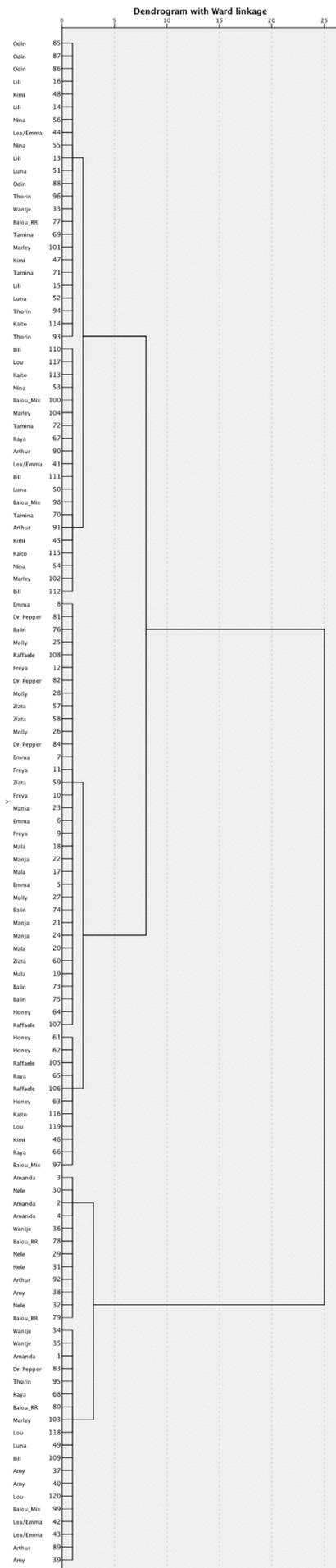
name	Walk	Cluster	Distance
Amanda	1	3	9,946
Amanda	2	3	10,8
Amanda	3	3	18,804
Amanda	4	3	10,776
Amy	1	3	4,863
Amy	2	3	5,749
Amy	3	3	13,472
Amy	4	3	3,971
Arthur	1	3	8,904
Arthur	2	1	5,133
Arthur	3	1	13,144
Arthur	4	3	7,836
Balin	1	2	2,871
Balin	2	2	3,098
Balin	3	2	2,526
Balin	4	2	3,098
Balou_Mix	1	2	16,286
Balou_Mix	2	1	8,333
Balou_Mix	3	3	8,35
Balou_Mix	4	1	3,355
Balou_RR	1	1	9,481
Balou_RR	2	3	3,22
Balou_RR	3	3	8,633
Balou_RR	4	1	10,171
Bill	1	1	11,139
Bill	2	1	6,845
Bill	3	1	13,206
Bill	4	1	25,722
Dr. Pepper	1	2	2,929
Dr. Pepper	2	2	3,252
Dr. Pepper	3	3	9,708
Dr. Pepper	4	2	2,816
Emma	1	2	4,021
Emma	2	2	3,434
Emma	3	2	2,463

name	Walk	Cluster	Distance
Emma	4	2	3,231
Freya	1	2	3,069
Freya	2	2	3,434
Freya	3	2	3,151
Freya	4	2	2,952
Honey	1	2	8,859
Honey	2	2	7,821
Honey	3	2	8,501
Honey	4	2	2,243
Kaito	1	1	6,287
Kaito	2	1	3,521
Kaito	3	1	8,444
Kaito	4	2	13,909
Kimi	1	1	7,724
Kimi	2	2	9,71
Kimi	3	1	5,946
Kimi	4	2	7,652
Lea/Emma	1	1	10,431
Lea/Emma	2	3	7,877
Lea/Emma	3	3	9,413
Lea/Emma	4	1	8,234
Lili	1	1	5,579
Lili	2	2	6,853
Lili	3	1	6,504
Lili	4	2	5,682
Lou	1	1	8,218
Lou	2	1	12,887
Lou	3	2	10,901
Lou	4	3	7,212
Luna	1	1	12,202
Luna	2	1	7,87
Luna	3	1	8,649
Luna	4	1	4,93
Mala	1	2	4,021
Mala	2	2	4,021
Mala	3	2	3,914
Mala	4	2	3,914
Manja	1	2	3,309

