THE EFFECTS OF MINDFULNESS MEDITATION ON ATTENTIONAL CONTROL, EXECUTIVE FUNCTIONS AND STEREOTYPE BEHAVIOR

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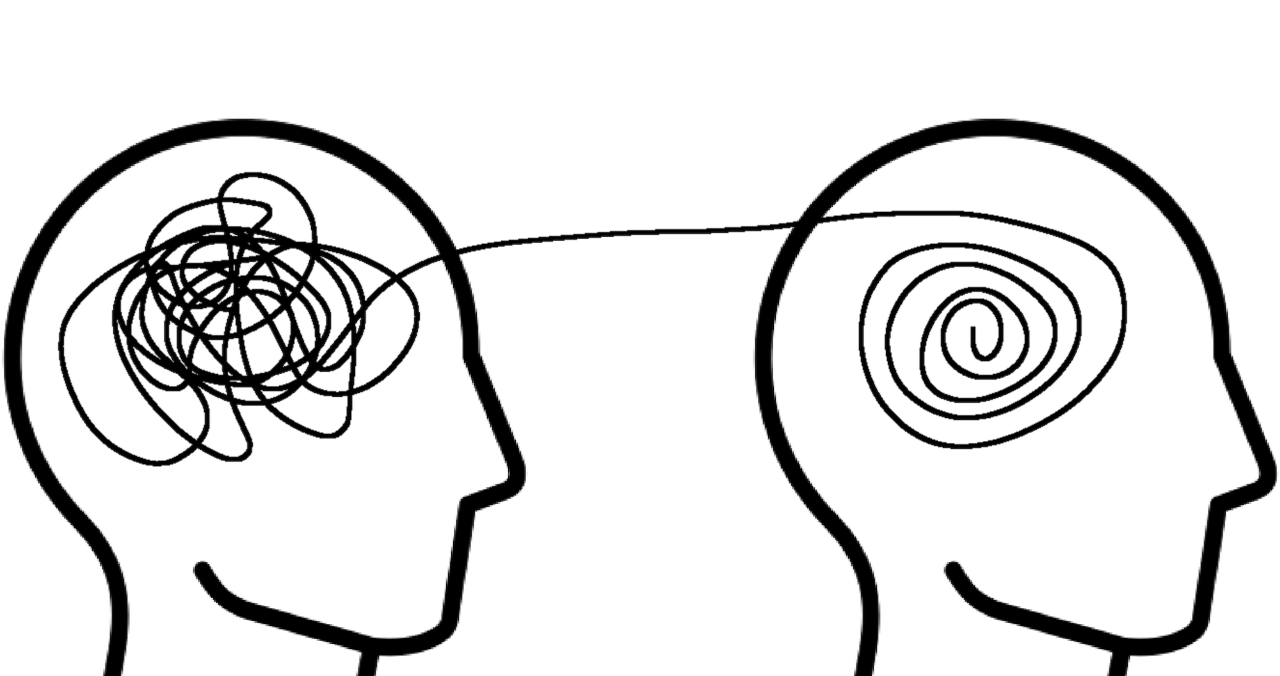

The Effects of Mindfulness Meditation on Attentional Control, Executive Functions & Stereotype Behavior

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“*In mindfulness one is not only restful and happy, but alert and awake. Meditation is not evasion; it is a serene encounter with reality*.”

Thich Nhat Hanh, The Miracle of Mindfulness: An Introduction to the Practice of Meditation (Nhat Hanh, 1975, p. 60)

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Abstract

Mindfulness describes a state of mind characterized by paying attention to the present moment while maintaining a non-judgmental and accepting attitude. Cognitive models postulate that practicing mindfulness improves attentional and executive control and such beneficial effects are partially confirmed by empirical studies. However, the dose-response relation between mindfulness and improvements in cognitive control is less understood. It has been argued that initial phases of the practice produce unspecific outcomes, which may also be attainable by induced relaxation. Therefore, this dissertation examined the effects of short mindfulness trainings of varying duration and frequency on attentional control (alerting, orienting and executive attention; Study 1) and executive functions (updating, inhibition and task switching; Study 1 & 2) with separate reaction-time tasks. In Study 3, it was investigated if improvements in cognitive control following short mindfulness trainings transfer to more complex behavioral control, namely the suppression of stereotype-biased behavior. Across three studies, mindfulness (breathing meditation) was contrasted with relaxation (progressive muscle relaxation) to investigate whether short mindfulness trainings produce specific effects or whether an initial underlying mechanism is state relaxation. Podcast listening was utilized as a passive control condition to control for effects of repeated testing.

Results of Study 1 revealed similar improvements for updating and executive attention following a mindfulness induction and relaxation compared to the passive control condition. Results for inhibition and task switching suggested differential, albeit not superior, effects following mindfulness compared to relaxation. No improvements were present for the alerting and orienting network. Thus, results suggested partly similar, partly differential mechanisms of mindfulness induction and relaxation. In Study 2, no effects on the executive functions updating, inhibition and task switching beyond repeated testing were found following an induction (Exp 1) and a brief training (Exp 2) in mindfulness and relaxation. Based on these findings, it could not be concluded that effects in the initial stages of mindfulness training differ from those of relaxation. It was discussed that effects on executive functioning following short mindfulness trainings might be too transient to be reliably measured in pre-post experimental designs. In Study 3, compared to a passive control condition, a mindfulness induction (Exp 1) and a brief training (Exp 2) increased the effect of stereotype bias on decision-making while relaxation reduced the effect. These findings provided additional evidence for differentiable effects of short mindfulness practices compared to relaxation. However, findings for mindfulness were not in line with theoretical propositions and previous research, and improvements following relaxation may suggest that processes outside of cognitive control affected performance. In summary, the results of the three studies suggest partially differential, partially overlapping mechanisms of short mindfulness trainings and relaxation. The present dissertation contributes to

understanding the development and specificity of cognitive effects in the initial phases of mindfulness practice and discusses implications for research in the field.

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Introduction

Mindfulness can be defined as the ability to purposeful direct one's attention to the present moment without judgment (Kabat-Zinn, 2009). While mindfulness has its roots in the Buddhist tradition (Buddhaghosa, 1976; Kiyota, 1978), it has been made popular in western psychology following the development of Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, 1982). MBSR is a structured 8-week-long intervention consisting of several formal meditation techniques and informal practices aimed at fostering participants' exploration of internal and external experiences on a moment-to-moment basis with an accepting, non-judgmental, and non-striving attitude. This specific way of focusing on the present can be described as the core of mindfulness practice. It is thought to increase awareness of one's current experiences and reactions to them, consequently enhancing self-regulation and reflective instead of reactive behavior (e.g., Bishop et al., 2004). Although mindfulness can be taught or trained through various techniques, breathing meditation is a central practice that stands at the beginning of most teaching traditions. During a breathing meditation, the practitioner focuses on the in- and outflow of the breath while maintaining a non-judgmental and curious attitude toward upcoming thoughts, sensations, and emotions. If the practitioner's attention is distracted by present experiences, such as mind wandering, they are to gently let the distraction go and redirect their focus on the breath. Describing the procedure of a breathing meditation already highlights why mindfulness is of interest to cognitive psychology. Namely, mindfulness practices entail and train the voluntary allocation and control of attentional resources. Accordingly, several cognitive models that specify components of a mindful state and its underlying mechanisms have been proposed. In all these models, attentional control, executive functioning, or an interplay of both are considered essential mechanisms of the practice. Models focusing on the role of the attentional networks as defined by Posner and Petersen (1990; Petersen & Posner, 2012) propose that alerting, orienting and executive attention are the core processes underlying mindful and meditative states. For example, both Hölzel et al. (2011) and Malinowski (2013) postulate that the alerting network allows the practitioner to achieve and maintain attentional vigilance to the meditational object in focus, which can be, for example, the somatosensory sensations of one's breathing. If any distractions arise, executive attention is involved in detecting and releasing such. Subsequently, the orienting network enables the practitioner to redirect and limit attentional resources to the desired focal point. Further models have highlighted the involvement of executive functions in mindfulness practice (i.e., set formation/updating, set shifting/cognitive flexibility, and set maintenance/inhibitory control, Suchy, 2009; Miyake et al., 2000). These are proposed to enable the practitioner to focus and sustain their attention to the experience of the present moment, inhibit competing cognitive processes that may divert attentional resources away from the current task (i.e., upcoming thoughts, emotions, and sensations), and flexibly shift attentional focus between objects, mental states, or goal-directed behavior (Bishop et al., 2004; Shapiro et al., 2006; Kang et al., 2013). Additionally, and in line with Kabat-Zinns' definition, which highlights *how* attention to the present moment is to be paid (i.e., in an open-minded, non-judgmental manner), models of mindfulness emphasize the relevance of the quality of attention or the attitude of the practitioner. For example, Bishop et al. (2004), Hölzel et al. (2011), Kang et al. (2013), and Shapiro et al. (2006) propose that the establishment and maintenance of an open, non-judgmental and accepting attitude towards internal and external experiences of the present moment, thus simply perceiving the current experience for what it is, fosters the practitioners' approach instead of avoidance of unwanted mental states, which in turn enables reflective instead of reactive behavior regulation. This interplay of being able to observe the contents of the present moment by involving attentional networks and/or executive functions and doing so with an accepting, non-reactive attitude is further proposed to allow for a change in the perspective of the self: The practitioner is enabled to be an observant of their contents of consciousness and perceive the self as a product of ongoing and transient mental processes. This change in self-perspective is subsequently proposed to reduce automatized or routinized behavioral pre-dispositions and support constructive behavioral modifications. The just-described improvement in meta-cognition by mindfulness (i.e., being aware of one's cognitive processes and being able to regulate them, e.g., Flavell, 1979; Livingston, 2003) is further outlined by Jankowski & Holas (2014) who argue that mindful states are characterized by both the conscious control of attentional processes and executive functioning. As the authors postulate, intentional, top-down alertness and sustained attention form the basis of focused attention during a mindful state, while bottom-up stimulus-driven orienting and intentional attention switching (i.e., executive attentional control) allow for the uptake of novel information about one's experience as it happens. Executive functions, especially inhibition and task-switching, support these attentional processes by inhibiting competing cognitive processes (e.g., mind-wandering or rumination) and switching attentional resources back to the meditative practice in case of distractions.

In summary, cognitive models postulate that the voluntary allocation and maintenance of attentional resources to the present moment while inhibiting irrelevant cognitive processes form the basis for the experience of a mindful state. Given that attention is paid with an open-minded, non-judgmental attitude and with repeated practice, this state of mind is proposed to alter the perspective on the self by improving the practitioner's awareness of their mental content, as well as to facilitate positive changes in self-regulatory abilities. Consequently, Posner et al. (2015) have defined mindfulness as a state training, meaning that mindfulness trains achieving a specific brain state which, as just outlined, influences attentional and executive functions favorably. Therefore, unlike exercises targeting specific brain networks or cognitive abilities (e.g., utilizing Go-/No-Go exercises to train inhibitory control specifically), effects of mindfulness have the potential for high generalizability and transfer. Conformingly, a wealth of psychological research has shown MBSR and other mindfulness-based interventions to improve subjective well-being by facilitating behavioral regulation and reducing rumination and emotional reactivity (for a review, see Keng et al., 2011). Accordingly, mindfulness training has been effectively implemented in various fields, ranging from clinical treatments (for a review, see Baer, 2003) to stress reduction in healthy individuals (e.g., Chiesa & Serretti, 2009).

While findings in applied psychology confirm the effectiveness as well as the generalizability of the effects of mindfulness-based trainings, the dose-response relationship between the practice and postulated improvements in cognitive control as well as mindfulness-specific states is still subject of research and requires differentiating between phases as well as practices which the practitioner undergoes as their proficiency in mindfulness progresses. Considering the course of mindfulness-based trainings, initial phases usually involve meditational techniques with a narrow attentional focus, called focused attention meditations (FAMs). Later phases incorporate techniques with a divided attentional state, called open monitoring meditations (OMMs). These two techniques have been proposed to involve and train cognitive control differently (Holas & Jankowski, 2013; Hölzel et al., 2011; Lee et al., 2018; Lippelt et al., 2014; Lutz et al., 2008; Lutz et al., 2015; Tang et al., 2015). As already described by the example of breathing meditation, FAM involves the intentional allocation of attention to an object in focus and, in case of distractions, the voluntary disengagement of attentional resources from a distractor (i.e., top-down attentional control). In comparison, OMM comprises the concurrent observation of all internal and external experiences of the present moment by bottom-up information uptake and attentional monitoring, while no explicit attentional focal point is maintained. It has been proposed that some proficiency in FAM is required to engage in OMM in later phases of mindfulness practice because the initial training of disengaging from attentional distractions and sustaining attentional resources to the task at hand during FAM forms the basis for the cognitive ability to initiate and maintain an unfocussed but concentrated state during OMM (Fell et al., 2010; Lutz et al., 2008). Furthermore, the experience and development of mindful meta-cognition in advanced practice is proposed to depend on both the development of stable attentional states (initially trained during FAM) as well as reflective awareness of the contents of one's consciousness (subsequently trained during OMM, e.g., Jankowski & Holas, 2014). As models of mindfulness propose that repeated practice is paramount for any long-lasting effects to unfold (e.g., Bishop et al., 2004; Jankowski & Holas, 2014; Malinowski, 2013), and, as just outlined, cognitive effects of different practices are considered to build up on each other, it follows that initial phases of FAM are likely to result in rather volatile improvements in cognitive control. Furthermore, such improvements are likely restricted to attentional and executive control abilities. This can be further exemplified by the phenomenological experiences through which practitioners of varying expertise pass during their meditative training by Lutz et al. (2015). According to the authors, novice practitioners typically find it effortful to evoke the attentive states required during mindfulness meditation and are easily distracted by, for example, mind-wandering. Therefore, while a novice may already succeed in allocating attentional resources to a narrow focal point (e.g., the breath), sustaining this state may be experienced as demanding more effort compared to an experienced FAM practitioner. Accordingly, early phases of FAM training may be more concerned with maintaining the meditative state despite frequent distractions. This less stable and less clear experience would less likely go along with achieving awareness about the transient nature of one's mental content. This view is also supported by Fell et al. (2010), who consolidated findings of neurophysiological correlates of meditative states. Based on the presented electroencephalographic evidence from intervention as well as case-control studies, Fell et al. postulate that brain states in the initial stages of mindfulness practice may be transient, unspecific to the practice, and more indicative of general states of attentional focus (i.e., slowing of alpha rhythm and increase in alpha power) as well as states of relaxation (i.e., increase in theta band activity), which may also be achievable through other practices, such as relaxation techniques. Only more experienced practitioners may experience meditation-specific states, which, based on the evidence, are associated with an increase in gamma activity considered relevant for cortical plasticity and the formation of new neural circuits. As the authors argue, such increases in cortical plasticity in more experienced meditators may be associated with developments of longer-lasting changes and new states of consciousness, which are also proposed by models of the practice (i.e., changes in self-perception and meta-cognition). The successful and sustainable induction of mindfulness-specific states thus requires repeated practice. It is yet to be understood what a minimal training dosage or a starting point for mindfulness unfolding its effects on attentional and executive control might be.

Research investigating the effects of single mediation sessions on cognitive control may provide evidence for this initial starting point. Studies investigating the effects of short training durations in FAM have provided no evidence for improvements in the attentional networks following a single session of 10 minutes (Norris et al., 2018, second experiment). Also, considering switching abilities, no improvement following single FAM sessions of up to 25 minutes has been found (Jankowski & Holas, 2020; Johnson et al., 2015). Results for cognitive inhibition are inconclusive, with Norris et al. (2018; first experiment) providing evidence for an improvement in inhibitory ability following 10 minutes of FAM, while a study by Larson et al. (2013) provided no evidence of improvement following 15 minutes of FAM. Since studies investigating the effectiveness of short FAM inductions have been limited to this date, reviews and meta-analyses in the field have investigated the effects of single-session inductions that include either FAM and/or OMM practices. Reviewing the effects of single-session inductions on executive functions, Leyland et al. (2019) found minor evidence supporting improvements in inhibitory control but no effects on updating or set shifting. However, a meta-analysis by Gill et al. (2020) found no evidence for improvements following single-session inductions in attentional networks, executive functions, or memory, but only in higher-order functions (i.e., verbal reasoning, judgment/decision making and creativity). While Leyland et al.'s findings reflect the proposition that novices are mainly concerned with practicing to maintain the meditative state despite distractions and are in line with the partial evidence for improvements following FAM inductions in inhibitory control by Norris et al., 2018, the findings by Gill et al. (2020) are contrary to the presented models of mindfulness, which propose that changes in higher cognitive functioning are a result of improved attentional and executive control and require prolonged practice. Thus, based on the current state of research, the dose-response relationship between mindfulness and postulated improvements in attentional and executive control is still up for debate.

Fell et al.'s notion that evoked brain states in the initial stages of meditational training are likely unspecific and obtainable through other practices raises another question in the field. Short-term mindfulness inductions may not directly improve cognitive control but are helpful in another way, namely by reducing dysfunctional tension and thereby freeing resources for improved cognitive performance (Eysenck et al., 2007). If the initial stages of mindfulness training and relaxation led to similar mental states, they should produce similar effects on attentional and executive control. In contrast, studies have provided evidence for improvements in cognitive inhibition following FAM compared to no improvements following relaxation (Mrazek et al., 2012; Wenk-Sormaz, 2005). However, the scarcity of studies makes it difficult to conclude whether initial stages of mindfulness and relaxation produce similar outcomes or whether short mindfulness trainings lead to differential effects (Baer, 2003; Chiesa et al., 2011; Shapiro et al., 2006), and more research is required.

In summary, two open questions in research investigating the effects of mindfulness meditation on cognitive control are I) the dose-response relationship between the initial phases of mindfulness training and attentional as well as executive control. How much FAM practice is necessary to initially trigger improvements in cognitive control postulated by models of mindfulness? Moreover, II) the specificity of effects following short FAM training durations. Do initial stages of FAM training produce specific effects, or are they achievable by other practices, specifically the practice of relaxation? Therefore, the present dissertation aimed to address these questions by contrasting the cognitive effects of short training periods in FAM of increasing frequency and duration with those of progressive muscle relaxation (Jacobson, 1938), which is an evidence-based technique for inducing relaxation (Manzoni et al., 2008; McCallie et al., 2006; Toussaint et al., 2021). To this end, three studies were employed. An overview will be given in the following.

Study 1 (Vieth & von Stockhausen, 2022a) examined the effects of an induction of a mindful state on cognitive control. Separate reaction-time tasks were utilized to assess the attentional networks (alerting, orienting, and executive attention) and executive functions (updating, inhibition and task switching) in a randomized controlled trial. The breathing meditation was selected as a FAM practice suitable for novice practitioners. PMR was utilized for inducing a relaxed state (active control condition) and listening to podcasts was utilized to control for effects of repeated testing (passive control condition). Inductions and podcast listening were delivered two times within a week. Repeated practice was employed so that participants could get familiar with the practice but restricted to 2 x 20 minutes so that the dosage was still justifiably within the realm of short induction studies (for a classification, see Heppner & Shirk, 2018). By doing so, the research design was suitable for investigating the cognitive effects of the initial stages of mindfulness practice. It was hypothesized that if an induction of a mindful state specifically improves attentional and executive control, the mindfulness condition should outperform both PMR and podcast listening. However, if relaxation is the underlying effect in the initial stages of mindfulness practice, both mindfulness and PMR should outperform the passive control condition.

Study 2 (Vieth & von Stockhausen, 2022b) included two randomized controlled double-blinded trials which further investigated the dose-response relations for mindfulness and the executive functions of updating, inhibition and task switching with increased training duration and frequency. Again, PMR served as the active control condition and podcast listening as the passive control condition. In Experiment 1, mindfulness and PMR were practiced three times within a week and with increasing duration (10, 15 and 20 minutes). The total training duration was thus comparable to Study 1 (i.e., 45 compared to 40 minutes) but spread across three instead of two sessions. This was done to assess the effects of spread compared to massed practice, as the former has been shown to lead to better learning outcomes (Carpenter et al., 2012; Ebbinghaus, 1885). In Experiment 2, training frequency and duration were increased to four practice sessions of 20 minutes each (total training duration of 80 minutes) over a week. Experiment 2 accordingly qualified as a brief mindfulness training. All other aspects of the research design were kept constant between the experiments, allowing for better comparability of the results regarding variations in training dosage. Like in Study 1, it was hypothesized that if short trainings in mindfulness lead to specific effects in executive functions, mindfulness should outperform PMR and the passive control condition. Furthermore, if short mindfulness trainings produce stable effects which unfold with practice frequency and duration, Experiment 2 should at least reproduce any effects uncovered in Experiment 1 or exceed them.

As longer-lasting effects of mindfulness training are postulated to depend on the cognitive control abilities fostered by initial FAM practice, investigating when effects on cognitive control start to unfold would provide crucial evidence for the dose-response relation between the practice and the development of mindfulness-specific states. Furthermore, these findings would help to understand whether a first mechanism of mindfulness training is state relaxation, which may lead to improved cognitive control efficiency by reducing dysfunctional tension, or whether improvements following short FAM trainings can be ascribed to mindfulness-specific effects on cognitive control.

Furthermore, as briefly outlined above, models of mindfulness specify effects on automatic cognitive processes, specifically the reduction of automatized associations or routinized behavioral pre-dispositions. Such changes in automatic cognitive processes may be beneficial for reducing stereotype-biased behavior. A stereotype can be defined as an association or belief about traits or attributes ascribed to a social group and its members (Greenwald & Banaji, 1995; Hilton & von Hippel, 1996). It has been proposed that while the automatic and unintentional activation of stereotypes is part of basic categorization processes, suppression of subsequent discriminatory behavior, which leads to unequal treatment of marginalized social groups, requires the awareness and ability to control automatically activated associations (Devine, 1989; Dovidio et al., 1997; Devine & Sharp, 2009). Accordingly, neurocognitive findings of networks involved in processes of stereotyping and discriminatory behavior have identified that the successful suppression of stereotype-biased behavioral tendencies requires that the individual is aware of the mismatch between an activated automatic association and the current experience (i.e., bottom-up stimulus-driven processing and monitoring of internal experiences) and can exert response inhibition as well as elect and execute an alternative, unbiased response (i.e., switching to goal-oriented behavior; Amodio, 2014). More precisely, the proposed control network of stereotype-biased behavior includes brain regions responsible for detecting a conflict between a biased behavioral tendency and the individuals' goal to act without bias, regions responsible for response inhibition and selection, and regions involved in monitoring external situational cues. Reconsidering the propositions made by models of mindfulness, if the practice improves both top-down attentional control and bottom-up information uptake, this may enable the individual to notice and suppress discriminatory behavior when confronted with stereotype cues. While such improvements in cognitive control may already result from shorter mindfulness training (specifically FAM), it may also be that heightened meta-cognitive awareness of automatic categorization processes is necessary to reduce the effect of stereotype activation on discriminatory behavior. In line with the latter, Kang et al. (2013) proposed that fostering the active awareness of one's mental content by mindfulness increases the observer's ability to notice when automatized associations arise and to be aware of the nature as well as possible fallibility of automatic cognitions. Similarly, Holas & Jankowski (2014) have postulated that mindfulness heightens the practitioner's ability to differentiate between the contents of one's mental state and reality itself, enabling the individual to perceive current experiences as novel and context-dependent rather than relying on static schemes and stereotypes (see also Bishop et al., 2004). Thus, the models by Kang et al. and Holas & Jankowski propose that effects on automatic cognition (i.e., stereotypes) require long-term meditational practice. However, reductions in stereotype activation and bias expression have already been found following short FAM trainings (Lueke & Gibson, 2015; 2016). This suggests that a short meditational practice can effectively reduce stereotype-biased behavior.

Thus, a third study (Vieth & von Stockhausen, 2022c) aimed to investigate the effects of short FAM trainings on stereotype-biased response behavior. As postulated, the underlying mechanism of improved suppression of otherwise biased behavior following FAM would be enhanced attentional and executive control. To examine this relationship, experiments in Study 2 included reaction time tasks utilized to assess the influence of stereotype bias on response speed and accuracy: In Experiment 1, the Shooter Task (Correll et al., 2002) was utilized and in Experiment 2, the Avoidance Task was used (Essien et al., 2017). Previous research utilizing joined analysis of response latency and accuracy of the Shooter task through drift diffusion modeling (DDM; Ratcliff, 1978; Ratcliff & Rouder, 1998) has revealed that stereotype bias facilitates the efficiency of information processing for a correct response in stereotype congruent compared to incongruent trials, but also that participants exert greater response control in an attempt to regulate stereotype biased behavior (Correll et al., 2015; Johnson et al., 2018; Pleskac et al., 2018; Mayerl et al., 2019). It was hypothesized that improved cognitive control following mindfulness training would strengthen attention (re-) allocation to task-relevant information while improving inhibition of processing task-irrelevant information (i.e., stereotype cues), and this improvement was postulated to lead to a reduction of the effect of stereotype bias on decision making.

This research can clarify if improvements in cognitive control following short FAM practice transfer to more complex behaviors, such as the successful regulation of otherwise stereotype-biased behavior. In the following chapters, the three studies outlined above will be presented.

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Mechanisms Underlying Cognitive Effects of Inducing a Mindful State

RESEARCH ARTICLE

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ABSTRACT

Mindfulness is understood as a state or practice of guiding attention to the present moment without judgment. While some studies on mindfulness-based interventions demonstrate beneficial effects on cognitive functions (e.g. Chiesa et al., 2011; Yakobi et al., 2021) it still appears challenging to identify underlying mechanisms due to the wide range of research designs and dependent measures used, as well as the frequent absence of active control conditions. Relatedly, processes underlying the effects of short inductions of a mindful state may be unspecific to mindfulness and attainable through other means, such as relaxation (Fell et al., 2010).

Therefore, the current study compared the effects of a brief mindfulness induction with a relaxation induction (via progressive muscle relaxation; active control condition) and listening to podcasts (passive control condition) in a pre-post experimental design. 78 participants without recent meditation experience were randomly assigned to the experimental conditions (mindfulness = 25; progressive muscle relaxation = 24; podcast listening = 30) and received corresponding instructions for a total of 40 minutes (2 × 20 minutes) a maximum of 3 days apart. Executive functions of inhibition, updating and switching as well as attentional networks were assessed with the continuous performance task, n-back task, number-letter task, and attention network task, respectively.

While updating and executive attention similarly benefited from meditation and relaxation compared to podcast listening, inhibition and shifting measures indicate differential effects of mindfulness induction. Alerting and orienting were not affected by any induction. Implications for mechanisms underlying the effects of mindfulness are discussed.

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There is a fast-growing literature on the potential effects of short inductions of a mindful state and mindfulness-based interventions on attention and executive functions (Chiesa et al., 2011; Guendelman et al., 2017; Tang et al., 2015; Yakobi et al., 2021). A common practice during these interventions is breathing meditation, during which participants are asked to guide their attention to the natural flow of their breathing and observe any internal events that may arise (such as thoughts, perceptions, or emotions) without engaging with or judging them. If the mind wanders off, practitioners are to let go of all distractions and return their attention to their breath. This task can be challenging, as our minds are easily distracted by internal and external events that attract our attention. Such breathing meditation practice reflects what is considered the essence of mindfulness in contemporary scientific approaches, as expressed by Kabat-Zinn (1994, p. 4), for example: *Mindfulness means paying attention in a particular way: on purpose, in the present moment, and non-judgmentally*.

Several models of mindfulness that specify components of a mindful state and underlying mechanisms have been proposed (e.g., Bishop et al., 2004; Hölzel et al., 2011; Malinowski, 2013; Shapiro et al., 2006). All of these models include attention regulation as a component, as there is consensus that attention regulation and executive control are required for guiding and maintaining attentional focus on a task within any meditation practice. Bishop et al.'s two-component model of mindfulness defines mindfulness as a meta-cognitive skill comprising attention regulation, in the sense of monitoring one's attention to the object of focus (i.e. the breath), and executive control, in the sense of switching one's attention back to the breath when distractions occur and inhibiting the elaborative processing of thoughts, feelings and sensations while maintaining an open and accepting attitude towards experience. Malinowski's (2013) Liverpool Mindfulness Model is based on the network model of attention by Posner and Peterson (1990; Peterson & Posner, 2012), which comprises an alerting network, an orienting network and a network for executive attention. During meditation, these networks are engaged to sustain attention on a selected object (such as the breath; alerting network), to disengage from mind wandering (executive attention network) and to shift attention back to the task (orienting network). Consequently, Malinowski considers attention to be a core feature of a mindful state. Shapiro et al.'s model (2006) comprises attention, intention and attitudes as central components whose interplay induces mindfulness on a moment-to-moment basis, namely through the experience of paying attention with a kind and open attitude, rooted in intentions about why one practices. Hölzel et al. (2011) propose attention regulation as one component mechanism of mindfulness alongside improved body awareness, emotion regulation and a changed perspective on the self. Thus, all of the described models consider improved attentional processes by way of improved sustained attention and better monitoring as well as more effective executive functioning (e.g., inhibiting irrelevant content, shifting between task sets; see Suchy, 2009; Miyake et al., 2000) as possible mechanisms contributing to the effects of mindfulness training. Furthermore, Jha et al. (2019) have argued that since aspects of attentional control (such as dis-/engagement, maintenance and monitoring) are essential for successful maintenance and manipulation of information held in working memory, improvements in attentional control following mindfulness trainings may be beneficial for working memory as well. However, any further specification of the mechanisms underlying mindfulness practice requires a more detailed consideration of what exactly is being practiced. In order to systematize frequently studied forms of practice, Lutz and colleagues (2008) proposed the now widely accepted distinction between focused attention meditation (FAM; i.e. sustained focus on a selected object, such as the breath) and open monitoring meditation (OMM; i.e. constantly monitoring whatever is experienced without focusing on and reacting to any particular object or process). FAM should narrow attentional focus and strengthen top-down attentional control whereas OMM should widen attentional focus and reduce attentional control (Lippelt et al., 2014; for empirical results see below).

In order to specify mechanisms through which mindfulness practice affects attention and executive functioning, it seems further necessary to separate the effects of inducing a mindful state (through one meditation of 10 to 30 minutes in length) from the effects of repeated practice (i.e. brief mindfulness trainings) or even sustained practice over weeks or years (i.e. mindfulness interventions or mindfulness-based therapies; Heppner & Shirk, 2018). Any measurable effect of a mindfulness induction necessarily represents a transient state which may only stabilize with repeated practice and can be described as the starting point for longer-lasting changes in cognitive functions. However, it is not yet clear what exactly this transient starting point might be.

Different proposals have been brought forward as to how short mindfulness inductions affect performance in tasks requiring attention and executive control. Studies by Wenk-Sormaz (2005; employing a Stroop task, among others) and Ostafin and Kassman (2012; studying insight problem-solving) suggest that FAM inductions reduce automatized cognitive processing by means of improved inhibition or enhanced retrieval of non-habitual information due to improved set shifting and higher cognitive flexibility (Suchy, 2009). Furthermore, Colzato et al. (2015, 2016) investigated differential effects of one-time FAM and OMM and conclude that OMM results in more parallel attention allocation – reducing attentional blinks in a rapid serial presentation task, for example – but also increases likelihood of responding to irrelevant stimulus features. By contrast, FAM increases top-down control, leading to better inhibition of irrelevant stimulus features.

In contrast to these proposed specific effects of single meditations, it has been argued that early stages of various meditational practices are characterized by processes unspecific to meditation, such as relaxation. For example, Fell et al. (2010) argue that during their first attempts to meditate, people may not succeed in keeping their attention focused. After an initial habituation phase, most meditation practices result in greater calmness and relaxation, which, however, could also be achieved with relaxation techniques. Only advanced practitioners may undergo meditation-specific processes and accordingly attain meditation-specific changes. The authors present evidence from EEG recordings of practitioners with different levels of expertise and show that certain changes during early stages of meditation practice, such as increased power and synchronization in alpha and theta activity, do not depend on the technique or on expertise. By contrast, other changes, such as increased power and synchronization in gamma band activity, depend on expertise and represent longer-lasting structural changes. In light of Fell and colleagues' findings of unspecific changes in early stages of meditational practice, it therefore appears to be possible that short mindfulness inductions do not directly improve attention and executive control, but are helpful because they reduce dysfunctional tension and free up resources for improved cognitive performance, for example. The findings by Colzato et al. (2015; 2016) reported above may suggest otherwise, but even in their studies differences between FAM and OMM were not found for all expected measures (see also Colzato, Sellaro, Samara & Hommel, 2015). Relatedly, Ainsworth et al. (2013) did not find differential effects of a brief mindfulness training with FAM vs. OMM on executive control (measured with a variant of the attention network task; ANT). Thus, if differences between FAM and OMM cannot be consistently found in studies of short inductions or brief trainings, this may suggest that effects at this stage of practice are unspecific to mindfulness meditation and that evidence so far does not eliminate the possibility of relaxation contributing to the cognitive effects of short mindfulness inductions.

Studies seeking to compare meditation and relaxation do not provide conclusive evidence of differential effects either, partly because several such studies using rest or relaxation as control conditions did not provide participants with instructions on how to obtain a state of rest or relaxation. Therefore, it is unclear whether or to what degree the participants actually achieved relaxation, influencing the studies' implications. In Wenk-Sormaz's study (2005), for example, the rest group was told to sit, rest, let their minds wander and stay awake. Mrazek et al. (2012, Experiment 2) showed that an eight-minute meditation reduced participants' errors and reaction time variability on a Go/No-Go task compared to a passive rest condition in which the rest group was instructed to relax and not fall asleep. The following two studies gave more detailed instructions to the relaxation group. Comparing the effects of a short meditation practice using integrative body-mind training (IBMT, which comprises relaxation, breathing practice and mental imagery) versus a relaxation training, Tang et al. (2007) found no group differences on the ANT for alerting or orienting, but higher scores in the IBMT group for executive attention. While these findings suggest that a combined meditation and relaxation training is more beneficial for executive attention than a pure relaxation training, it is difficult to specify the impact of meditation alone. Johnson et al. (2015) compared the effects of a single mindful breathing meditation with a sham meditation (instructions to breathe deeply, relax and to sit still in silence) and an audiobook control group. In their post-test-only design, both meditation and sham meditation exhibited positive effects on state mindfulness and mood compared to the control group, but no effects on attention or working memory were found. To summarize, based on the existing evidence, it cannot be ruled out that the cognitive benefits of brief mindfulness inductions are caused by non-meditation-specific states and that relaxation is a main component of this process. Investigating the specific effects of a mindfulness induction as compared to relaxation requires clearly separating mindfulness from relaxation and providing instructions for both states in comparable detail. It also requires a randomized pre-/post design with an active and passive control condition to control for both effects unspecific to mindfulness practice as well as effects of repeated testing. This research gap is addressed in the present study.

In a randomized controlled trial with an active and passive control group, we compared the effects of a short mindfulness induction (2 × 20 minutes of breathing meditation instructions) to the effects of a progressive muscle relaxation technique (PMR) training of the same length as an active control condition and podcast listening as a passive control condition to control for the effects of repeated testing. This design allows us to identify possible specific effects of mindfulness induction beyond mere relaxation on attention and executive control. Breathing meditation was selected as an effective form of focused attention practice for beginners. Completing two sessions of 20 minutes allowed participants in the mindfulness condition to become more familiar with the practice of controlling their attentional focus on the breath than is possible in a one-time trial, while still sufficiently restricting exposure to training such that no long-term processes specific to mindfulness could unfold. PMR was selected as a standardized and evidence-based set of instructions for achieving a relaxed state (Manzoni et al., 2008; McCallie et al., 2006). Testing for effects after such short-term inductions aims at identifying processes during the first stages of mindfulness intervention, before longer-term processes can unfold through practice. We assessed the fundamental executive functions of set formation, set maintenance, and set shifting (Miyake et al., 2000; Suchy, 2009) and employed the ANT (Fan et al., 2002) to assess attentional networks (Petersen & Posner, 2012; Posner & Petersen, 1990). If the induction of a mindful state in particular improves attention and executive control, it was hypothesized that the mindfulness group should outperform both PMR and the passive control group. If relaxation is the essential effect in short inductions, both mindfulness and PMR should outperform the passive control group.

METHODS

PARTICIPANTS

Seventy-nine participants who were recruited on campus and through Facebook groups took part in the experiment. The sample was a white European sample (68 female) and ranged in age from 18 to 65 years (M = 26,44, SD = 10,2). Based on a screening questionnaire, individuals who were younger than 17 and/or reported having engaged in meditation or other mindfulness practices during the last three months were excluded from the study. To ensure accurate measurements for the questionnaires and comprehension of instructions, German was required to be participants' first language. Persons who met all criteria were contacted by e-mail or telephone and invited to participate in two experimental sessions in a laboratory at the University of Duisburg-Essen. They were provided with written information about the methodology used, data protection and research ethics prior to participation. After completing the study, participants received either course credit or a booklet and CD containing information about mindfulness meditation and instructions for guided meditations for compensation. Data storage and anonymization met the standards of the European Union's General Data Protection Regulation (GDPR 2016/679). The experiment was approved by the ethical commission of the Department of Psychology at the University of Duisburg-Essen, Germany (Ethics Vote 2019/26/07).

ASSESSMENT OF EXECUTIVE FUNCTIONS AND ATTENTION NETWORKS

All tasks were programmed with and presented (including standardized written instructions) via the Experiment Builder software (SR Research Ltd., 2015). Participants viewed the stimuli on a 23-inch Dell LED monitor from a distance of approximately 50 cm. Responses were recorded with a Cedrus RB-540 response pad (Cedrus Corporation, 2019). In all tasks, participants were instructed to respond as quickly as possible without making mistakes.

Continuous Performance Test-II

The Continuous Performance Test-II (also called non-X CPT; Conners et al., 2003; Conners, 2004) is a variant of the CPT used to investigate participants' capacities for set maintenance/cognitive inhibition (Suchy, 2009) by assessing executive control and impulse control in response to a rarely occurring non-target. Participants were presented with consecutive letters and had to press a button every time a letter other than the letter "X" appeared on the screen (90% target trials; 10% non-target trials). Reaction times for correct and incorrect responses as well as frequencies of correct and incorrect responses were collected to assess participants' ability to react to target trials while inhibiting a response to distractor trials.[1] Inclusion of different interstimulus intervals (ISIs; 1000 ms, 2000 ms, 4000 ms) allowed us to investigate participants' ability to adapt to task demands (Ballard, 2001). ***Figure 1*** shows a display sequence with presentation durations and ISIs. Participants were instructed to place their right index finger on the response button and to indicate targets by pressing the button. During the task, participants wore headphones for noise cancellation. A session consisted of 360 trials separated into 18 experimental blocks (20 trials per block). After three blocks, participants were instructed to take a break. Total task duration was 14 minutes on average.

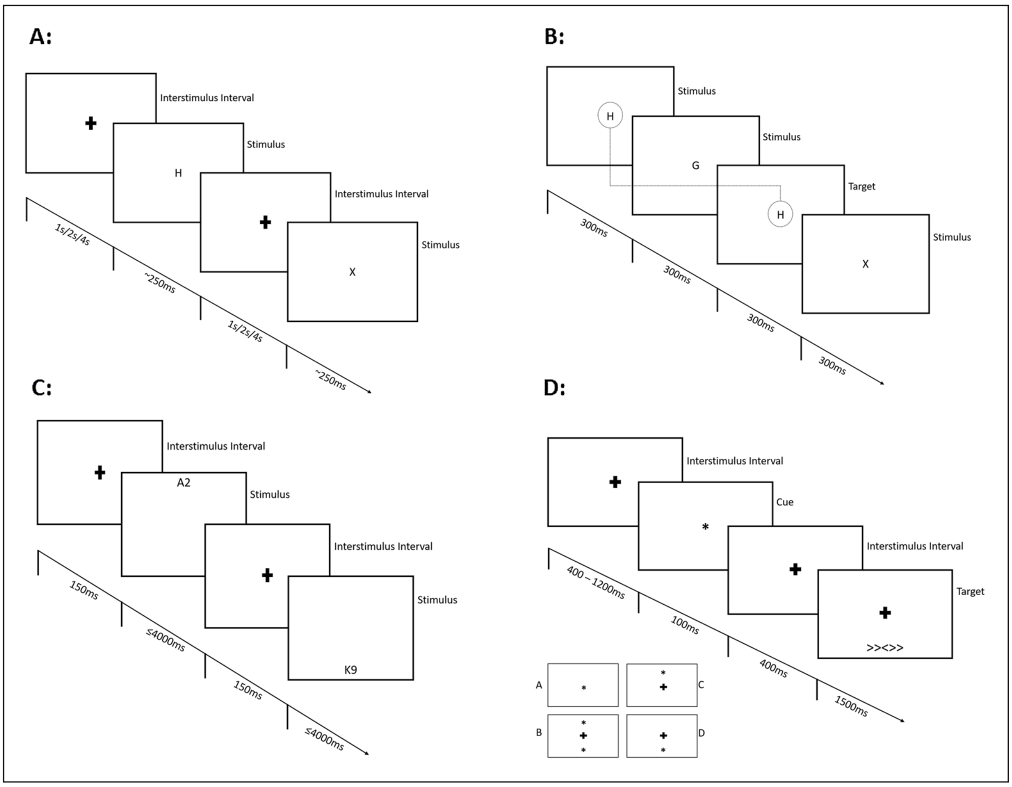

Figure 1 Display Sequences of the Reaction Time Tasks.

Note: Panel A: During the CPT-II, participants were presented with a consecutive stream of single capital letters (for example: H – O – T – X – Z) and were to press a button every time a letter appeared on the screen, except for the letter "X" (90% target trials; 10% non-target trials). Panel B: During the N-Back Task, in a 2-back block (n = 2), participants were to indicate a target trial if the following stream of letters occurred: H – G – H, but not if the presented letters were: H – G – X. Panel C: During the Number-Letter Task, if the number-letter combination appears in the upper half of the screen, participants are instructed to indicate whether the presented number is odd or even. If the number-letter combination appears in the lower half of the screen, participants are asked to indicate whether the letter is a consonant or a vowel. Panel D: During the Attention Network Task, in no cue trials, participants were presented with a fixation cross in the center of the screen prior to target onset. In center cue trials (A), an asterisk was shown in the center of the screen instead of a fixation cross. In double cue trials (B), two asterisks were presented simultaneously at the two possible target locations (above and below the fixation cross). In spatial cue trials (C and D), the cue was displayed at the position of the upcoming target.

N-Back Task

The N-back task (Kirchner, 1958) is used to assess set formation and working memory capacity (Chatham et al., 2011; Suchy, 2009). Participants are presented with a stream of individual letters and are asked to indicate whether the current letter matches the one shown *n* steps before. To complete the task, participants need to keep information about previous stimuli in memory, make a comparison with the current stimulus, and constantly update the information held in memory. The factor *n* is varied between blocks to increase or decrease the task's difficulty (see ***Figure 1*** for an example from a 2-back block). Reaction times of correct and incorrect responses as well as frequencies of correct and incorrect responses were collected to assess participants' ability to react to n-back and non-back trials. Participants were instructed to place their respective index fingers on a left and right button on the response pad and press these buttons to indicate n-back and non-n-back trials respectively. During the task, participants wore headphones for auditory feedback during the practice blocks and for noise cancellation

1 While this variant of the CPT may also assess aspects of vigilance, it mainly requires inhibition. Throughout the task, the participant is instructed to produce a readiness to withhold a response once a rare target (X) is detected. This differs from classical CPTs in which the participant is instructed to execute a response when a frequent target (X) is detected (for a discussion see Ballard, 2001).

during the remaining tasks. A session consisted of two practice and eight experimental blocks (two 0-, 1-, 2- and 3-back blocks each in randomized order); each experimental block contained 48 trials, following which participants were instructed to take a break. Total task duration was 25 minutes on average.