name	Walk	Cluster	Distance
Manja	2	2	4,021
Manja	3	2	3,434
Manja	4	2	3,309
Marley	1	1	8,243
Marley	2	1	7,603
Marley	3	1	11,745
Marley	4	1	3,189
Molly	1	2	3,252
Molly	2	2	2,816
Molly	3	2	3,73
Molly	4	2	2,084
Nele	1	3	3,894
Nele	2	3	14,259
Nele	3	3	7,836
Nele	4	3	6,946
Nina	1	1	6,986
Nina	2	1	8,104
Nina	3	2	8,837
Nina	4	2	4,904
Odin	1	1	10,845
Odin	2	2	9,147
Odin	3	1	10,845
Odin	4	1	9,565
Raffaele	1	2	11,189
Raffaele	2	2	7,625
Raffaele	3	2	2,823
Raffaele	4	2	2,546
Raya	1	2	9,621
Raya	2	2	6,314
Raya	3	1	4,083
Raya	4	1	10,35
Tamina	1	1	6,006
Tamina	2	1	10,812
Tamina	3	1	5,48
Tamina	4	1	4,665
Thorin	1	1	7,751
Thorin	2	1	2,882
Thorin	3	3	5,728

name	Walk	Cluster	Distance
Thorin	4	1	8,923
Wantje	1	1	9,802
Wantje	2	3	10,278
Wantje	3	3	8,176
Wantje	4	3	4,114
Zlata	1	2	3,967
Zlata	2	2	4,136
Zlata	3	2	3,151
Zlata	4	2	3,914

Dendrogram depicting each dog. Based on the great individual variance displayed by the dogs a hierarchical Cluster analysis using Ward linkage and squared Euclidean Distance measure was applied to establish an appropriate number of clusters. Based thereon the dendrogram was drawn, see next page. The dendrogram can be read from left to the right side. Increasing values of the x-axis indicate increasing heterogeneity within the clusters. On the left side (y-axis) all 120 individual walks of the dogs are shown. In the first step the walks are grouped with respect to statistical distance and equivalence measures. Firstly 6 groups are built. Within a second step 2 of these groups are combined, so 3 groups are resulting. Furthermore the upper two groups are combined and at the last step the remaining 2 groups are combined to one (overall) group having maximal heterogeneity.



Appendix Part 2.12 Travelling patterns of dog dyads/triads – correlations

Table R2.15.1: The seven travelling patterns of dogs of one owner (teams) in comparison.

Team		Runs ahead waits/follows		Star		loop		Loop+Star		Mix form runs ahead&loop		Mix form rund ahead&star		runs parallel then meets owner		number of runs >20m	
		n	% der runs	N	% der runs	n	% der runs	n	% der runs	n	% der runs	n	% der runs	n	% der runs	n	% der runs
1	Amanda	172	84,31 %	5	2,45 %	0	0,00 %	0	0,00 %	0	0,00 %	25	12,25 %	2	1,15	204	100,00 %
	Wantje	119	96,75 %	1	0,81 %	0	0,00 %	0	0,00 %	0	0,00 %	2	1,63 %	1	1	123	100,00 %
	p-Wert	0,073		0,905		0,631		0,407		0,750		0,500		0,138		0,157	
2	Balou	77	44,25 %	34	19,54 %	31	17,82 %	4	2,30 %	15	8,62 %	1	0,57 %	12	4,9	174	100,00 %
	Lilli	48	64,86 %	18	24,32 %	4	5,41 %	0	0,00 %	0	0,00 %	0	0,00 %	4	1,63	74	100,00 %
	p-Wert	0,125		0,250		1,000		1,000		1,000		0,125		1,000		0,125	
3	Balou_RR	129	93,48 %	2	1,45 %	2	1,45 %	0	0,00 %	2	1,45 %	0	0,00 %	3	1,91	138	100,00 %
	Luna	75	50,34 %	31	20,81 %	19	12,75 %	1	0,67 %	10	6,71 %	3	2,01 %	10	3,46	149	100,00 %
	p-Wert	0,375		0,250		0,125		0,500		0,500		1,000		0,375		0,125	
4	Amy	155	74,52 %	28	13,46 %	14	6,73 %	0	0,00 %	0	0,00 %	0	0,00 %	11	4,12	208	100,00 %
	Nele	187	93,03 %	6	2,99 %	1	0,50 %	0	0,00 %	0	0,00 %	0	0,00 %	7	3,42	201	100,00 %
	p-Wert	0,375		0,125		0,125		1,000		0,500		1,000		0,125		1,000	
5	Dr. Pepper	34	77,27 %	4	9,09 %	6	13,64 %	0	0,00 %	0	0,00 %	0	0,00 %	0	0	44	100,00 %
	Raiya	55	51,89 %	30	28,30 %	9	8,49 %	3	2,83 %	1	0,94 %	3	2,83 %	5	1,91	106	100,00 %
	p-Wert	0,125		0,125		0,250		1,000		1,000		1,000		0,750		0,625	
6	Kimi	53	55,21 %	27	28,13 %	15	15,63 %	1	1,04 %	0	0,00 %	0	0,00 %	0	0	96	100,00 %
	Nina	50	48,54 %	31	30,10 %	14	13,59 %	1	0,97 %	0	0,00 %	0	0,00 %	7	1,91	103	100,00 %
	p-Wert	0,625		0,125		1,000		1,000		1,000		0,500		0,250		0,250	