Number-Letter Task

The Number-Letter Task assesses the cognitive ability of set shifting/task switching (Rogers & Monsell, 1995; Suchy, 2009). Participants are presented with pairs of numbers and letters (for example A2, K9) above or below a fixation cross. If the number-letter pair appears in the upper half of the screen, participants must indicate whether the number is odd or even. If the pair appears in the lower half of the screen, participants must indicate whether the letter is a consonant or a vowel. Stimuli occurred equally often in both positions, in randomized order, resulting in switch trials when the stimulus position (and thus also the task) changed and non-switch trials when the stimulus position remained the same. Participants' reaction times for correct and incorrect responses as well as frequencies of correct and incorrect responses in non-switch and switch trials were recorded to assess participants' ability to flexibly switch between tasks (***Figure 1*** shows a display sequence). Participants were instructed to place their respective index fingers on left and right buttons on the response pad, which they then used to specify whether the number was odd or even or the letter was a consonant or vowel, depending on the task. During the task, participants wore headphones for noise cancellation. A session consisted of three short practice blocks and one experimental block. Participants received feedback during the practice blocks. The experimental block contained 160 trials and was presented in a single run. Total task duration was about 17 minutes.

Attention Network Task

The ANT assesses the networks of alerting, orienting and executive attention based on the model of attention by Posner and Petersen (Fan et al., 2002; Petersen & Posner, 2012; Posner & Petersen, 1990). Different conditions within the task allow the efficacy of the three networks to be assessed separately. The ANT used in this experiment was developed and evaluated by Weaver et al. (2013). We recorded reaction times for correct and incorrect responses as well as frequencies of correct and incorrect responses to assess participants' alerting, orienting and executive networks. Participants were presented with a left- or right-facing arrow (target) in the upper or lower half of the screen and were asked to indicate the direction of the target by pressing a button. The target was flanked by two arrows on each side, which either pointed in the same (congruent) or opposite (incongruent) direction of the target arrow. RTs and frequencies of responses for congruent and incongruent flanker trials were used to calculate the effect of the executive network (Executive = incongruent – congruent; Fan et al., 2002).

In some trial conditions, participants were presented with a brief cue prior to the onset of the target. ***Figure 1*** shows the sequence of a cue and target presentation and the four different cue conditions. In *no cue* trials, no cue appeared; therefore, neither the alerting nor orienting network was expected to be activated. *Double cues* were presented simultaneously at the two possible target locations and expected to engage the alerting network by forewarning the participant of the upcoming target at each target location. Comparing response times and response accuracy between these two cue conditions therefore allowed us to calculate the effect of the alerting network (Alerting = double cue – no cue). *Spatial cues* occurred at the same position as the upcoming target and should activate both the alerting and orienting networks for the subsequent target presentation. *Center cues* were shown in the center of the screen and used to alert participants of the upcoming target, without providing any orientation as to possible target locations. Comparing response times and response accuracy between these two cue conditions allowed us to calculate the effect of the orienting network (Orienting = spatial cue – center cue).

Participants were instructed to place their left and right index fingers on respective buttons on the response pad and to indicate the direction of the target stimulus for each trial. Participants wore headphones for noise cancellation. A session consisted of a practice block (24 trials) and three experimental blocks with 96 trials each. Each experimental block included all 4 cue conditions in randomized order. The practice block lasted up to 2 minutes, while each experimental block took approximately 5 minutes.

QUESTIONNAIRES

To control for possible influences of mood on attention and executive control (Van Steenbergen et al., 2010) and for a priori differences in dispositional mindfulness, the Positive and Negative Affect Schedule (PANAS, Watson et al., 1988; German: Breyer & Bluemke, 2016) and the Mindful Attention and Awareness Scale (MAAS, Brown & Ryan, 2003; German: Michalak et al. 2008) were employed. The scales and their respective results are described in detail in Appendix A.

PROCEDURE

The experiment consisted of two sessions. Participants were greeted by the experimenter and given the written informed consent form. After participants read the form, asked questions and gave their consent, the first session started with the CPT, followed by the N-back task, MAAS, PANAS, number-letter task, and ANT. This sequence was identical for all participants. After the pre-measurement, participants received their first practice session. Depending on the experimental condition, they either received oral instructions (mindfulness/PMR) or listened to a randomly selected podcast with headphones. Afterwards, participants were thanked and invited to participate in the second session. The two sessions were a maximum of three days apart. Participants did not engage in practice between the sessions. The session started with the second mindfulness or PMR practice or listening to a different podcast. Afterwards, participants again completed all tasks and questionnaires. At the end, they received their reward for participation and were thanked by the experimenter.

RESEARCH DESIGN

The research design was a 3 (mindfulness meditation, progressive muscle relaxation or podcast listening) × 2 (time of measurement) experimental design. Participants were randomly assigned to one condition, and measurements took place pre- and post-induction or podcast listening. While mindfulness meditation served as the experimental condition, progressive muscle relaxation was the active control group and listening to podcasts served as a non-treatment control condition. Random assignment was ensured via a randomized number list created by the first author, according to which participants were assigned to either the induction of a mindful state ($n = 25$), relaxation ($n = 24$) or the podcast listening condition ($n = 30$) by the experimenter at the beginning of their first session. Participants were not aware of their assignment or the existence of different conditions.

EXPERIMENTAL CONDITIONS

The mindfulness and relaxation inductions as well as podcast listening each took approximately 20 minutes and were conducted twice with a maximum of three days in between. This procedure allowed participants in the mindfulness condition to become more familiar with the practice of controlling their attentional focus than is possible in a one-time trial, while still restricting practice sufficiently that no long-term processes specific to mindfulness could unfold. Instructions (see Appendix B) were read to participants by the experimenter, who had been trained by the authors to deliver both mindfulness meditation and PMR inductions from a written script with a calm voice. To ensure clear differentiation between the mindfulness and relaxation conditions, the mindfulness instructions did not contain any phrases implying or directly instructing participants to engage in relaxation. Instructions for the progressive muscle relaxation were based on Jacobson (1938) and adjusted so that they did not include mindfulness-related phrasing (e.g. accepting the present experience). Podcasts were pretested for not evoking strong emotional reactions (assessed via levels of subjective arousal and valence) and for eliciting an average level of interest and engagement. The three selected podcasts concerned historical sites and exceptional landscapes.

DATA ANALYSIS

Generalized linear mixed models (GLMM) were used to analyze the reaction time data. GLMMs allow for the analysis of single-trial, raw RT data without applying (non-linear) transformations or averaging across participants. In doing so, we accounted for the typically positively skewed distribution of empirical reaction times (Balota & Yap, 2011; Lo & Andrews, 2015) and for meaningful differences in response patterns within and between individuals (Speelman &

McGann, 2013). Additionally, the effect structure of GLMMs makes it possible to specify multiple sources of non-independence within the data (Brauer & Curtin, 2018). For theoretical reasons and based on the model fit for the current data compared to other functions, the inverse Gaussian distribution (Johnson et al., 1970; Tweedie, 1957) was selected. In order to account for possible influences of accuracy on response times, we included the accuracy factor in our models for the RT analysis.

The signal detection measure of discriminability (*d'* = z[Hits] – z[False Alarms]) was analyzed with linear regressions. Response frequencies were analyzed with multilevel logistic regressions, which allow for the modelling of a binomial distribution while taking data dependencies into account. Contrast coding schemes for accuracy models are equal to the respective generalized linear mixed model.

In addition to the task-specific fixed effects of interest, experimental condition and time of measurement (pre/post) were included as a fixed-effect interaction term. Where applicable, we additionally added a three-way interaction including task-specific factors of interest. As recommended by Barr et al. (2013), we included random slopes for the highest-order combination of within-unit factors included in the interactions. The models' significance was tested via likelihood ratio chi-square tests (with maximum likelihood estimation) in which the full model was compared to restricted models and a null model. Since the interactions included in the models compare either mindfulness or PMR with the reference category of podcast listening (treatment coding scheme), we utilized planned comparisons of the respective interactions' estimated marginal means for follow-up analyses comparing pre-/post differences between all three conditions and also between test-specific factor levels affecting dependent variables (such as ISI for the CPT-II or n-level for the n-back task) included in the three-way interactions. We utilized the Tukey method for comparing a family of 3 estimates to control for heightened Type I error when carrying out multiple comparisons. Further information on model building, contrast coding for each test, the statistical software utilized as well as full models including 95% confidence intervals can be found in Appendix C.

All data files are available on the Open Science Framework (DOI 10.17605/OSF.IO/QN784).

RESULTS

The RT data were cleaned for RTs below 100 ms and above 1500 ms. Unless otherwise specified, the RT data included both correct and incorrect trials, allowing for the modelling of accuracy as a fixed effect. The cut-off value for excluding participants after data cleaning was more than 40% of trials missing. With respect to accuracy, we examined the data for respondents with low performance (share of correct trials < 50%). No participant needed to be excluded based on this criterion.

The description of results will focus on the hypotheses examined in this paper (i.e. interactions with time of measurement and condition and associated simple main effects) and task-specific effects of interest. Only effects with a significance level of $p \leq 0.05$ are reported.

CONTINUOUS PERFORMANCE TASK

One participant was removed due to too many missing data points (only 2 data points were available; total data loss: 0.07%).

Reaction Time

As incorrect responses (i.e. responses to non-targets) were rare, only correct responses were included in the analysis. The model included a fixed effect for age, a random slope for time of measurement by participant and a three-way interaction between time of measurement, condition, and ISI (with 1000 ms as the reference category), and thus also all two-way interactions containing these factors (see full model in Appendix C, Table C1). ISI was included in the three-way interaction since specific effects of mindfulness in the sense of improved cognitive inhibition might be particularly likely to surface within shorter ISIs.[2]

2 Re-running our analysis without ISI did not change the significance of any interactions of interest and did not provide a better fit to the data.

Simple and Main Effects
The analysis showed a main effect of age, $\beta = 2.13$, $SE = 0.42$, $p < 0.001$, with RT increasing as age increased. Simple effects were present for ISI 2000 ms, $\beta = 15.26$, $SE = 0.80$, $p < 0.001$, and 4000 ms, $\beta = 49.13$, $SE = 0.88$, $p < 0.001$, indicating slower RTs for longer ISIs, and for time of measurement, $\beta = -11.74$, $SE = 2.91$, $p < 0.001$, with RTs decreasing from pre- to post-measurement.

Interactions of Interest
A two-way interaction between time of measurement and condition (mindfulness) was found, $\beta = -15.04$, $SE = 2.80$, $p < 0.001$, with a larger decrease in RT from pre- to post measurement for mindfulness compared to podcast listening. A two-way interaction between time of measurement and ISI (2000 ms) was found, $\beta = 6.98$, $SE = 1.47$, $p < 0.001$, suggesting less pre-post improvement in RT for an ISI of 2000 ms compared to an ISI of 1000 ms. All other two-way interactions including the factor time of measurement were non-significant, $p \geq 0.527$. There was also a three-way interaction between time of measurement, condition, and ISI for mindfulness and the ISI of 2000 ms, $\beta = 8.04$, $SE = 2.23$, $p < 0.001$, indicating that in the mindfulness compared to the podcast condition, RTs decreased more strongly from pre- to post-measurement for the shorter ISI of 1000 ms compared to 2000 ms. No significant difference was found for mindfulness and the ISI 4000 ms compared to 1000 ms, $p = 0.106$. The three-way interaction between PMR, time of measurement and ISI was significant for both ISI of 2000 ms, $\beta = -17.11$, $SE = 2.57$, $p < 0.001$, and ISI of 4000 ms, $\beta = -21.63$, $SE = 2.83$, $p < 0.001$, indicating that after PMR (compared to listening to podcasts), RTs decreased more strongly from pre- to post-measurement for both the ISI of 2000 ms and 4000 ms compared to the ISI of 1000 ms.

Likelihood ratio tests compared the model fit to a set of restricted models (see Appendix D). The described model fit significantly better than a model with a two-way interaction of time of measurement by condition only, χ^2 (10) = 106.99, $p < 0.001$, a model without interaction terms, χ^2 (12) = 110.13, $p < 0.001$, and a null model, χ^2 (18) = 3134.6, $p < 0.001$.

Figure 2 displays the EMMs for the three-way interaction between time of measurement, condition and ISI. Planned comparisons were computed with RT change scores ($EMM_{t1} - EMM_{t0}$) between all conditions within each ISI (see ***Table 1***). For the ISI of 1000 ms, the increase in speed from pre- to post-measurement was larger after mindfulness induction than after podcast listening, while the increase in speed was smaller after PMR than after podcast listening as well as after mindfulness. For the ISI of 2000 ms, the increase in speed was larger after mindfulness than after podcast listening. For the ISI of 4000 ms, both induction groups exhibited a larger increase in speed from pre- to post-measurement than the podcast listening group.

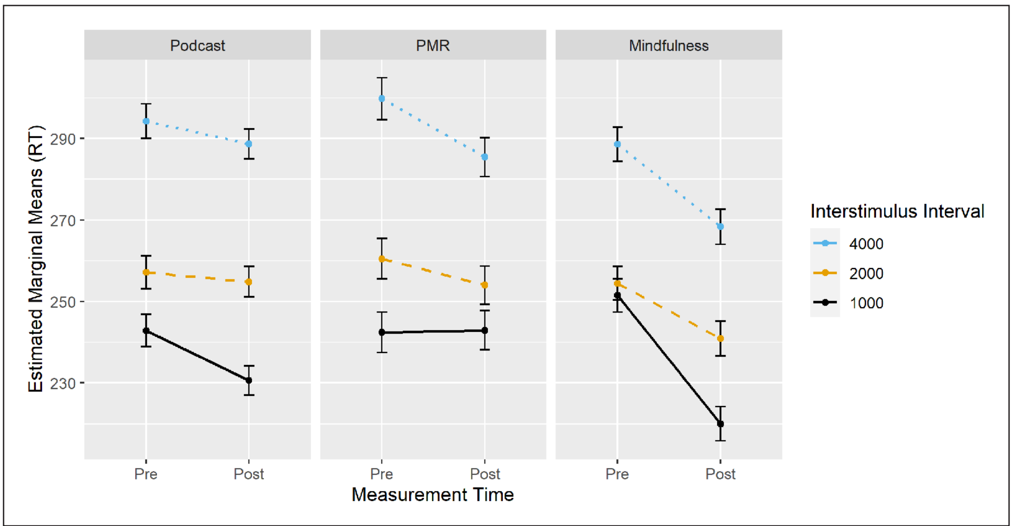

Figure 2 CPT-II: Changes in RT from Pre- to Post-Measurement by Condition and ISI.

Taken together, the results indicate that both induction conditions resulted in RT benefits compared to the podcast listening condition, although in different ways. The RT benefit of mindfulness was already apparent at the shortest ISI, whereas the benefit of PMR only arose at longer ISIs. Interestingly, for the short ISI, performance declined after PMR compared to the other two groups.

	PODCAST – MINDFULNESS		PODCAST – PMR		MINDFULNESS – PMR	
	T1 – T0: ESTIMATE (SE)	*P*	*T1 – T0: ESTIMATE (SE)*	*P*	*T1 – T0: ESTIMATE (SE)*	*p*
CPT-II RT (ISI_{1000})	19.22 (2.95)	**<.001**	−12.86 (3.07)	**<.001**	−32.08 (4.33)	**<.001**
CPT-II RT (ISI_{2000})	11.18 (3.36)	**0.003**	4.25 (3.39)	0.423	−6.93 (4.43)	0.260
CPT-II RT (ISI_{4000})	14.72 (3.43)	**<.001**	8.77 (3.73)	**0.049**	−5.95 (4.61)	0.400
CPT-II *d'*	−0.30 (0.25)	0.453	−0.62 (0.24)	**0.028**	−0.32 (0.24)	0.386
CPT-II Errors of Omission	0.04 (2.85)	1.000	6.64 (2.75)	**0.043**	6.60 (2.78)	**0.048**
N-Back RT	36.00 (6.70)	**<.001**	21.20 (5.02)	**<.001**	−14.70 (7.20)	0.101
N-Back *d'*	–	–	–	–	–	–
N-Back Errors of Omission	−1.32 (1.01)	0.396	−2.06 (1.02)	0.108	−0.74 (1.05)	0.762
Number-Letter RT	2.76 (6.68)	0.910	−29.40 (7.73)	**<0.001**	−32.16 (9.75)	**0.003**
Number-Letter Accuracy	–	–	–	–	–	–
ANT Executive Network RT	12.66 (2.58)	**<.001**	14.02 (2.57)	**<.001**	1.36 (3.33)	0.913
ANT Executive Network Accuracy	–	–	–	–	–	–
ANT Alerting Network RT	−3.51 (4.27)	0.690	−9.54 (4.39)	0.076	−6.03 (4.23)	0.327
ANT Alerting Network Accuracy	–	–	–	–	–	–
ANT Orienting Network RT	3.13 (3.78)	0.686	−6.49 (4.54)	0.326	−9.61 (4.93)	0.125
ANT Orienting Network Accuracy	–	–	–	–	–	–

Table 1 Planned Comparisons of Measures of Attention and Executive Control for Significant Interactions in Generalized Linear Mixed Models and Regression Analyzes.

Note: T0 = pretest; T1 = posttest. P value adjustment: Tukey method for comparing a family of 3 estimates. Empty rows represent models that did not produce any significant effects of interest but are reported in the Results section.

Accuracy Analysis

Discriminability (*d'*) was analyzed with a model including a fixed effect for age and a three-way interaction between time of measurement, condition and ISI (see full model in Appendix C, Table C2). The analysis yielded a simple effect for ISI, 4000 ms, $\beta = 0.39$, $SE = 0.12$, $p = 0.001$, indicating better discriminability following an ISI of 4000 ms compared to 1000 ms. All other simple and main effects were non-significant, $p \geq 0.227$. Moreover, a two-way interaction between time of measurement and condition (PMR) was found, $\beta = 0.62$, $SE = 0.24$, $p = 0.010$, with a greater increase in *d'* from pre- to post measurement for PMR compared to podcast listening. All other two-way interactions including the factor time of measurement were non-significant, $p \geq 0.230$. All three-way interactions were also non-significant, $p \geq 0.260$.

Figure 3 displays EMMS for the two-way interaction of time of measurement by condition. Planned comparisons were computed with *d'* change scores ($EMM_{t1} - EMM_{t0}$, see ***Table 1***). As already suggested by the two-way interaction, the increase in *d'* was higher after PMR induction than after podcast listening.

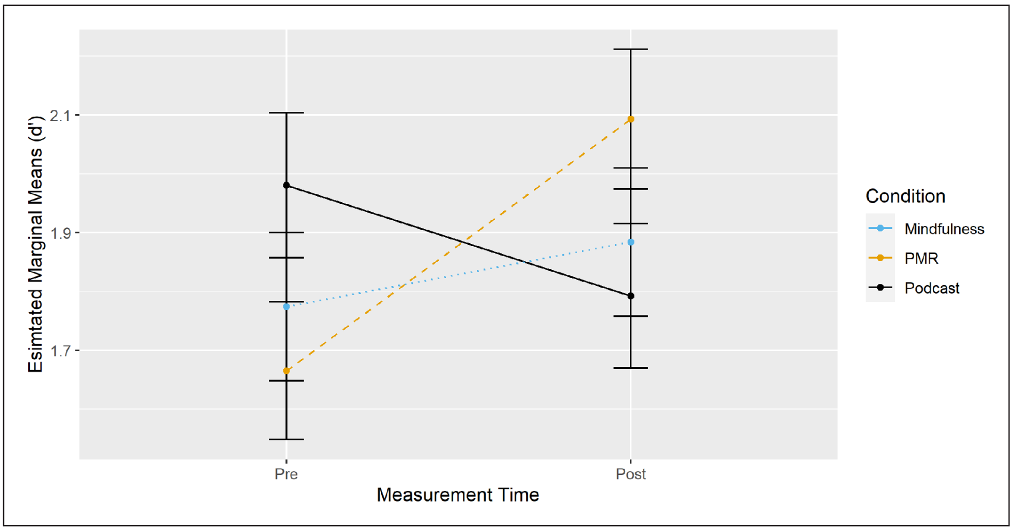

Figure 3 CPT-II: Changes in d' from Pre- to Post-Measurement by Condition.

To further differentiate the processes underlying performance, analogous models were run with errors of omission (i.e. misses) as the dependent measure (see Appendix C, Table C3). They showed a two-way interaction between time of measurement and condition (PMR), $\beta = -6.64$, $SE = 2.75$, $p = 0.016$, indicating a greater reduction in errors of omission from pre- to post-measurement for PMR compared to the podcast listening group; all other interactions including the factor time of measurement were non-significant, $p \geq 0.227$. EMM contrasts (***Table 1***) showed a lower number of misses after PMR compared to both podcast listening and mindfulness.

The results indicate that inducing relaxation through PMR increased discriminability and reduced errors of omission compared to both mindfulness and podcast listening. Mindfulness did not affect discriminability compared to listening to a podcast.

N-BACK TASK

One participant was removed due to too many missing data points (data loss through data cleaning: 6.59%).

Reaction Time

The model included a fixed effect for target, age and accuracy, a random slope for time of measurement by participant and a three-way interaction of time of measurement by condition by n-back level (including 1-, 2- and 3-back trials; 1-back as the reference category; see Appendix C, Table C4). N-back level was included in the three-way analysis because possible specific effects of mindfulness induction might be particularly likely to surface in the more difficult n-conditions which require more working memory engagement.[3]

Simple and Main Effects

The analysis showed a main effect for accuracy, $\beta = -9.41$, $SE = 2.59$, $p < 0.001$, with shorter RT for accurate compared to inaccurate trials, and a main effect for target type, $\beta = 8.88$, $SE = 1.24$, $p < 0.001$, indicating longer RTs for target compared to non-target trials. Simple effects were present for the n-back levels 2-back, $\beta = 68.47$, $SE = 1.81$, $p < 0.001$, and 3-back, $\beta = 85.23$, $SE = 1.84$, $p < 0.001$, indicating longer RTs for higher n-trials, and for time of measurement, $\beta = -74.73$, $SE = 3.51$, $p < 0.001$, with a decrease in RT from pre- to post-measurement.

Interactions of Interest

There was a two-way interaction between time of measurement and condition: mindfulness, $\beta = -35.98$, $SE = 6.70$, $p < 0.001$, and PMR, $\beta = -21.24$, $SE = 5.02$, $p = 0.002$, with a larger decrease in RT for both mindfulness and PMR compared to podcast listening from pre- to post-measurement, and for time by n-back: 2-back, $\beta = -27.38$, $SE = 2.58$, $p < 0.001$, and 3-back, $\beta = -10.85$, $SE = 2.77$, $p = 0.008$, indicating a larger decrease in RT from pre- to post measurement for 2-back and 3-back trials compared to 1-back trials. The analysis showed no significant three-way interaction between time of measurement, condition, and n-back, $p \geq 0.150$.

Likelihood ratio tests (cf. Appendix D) showed that the described model fit significantly better than a model with a two-way interaction of time of measurement by condition only, χ^2 (10) = 83.64, $p < 0.001$, a model with no interaction terms, χ^2 (12) = 85.76, $p < 0.001$, and a null model, χ^2 (20) = 2257.90, $p < 0.001$.

Figure 4 displays EMMs for the two-way interaction of time of measurement by condition. Planned comparisons were computed with RT change scores ($EMM_{t1} - EMM_{t0}$) between all conditions (see ***Table 1***). In comparison to the podcast listening group, both mindfulness and PMR exhibited a larger decrease in RT over time of measurement.

Taken together, the results show improved updating for both mindfulness and PMR induction compared to podcast listening and no significant differences between mindfulness and PMR.

3 Re-running our analysis without n-back level did not change the significance of any interactions of interest and did not provide a better fit to the data.

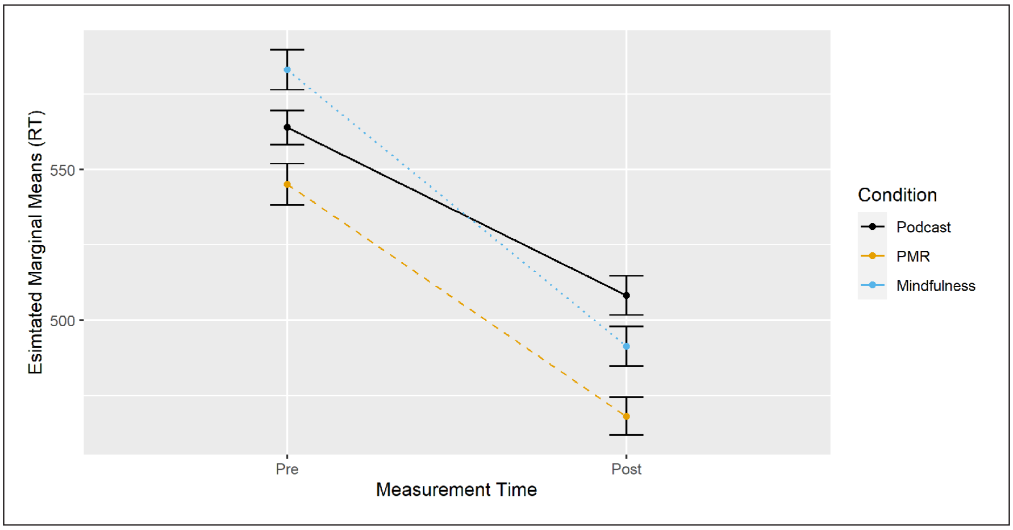

Figure 4 N-Back: Changes in RT from Pre- to Post-Measurement by Condition.

Accuracy Analysis

Discriminability (*d'*) was analyzed with a model including a fixed effect for age and a three-way interaction between time of measurement, condition and n-back level (see Appendix C, Table C5).

The analysis showed a simple effect of n-back level: 2-back, β = –0.48, *SE* = 0.11, $p < 0.001$, and 3-back, β = –1.30, *SE* = 0.11, $p < 0.001$, indicating lower *d'* for the 2- and 3-back conditions compared to the 1-back condition. All other simple and main effects were non-significant, $p \geq 0.167$. All two-way interactions including the factor time of measurement were non-significant, $p \geq 0.132$, as were all three-way interactions, $p \geq 0.155$.

Analogous models with errors of omission as the dependent variable (see Appendix C, Table C6) showed a two-way interaction between time of measurement and condition (PMR), β = –1.03, *SE* = 0.51, *p* = 0.044. Whereas errors of omission decreased in the podcast group, they increased slightly after PMR; all other interactions including the factor time of measurement were non-significant, $p \geq 0.194$. EMM contrasts for errors of omission showed no significant differences between groups (see ***Table 1***).

Thus, the results indicate no significant differences between mindfulness and PMR compared to podcast listening regarding discriminability and errors of omission.

NUMBER-LETTER TASK

Two participants were removed due to technical difficulties with recording (total data loss: 13.47%; this high level of data loss was partly due to equipment failure. However, the data loss was equally distributed across conditions and across measurement points).

Reaction Time

The model included fixed effects for age and accuracy, a random slope for time of measurement by participant and a three-way interaction of time of measurement by condition by switch factor (non-switch as the reference category; see Appendix C, Table C7). The switch factor was included in the three-way analysis to investigate the effect of non-switch versus switch trials and to calculate switch costs for planned comparisons.

Simple and Main Effects

The analysis showed a main effect of accuracy, β = 26.12, *SE* = 5.54, p < 0.001, with higher RT for correct compared to incorrect trials, and a main effect of age, β = 1.42, *SE* = 0.77, $p < 0.001$, with RT increasing as participants' age increased. Simple effects were present for the switch factor, β = 97.76, *SE* = 3.59, $p < 0.001$, with longer RT for switch compared to non-switch trials. There was also a simple effect for time of measurement, β = –80.91, *SE* = 4.79, $p < 0.001$, with RT decreasing from pre- to post-measurement.

Interactions of Interest

A two-way interaction between time of measurement and switch was found, β = –44.77, *SE* = 5.02, *p* < 0.001, indicating a decrease in switch costs from pre- to post-measurement, as well as a significant interaction between time of measurement and condition (mindfulness), β = –28.08, *SE* = 6.78, *p* < 0.001, with RT decreasing for mindfulness compared to podcast listening from pre- to post-measurement. The two-way interaction for time of measurement and PMR was non-significant, *p* = 0.092. Additionally, the three-way interaction between time of measurement, condition, and switch was significant for PMR, β = 29.40, *SE* = 7.73, *p* < 0.001, indicating that the increase in speed (decrease in RT) for PMR compared to the podcast group was smaller for switch compared to non-switch trials. Thus, the reduction in switch costs from pre- to post-measurement was smaller for PMR compared to the podcast listening group.

Likelihood ratio tests (see Appendix D) showed that the model described above fit significantly better than a model with a two-way interaction of time of measurement by condition only, χ^2 (5) = 46.01, *p* < 0.001, a model with no interaction terms, χ^2 (7) = 46.95, *p* < 0.001, and a null model, χ^2 (13) = 585.47, *p* < 0.001.

Figure 5 displays EMMs for the three-way interaction between time of measurement, condition and the switch factor. Planned comparisons were calculated for pre-post differences in switch costs ($EMM_{switch} - EMM_{nonswitch}$) between all conditions (***Table 1***). Mindfulness resulted in a larger decrease in switch costs over time than PMR, which resulted in a lesser decrease in switch costs than podcast listening.

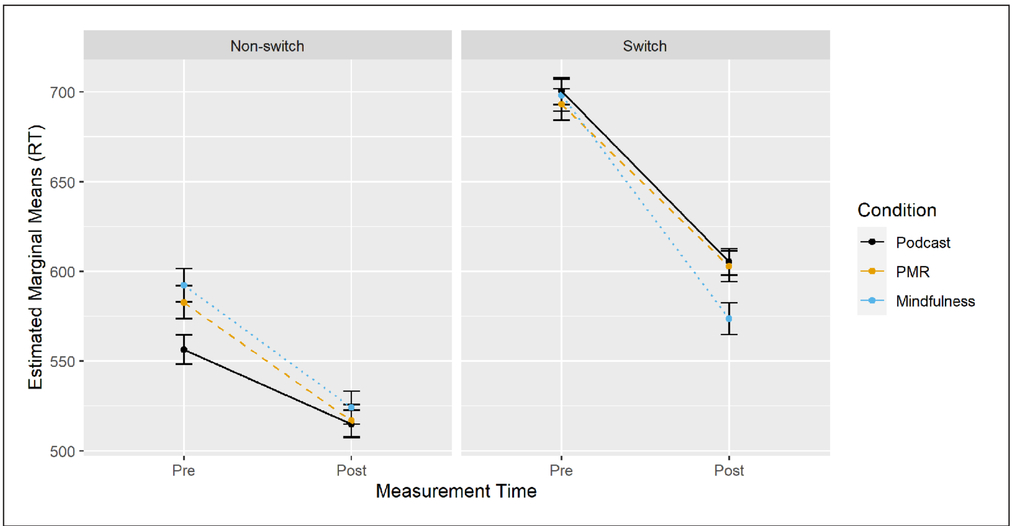

Figure 5 Number-Letter Task: Changes in RT from Pre- to Post-Measurement by Condition and Trial Type.

Taken together, the results indicate differential effects of mindfulness and PMR compared to podcast listening. The decrease in RT following mindfulness induction was larger than in the podcast group irrespective of the switch factor. However, following PMR, a larger decrease in RT over time compared to podcast listening occurred only for non-switch trials. Analyzing switch costs revealed an improvement in task-switching abilities for mindfulness compared to PMR and a decrease for PMR compared to podcast listening. Switch costs did not differ between mindfulness and podcast listening.

Accuracy Analysis

The model included a fixed effect for age, a random slope for time of measurement by participant and a three-way interaction between time of measurement, condition and switch factor, as well as all two-way interactions containing these factors (see Appendix C, Table C8).

There was a significant two-way interaction between time of measurement and switch, β = –0.26, *SE* = 0.12, *p* = 0.027, indicating that from pre- to post-measurement, accurate response rates decreased for switch trials compared to non-switch trials. All other two-way interactions including the factor time of measurement were non-significant, *p* ≥ 0.638, as were all three-way interactions, *p* ≥ 0.219.

Taken together, the results indicate no effects on response accuracy from pre- to post measurement for mindfulness or PMR compared to podcast listening.

ATTENTION NETWORK TASK

Two participants were removed from the analysis due to too many missing data points (total data loss after data cleaning: 3%).

Reaction Time

Possible effects on attentional networks were tested in separate models including a three-way interaction of time of measurement by condition by target type (executive network) or time of measurement by condition by type of cue (alerting vs. orienting). The network effects were calculated as proposed by Fan et al. (2002).

The model for **the executive network** included fixed effects for cue (with no cue as the reference category), age and accuracy; a random slope for time of measurement by participant and a three-way interaction of time of measurement by condition by target type (congruent vs. incongruent, with congruent trials as the reference category; see Appendix C, Table C9). Target type was included in the three-way interaction to investigate the effect of congruent versus incongruent trials and to calculate the executive network score for planned comparisons.

Simple and Main Effects

There was a main effect of age, $\beta = 3.39$, $SE = 0.53$, $p < 0.001$, with RT increasing with participants' age, and a main effect of accuracy, $\beta = 82.79$, $SE = 1.32$, $p < 0.001$, with higher RT in accurate compared to inaccurate trials. Simple effects were present for target type, $\beta = 103.58$, $SE = 0.90$, $p < 0.001$, reflecting slower RT for incongruent compared to congruent trials, and time of measurement, $\beta = -37.82$, $SE = 2.55$, $p < 0.001$, reflecting a decrease in RT from pre- to post-measurement.

Interactions of Interest

A two-way interaction was found between time of measurement and target, $\beta = -21.44$, $SE = 1.66$, $p < 0.001$, indicating that RT decreased to a larger degree from pre- to post-measurement in incongruent trials than in congruent trials. All other two-way interactions including the factor time of measurement were non-significant, $p \geq 0.075$. Furthermore, the model yielded a significant three-way interaction between time of measurement, condition, and target type for both mindfulness, $\beta = -12.66$, $SE = 2.58$, $p < 0.001$, and PMR, $\beta = -14.02$, $SE = 2.57$, $p < 0.001$. For both mindfulness and PMR, RTs for incongruent trials improved to a larger degree from pre- to post-measurement compared to congruent trials and compared to the podcast listening condition, indicating improved conflict resolution after both inductions.

Likelihood ratio tests (see Appendix D) showed that the model described above fit significantly better than a model with a two-way interaction of time of measurement by condition only, χ^2 (5) = 211.71, $p < 0.001$, a model with no interaction terms, χ^2 (7) = 212.05, $p < 0.001$, and a null model, χ^2 (16) = 11825, $p < 0.001$.

Figure 6 displays conflict effects for the three-way interaction of time of measurement, condition and target. Executive network scores ($EMM_{incongruent} - EMM_{congruent}$) are displayed on the y-axis. Planned comparisons of pre-post differences ($EMM_{t1} - EMM_{t0}$) between conditions (***Table 1***) showed that both mindfulness and PMR resulted in an improvement compared to podcast listening.

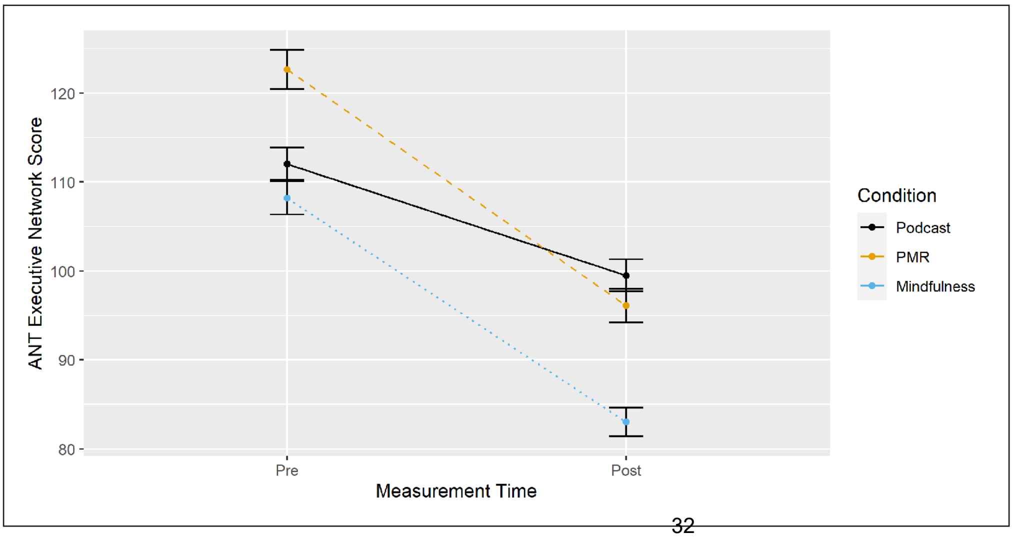

Figure 6 ANT: Executive Network Score from Pre- to Post-Measurement by Condition.

The results suggest that RTs for incongruent compared to congruent trials improved to a larger degree following both mindfulness and PMR compared to podcast listening. Accordingly, both inductions improved conflict resolution compared to the podcast group. Mindfulness did not differ significantly from PMR.

The model for **the alerting and orienting networks** included fixed effects for target, age and accuracy, a random slope for time of measurement by participant and a three-way interaction of time of measurement by condition by cue (see Appendix C, Table C10). Cue type was included in the three-way interaction to investigate the differential effects of the cue versus no-cue trials and to calculate the alerting and orienting network scores for planned comparisons.

Simple and Main Effects

There was a main effect of age, β = 3.41, *SE* = 0.55, $p < 0.001$, with RT increasing with participants' age, and a main effect of accuracy, β = 84.13, *SE* = 1.34, $p < 0.001$, with higher RT in accurate compared to inaccurate trials. Additionally, simple effects were found for cue types: middle cue, β = –11.39, *SE* = 1.17, $p < 0.001$, spatial cue, β = –12.67, *SE* = 1.16, $p < 0.001$, double cue, β = –11.85, *SE* = 1.18, $p < 0.001$. Compared to no cue trials, RT improved in trials in which the aforementioned cues were presented. A simple effect was found for time of measurement, β = –34.76, *SE* = 3.80, $p < 0.001$, reflecting a decrease in RT from pre- to post-measurement.

Interactions of Interest

All two-way interactions including time of measurement were non-significant, $p \geq 0.160$. Additionally, the three-way interaction between time of measurement, condition, and cue was significant for mindfulness and middle cue, β = 12.36, *SE* = 3.49, $p < 0.001$, and spatial cue, β = 9.23, *SE* = 3.49, p = 0.008, indicating that for both cues, compared to no cue trials, a larger decrease in RT from pre- to post-measurement was found for podcast listening compared to mindfulness. For PMR, a three-way interaction was found with spatial cue, β = 12.49, *SE* = 5.09, p = 0.014, and double cue, β = 9.54, *SE* = 4.39, p = 0.030, indicating a larger decrease in RT from pre- to post-measurement compared to no cue trials for the podcast group compared to PMR; $p \geq 0.110$.

Likelihood ratio tests (see Appendix D) showed that the model described above fit significantly better than a model with a two-way interaction of time of measurement by condition only, χ^2 (15) = 27.42, p = 0.026, a model with no interaction terms, χ^2 (17) = 27.75, p = 0.048, and a null model, χ^2 (26) = 11641, $p < 0.001$.

Alerting and orienting effects for the three-way interaction of time of measurement, condition and cue (Alerting Network Score = $EMM_{doublecue}$ – EMM_{nocue}; Orienting Network Score = $EMM_{spatialcue}$ – $EMM_{centercue}$) are displayed in ***Figure 7*** and ***Figure 8***, with alerting and orienting network scores on the y-axes respectively. Planned comparisons of pre-post differences (EMM_{t1} – EMM_{t0}) between conditions (***Table 1***) showed no significant effects.

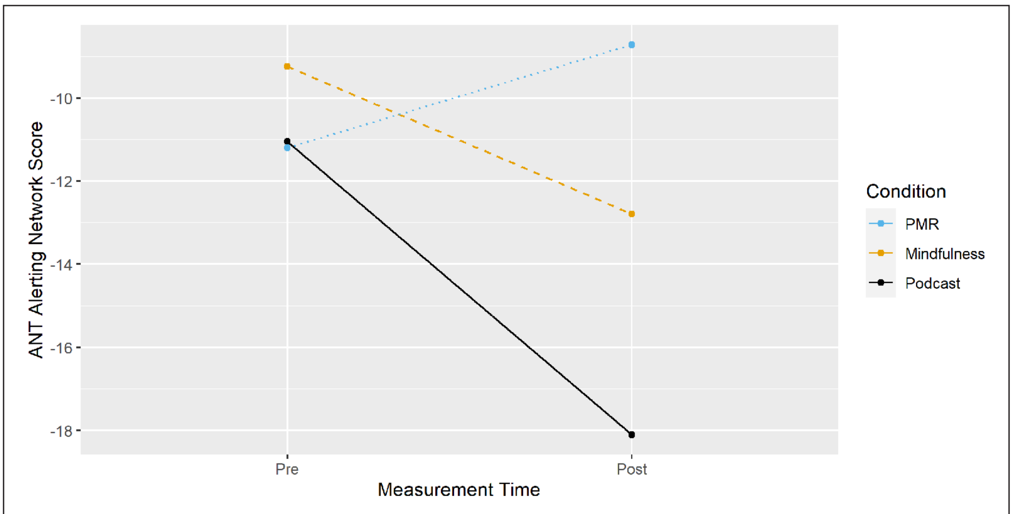

Figure 7 ANT: Alerting Network Score from Pre- to Post-Measurement by Condition.

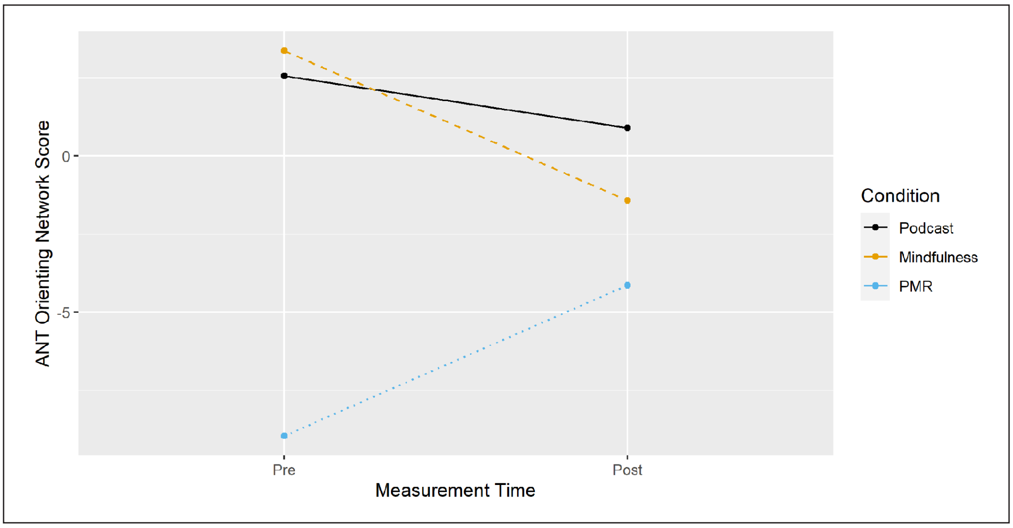

Figure 8 ANT: Orienting Network Score from Pre- to Post-Measurement by Condition.

The results suggest a general advantage of cue over non-cue conditions and a benefit for the podcast compared to both induction conditions in responding to individual cue conditions. However, planned comparisons for the calculated alerting and orienting network scores did not reveal any differential effects between groups.