Team		Runs ahead waits/follows		Star		loop		Loop+Star		Mix form runs ahead&loop		Mix form rund ahead&star		runs parallel then meets owner		number of runs >20m	
		n	% der runs	N	% der runs	n	% der runs	n	% der runs	n	% der runs	n	% der runs	n	% der runs	n	% der runs
7	Manja	0	0,00 %	3	60,00 %	0	0,00 %	0	0,00 %	0	0,00 %	0	0,00 %	2	1,15	5	100,00 %
	Raffaele	8	17,02 %	27	57,45 %	9	19,15 %	1	2,13 %	0	0,00 %	0	0,00 %	2	1,15	47	100,00 %
	p-Wert	1,000		0,875		1,000		1,000		1,000		1,000		0,125		0,500	
8	Marley	87	54,72 %	38	23,90 %	12	7,55 %	0	0,00 %	6	3,77 %	5	3,14 %	11	4,12	159	100,00 %
	Tamina	71	48,30 %	31	21,09 %	18	12,24 %	4	2,72 %	2	1,36 %	6	4,08 %	15	5,26	147	100,00 %
	p-Wert	0,500		0,250		0,250		1,000		1,000		1,000		1,000		0,125	
9	Bill	88	39,82 %	66	29,86 %	46	20,81 %	4	1,81 %	0	0,00 %	0	0,00 %	17	4,43	221	100,00 %
	Kaito	60	40,54 %	38	25,68 %	26	17,57 %	3	2,03 %	0	0,00 %	0	0,00 %	21	9,29	148	100,00 %
	Lou	97	53,30 %	33	18,13 %	16	8,79 %	3	1,65 %	0	0,00 %	0	0,00 %	33	3	182	100,00 %
	p-Wert	0,125		0,500		0,500		0,250		0,750		1,000		0,875		0,625	
10	Emma	3	50,00 %	2	33,33 %	1	16,67 %	0	0,00 %	0	0,00 %	0	0,00 %	0	0	6	100,00 %
	Zlata	0	0,00 %	1	9,09 %	7	63,64 %	1	9,09 %	0	0,00 %	0	0,00 %	2	1,15	11	100,00 %
	Mala	0	0,00 %	0	0,00 %	0	0,00 %	0	0,00 %	0	0,00 %	0	0,00 %	2	1,15	2	100,00 %
	p-Wert	0,500		1,000		0,500		1,000		1,000		1,000		0,500		0,625	
total	Dog 1	798	63,59 %	209	16,65 %	127	10,12 %	9	0,72 %	23	1,83 %	31	2,47 %	58	12,48	1255	100,00 %
	Dog 2	673	60,69 %	214	19,30 %	107	9,65 %	14	1,26 %	13	1,17 %	14	1,26 %	74	14,5	1109	100,00 %
	Dog 3	97	52,72 %	33	17,93 %	16	8,70 %	3	1,63 %	0	0,00 %	0	0,00 %	35	12,09	184	100,00 %
	p-Wert	0,073		0,631		0,407		0,750		0,500		0,138		0,157			

Appendix Part 2.13 Comparison of duration; difference in walking time; time travelled >20m; time inbound /outbound; total distance of the dog walks, total runs > 20 m, the maximum distance of runs in meter and inbound/outbound travelling distance for Multi-dog teams (dyad/triad)

Table R2.16.1.1: Duration of dogs travelling rounds in minutes and differences in walking times between the teams, Mean and Median. Dot indicates no POR.