Accuracy Analysis

Possible effects were tested in separate models including a three-way interaction of time of measurement by condition by target (executive network) or time of measurement by condition by cue (alerting and orienting).

The model for **the executive network** included fixed effects for age and cue type, a random slope for time of measurement by participant and a three-way interaction between time of measurement, condition and target type, as well as all two-way interactions containing these factors (see Appendix C, Table C11).

There was a significant two-way interaction for target type by time of measurement, $\beta = 0.27$, $SE = 0.13$, $p = 0.034$, indicating that participants' accuracy in incongruent trials compared to congruent trials improved from pre- to post-measurement. All other two-way interactions including the factor time of measurement were non-significant, $p \geq 0.141$, as were all three-way interactions, $p \geq 0.693$.

Taken together, the results for conflict resolution indicate no influence of either mindfulness or PMR induction compared to podcast listening on response accuracy within the executive network.

The model **for the alerting and orienting networks** included fixed effects for age and target type, a random slope for time of measurement by participant and a three-way interaction between time of measurement, condition and cue type, as well as all two-way interactions containing these factors (see Appendix C, Table C12).

All two-way interactions including the factor time of measurement were non-significant, $p \geq 0.118$, as were all three-way interactions, $p \geq 0.167$.

Taken together, there was no indication of any effects of mindfulness or PMR induction compared to podcast listening on response accuracy within the alerting or orienting networks.

QUESTIONNAIRES

Two-way repeated-measures analyses of variance (ANOVA) were carried out on the PANAS and MAAS scores. Results showed no significant main effects or interactions for negative affect (PANAS) or MAAS scores ($p \geq 0.297$). Main effects for positive affect were also non-significant, however, there was a significant interaction for group and time of measurement. Therefore, GLMMs were run to test for possible influences of positive affect on reaction time on all cognitive tasks utilized. No significant results were found ($p \geq 0.096$). Further information about the scales and statistical results are described in Appendix A.

DISCUSSION

While scientific models of mindfulness meditation identify improved attention and executive functioning as possible mechanisms, there is ongoing discussion about how much practice is required to spark mindfulness-specific effects (Fell et al., 2010). In particular, it is unclear whether the effects of short mindfulness inductions are specific to mindfulness or can also be achieved through other means such as relaxation. We addressed this research question by employing a randomized controlled pre-post design, contrasting mindfulness with a relaxation induction as an active control condition and listening to podcasts as a passive control condition. Our results revealed differential effects of mindfulness compared to PMR and podcast listening on the executive functions of set maintenance/inhibition and set shifting/switching. However, specific *benefits* of mindfulness arose only for the switching task, and both inductions yielded comparable benefits regarding updating/working memory and attention networks. We discuss our findings for each assessed executive or attentional function below. We relate our findings to studies that employed similar assessment tasks but longer periods of practice and to mechanisms proposed by models of mindfulness discussed in the introduction.

The mindfulness induction improved **inhibition** latencies from pre- to post-measurement compared to both PMR and podcast listening. Interestingly, inducing relaxation prolonged latencies in the shortest ISI but improved them in longer ISIs. Taking response quality into account showed that PMR induction improved discriminability compared to podcast listening and reduced errors of omission compared to both mindfulness and podcast listening. These dissimilar effects suggest differential mechanisms underlying mindfulness and relaxation, and some advantages of mindfulness – albeit not exclusively. Relatedly, Wenk-Sormaz (2005) found improved inhibition as reflected in reduced Stroop interference in RTs after 20 minutes of focused attention meditation in comparison to cognitive control tasks and a passive rest condition. In a correlational study, Schmertz et al. (2009) found an association between higher scores on trait mindfulness (MAAS) and fewer omissions in a CPT-II. Therefore, whereas the benefits of mindfulness induction for inhibition latency emerge instantly (but not after relaxation induction), effects on response quality did not and may require longer practice or high trait mindfulness.

Mindfulness induction and PMR both resulted in improved **updating** latencies compared to podcast listening but no effects on updating accuracy. Similarly, Johnson et al. (2015) found no differences in response speed or extended hit rate in a modified 2-back task after a short meditation, a sham meditation or listening to an audiobook. Zeidan et al. (2010) likewise found no benefits of a brief mindfulness intervention over four training sessions compared to audiobook listening in accuracy in a modified 2-back task, but only regarding extended hit runs (i.e. number of correct responses in a row).[4] However, when examining the effects of longer mindfulness interventions on working memory, Basso et al. (2019) reported that eight weeks of meditation improved response accuracy on the n-back task compared to a podcast listening condition. Therefore, we conclude that specific effects of mindfulness on updating and working memory capacity like those proposed by Jha et al. (2019) may only unfold over time and would need consolidation through practice.

Analyzing switch costs revealed an improvement in **task switching** for mindfulness compared to PMR and a decline in task switching for PMR compared to podcast listening. In line with our findings of improved overall speed after mindfulness, Jankowski and Holas (2020) found improved response speed across switch and non-switch trials after mindfulness induction compared to a worry induction and free mind-wandering in a study investigating the effects of induced negative affect. However, these authors reported no reduction in switch costs for mindfulness compared to the control conditions. Chambers et al. (2008) investigated the effects of a 10-day mindfulness retreat on the internal switching task, finding an improvement in RTs for the mindfulness condition compared to a wait-list control condition. Employing the number-letter task in a study on the effects of a mindfulness intervention over seven bi-weekly sessions, Wimmer et al. (2020) found that mindfulness but not the active control condition (awareness training) resulted in a greater overall speed improvement than the passive control

4 Supplementary analyses of extended hit runs in the n-back task revealed that PMR exceeded both the mindfulness and passive control conditions in hit run gains from pre- to post-measurement. Such a gain was also present for mindfulness compared to the passive control group, but did not reach significance.

condition (no training). Based on our findings and previous studies, we conclude that the benefits of mindfulness for switch costs rely on specific mechanisms that can be differentiated from the effects of relaxation even after brief inductions of a mindful state.

Our results show that both mindfulness and PMR similarly improved conflict resolution through the **executive network** and thus yielded no evidence for specific effects of a brief mindfulness induction. However, Tang et al. (2007), investigating a five-day integrative body-mind training compared to PMR, and Kwak et al. (2020), investigating an intensive four-day mindfulness retreat compared to non-guided relaxation, found effects on conflict resolution after meditation but not after relaxation practice. Specific benefits of mindfulness may therefore require more practice time to unfold. Neither mindfulness nor PMR affected the performance of the **alerting and orienting networks** in the present study. Examining effects of longer mindfulness interventions on attentional networks, Jha et al. (2007) showed an improvement in orientation latencies after eight weeks of MBSR training compared to a passive control condition. Again, these effects may require more practice time to unfold.

It appears worth noting that for all functions assessed in the present study (except alerting and orienting, which were not affected by either induction), we found an improvement in reaction times following mindfulness induction compared to the podcast listening group. While participants increased the speed of their responses from pre- to post measurement, they maintained their rates of correct answers. That is, the mindfulness induction did improve performance. However, this improvement in reaction times was also found following PMR, except for the short ISI inhibition and task switching, indicating that a short relaxation induction also appears to enhance and/or reduce interference with the respective processes. Thus, specific benefits of mindfulness compared to relaxation apart from task switching seem to require longer periods of practice.

Relating our results and those of studies with longer periods of practice to mechanisms proposed by models of mindfulness shows that these models correctly predict several outcomes, such as better inhibition and task switching (Bishop et al., 2004), better executive attention (Malinowski, 2013), or improvement in working memory (Jha et al., 2019) following mindfulness practice. However, not all predicted benefits of mindfulness practice turned out to be specific. In light of our findings of a mindfulness-specific benefit for task switching as well as partly specific improvement in inhibition, executive functions may indeed lie at the core of effects that can be considered specific to mindfulness practice and are clearly distinguishable from effects of relaxation even after short inductions. However, we found comparable effects for mindfulness and relaxation for the executive attention network, which is proposed to be involved in disengagement from mind wandering during practice. Also, we found that both mindfulness and relaxation improved working memory capacity. Furthermore, no effects for alerting or orienting arose. Therefore, this discussion shows that the dose-response relation and the specificity of mindfulness-based mechanisms need to be further specified in theoretical approaches. The phenomenological matrix approach by Lutz et al. (2015) might be considered a step in this direction. In order to systematize the phenomenological experience of mental states in general, that is, inside as well as outside meditation practice, Lutz et al. (2015) proposed three dimensions along which states of mind can be arranged. These are object orientation (which is high in FAM but also in states of craving), dereification (i.e., the degree to which one considers states of mind as passing mental processes rather than valid representations of reality; dereification is low in states of craving and high in intensely practiced OMM), and meta-awareness, comprising awareness of the task set and at the same time of the larger context of one's subjective experience. Mental states on these dimensions can further be qualified in terms of how open vs. focused they are, how clear and stable, and how much effort goes into maintaining them (the latter of which is, for example, low in craving and high in a novice's focused attention meditation). This categorization also makes it possible to clearly distinguish qualities of the mental states of novice and expert practitioners. For example, novice practitioners will need to put in more effort to maintain their meditative state and not get carried away through mind wandering than experts, and when practicing focused attention meditation (FAM), they may only achieve a high level of object orientation after a certain period of practice (Lutz et al., 2008; Lutz et al., 2015). Object orientation during PMR, on the other hand, may be easier to achieve without much practice, as attentional focus is grounded in immediate proprioceptive feedback through the alternating constriction and relaxation of muscles. However, both meditation with a focus on the breath (e.g. FAM) and PMR require the practitioner to both focus their attention to somatosensory experiences and narrow their attentional scope to the object that is to be observed (i.e. the quality of narrow aperture, according to Lutz et al., 2015). Selecting active control groups along these dimensions and also controlling for changes in dimensions over practice time may help us to better understand which mindfulness effects are specific to how much practice.

CONCLUSION

Our results suggest partly differential, partly overlapping mechanisms of mindfulness compared to relaxation induction on attention and executive functions and are therefore partly in line with Fell et al.'s (2010) proposal that the cognitive benefits found for initial steps of meditative development may be not specific to the practice. However, based on our results and previous studies, we propose that differential effects of mindfulness across attentional processes and executive functions may become apparent after longer practice.

LIMITATIONS AND FUTURE RESEARCH

We chose to deliver the mindfulness and PMR instructions in person to support participants' engagement with the practice. However, in-person instructions are less standardized than pre-recorded instructions, meaning that our choice may have reduced internal validity (for a related discussion, see Cavanagh et al., 2014; Fish et al., 2016).

In our design, we opted to screen for participants who had not engaged in mindfulness practice within the last three months. While the exact dose-response relationship as well as the longevity of effects following mindfulness trainings are still up for debate, there is consensus that continued practice is necessary to maintain these effects (e.g. Fell et al., 2010; Malinowski, 2013). Nevertheless, future studies may wish to consider longer periods of non-practice or test only naive participants to exclude the possibility of reactivating effects of previous meditation practice.

Based on our results and previous studies, we argue that benefits specific to mindfulness practice may require training to consolidate. This raises the question of the dosage-response relationship between mindfulness, attention, and executive functioning. Therefore, it would be interesting to investigate such changes by increasing the training dosage in small increments and employing repeated testing.

We controlled for possible influences of trait mindfulness and emotions, but more detailed information about how calm, relaxed and/or mindful participants actually felt after the inductions might be interesting to assess as a manipulation check in future studies, e.g. using the Smith Relaxation States Inventory 3 (SRSI3; Smith, 2017 & 2020; German version: Vieth et al., 2020).

Replicating our results with further measures of attention and executive control would obviously be desirable. Furthermore, active control conditions are essential for studying the mechanisms underlying mindfulness induction, as advantages compared to passive conditions alone leave open what exactly the transient starting points of longer-lasting practice effects are.

ADDITONAL FILES

The additonal files for this article can be found as follows:

- **Appendix A.** Supplementary Material on Questionnaires Used to Control for Possible Influences of Mood on Attentional and Executive Control. DOI: *https://doi.org/10.5334/joc.205.s1*
- **Appendix B.** Supplementary Material Containing Instructions for the Mindfulness Meditation and Progressive Muscle Relaxation. DOI: *https://doi.org/10.5334/joc.205.s2*
- **Appendix C.** Supplementary Material Containing Statistical Analysis and Results Tables. DOI: *https://doi.org/10.5334/joc.205.s3*
- **Appendix D.** Generalized Linear Mixed Model Comparison of Measures of Attentional Control and Executive Functioning. DOI: *https://doi.org/10.5334/joc.205.s4*

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COMPETING INTERESTS

The authors have no competing interests to declare.

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Appendix A

Supplementary Material on Questionnaires Used to Control for Possible Influences of Mood on Attentional and Executive Control

The PANAS is a questionnaire measuring positive and negative emotions on two respective subscales and consists of 20 items in total, ten describing positive and ten describing negative affective states. Participants are asked to indicate on a 5-point Likert-type scale how well a certain affective state (e.g. "scared") applies to them currently. The Mindful Attention and Awareness Scale is a 15-item scale used to measure awareness of and attention to the present moment.

In order to control for possible effects of affect, two-way repeated-measures analyses of variance (ANOVA) were carried out on the PANAS scores. The results showed changes in mood over time between groups related to positive, $F(2, 76) = 4.481$, $p = 0.015$, but not for negative affect $F(2, 76) = 0.579$, $p = 0.563$. Separate GLMMs for each cognitive task with RT as the dependent variable and positive affect scores per measurement point as independent variables suggested no significant influence of positive affect on reaction time for all tasks described in the results section. Similarly, to control for possible differences in trait mindfulness between pre- and post-measurement as well as between groups, a two-way repeated measures ANOVA was conducted, revealing no pre-post differences in MAAS scores between groups, $F(2, 78) = 1.100$, $p = 0.338$.

Appendix B

Supplementary Material Containing Instructions for the Mindfulness Meditation and Progressive Muscle Relaxation

Inductions were read to the participants in German. Below are translated versions of the instructions.

Mindfulness Meditation

The mindfulness instructions focused on being present in and aware of the present moment, observing one's flow of breath without interfering with it, observing and letting go of thoughts and emotions that arise, and overall acceptance of the present moment.

Breathing Meditation Instructions

Sit down in a way that allows you to sit for a while in a well-balanced position. Straighten up slightly. Some people imagine a golden thread at the crown of their head that is pulling their head up.

(If you like,) close your eyes. If you tend to get sleepy, fixate on any point in the room in front of you.

Feel where your body is in contact with the chair, where it is supported and sustained.

1-minute pause

Now focus your attention on your breath. Breathe in and breathe out and be aware of this process of breathing. Become aware of your breath, where your body moves in the rhythm of your breath, and how. In the chest, in the stomach, or some other place?

2-minute pause

Feel the ever-changing sensations as the current of your breath flows in and out of the body.

3-minute pause

Allow your body to breathe with its own rhythm. You don't need to change or monitor anything. You are an observer of the processes that come naturally, from one moment to the next.

1-minute pause

Thoughts of all kinds may come to your mind. This is totally fine. Once you've taken note of this, simply direct your attention back to your breathing.

1-minute pause

If you are being critical of yourself, notice this and bring your attention back to your breathing. Be patient with yourself.

2-minute pause

Now take in the complete breathing process once again:

On the inhale, how breath flows in through the nose and lifts the chest and stomach.

On the exhale, how it flows out from the nose and then lowers the chest and belly and the pause after the exhale.

3-minute pause

Broaden your attention again to your whole body and to the space where you are sitting. Let your breath flow again without observing it.

2-minute pause

When you feel ready, open your eyes or let your gaze wander around the room. Be ready and awake for what is next in store for you.

Progressive Muscle Relaxation

During PMR, the participant is instructed to contract a specific muscle group (e.g. the upper thighs) for five to ten seconds during inhalation, and to let go of the tension during exhalation. The instructions start with rounds of contraction and release focused on the lower extremities and gradually progress upwards through the body. Between muscle groups, subjects are asked to take ten to 20 seconds for relaxation and to focus on changes in their physiological experience when releasing the tension.

Progressive Muscle Relaxation Instructions

Notes

Tension: 5 seconds.

Pause between steps: 10 seconds.

Introduction

Tighten each muscle of your body one by one for about 5 seconds, not too much but just until you feel a slight stretch, and hold the tension. Then release the tension without moving around much. Next, consciously pay attention to the feeling of relaxation for about 10 seconds.

If you don't feel the relaxation the first time, repeat it again. While tensing each muscle, try to keep all other muscles as relaxed as possible. Concentrate solely on the particular muscle group you are tensing.

Posture

Sit up straight. Your head is straight between your shoulders and your legs are together. Your arms are resting on your thighs.

Your feet are firmly on the floor.

Unless you find it uncomfortable, close your eyes. If you become slightly drowsy, fixate on a point about 2m in front of you on the floor.

Now take a few deep breaths and let your body become loose and pleasantly heavy. Take your time here.

1. Now clench your right hand into a fist and tighten it. Count slowly from 1 to 5... and release the tension. Now enjoy the feeling of relaxation.
2. Now clench your left hand into a fist, count slowly from 1 to 5....and then relax again.
3. Now tense your forearm muscles by reaching up your hands. Your forearms should remain on your thighs. Hold the tension... and relax again. Feel the relaxation.
4. Now tense your forearm muscles by bending your elbows with open hands. Hold the tension... and relax again.
5. Now crunch up your forehead. While doing so, open your eyes wide. Raise your eyebrows so that your forehead becomes wrinkled, hold the tension... and relax again. If you like, close your eyes again. Continue breathing calmly and relaxed. Enjoy the feeling of relaxation.
6. Now draw your eyebrows together so that a vertical frown line appears on your forehead. Hold the tension...and relax again.
7. Now close your eyes more firmly and count slowly from 1 to 5.... hold the tension...and relax again. Continue to breathe in a relaxed manner.
8. Now press your lips together without clenching your teeth. Hold the tension...and relax again.
9. Now press your tongue against the roof of your mouth. Hold the tension...and relax again. Let your tongue lie loosely in your mouth. Your breath is flowing calmly and relaxed.
10. Now clench your teeth, hold the tension... and relax again. Enjoy the feeling of relaxation.
11. Now tilt your head down to your right shoulder. Hold the tension...and relax again.
12. Now tilt your head down to your left shoulder. Hold the tension... and relax again. Breathe calmly and relaxed.
13. Now pull your shoulders up to your ears. Hold the tension...and relax again.
14. Now press your shoulder blades together towards the back of your spine. Hold the tension... and relax again.

15. Now inhale deeply so that your chest expands. Hold your chest like this and continue breathing lightly. Hold the tension. Then let your chest collapse .... and relax again. Breathe calmly and relaxed once again.

16. Now push your stomach out and hold it for a moment while continuing to breathe. Hold the tension. Then pull your stomach in... And relax again.

17. Now tense the muscles in your buttocks. Hold the tension... and relax again.

18. Now tense your thighs by pressing your heels into the floor and lifting your toes off the floor. Hold the tension...and relax again.

19. Tense your calves by pressing your feet down onto the floor. Not too hard. Hold the tension... and relax again.

20. Inhale again in a completely relaxed way... and exhale... Repeat this five times... When you feel ready, slowly open your eyes.

Appendix C

Supplementary Material Containing Statistical Analysis and Results Tables

Statistical Analyses

Analyses were carried out using the R statistics software (R Core Team, 2020). Generalized linear models were fitted using the package 'lme4' (Bates, Maechler, Bolker & Walker, 2015) and p-values were obtained with the package 'lmerTest' (Kuznetsova, Brockhoff & Christensen, 2017). Estimated marginal means were calculated using the 'emmeans' package by Lenth (2020). All plots were created with the 'ggplot2' package by Wickham (2016).

Contrast Coding

For all models, the measurement time factor was coded as 0 = pre-measurement and 1 = post-measurement. For the experimental condition factor, the non-treatment control condition was coded as the reference category (treatment coding). The effect of age was controlled by adding the participant's age (grand-mean centered) as a fixed effect. For accuracy, non-accurate trials were coded as the reference category.

Table C1

Generalized Linear Mixed Model of RT During the Continuous Performance Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	259.74	2.76	254.33 – 265.16	**<0.001**
Time	-11.74	2.91	-17.44 – -6.05	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$	-7.44	3.34	-13.98 – -0.90	**0.026**
$\text{Condition}_{\text{PMR}}$	2.80	4.58	-6.17 – 11.76	0.541
ISI_{2000}	15.26	0.80	13.70 – 16.83	**<0.001**
ISI_{4000}	49.13	0.88	47.41 – 50.86	**<0.001**
$\text{Age}_{\text{Grand Mean Centered}}$	2.13	0.42	1.31 – 2.95	**<0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$	-15.04	2.80	-20.54 – -9.54	**<0.001**
Time : $\text{Condition}_{\text{PMR}}$	-0.05	2.93	-5.80 – 5.70	0.986
Time : ISI_{2000}	6.98	1.47	4.11 – 9.85	**<0.001**
Time : ISI_{4000}	1.04	1.64	-2.18 – 4.26	0.527
$\text{Condition}_{\text{Mindfulness}}$: ISI_{2000}	-7.27	1.53	-10.25 – -4.28	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$: ISI_{4000}	-12.00	1.81	-15.55 – -8.46	**<0.001**
$\text{Condition}_{\text{PMR}}$: ISI_{2000}	-4.69	1.59	-7.80 – -1.57	**0.003**
$\text{Condition}_{\text{PMR}}$: ISI_{4000}	-4.81	1.92	-8.58 – -1.04	**0.012**
Time : $\text{Condition}_{\text{Mindfulness}}$: ISI_{2000}	8.04	2.23	3.67 – 12.42	**<0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$: ISI_{4000}	4.51	2.79	-0.96 – 9.97	0.106
Time : $\text{Condition}_{\text{PMR}}$: ISI_{2000}	-17.11	2.57	-22.14 – -12.08	**<0.001**
Time : $\text{Condition}_{\text{PMR}}$: ISI_{4000}	-21.63	2.83	-27.17 – -16.09	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	155.50	Observations	46731
τ_{11} Subject : Time	238.69	Df	46708
ρ_{01} Subject	-0.06	Deviance	536141.3
N Subject	78	AIC	536187.3
		log-Likelihood	-268070.6

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table C2

Linear Regression of d' During the Continuous Performance Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	1.86	0.05	1.77 – 1.96	**<0.001**
Time	0.12	0.10	-0.08 – 0.31	0.240
$\text{Condition}_{\text{Mindfulness}}$	-0.06	0.12	-0.30 – 0.19	0.643
$\text{Condition}_{\text{PMR}}$	-0.01	0.12	-0.25 – 0.23	0.953
ISI_{2000}	0.15	0.12	-0.09 – 0.39	0.227
ISI_{4000}	0.39	0.12	0.15 – 0.63	**0.001**
$\text{Age}_{\text{Grand Mean Centered}}$	0.01	0.01	-0.01 – 0.02	0.347
Time : $\text{Condition}_{\text{Mindfulness}}$	0.30	0.25	-0.19 – 0.78	0.23
Time : $\text{Condition}_{\text{PMR}}$	0.62	0.24	0.15 – 1.09	**0.01**
Time : ISI_{2000}	0.13	0.24	-0.35 – 0.61	0.596
Time : ISI_{4000}	0.12	0.24	-0.36 – 0.60	0.616
$\text{Condition}_{\text{Mindfulness}}$: ISI_{2000}	0.23	0.30	-0.37 – 0.82	0.459
$\text{Condition}_{\text{Mindfulness}}$: ISI_{4000}	0.23	0.30	-0.37 – 0.82	0.459
$\text{Condition}_{\text{PMR}}$: ISI_{2000}	0.13	0.29	-0.44 – 0.71	0.653
$\text{Condition}_{\text{PMR}}$: ISI_{4000}	0.06	0.29	-0.52 – 0.63	0.845
Time : $\text{Condition}_{\text{Mindfulness}}$: ISI_{2000}	-0.65	0.61	-1.85 – 0.54	0.283
Time : $\text{Condition}_{\text{Mindfulness}}$: ISI_{4000}	-0.54	0.61	-1.73 – 0.66	0.378
Time : $\text{Condition}_{\text{PMR}}$: ISI_{2000}	-0.66	0.58	-1.81 – 0.49	0.260
Time : $\text{Condition}_{\text{PMR}}$: ISI_{4000}	-0.30	0.58	-1.44 – 0.85	0.614
Model Specifications				
Observations	462			
Df	443			
Deviance	499.889			
AIC	1387.515			
log-Likelihood	-673.757			

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C3

Linear Regression of Errors of Omission During the Continuous Performance Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	6.41	0.57	5.29 – 7.53	**<0.001**
Time	0.17	1.14	-2.07 – 2.42	0.879
$\text{Condition}_{\text{Mindfulness}}$	-0.03	1.43	-2.84 – 2.78	0.983
$\text{Condition}_{\text{PMR}}$	-1.30	1.42	-4.09 – 1.48	0.359
ISI_{2000}	-4.96	1.40	-7.70 – -2.21	**<0.001**
ISI_{4000}	-8.14	1.40	-10.89 – -5.40	**<0.001**
$\text{Age}_{\text{Grand Mean Centered}}$	0.24	0.06	0.11 – 0.36	**<0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$	-0.04	2.85	-5.65 – 5.57	0.989
Time : $\text{Condition}_{\text{PMR}}$	-6.64	2.75	-12.05 – -1.23	**0.016**
Time : ISI_{2000}	-2.42	2.79	-7.91 – 3.08	0.388
Time : ISI_{4000}	-3.38	2.79	-8.87 – 2.11	0.227
$\text{Condition}_{\text{Mindfulness}}$: ISI_{2000}	0.28	3.50	-6.59 – 7.15	0.936
$\text{Condition}_{\text{Mindfulness}}$: ISI_{4000}	-0.21	3.50	-7.08 – 6.66	0.952
$\text{Condition}_{\text{PMR}}$: ISI_{2000}	2.00	3.37	-4.61 – 8.62	0.552
$\text{Condition}_{\text{PMR}}$: ISI_{4000}	3.08	3.37	-3.54 – 9.70	0.361
Time : $\text{Condition}_{\text{Mindfulness}}$: ISI_{2000}	1.28	6.99	-12.46 – 15.02	0.855
Time : $\text{Condition}_{\text{Mindfulness}}$: ISI_{4000}	-0.92	6.99	-14.66 – 12.82	0.896
Time : $\text{Condition}_{\text{PMR}}$: ISI_{2000}	4.19	6.73	-9.05 – 17.42	0.534
Time : $\text{Condition}_{\text{PMR}}$: ISI_{4000}	2.90	6.73	-10.34 – 16.13	0.667
Model Specifications				
Observations	462			
Df	443			
Deviance	66289.447			
AIC	3645.493			
log-Likelihood	-1802.747			

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C4

Generalized Linear Mixed Model of RT During the N-Back Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	531.47	5.23	521.22 – 541.72	**<0.001**
Time	-74.73	3.51	-81.61 – -67.84	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$	1.12	3.80	-6.33 – 8.57	0.769
$\text{Condition}_{\text{PMR}}$	-29.48	4.35	-38.01 – -20.95	**<0.001**
$\text{Nback}_{\text{2back}}$	68.47	1.81	64.92 – 72.02	**<0.001**
$\text{Nback}_{\text{3back}}$	85.23	1.84	81.63 – 88.83	**<0.001**
$\text{Age}_{\text{Grand Mean Centered}}$	1.43	0.76	-0.06 – 2.92	0.059
Accuracy	-9.41	2.59	-14.48 – -4.34	**<0.001**
Target	8.88	1.24	6.45 – 11.31	**<0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$	-35.98	6.70	-49.10 – -22.85	**<0.001**
Time : $\text{Condition}_{\text{PMR}}$	-21.24	5.02	-31.08 – -11.40	**<0.001**
Time : $\text{Nback}_{\text{2back}}$	-27.38	2.58	-32.44 – -22.32	**<0.001**
Time : $\text{Nback}_{\text{3back}}$	-10.85	2.77	-16.27 – -5.43	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{2back}}$	-18.43	2.55	-23.44 – -13.43	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{3back}}$	-8.91	2.65	-23.44 – -13.43	**<0.001**
$\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{2back}}$	-25.08	2.97	-30.89 – -19.26	**<0.001**
$\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{3back}}$	-14.30	2.93	-20.05 – -8.56	**<0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{2back}}$	4.14	3.49	-2.70 – 10.97	0.235
Time : $\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{3back}}$	0.78	3.66	-6.39 – 7.95	0.832
Time : $\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{2back}}$	-4.48	3.11	-10.58 – 1.62	0.150
Time : $\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{3back}}$	3.66	4.33	-4.83 – 12.14	0.398

Random Effects		*Model Specifications*	
τ_{00} Subject	1165.75	Observations	41084
τ_{11} Subject : Time	1106.84	Df	41059
ρ_{01} Subject	-0.17	Deviance	532840.305
N Subject	78	AIC	532890.305
		log-Likelihood	-266420.152

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table C5

Linear Regression of d' During the N-Back Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	2.26	0.05	2.17 – 2.35	**<0.001**
Time	0.02	0.09	-0.16 – 0.20	0.820
$\text{Condition}_{\text{Mindfulness}}$	0.16	0.12	-0.07 – 0.39	0.167
$\text{Condition}_{\text{PMR}}$	0.12	0.12	-0.11 – 0.35	0.292
$\text{Nback}_{\text{2back}}$	-0.48	0.11	-0.70 – -0.27	**<0.001**
$\text{Nback}_{\text{3back}}$	-1.30	0.11	-1.52 – -1.08	**<0.001**
$\text{Age}_{\text{Grand Mean Centered}}$	-0.01	0.00	-0.01 – 0.00	0.183
Time : $\text{Condition}_{\text{Mindfulness}}$	0.12	0.22	-0.30 – 0.55	0.568
Time : $\text{Condition}_{\text{PMR}}$	0.21	0.22	-0.22 – 0.64	0.333
Time : $\text{Nback}_{\text{2back}}$	0.33	0.22	-0.10 – 0.77	0.132
Time : $\text{Nback}_{\text{3back}}$	0.27	0.22	-0.17 – 0.70	0.231
$\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{2back}}$	-0.06	0.27	-0.59 – 0.46	0.814
$\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{3back}}$	-0.16	0.27	-0.68 – 0.37	0.560
$\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{2back}}$	-0.17	0.27	-0.70 – 0.36	0.525
$\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{3back}}$	-0.22	0.27	-0.75 – 0.31	0.412
Time : $\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{2back}}$	-0.62	0.53	-1.67 – 0.43	0.245
Time : $\text{Condition}_{\text{Mindfulness}}$: $\text{Nback}_{\text{3back}}$	-0.76	0.53	-1.81 – 0.29	0.155
Time : $\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{2back}}$	-0.26	0.54	-1.31 – 0.79	0.625
Time : $\text{Condition}_{\text{PMR}}$: $\text{Nback}_{\text{3back}}$	-0.18	0.54	-1.24 – 0.89	0.746
Model Specifications				
Observations	495			
Df	476			
Deviance	476.863			
AIC	1426.271			
log-Likelihood	-693.136			

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C6

Linear Regression of Errors of Omission During the N-Back Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	6.51	0.21	6.10 – 6.92	**<0.001**
Time	0.15	0.21	-0.26 – 0.56	0.469
$Condition_{Mindfulness}$	-0.59	0.54	-1.64 – 0.46	0.271
$Condition_{PMR}$	-0.17	0.54	-1.23 – 0.90	0.758
$Nback_{2back}$	1.05	0.52	0.04 – 2.06	**0.043**
$Nback_{3back}$	5.54	0.52	4.52 – 6.55	**<0.001**
$Age_{Grand\ Mean\ Centered}$	0.03	0.02	-0.01 – 0.07	0.179
Time : $Condition_{Mindfulness}$	-0.66	0.51	-1.66 – 0.34	0.194
Time : $Condition_{PMR}$	-1.03	0.51	-2.03 – -0.03	**0.044**
Time : $Nback_{2back}$	0.46	0.52	-0.55 – 1.48	0.369
Time : $Nback_{3back}$	0.47	0.52	-0.54 – 1.48	0.362
$Condition_{Mindfulness}$: $Nback_{2back}$	0.33	1.24	-2.11 – 2.77	0.788
$Condition_{Mindfulness}$: $Nback_{3back}$	-1.09	1.24	-3.53 – 1.35	0.382
$Condition_{PMR}$: $Nback_{2back}$	-0.24	1.24	-2.69 – 2.20	0.844
$Condition_{PMR}$: $Nback_{3back}$	-0.41	1.25	-2.87 – 2.06	0.744
Time : $Condition_{Mindfulness}$: $Nback_{2back}$	-0.51	1.24	-2.94 – 1.93	0.684
Time : $Condition_{Mindfulness}$: $Nback_{3back}$	1.53	1.24	-0.91 – 3.97	0.218
Time : $Condition_{PMR}$: $Nback_{2back}$	0.45	1.24	-2.00 – 2.89	0.720
Time : $Condition_{PMR}$: $Nback_{3back}$	0.47	1.25	-2.00 – 2.93	0.709
Model Specifications				
Observations	462			
Df	443			
Deviance	66289.447			
AIC	3645.493			
log-Likelihood	-1802.747			

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C7

Generalized Linear Mixed Model of RT During the Number-Letter Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	583.70	5.84	572.26 – 595.14	**<0.001**
Time	-80.91	4.79	-90.30 – -71.52	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$	2.77	6.19	-9.36 – 14.91	0.654
$\text{Condition}_{\text{PMR}}$	4.64	5.43	-6.00 – 15.28	0.393
Switch	97.76	3.59	90.74 – 104.79	**<0.001**
Accuracy	26.12	5.54	15.25 – 36.98	**<0.001**
$\text{Age}_{\text{Grand Mean Centered}}$	1.42	0.77	-0.09 – 2.94	0.066
Time : $\text{Condition}_{\text{Mindfulness}}$	-28.08	6.78	-41.36 – -14.79	**<0.001**
Time : $\text{Condition}_{\text{PMR}}$	-9.90	5.89	-21.44 – 1.63	0.092
Time : Switch	-44.77	5.02	-54.61 – -34.92	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$: Switch	-39.44	4.67	-48.59 – -30.29	**<0.001**
$\text{Condition}_{\text{PMR}}$: Switch	-18.97	5.55	-29.85 – -8.10	**0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$: Switch	-2.76	6.68	-15.85 – 10.33	0.679
Time : $\text{Condition}_{\text{PMR}}$: Switch	29.4	7.73	14.24 – 44.56	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	1873.85	Observations	20980
τ_{11} Subject : Time	1092.14	Df	20962
ρ_{01} Subject	-0.08	Deviance	293658.086
N Subject	77	AIC	293694.086
		log-Likelihood	-146829.043

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table C8

Multilevel Logistic Regression of Accuracy During the Number-Letter Task

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	2.90	0.09	2.72 – 3.08	**<0.001**
Switch	-0.33	0.06	-0.45 – -0.22	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$	-0.49	0.23	-0.93 – -0.05	**0.030**
$\text{Condition}_{\text{PMR}}$	-0.11	0.23	-0.55 – 0.34	0.639
Time	-0.05	0.09	-0.21 – 0.12	0.583
$\text{Age}_{\text{Grand Mean Centered}}$	-0.01	0.01	-0.02 – 0.01	0.404
$\text{Condition}_{\text{Mindfulness}}$: Switch	0.20	0.14	-0.07 – 0.48	0.152
$\text{Condition}_{\text{PMR}}$: Switch	0.19	0.15	-0.10 – 0.49	0.200
Time : Switch	-0.26	0.12	-0.50 – -0.03	**0.027**
Time : $\text{Condition}_{\text{Mindfulness}}$	0.09	0.20	-0.30 – 0.48	0.667
Time : $\text{Condition}_{\text{PMR}}$	0.10	0.21	-0.31 – 0.50	0.638
Time : $\text{Condition}_{\text{Mindfulness}}$: Switch	0.35	0.28	-0.21 – 0.90	0.219
Time : $\text{Condition}_{\text{PMR}}$: Switch	0.18	0.30	-0.41 – 0.77	0.553

Random Effects		*Model Specifications*	
τ_{00} Subject	0.55	Observations	20980
τ_{11} Subject : Time	0.20	Df	20964
ρ_{01} Subject	-0.10	Deviance	9216.621
N Subject	77	AIC	9248.621
		log-Likelihood	-4608.311

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: binomial (logit).

Table C9

Generalized Linear Mixed Model of RT During the Attention Network Task for the Executive Control Network

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	375.98	2.74	370.62 – 381.35	**<0.001**
Target	103.58	0.90	101.82 – 105.35	**<0.001**
$Age_{Grand\ Mean\ Centered}$	3.39	0.53	2.35 – 4.43	**<0.001**
Accuracy	82.79	1.32	80.20 – 85.37	**<0.001**
Time	-37.82	2.55	-42.81 – -32.82	**<0.001**
$Condition_{Mindfulness}$	-20.7	3.72	-28.00 – -13.41	**<0.001**
$Condition_{PMR}$	13.02	3.68	5.82 – 20.23	**<0.001**
Cue_{Middle}	-11.29	1.10	-13.45 – -9.14	**<0.001**
$Cue_{Spatial}$	-12.32	1.11	-14.49 – -10.14	**<0.001**
Cue_{Double}	-11.93	1.10	-14.09 – -9.77	**<0.001**
Time : $Condition_{Mindfulness}$	0.07	4.51	-8.77 – 8.92	0.987
Time : $Condition_{PMR}$	-7.33	4.12	-15.40 – 0.74	0.075
Time : Target	-21.44	1.66	-24.70 – -18.18	**<0.001**
$Condition_{Mindfulness}$: Target	-10.18	1.84	-13.80 – -6.57	**<0.001**
$Condition_{PMR}$: Target	3.60	2.06	-0.44 – 7.63	0.081
Time : $Condition_{Mindfulness}$: Target	-12.66	2.58	-17.72 – -7.61	**<0.001**
Time : $Condition_{PMR}$: Target	-14.02	2.57	-19.05 – -8.99	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	261.62	Observations	46658
τ_{11} Subject : Time	354.24	Df	46637
ρ_{01} Subject	-0.07	Deviance	558291.759
N Subject	77	AIC	558333.759
		log-Likelihood	-279145.88

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table C10

Generalized Linear Mixed Model of RT During the Attention Network Task for the Alerting & Orienting Network

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	374.36	3.76	367.00 – 381.73	**<0.001**
Target	101.11	0.92	99.30 – 102.91	**<0.001**
$Age_{Grand\ Mean\ Centered}$	3.41	0.55	2.33 – 4.49	**<0.001**
Accuracy	84.13	1.34	81.50 – 86.76	**<0.001**
Time	-34.76	3.80	-42.20 – -27.31	**<0.001**
$Condition_{Mindfulness}$	-19.06	5.48	-29.80 – -8.33	**0.001**
$Condition_{PMR}$	12.41	8.37	-4.00 – 28.82	0.138
Cue_{Middle}	-11.39	1.17	-13.69 – -9.09	**<0.001**
$Cue_{Spatial}$	-12.67	1.16	-14.94 – -10.40	**<0.001**
Cue_{Double}	-11.85	1.18	-14.17 – -9.53	**<0.001**
Time : $Condition_{Mindfulness}$	1.97	7.30	-12.34 – 16.28	0.787
Time : $Condition_{PMR}$	-5.34	4.64	-14.43 – 3.76	0.250
Time : Cue_{Middle}	1.86	1.98	-2.02 – 5.74	0.347
Time : $Cue_{Spatial}$	1.32	1.97	-2.55 – 5.19	0.504
Time : Cue_{Double}	-2.71	1.93	-6.49 – 1.07	0.160
$Condition_{Mindfulness}$: Cue_{Middle}	2.65	2.30	-1.86 – 7.15	0.250
$Condition_{Mindfulness}$: $Cue_{Spatial}$	1.89	2.58	-3.16 – 6.94	0.463
$Condition_{Mindfulness}$: Cue_{Double}	3.56	2.21	-0.77 – 7.89	0.107
$Condition_{PMR}$: Cue_{Middle}	6.33	2.65	1.13 – 11.52	**0.017**
$Condition_{PMR}$: $Cue_{Spatial}$	-1.95	2.75	-7.33 – 3.43	0.478
$Condition_{PMR}$: Cue_{Double}	4.62	2.76	-0.80 – 10.04	0.095
Time : $Condition_{Mindfulness}$: Cue_{Middle}	12.36	3.49	5.52 – 19.20	**<0.001**
Time : $Condition_{Mindfulness}$: $Cue_{Spatial}$	9.23	3.49	2.39 – 16.07	**0.008**
Time : $Condition_{Mindfulness}$: Cue_{Double}	3.51	4.27	-4.87 – 11.88	0.412
Time : $Condition_{PMR}$: Cue_{Middle}	6.00	3.76	-1.37 – 13.37	0.110
Time : $Condition_{PMR}$: $Cue_{Spatial}$	12.49	5.09	2.52 – 22.46	**0.014**
Time : $Condition_{PMR}$: Cue_{Double}	9.54	4.39	0.94 – 18.13	**0.030**

Random Effects		*Model Specifications*	
τ_{00} Subject	262.41	Observations	46658
τ_{11} Subject : Time	353.58	Df	46627
ρ_{01} Subject	-0.08	Deviance	558476.054
N Subject	77	AIC	558538.054
		log-Likelihood	-279238.027

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table C11

Multilevel Logistic Regression of Accuracy During the Attention Network Task for the Executive Control Network

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	3.73	0.14	3.45 – 4.01	**<0.001**
Target	-2.76	0.07	-2.89 – -2.64	**<0.001**
$Condition_{Mindfulness}$	0.40	0.36	-0.30 – 1.10	0.265
$Condition_{PMR}$	0.22	0.37	-0.51 – 0.95	0.558
Time	0.03	0.14	-0.24 – 0.30	0.838
Cue_{Middle}	-0.08	0.06	-0.19 – 0.04	0.193
$Cue_{Spatial}$	-0.09	0.06	-0.21 – 0.03	0.132
Cue_{Double}	-0.07	0.06	-0.19 – 0.04	0.211
$Age_{Grand\ Mean\ Centered}$	0.05	0.02	0.02 – 0.08	**0.001**
$Condition_{Mindfulness}$: Target	-2.06	0.16	-2.38 – -1.74	**<0.001**
$Condition_{PMR}$: Target	-0.31	0.15	-0.60 – -0.01	**0.042**
Time : Target	0.27	0.13	0.02 – 0.53	**0.034**
Time : $Condition_{Mindfulness}$	-0.26	0.33	-0.90 – 0.39	0.437
Time : $Condition_{PMR}$	-0.49	0.34	-1.15 – 0.16	0.141
Time : $Condition_{Mindfulness}$: Target	0.13	0.33	-0.52 – 0.77	0.693
Time : $Condition_{PMR}$: Target	0.02	0.30	-0.57 – 0.61	0.946

Random Effects		*Model Specifications*	
τ_{00} Subject	1.48	Observations	46843
τ_{11} Subject : Time	1.00	Df	46824
ρ_{01} Subject	-0.25	Deviance	16872.924
N Subject	77	AIC	16910.924
		log-Likelihood	-8436.462

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: binomial (logit).