Team	Duration of dogs traveling round in min					Difference_walking_time				
	mean	sd	min	median	max	mean	sd	min	median	max
Amanda	77	5	74	75	85	-5	5	-11	-5	0
Wantje	77	4	74	76	83	-5	4	-11	-3	-2

Balou	80	11	67	79	94	-2	3	-5	-2	3
Lilli	80	13	69	77	95	-1	2	-3	-2	1

Balou_RR	95	6	91	93	103	0	2	-2	0	2
Luna	99	4	93	100	103	1	1	0	1	2

Amy	69	3	65	69	73	-2	1	-3	-2	0
Nele	69	3	66	69	72	-2	1	-3	-2	-1

Dr. Pepper	77	4	72	79	80	-4	8	-15	-1	1
Raiya	66	13	50	67	79	-1	1	-3	-1	0

Kimi	77	7	69	76	85	0	2	-2	-1	2
Nina	74	10	60	76	84	-3	6	-11	-2	2

Manja	112	31	69	118	142	0	2	-3	0	3
Rafaele	112	34	79	104	159	0	2	-3	0	2

Marley	82	5	77	81	89	-3	3	-6	-2	0
Tamina	83	5	80	82	90	-1	2	-3	-2	1

Bill	93	6	88	93	100	-2	1	-3	-2	0
Kaito	90	10	77	91	99	-3	2	-5	-2	-1
Lou	110	30	75	111	144	-1	1	-2	-1	1
Emma	114	31	81	112	149	-2	4	-8	-1	1
Zlata	143	19	121	145	160	0	2	-2	1	1
Mala	126	6	121	126	132	0	1	-2	0	1
dog 1	87	20	65	81	149	-2	4	-15	-2	3
dog 2	89	26	50	82	160	-2	3	-11	-1	2
dog 3	118	22	75	123	144	-1	1	-2	-1	1