Table C12

Multilevel Logistic Regression of Accuracy During the Attention Network Task for the Alerting & Orienting Network

Predictors	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	3.78	0.14	3.50 – 4.06	**<0.001**
Cue_{Middle}	-0.08	0.06	-0.19 – 0.04	0.210
$Cue_{Spatial}$	-0.09	0.06	-0.20 – 0.03	0.149
Cue_{Double}	-0.06	0.06	-0.18 – 0.06	0.340
$Condition_{Mindfulness}$	-0.42	0.34	-1.09 – 0.25	0.218
$Condition_{PMR}$	0.11	0.36	-0.59 – 0.81	0.761
Time	0.14	0.14	-0.12 – 0.41	0.298
Target	-2.90	0.07	-3.03 – -2.77	**<0.001**
$Age_{Grand\ Mean\ Centered}$	0.05	0.02	0.02 – 0.08	**0.001**
$Condition_{Mindfulness}$: Cue_{Middle}	-0.04	0.14	-0.33 – 0.24	0.771
$Condition_{Mindfulness}$: $Cue_{Spatial}$	-0.09	0.14	-0.37 – 0.20	0.552
$Condition_{Mindfulness}$: Cue_{Double}	-0.16	0.14	-0.45 – 0.12	0.252
$Condition_{PMR}$: Cue_{Middle}	-0.11	0.15	-0.42 – 0.19	0.459
$Condition_{PMR}$: $Cue_{Spatial}$	-0.02	0.15	-0.32 – 0.28	0.886
$Condition_{PMR}$: Cue_{Double}	-0.01	0.16	-0.31 – 0.30	0.972
Time : Cue_{Middle}	0.15	0.12	-0.08 – 0.39	0.206
Time : $Cue_{Spatial}$	-0.03	0.12	-0.26 – 0.20	0.802
Time : Cue_{Double}	-0.05	0.12	-0.29 – 0.18	0.649
Time : $Condition_{Mindfulness}$	-0.21	0.32	-0.84 – 0.41	0.504
Time : $Condition_{PMR}$	-0.53	0.34	-1.19 – 0.13	0.118
Time : $Condition_{Mindfulness}$: Cue_{Middle}	-0.40	0.29	-0.96 – 0.17	0.167
Time : $Condition_{Mindfulness}$: $Cue_{Spatial}$	-0.28	0.28	-0.84 – 0.27	0.318
Time : $Condition_{Mindfulness}$: Cue_{Double}	-0.33	0.29	-0.89 – 0.23	0.251
Time : $Condition_{PMR}$: Cue_{Middle}	0.06	0.31	-0.54 – 0.67	0.840
Time : $Condition_{PMR}$: $Cue_{Spatial}$	0.27	0.31	-0.33 – 0.87	0.380
Time : $Condition_{PMR}$: Cue_{Double}	-0.19	0.31	-0.80 – 0.42	0.546

Random Effects		*Model Specifications*	
τ_{00} Subject	1.40	Observations	46843
τ_{11} Subject : Time	1.14	Df	46814
ρ_{01} Subject	-0.28	Deviance	17056.148
N Subject	77	AIC	17114.148
		log-Likelihood	-8528.074

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: binomial (logit).

Appendix D

Generalized Linear Mixed Model Comparison of Measures of Attentional Control and Executive Functioning

							LRT Test against final		
Task	*Model*	*AIC*	*BIC*	*logLik*	*deviance*	*df*	*Chi df*	*X2*	*p*
CPT	Interaction (final)	536187	536389	-268071	536141	23	-	-	-
	Main Effects	536273	536370	-268126	536251	11	12	110.13	**< 0.001**
	Random Effects	539286	539330	-269638	539276	5	18	3134.60	**< 0.001**
N-Back	Interaction (final)	532890	533106	-266420	532840	25	-	-	-
	Main Effects	532952	533064	-266463	532926	13	12	85.76	**<0.001**
	Random Effects	535108	535151	-267549	535098	5	20	2257.90	**<0.001**
Number-Letter	Interaction (final)	293694	293837	-146829	293658	18	-	-	-
	Main Effects	293727	293814	-146853	293705	11	7	46.95	**<0.001**
	Random Effects	294254	294293	-147122	294244	5	13	585.47	**<0.001**
ANT Executive Network	Interaction (final)	558334	558518	-279146	558292	21	-	-	-
	Main Effects	558532	558654	-279252	558504	14	7	212.05	**< 0.001**
	Random Effects	570127	570170	-285058	570117	5	16	11825	**< 0.001**
ANT Alerting & Orienting Network	Interaction (final)	558538	558809	-279238	558476	31	-	-	-
	Main Effects	558532	558654	-279252	558504	14	17	27.75	**0.048**
	Random Effects	570127	570170	-285058	570117	5	26	11641	**< 0.001**

Note . LTR = Likelihood ratio tests. Comparisons against models with main effects only and random effects only

Effects of Short Mindfulness Trainings on Executive Functioning in Two Randomized Controlled Double-Blinded Experiments

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ABSTRACT

While current models of mindfulness propose involvement of and benefits to cognitive control through mindfulness practice, empirical findings on the effects of short mindfulness trainings are inconclusive regarding their specificity and dose-response relations. Therefore, we compared a short mindfulness induction (Experiment 1, 45 minutes over three sessions) and a brief mindfulness training (Experiment 2, 80 minutes over four sessions) with relaxation trainings (progressive muscle relaxation; active control) and listening to podcasts (passive control) in two randomized controlled double-blinded trials. Reaction time tasks were used to assess the executive functions of updating (n-back), inhibition (CPT-II), and cognitive flexibility (number-letter task). Results of both experiments suggest no mindfulness-specific improvements in executive functions. We conclude that effects following the first stages of mindfulness training may not be specific to the practice or too transient to be reliably measured in pre-post intervention designs. Implications for research in the field are discussed.

Keywords: state mindfulness; focused attention meditation; progressive muscle relaxation; executive functions; inhibitory control; task switching; updating/working memory; cognitive training

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Mindfulness is defined as the ability to focus one's attention on being aware of the present moment, while maintaining a non-judgmental attitude towards current experiences, including any emotions, thoughts, and feelings that may be present (Kabat-Zinn, 1994). Cognitive models of mindfulness have proposed that core mechanisms of the practice involve attentional systems and/or executive functioning. A common denominator in these models is the involvement of attentional monitoring and cognitive control capacities to evoke and maintain attentional focus during meditational practices, such as focusing on the flow of breath in a breathing meditation. For example, both Bishop et al. (2004) and Jankowski & Holas (2014) define mindfulness as a meta-cognitive skill that consists of monitoring and control processes. Accordingly, Bishops et al.'s model posits two cognitive aspects of mindfulness (alongside the non-cognitive aspect of orientation to experience): 1) the monitoring of directed attention to the object in focus (e.g., the breath during a focused breathing meditation) and 2) executive control, enabling the inhibition of irrelevant thoughts, feelings, and sensations, as well as switching attention back to the object in focus when distractions arise. Similarly, Jankowski and Holas postulate that the evocation and maintenance of a mindful state stems from monitoring current experiences (e.g., thoughts, perceptions, imaginations) which in turn enables disengagement from distractions through cognitive control mechanisms (such as sustained attention, inhibition and task switching). In a similar vein, Malinowski's (2013) Liverpool Mindfulness Model, based on the network model of attention by Posner and Peterson (1990; Peterson & Posner, 2012), postulates that the attentional networks of alerting, orienting and executive control are the core processes involved in mindful states: Maintaining attention on the object of focus by means of sustained attention is accomplished by the alerting network; detecting and disengaging from distractions or mind wandering occurs via the involvement of the salience and executive control networks, respectively; and lastly, attention is shifted back to the task at hand by the orienting network. Attention regulation is also emphasized as a key aspect of mindful states in models that aim to conceptualize mindfulness beyond its cognitive mechanisms. For example, according to Shapiro et al. (2006), mindfulness encompasses paying attention with a kind and open attitude and specific intentions about the practice, and Hölzel et al. (2011) define five distinct but closely interacting component mechanisms, including attention regulation (especially conflict monitoring) in addition to body awareness, emotion regulation, and a change in perspective on the self, achieved by monitoring the moment-to-moment contents of experience. In line with the described propositions regarding the involvement and training of attentional and executive control in mindfulness practice, Jha et al. (2019) argue that training maintenance, monitoring, and disengagement from irrelevant information in mindfulness practice may improve working memory abilities.

In recent years, a growing body of research has focused on these postulated effects on attention and executive functioning after even short inductions of a mindful state or brief mindfulness trainings. Studies investigating the underlying cognitive mechanisms have either employed a single training session or several short meditations over a brief period, usually over the course of a week (for a classification of trainings by length, see Heppner & Shirk, 2018). Research in this area has mainly utilized breathing meditation, during which the practitioner is instructed to focus their attention on the in- and outflow of breath, for example by focusing on the sensation of air streaming in and out of the nostrils or the sensation of the chest rising and falling during breathing. If the mind is distracted by emerging thoughts, emotions or bodily sensations, the practitioner is to direct their attention back to the breath, while maintaining a non-judgmental attitude towards any distractions and gently letting them go. Breathing meditation is an example of a so-called focused attention meditation (FAM), which can be contrasted with a form of meditation during which the practitioner is to monitor whatever experiences arise in the present moment without a particular object of focus, known as open monitoring meditation (OMM; Lutz et al., 2008). It has been proposed that, in accordance with the meditational practices of either narrowing attentional focus in FAM or broadening attentional monitoring in OMM, FAM should strengthen top-down attentional control, while OMM should reduce attentional control processes (e.g., Colzato, Sellaro, Samara, Baas & Hommel, 2015; Colzato, Sellaro, Samara & Hommel, 2015; Colzato et al. 2016). However, replications of such differential effects following short inductions have been inconclusive (e.g., Ma et al., 2021; Sharpe et al., 2021), and some authors argue that at least some experience in FAM is necessary for a person to be able to establish a mental state of open monitoring (OM; Lutz et al., 2008; Malinowski, 2013; Vago & Silbersweig, 2012; but see Gill et al., 2020).

Whether short inductions or brief trainings of mindfulness have a specific effect on attentional control and executive functioning, and if so, based on what dose-response relationship, is still up to debate, as existing findings are inconclusive. In the following, we discuss studies that utilized short FAM inductions of either one or two practice sessions in a pre-post design, i.e., assessed cognitive functions before and after training. Jankowski & Holas (2020) compared the effects of a 10-minute breathing meditation with an auditory worry induction and free mind-wandering on an attention switching task after participants in all conditions received an induction of negative affect (which was assumed to reduce cognitive resources and decrease task efficiency). No differences in switch costs between conditions were present. Similarly, in a study using two practice sessions of 15 minutes each, Polak (2009) reported no effects of a mindful breathing meditation compared to a relaxation induction and a control condition (instructed to make a mental list of activities from the previous day) on the alerting, orienting and executive control network (measured with the Attention Network Task; ANT) and inhibitory control (Stroop Task). In comparison, Vieth & von Stockhausen (2022) compared the effects of a 2 x 20-minute breathing meditation with a relaxation induction (progressive muscle relaxation; PMR) and listening to podcasts as a passive control condition and found that switch costs in a Number-Letter Task improved for mindfulness compared to relaxation, although neither induction outperformed the passive control condition. Additionally, improvements in RT (but not in accuracy) were present for both mindfulness and relaxation on measures of executive control (ANT), inhibitory control (Continuous Performance Test-II; CPT-II) and updating/working memory (N-Back Task) compared to the passive control condition. Turning now to pre-post designs investigating the cognitive effects of slightly longer but still brief mindfulness trainings, Zeidan et al. (2010) compared the effects of a week-long breathing meditation training of 4 x 20 minutes to a passive control condition with audiobook listening on updating/working memory. The authors reported that compared to the passive control condition, the meditation group improved on a Symbol Digit Modalities Test (during which participants were asked to pair specific numbers with geometric figures using a reference key), but no effects were found for a variant of the N-back Task. In another study with a similar training duration, Tang et al. (2007) investigated the effects of a 5-day integrative body-mind training (consisting of body relaxation, breathing practice, mental imagery, and mindfulness), performed for 20 minutes each day, compared to a relaxation control condition (PMR) on attentional networks as measured by the ANT. Greater improvement was found for executive control following the integrative body-mind training compared to the relaxation training, but no changes between groups were found for the alerting and orienting network.

Mixed findings also come from studies which assessed cognitive functions only once after training. Norris et al. (2018) compared a 10-minute mindful breathing induction to a passive control condition in which participants listened to a recording of a magazine article and found an improvement in accuracy (but not RT) in incongruent Flanker trials and no differences between conditions in attentional network scores (ANT). In contrast to Norris et al.'s results, Larson et al. (2013) reported no effects on conflict resolution in a Flanker Task following a 15-minute breathing meditation compared to a passive control condition. Mrazek et al. (2012; second experiment) investigated the effects of 8 minutes of mindful breathing compared to a relaxation condition (active control; participants were asked to relax without falling asleep) and a reading condition (passive control) on mind wandering on the Sustained Attention to Response Task, in which the participant is asked to withhold a response to an infrequently occurring target. They found that both errors of commission (i.e., failure to withhold a response to a nontarget) and response time variability were reduced following the breathing meditation compared to both control conditions. Similarly, Wenk-Sormaz (2005; Study 1) investigated the effect of a 20-minute breathing meditation in comparison to a memory task (cognitive control) and a rest condition in which participants were told to rest in a seated position while letting their minds wander. The meditation condition exhibited smaller interference in incongruent Stroop trials compared to both control conditions. Lastly, Johnson et al. (2015) assessed attentional switching, which was measured by the Trail Making Test, and working memory, measured with the Symbol Digit

Modalities Test and a variant of the N-Back Task, and found no differences between participants who listened to a 25-minute breathing meditation, a sham meditation (lacking instructions for guiding attention to the breath and including longer periods of silence) or an audiobook listening control condition.

As can be seen, findings regarding the effects of short inductions and brief trainings in mindfulness are inconsistent for attentional networks as well as executive functions (i.e., response inhibition, task switching and updating/working memory). What is more, the integration of the described results is impeded by methodological differences between the studies. For example, while some studies include only active control conditions (e.g., Tang et al., 2007), others only include passive ones (e.g., Zeidan et al., 2010). However, to interpret findings as mindfulness-specific effects that go beyond effects of repeated testing, both an active and a passive control condition are required (Davidson, 2010; Vago et al. 2019). Another challenge in comparing results stems from variations between active control conditions (e.g., mind wandering in Jankowski & Holas, 2020; sham meditation in Johnson et al., 2015; relaxation in Vieth & von Stockhausen, 2022). While active controls are necessary to identify specific effects of mindfulness training, those discussed above control for very different aspects of training or contrasting mental states.

The described methodological differences and inconsistencies also render it impossible to estimate dose-response relations. For example, using pre-post designs with active and passive control conditions, Polak (2009) and Vieth and von Stockhausen (2022) found no mindfulness-specific effects on inhibitory control after total training durations of 30 and 40 minutes, while Mrazek et al. (2012) report improvements in inhibitory control (i.e., fewer errors of commission) following 8 minutes of mindful breathing compared to a relaxation condition and a passive control condition.

These inconclusive findings are also reflected in systematic reviews and meta-analyses. According to Chiesa et al.'s (2011) review, studies with short training durations show improvements in executive attention, but not in sustained and selective attention or attention switching. A review by Leyland et al. (2019) suggests no effects of mindfulness inductions on updating and set shifting, but minor evidence in support of effects on inhibition. In contrast, a meta-analysis by Gill et al. (2020) found no evidence for improvements in attention, basic executive functions, and memory; improvements were limited to higher-order functions (i.e., verbal reasoning, judgement/decision making and creativity). Regarding the dose-response relationship, Gill et al. (2020) found no significant effect of training duration in their meta-analyses.

In summary, while models of mindfulness predict positive effects of training on attentional control and executive functions, results following short mindfulness inductions and brief trainings are inconclusive. The high heterogeneity in experimental designs (e.g., lack of active or passive control conditions, variety of active control conditions or the lack of pre-post designs) hinders the integration and generalizability of findings. Obviously, these methodological problems cannot be solved with one or two studies. However, the present study aims to address these issues across two experiments in the following way: First, we follow up on the discussion of underlying mechanisms of short inductions or brief trainings. Given that maintaining attentional focus is difficult and effortful for FAM novices (Lutz et al., 2015), it has been argued that effects of mindfulness inductions or brief trainings in beginners may be unspecific to the practice and may in fact be achieved through relaxation (Fell et al., 2010; Vieth & von Stockhausen, 2022). It may be that for novices, FAM does not specifically improve attentional control and executive functioning, but rather evokes relaxation, which reduces dysfunctional tension, freeing up resources for improved attentional control and executive functioning (Eysenck et al., 2007). Contrasting the effects of FAM with relaxation techniques in short induction designs may thus provide insights into which mechanisms are at play at the first stages of meditational training. Therefore, we controlled for relaxation effects (active control) as well as for effects of repeated testing (podcast listening; passive control) and assessed states of mindfulness and relaxation as a manipulation check. Secondly, we addressed the question of dose-response relation by varying the spread and duration of practice time while keeping the total experimental time frame constant (over the course of 5 days). Regarding practice spread, it has long been established that distributed practice leads to better learning outcomes in comparison to massed practice (Carpenter et al., 2012; Ebbinghaus, 1885), and improves training transfer in cognitive trainings (e.g., Wang et al., 2014). Therefore, by keeping total practice time comparable to a previous study by Vieth & von Stockhausen (2022), but spreading practice across three instead of two sessions, Experiment 1 allows for a comparison of spread versus massed practice in short mindfulness inductions. Regarding total practice duration, we increased practice time from 45 minutes (Experiment 1) to 80 minutes (Experiment 2), in order to provide insights into when mindfulness-specific processes may start to unfold.

In the present study, we report on two randomized controlled double-blinded trials in which we compared the effects of a short induction (Experiment 1, three sessions of a breathing meditation) and a brief mindfulness training (Experiment 2, four sessions of a breathing meditation) with the effects of a relaxation training as an active control condition and podcast listening as a passive control condition on the executive functions of updating, inhibition, and cognitive flexibility (Miyake et al., 2000; Suchy, 2009). Relaxation was induced by PMR, which was selected as a standardized and evidence-based method for inducting a relaxed state (Manzoni et al., 2008; McCallie et al., 2006; Toussaint et al., 2021). All aspects of the experimental design except for training duration and number of training sessions were kept constant between the experiments to allow for a direct investigation of the dose-response relationship of mindfulness meditation. Furthermore, the experimental designs closely followed Vieth & von Stockhausen (2022), who found specific benefits of a short mindfulness induction (compared to relaxation) only for task switching but not for inhibition, updating/working memory or attentional networks and argued that mindfulness-specific effects might need more practice time to unfold. To test this prediction, we implemented a greater spread of practice time in Experiment 1 and extended the training duration and number of training sessions in Experiment 2. Executive functions were assessed with separate reaction time tasks. Both inductions and testing were delivered online.

If the effects of mindfulness inductions are different from those of relaxation, Experiment 1 should find improved task switching (as found by Vieth & von Stockhausen, 2022), improved inhibition (in accordance with Mrazek et al., 2012; Wenk-Sormaz, 2005), and improved updating (in line with Zeidan et al. 2010) in comparison to relaxation training (and compared to the passive control condition). Furthermore, if effects of short mindfulness trainings are stable and unfold with practice frequency and practice time, Experiment 2 should at least reproduce the findings of Experiment 1 or go beyond them.

1 General Method

1.1 Participants

A total of 96 participants took part in Experiment 1 (74 female, 1 non-binary, M_{age} = 23.5, SD_{age} = 5.43), and a total of 69 participants in Experiment 2 (57 female, 1 non-binary, M_{age} = 22.0, SD_{age} = 5.62). Participants were recruited through social media and university internal message boards for research participation. Participation was restricted to individuals aged 18 or older who reported not having engaged in meditation or mindfulness practice on a regular basis during the last three months[1]. If a person met the respective criteria, they were contacted by e-mail to arrange dates for online participation. At the date the participant had chosen for their first measurement point, they received an e-mail invitation with further information about participating in the online research (technical requirements and appropriate environment for participation) and a participation link. The link directed them to a page with written information about the used methodology, data protection and research ethics. After giving informed consent to participation and data storage, participants could begin with the first measurement. Invitations to the practice sessions and post-measurement were sent by e-mail as well. After completing the study, participants received course credit for compensation. Data collection, storage and anonymization met the current standards of the General Data Protection

[1] As experiments were conducted one year apart from each other, it was possible for participants to take part in both studies.

Regulation of the European Union (GDPR 2016/679). The experiments were approved by the ethical commission of the Department of Psychology at the local university.

1.2 Assessment of Executive Functions

All tasks were programmed with OpenSesame (Mathôt et al., 2012; version 3.3.11) and presented on a server using a JATOS interface (Lange et al., 2015; version 03.06.2001). Access to reaction time tasks was restricted to desktop computers and participants were instructed not to use mobile devices or devices with a touch screen and to wear headphones to reduce background noise. Responses were recorded via participants' keyboards.

1.2.1 Continuous Performance Test-II

The CPT-II (Conners, 2000; Conners et al., 2003) measures executive and impulse control in responses to a rarely occurring non-target and allows for the investigation of set maintenance/cognitive inhibition (Suchy, 2009). During the CPT-II, participants were presented with a continuous stream of single capital letters and were to indicate by key press every time a letter appeared on the screen, with the exception of the letter "X" (90% target trials; 10% non-target trials). Because the CPT-II requires responses to the frequent event of a target and not to the rare event of a non-target, it is well suited for collecting and investigating response times. Additionally, varying interstimulus intervals (ISI; 1000 ms, 1500 ms, 2000 ms) allow for investigating the ability to adapt to task demands (i.e., response speed in correspondence with ISI duration; Ballard, 2001).

Participants were instructed to place their right index finger on the space bar, to indicate targets by key press and to respond as quickly as possible without making mistakes. A session consisted of 360 trials (18 experimental blocks; 20 trials per block). After three blocks participants could take a short break if needed and were instructed to then continue with the experiment by key press. Between trials, participants were instructed to fixate on a fixation cross. Total task duration was 14 minutes on average.

1.2.2 N-Back Task

The N-back task (Kirchner, 1958) is used to assess set formation/updating abilities and working memory capacity (Chatham et al., 2011; Suchy, 2009). During the task, participants are presented with a stream of single letters and are to indicate if the letter currently presented matches the letter shown n steps before. To complete this task, participants need to keep information about previously presented letters in memory and make a comparison to the currently presented letter. As the task runs consecutively, participants need to constantly update the information held in memory. For example, during a 2-back block (n = 2), participants would indicate a target trial correctly if the following stream of letters occurred: H – G – H, but not if the presented letters were: H – G – X. The factor n is varied between blocks to in- or decrease the task's difficulty. Blocks were presented with equal frequencies and in randomized order.