Appendix Part 2.14 Geomagnetic field orientation of point of return

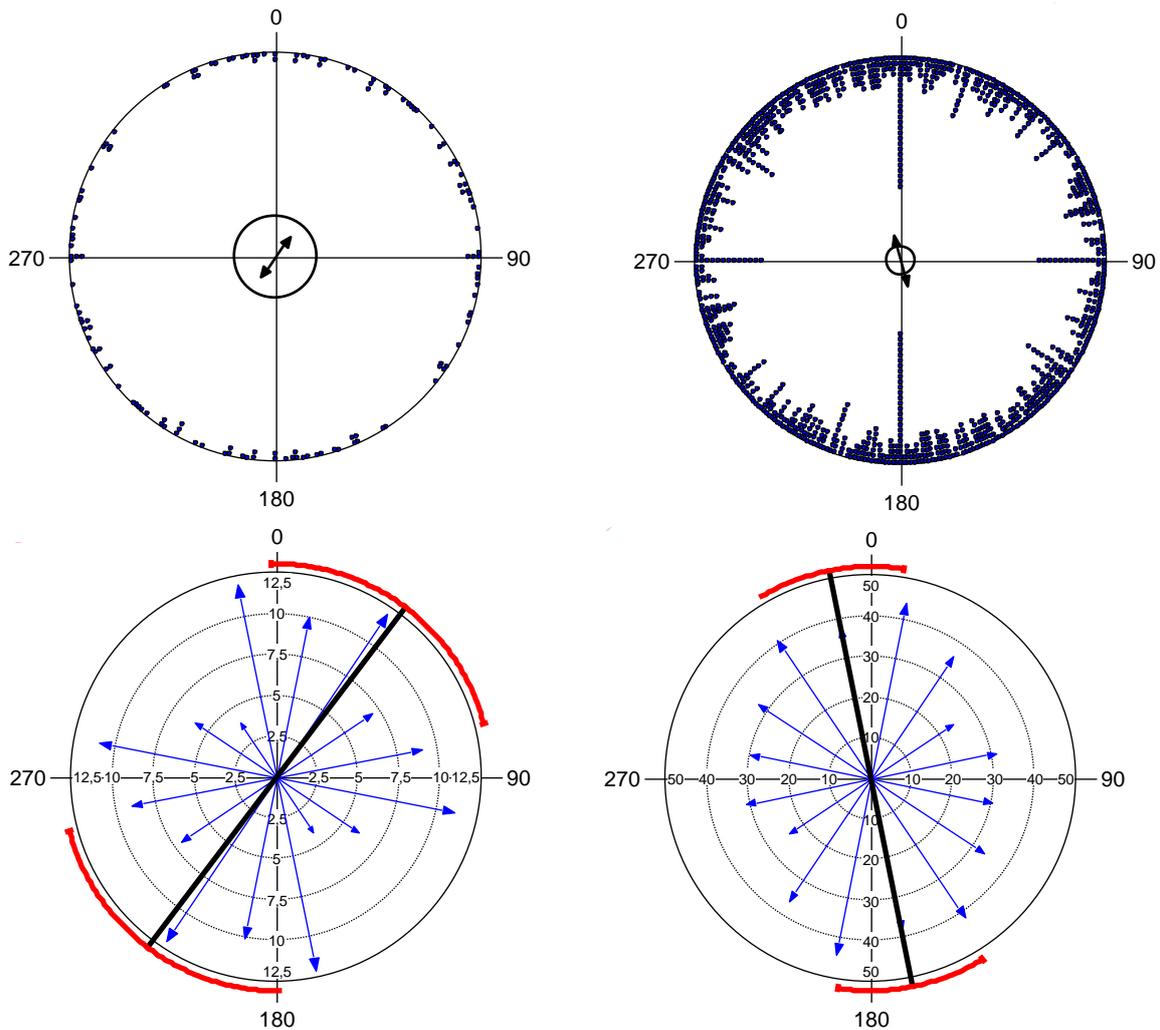


Fig. R2.17.4 a. Variable axial, all intact female dogs' (n=5) point of return (POR) Number of Observations: 71. Mean Vector (μ): 37°. Length of Mean Vector (r): 0.12 .Median 42,2° Circular Standard Deviation: 59°. 95 % Confidence Interval (-/+) for μ : 359°/ 75°.99 % Confidence Interval (-/+) for μ : 346°/87°. Rayleigh Test (p): 0,347. Rao's Spacing Test (p): < 0.01. Watson's U^2 Test (p) 0.5 > p > 0.25. Not significant.

Fig. R2.17.4.b. Variable axial, all spayed female dogs' (n=11) point of return (POR) Number of Observations: 277. Mean Vector (μ): 169°. Length of Mean Vector (r): 0.12. Median 168,6° Circular Standard Deviation: 59°. 95 % Confidence Interval (-/+) for μ : 149°/ 189°.99 % Confidence Interval (-/+) for μ : 142°/195°. Rayleigh Test (p): 0,022. Rao's Spacing Test (p): 0.50 > p > 0.10. Watson's U^2 Test (p) < 0.05.

Fig. R2.17.4 a/b: Point of return all intact female dogs (a) and all spayed female dogs (b), all runs > 20m.

Each pair of opposite dots indicates the axis of the vector of observations of the data points (direction in degree) where each dog decreased its speed and changed its direction to return to its owner, the so-called "point of return" collected during the run >20m in 2 sec segments by the GPS.. The mean vector (μ) and vector length (r) are indicated by the direction and length of the black (double) arrow(s), respectively. Small inner circles indicate the 5 %-significance level of the Rayleigh test. The lengths of the blue arrows indicate the frequencies for each class of observation.

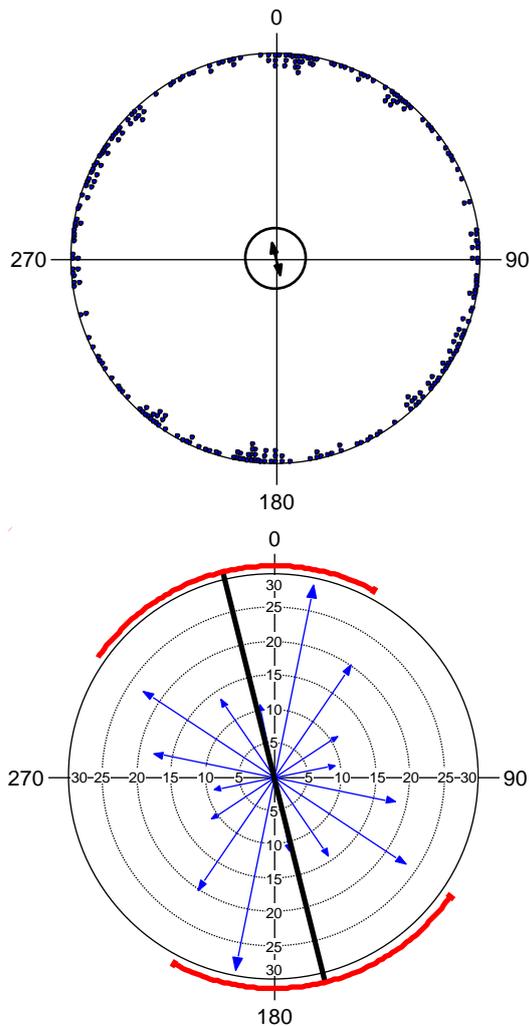


Fig. R2.17.5 a. Variable axial, all intact male dogs' (n=3) point of return (POR) Number of Observations: 135. Mean Vector (μ): 166°. Length of Mean Vector (r): 0.08 .Median 3° Circular Standard Deviation: 64°. 95 % Confidence Interval (-/+) for μ : 124°/ 208°.99 % Confidence Interval (-/+) for μ : 111°/221°. Rayleigh Test (p): 0,406. Rao's Spacing Test (p): 0.50 > p > 0.10. Watson's U^2 Test (p) 0.15 > p > 0.1

Not significant.

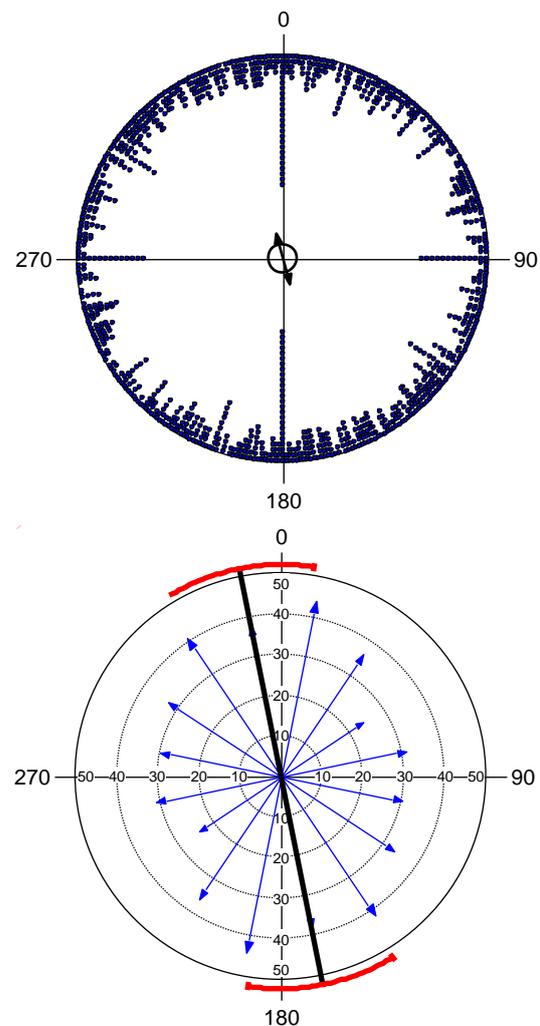


Fig. R2.17.5 b. Variable axial, all neutered male dogs' (n=8) point of return (POR) Number of Observations: 297. Mean Vector (μ): 165°. Length of Mean Vector (r): 0.14. Median 174°. Circular Standard Deviation: 57°. 95 % Confidence Interval (-/+) for μ : 149°/ 181°.99 % Confidence Interval (-/+) for μ : 144°/186°. Rayleigh Test (p): 0,002. Rao's Spacing Test (p): < 0.01. Watson's U^2 Test (p) < 0.005.

Fig. R2.17.5 a/b: *Point of return all intact male dogs (a) and all neutered male dogs (b), all runs > 20m .*

Each pair of opposite dots indicates the axis of the vector of observations of the data points (direction in degree) where each dog decreased its speed and changed its direction to return to its owner, the so-called "point of return" collected during the run >20m in 2 sec segments by the GPS.. The mean vector (μ) and vector length (r) are indicated by the direction and length of the black (double) arrow(s), respectively. Small inner circles indicate the 5 %-significance level of the Rayleigh test. The lengths of the blue arrows indicate the frequencies for each class of observation.

Curriculum Vitae

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Hiermit erkläre ich, gem. § 7 Abs. (2) d) + f) der Promotionsordnung der Fakultät für Biologie zur Erlangung des Dr. rer. nat., dass ich die vorliegende Dissertation selbständig verfasst und mich keiner anderen als der angegebenen Hilfsmittel bedient, bei der Abfassung der Dissertation nur die angegebenen Hilfsmittel benutzt und alle wörtlich oder inhaltlich übernommenen Stellen als solche gekennzeichnet habe.

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