Participants were instructed to place their right index finger on the 'L' key and their left index finger on the 'A' key and indicate n-back and non-n-back trials accordingly. During the task, participants were instructed to wear headphones for auditory feedback during the practice blocks and for noise reduction during the rest of the task. Participants were instructed to respond as quickly as possible without making mistakes. A session consisted of two practice and eight experimental blocks (48 trials each). After each block, participants could take a short break if needed and were instructed to then continue with the experiment by key press. Total task duration was 18 minutes on average.

1.2.3 Number-Letter Task

The Number-Letter Task assesses set shifting/task switching (Rogers & Monsell, 1995; Suchy, 2009). During the task, participants are presented with pairs of numbers and letters (for example A2, G5, K9) and are to execute one of two tasks depending on the stimulus' location. If the number-letter combination appears in the upper half of the screen (50% of all trials), participants should indicate whether the presented number is odd or even. If the number-letter combination appears in the lower half of the screen, participants should indicate whether the letter is a consonant or a vowel. Stimulus location was randomized, with participants either responding to repeated trials in the same location or switching tasks when the stimulus location changed. Comparing reaction time and response accuracy between tasks with and without task switching allows for investigating the ability to flexibly switch attention between tasks.

Participants were instructed to place their right index finger on the 'L' key and their left index finger on the 'A' key and to indicate either vowels or consonants or even or odd numbers, depending on the trial. Participants were instructed to respond as quickly as possible without making mistakes. A session consisted of three short practice blocks, during which participants received visual feedback in the form of either a green fixation cross indicating a correct response or a red fixation cross indicating a false response, followed by a single experimental block of 160 trials. Participants were instructed to fixate on a fixation cross in the center of the screen between trials. Total task duration was about 17 minutes.

1.3 Questionnaires

As a manipulation check, changes in state relaxation and mindfulness were assessed with the German version of the Smith Relaxation States Inventory 3s (SRSI3s; Smith, 2019 & 2020; German version: Vieth et al., 2020). The SRSI3s is a multi-dimensional inventory which assesses states of relaxation-, meditation-, and mindfulness-related experiences on four levels: basic relaxation (e.g., "*I feel rested and refreshed*"), quiet focus and awakening (e.g., "*My mind is quiet and still*"), transformation/transcendence (e.g., "*Things seem timeless, boundless, or infinite*"), and positive transcendent emotion (e.g., "*I feel thankful*"). Furthermore, the inventory includes scales for physical, emotional, and cognitive stress, which will not be utilized in the current paper. Participants are asked to indicate on a 6-point Likert-type scale to what degree the presented statements apply to their current feelings. The SRSI3s consists of 38 items in total.

To control for possible influences of mood (Van Steenbergen et al., 2010) and dispositional mindfulness on attentional and executive control, the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988; German version: Breyer & Bluemke, 2016) and the Five-Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006; German Version: Michalak et al., 2016) were used. The PANAS measures positive and negative emotions on two sub-scales and consists of 20 items in total, with ten items each assessing positive and negative affective states. Participants are asked to indicate on a 5-point Likert-type scale how well a certain affective state (e.g., "*scared*") applies to them currently. The FFMQ is a multi-facet questionnaire and assesses trait mindfulness on five dimensions: observing, describing, acting with awareness, nonjudging of inner experience and nonreactivity to inner experience. Participants were asked to indicate on a 5-point Likert-type scale how often the presented experiences (e.g., "*I am good at finding words to describe my feelings.*") applied to them generally. The FFMQ consists of 39 items in total.

Sociodemographic items concerned participants' age, gender, marital status, education, employment, and number of people in the household. Additionally, experienced impairment due to the COVID-19 pandemic (work/personal) and experienced burden due to the COVID-19 pandemic (work/personal) were assessed to control for their influences on induction effectiveness. Lastly, prior experience with mindfulness, related meditation practices and relaxation training were assessed[2].

[2]Further measures which were assessed but are not reported in this paper were the state anxiety scale of the State-Trait-Anxiety Inventory (STAI; Spielberger et al., 1970; German Version: Grimm, 2009) and the HEXACO scales for emotionality, openness to experience and agreeableness from the short version of the HEXACO Personality Inventory (HEXACO-60; Ashton & Lee 2007; German Version: Moshagen et al., 2014). Furthermore, both experiments assessed implicit bias (as the final task after assessment of executive functions): during Experiment 1, implicit bias was measured with the Shooter Task (Correll et al., 2002), which assesses the effect of ethnicity on shooting decisions, and during Experiment 2, the Avoidance Task (Essien and Stelter, 2017) was utilized, in which the effect of ethnicity on avoidance behavior in a social situation is measured.

1.4 Sound and Fidelity Checks for Online Inductions and Testing

1.4.1 Sound Check

To ensure that participants could hear the audio inductions (mindfulness, PMR) and podcasts correctly and to give them an opportunity to adjust the audio volume prior to inductions, a sound check was conducted with participants before induction deliverance. During the sound check, participants listened to a short audio-snippet of an animal noise (the sound of a cat, frog, horse, or dog) and were to select the correct animal out of 10 options. The sound was chosen randomly and could be replayed as often as participants chose. If the sound check was completed correctly, participants were directed to a page with written instructions regarding sitting posture, usage of headphones, and appropriate environment (participants were asked to find a separate room, if possible, where the induction and testing could be carried out in silence and to eliminate possible disturbances prior to starting the induction). After participants confirmed that they had carefully read the instructions and adhered to them, they were redirected to a page where they could start the induction (breathing meditation or PMR) or start the podcast by pressing a play button. If the sound check was not answered correctly, participants had two more trials to complete the task of identifying the correct animal. If participants failed to identify the animal correctly three times, they were notified that participation would only be possible if they were able to play and listen to audio files on their computer without complications. They were instructed to contact the experimenter if any technical issues had occurred during the sound check and that they would be able to continue their participation once the issues were resolved.

1.4.2 Fidelity of Online Testing and Deliverance

Participants' compliance was ensured by collecting data on whether audio files were played to completion and by informing participants that full compensation depended on completing all audio instructions as well as tasks and questionnaires. Participants who did not complete all audio files received partial compensation but were excluded from the final sample. Furthermore, participants were asked whether they were able to follow the audio instructions and to name any disturbances that had occurred (noise, interruption by another person, issues with internet connection or other). To ensure that participants completed the RT measures correctly, they were given written information on what to expect next throughout the experiment. In addition to detailed instructions for each RT task, this also included reminders between RT tasks regarding sitting posture, height of the computer screen, creating a distraction-free environment and using headphones for auditory feedback or noise reduction. Participants were also reminded to follow the task-specific instructions regarding taking breaks and received notification that the RT tasks would open in a separate browser window. After completion, each RT measurement was followed by a manipulation check in which the participant had to answer a multiple-choice question about which task they had just executed (4 options were given for each task; e.g. for the CPT-II, the correct answer would be "*During the task I had to react to every letter presented on the screen, except for when the letter 'X' occurred.*" and an example of an incorrect option is: "*During the task I had to react to a stimulus every time an audio signal was played.*"). Also, participants were asked to indicate whether distractions had occurred during the RT tasks (noise, interruption by another person, issues with internet connection or other). After each training as well as after finishing the assessment of executive functions (before the first training and after the last one), participants were asked to rate the overall disturbance intensity on a 4-point Likert-type scale from weak to strong.

1.5 Research Design

The research design was a 3 (mindfulness, PMR or podcast listening) x 2 (measurement point) experimental design. Inductions were delivered three times during Experiment 1 (after pre-measurement, between pre- and post-measurement and before post-measurement) and four times during Experiment 2 (after pre-measurement, two times between pre- and post-measurement, and before post-measurement). The mindfulness meditation was the experimental condition, PMR was the active control group and listening to podcasts served as a passive control condition. Participants were not informed about the existence of different experimental conditions but were all given the same information about taking part in a concentration training. Assignment of experimental group was randomized and executed automatically within the online experimental environment. Therefore, both experiments reported qualify as randomized controlled double-blinded research designs.

1.5.1 Experimental Conditions

In Experiment 1, mindfulness and relaxation instructions as well as podcast listening were delivered three times over the course of five days and in increasing length (10, 15 and 20 minutes). In Experiment 2, the trainings were delivered four times over the course of five days, with an equal length of 20 minutes, resulting in a longer total training duration while keeping the delivery time frame constant and thus remaining within the framework of short inductions and brief mindfulness trainings. Delivery took place via pre-recorded audio files. To vary the induction length, a 20-minute recording was shortened to obtain 10- and 15-minute versions. This was done to keep the inductions as standardized as possible (i.e., no added variations in speaker voice or speaking rate).

1.5.1.1 Mindfulness Meditation.

The mindfulness instructions focused on being present in and aware of the present moment, observing the flow of breath without interfering with it, observing and letting go of occurring thoughts and emotions, and overall acceptance of the present moment (source material for both mindfulness and PMR can be found in Appendix A). To achieve a conceptually clear differentiation between the mindfulness and relaxation conditions, the mindfulness instructions were clear of any phrases implying or directly instructing relaxation. The mindfulness instructions had been previously recorded by speakers (both male and female) whom the authors had trained to deliver mindfulness meditation inductions from a written script with a calm voice and a total length of approximately 20 minutes.

1.5.1.2 Progressive Muscle Relaxation.

During PMR (Jacobson, 1938), the participant is instructed to contract a muscle group (e.g., the upper thighs) for five to ten seconds while inhaling, and to let go of the contraction while exhaling. The instructions begin with contraction and release focused on the lower extremities and gradually progress upwards through the body. Between muscle groups, participants are asked to relax for 10 to 20 seconds and to focus on the changes in physiological experience when releasing the tension. The audio files for PMR with a female and male speaker were provided by two experienced PMR trainers who gave the authors permission to use their work (Bödeker, 2013; Kristenich, 2017). The recorded instructions were edited in such a way that they did not include any mindfulness-related phrasings (e.g., acceptance of the present moment).

1.5.1.3 Listening to Podcasts.

Four different podcasts were used which discussed historical sites and exceptional landscapes. They had been pretested for not evoking strong positive or negative emotional reactions (assessed via levels of arousal and valence) and for eliciting an average level of interest and engagement. In Experiment 1, podcast length was adjusted to the length of the mindfulness and PMR instructions. In both experiments, podcasts were presented in random order and no participant listened to the same podcast twice.

1.6 Procedure

The experiments consisted of two experimental sessions (i.e., two measurement points, including practice sessions), with either one (Experiment 1) or two (Experiment 2) audio-guided practice sessions (of meditation or relaxation or listening to a podcast) in between. After clicking on the URL provided by e-mail, participants were greeted in writing and provided with the written informed consent form. After participants read the form, were informed how they could reach the authors in case of questions and gave their consent, the first session started with a questionnaire regarding sociodemographic variables followed by questionnaires and assessments of executive functions in the following order: SRSI3s, CPT-II, STAI, PANAS, N-back Task, FFMQ-D, Number-Letter

Task, HEXACO-60 subscales, task to assess implicit bias (not reported here). Manipulation checks for the RT measures and the assessment of participation compliance and fidelity were placed as described above. The sequence of questionnaires and tests was the same across all measurement points and for all participants. Participants could take self-paced breaks between tasks. Following pre-measurement, participants proceeded to the sound check, and after completing it received the first audio induction (breathing meditation, PMR or podcast listening). Afterwards, participants were thanked and notified that they would be invited to the second session via e-mail. The second session (as well as third session in Experiment 2) only consisted of the second induction or podcast listening. The last session started with mindfulness or PMR practice or podcast listening. Afterwards, participants again completed all tasks and questionnaires in the same order. After completing all parts of the study, participants were debriefed about the purpose of the study, thanked for their participation, and received course credit.

2 Statistical Analyzes

Data pre-processing included cleaning RTs below 100 ms and above 1500 ms for the CPT-II and N-back tasks. Due to a greater response time window of up to 4000 ms in the Number-Letter Task, RT cut-off values below 100 ms and above 2000 ms were chosen. Unless stated otherwise, RT data included accurate and inaccurate trials, so that accuracy could be modeled as a fixed main effect. Participants were excluded if more than 40% of trials were missing. Following data pre-processing, single-trial RT data were analyzed with generalized linear mixed models (GLMMs) by maximum likelihood estimation. To account for the typically positively skewed distribution of empirical reaction times (Balota & Yap, 2011; Lo & Andrews, 2015) and based on the model fit of the current data, the inverse Gaussian distribution (Johnson et al., 1970; Tweedie, 1957) was selected. To test our hypothesis of mindfulness-specific effects on executive functioning following short training periods, likelihood ratio tests were used to compare models with an interaction term between measurement point and condition against a restricted model with main effects only. If the model with the interaction term explained substantially more variance in the data and the interaction reached significance, planned comparisons between conditions were conducted by calculating and testing estimated marginal mean (EMM) contrasts. The Tukey method for p-value adjustment was selected.

Discriminability (d' = z[Hits] - z[False Alarms]) was analyzed with linear regressions. Response frequencies (accuracy) were analyzed with logistic regressions, which allow for modeling a binomial distribution. Modelling of signal detection measures (i.e., fixed effects, contrast coding schemes, model testing) was analog to the analysis of reaction times.

Linear regressions were also used to analyze participants' experienced burden due to the COVID-19 pandemic, changes in state relaxation and mindfulness (SRSI3s) as a manipulation check, as well as to assess possible differences in trait mindfulness (FFMQ) at pre-measurement and changes in positive and negative affect (PANAS) as covariates in the RT models. Contrast coding schemes for measurement point and condition and model fit testing for the described models were performed as described above.

Data were modeled in R (R Core Team, 2020; version 4.0.2). Generalized linear mixed modeling was done with the lme4 package (Bates et al. 2015; version 1.1-23), p-values were obtained with the lmerTest package (Kuznetsova et al., 2017; version 3.1-2). Measures of signal detection (i.e., discriminability) were obtained with the psycho package (Makowski, 2018, version 0.5.0). EMMs were calculated with the emmeans package (Lenth, 2020; version 1.4.8.), figures of the results were obtained using the ggplot2 package (Wickham, 2016; 3.3.6).

3 Results

The reported model results will focus on effects of interest, which encompass task-specific effects (e.g., variation of ISI in the CPT-II) as well as interactions central to the hypothesis of the current paper (i.e., interaction terms comprising the factors measurement point and condition and their respective lower-order terms). The condition factor was coded with a custom contrast scheme with podcast listening as the reference category, comparing mindfulness and PMR to podcast listening. Therefore, simple effects for mindfulness and PMR as well as interactions including the factor condition always compare either mindfulness or PMR to podcast listening, while the intercept corresponds to the grand mean. Measurement point, accuracy, as well as task-specific effects of interest (e.g., ISI during the CPT-II) were contrast coded, meaning that each level of the respective categorial variable was compared to a reference category. The reference category for measurement point was pre-measurement, the reference category for accuracy was inaccurate trials. Furthermore, models included random intercepts for participants and random slopes for measurement point as recommended by Barr et al. (2013). Further references for test-specific variables are defined in the respective model descriptions below. Full models for all described analyses can be found in the supplementary material Appendix B (Experiment 1: Table B.1 –B.6; Experiment 2: Table B.7 – B.12). Likelihood ratio tests for model comparisons are reported in the results section, fit indices for GLMMs (Akaike information criterion, AIC; and Bayesian information criterion, BIC) can be found in the respective full model table. Planned comparisons ($EMM_{t1} - EMM_{t0}$) are reported to follow up on significant interaction terms, allowing for a comparison between all three conditions.

3.1 Experiment 1

3.1.1 Continuous Performance Test-II

One participant from the podcast listening condition provided only data at pre-measurement and was therefore removed. As incorrect responses (i.e., responses to non-targets) were rare at pre- and post-measurement (≤ 3.08% of all trials), only correct responses were included in the analysis (total data loss after cleaning: 3.89%).

3.1.1.1 Reaction Time.

The interaction model included a fixed effect for ISI (with 1000 ms as the reference category), a two-way interaction between measurement point and condition as well as a random intercept for participants and a random slope for measurement point. To test whether an interaction between measurement point and condition (i.e., effects of inductions) explains substantial variance in the data, the interaction model was compared to a restricted main effects-only model. A likelihood ratio test showed that the interaction model did not fit significantly better than a model without an interaction term, $\chi^2(2) = 2.43$, $p = 0.296$. According to this finding, neither mindfulness nor PMR induction affected inhibition RT performance from pre- to post-measurement beyond the effects of repeated testing, and the main effects-only model will be reported.

For the main effects-only model, the analysis showed a main effect for the ISI of 1500 ms, $\beta = 6.87$, $SE = 1.01$, $p < 0.001$, and the ISI of 2000 ms, $\beta = 14.87$, $SE = 1.02$, $p < 0.001$, with larger RT for longer ISIs in comparison to the ISI of 1000 ms, replicating effects of adaptation to task demands (i.e., increase in RT corresponding with ISI duration). Further main effects were present for measurement point, $\beta = -10.01$, $SE = 2.75$, $p < 0.001$, with RT decreasing from pre- to post-measurement, and for mindfulness, $\beta = 5.22$, $SE = 2.35$, $p = 0.026$, indicating overall greater RT for mindfulness compared to podcast listening.

3.1.1.2 Discriminability.

The interaction model for *d′* included a fixed effect for ISI and a two-way interaction between measurement point and condition. The comparison to a restricted main effects-only model showed that the described model did not fit better, $F(2, 515) = 2.53$, $p = 0.081$. The results thus indicate that a short mindfulness or relaxation induction had no effect on inhibition accuracy beyond repeated testing. The results of the main effects-only model showed that that all main effects were non-significant, $p \geq 0.075$.

3.1.2 N-Back Task

One participant (podcast condition) for which only data at pre-measurement was available was removed. Total data loss after data cleaning: 6.70%.

3.1.2.1 Reaction Time.

The interaction model included a fixed effect for accuracy, n-back level (with 1-back as the reference category) and target type (with non-target trials as the reference category), a two-way interaction between measurement point and condition, a random intercept for participants and a random slope for measurement point. A likelihood ratio test compared the interaction model to a restricted main effects-only model. The described model did not fit significantly better than a model without the interaction term, $\chi^2(2) = 0.048$, $p = 0.976$. Thus, results do not suggest a benefit of mindfulness or relaxation for updating latencies beyond repeated testing, and the main effects-only model will be reported.

The analysis showed a main effect for accuracy, β = -42.83, *SE* = 1.89, $p < 0.001$, with smaller RTs for correct than incorrect trials, and for target type, β = -34.93, *SE* = 1.93, $p < 0.001$, indicating shorter RTs for target compared to non-target trials. Furthermore, main effects were present for the n-back level 2-back, β = 118.23, *SE* = 1.90, $p < 0.001$, and 3-back, β = 123.51, *SE* = 1.95, $p < 0.001$, with RT larger for 2- and 3-back compared to 1-back trials, replicating findings of increasing task difficulty with greater *n*. A main effect was also present for measurement point, β = -96.61, *SE* = 3.45, $p < 0.001$, with RT decreasing from pre- to post-measurement, and for PMR, β = -9.58, *SE* = 3.40, $p = 0.005$, with RTs smaller in the relaxation induction group compared to podcast listening.

3.1.2.2 Discriminability.

The model analyzing discriminability (*d'*) included n-back level and target type and a two-way interaction between measurement point and condition. The model including the interaction term was compared to a restricted main effects-only model. Results show that the described model did not fit better, $F(2, 1133) = 0.13$, $p = 0.878$. Accordingly, the main effects-only model will be reported. A main effect was found for 3-back trials, β = 0.14, *SE* = 0.04, $p = 0.001$, indicating higher levels of discriminability for 3-back in comparison to 1-back trials, and for target type, β = -2.43, *SE* = 0.04, $p < 0.001$, indicating lower discriminability for target compared to non-target trials.

Thus, discriminability was not improved by the inductions compared to the passive control condition. Interestingly, higher discriminability was found for 3-back trials. As the RT analysis suggested longer RT for 3-back trials, participants may have achieved higher discriminability by trading speed for accuracy in trials with higher task demands.

3.1.3 *Number-Letter Task*

No participants needed to be removed. Total data loss after data cleaning: 2.29%.

3.1.3.1 Reaction Time.

The interaction model included a fixed effect for accuracy, a three-way interaction between measurement point, condition, and switch factor (with non-switch trials as the reference category), a random intercept for participant and a random slope for measurement point. A likelihood ratio test compared the model fit to a set of restricted models (a model including a two-way interaction excluding the switch factor and a main effects-only model). The described model fit significantly better than the model with a two-way interaction between measurement point and condition, $\chi^2(5) = 134.35$, $p < 0.001$, and the model without an interaction term, $\chi^2(7) = 134.87$, $p < 0.001$. Thus, results are reported for the model including the interaction between measurement point, condition, and switch factor.

A main effect was present for accuracy, β = -10.32, *SE* = 3.16, $p = 0.001$, indicating shorter RTs for correct trials. Simple effects were present for measurement point, β = -116.68, *SE* = 8.48, $p < 0.001$, indicating a decrease in RT from pre- to post-measurement in non-switch trials, and for the switch factor, β = 359.09, *SE* = 5.07, $p < 0.001$, with RT slower in switch compared to non-switch trials at pre-measurement, replicating the effects of switch costs on response latencies. Additionally, a simple effect for condition showed shorter RT for the mindfulness condition, β = -39.24, *SE* = 7.29, $p < 0.001$, and longer RT for PMR, β = 18.68, *SE* = 8.82, $p = 0.034$, in non-switch trials in comparison to podcast listening at pre-measurement. There was a two-way interaction between measurement point and mindfulness, β = -15.02, *SE* = 6.10, $p = 0.014$, and for PMR, β = -70.60, *SE* = 5.90, $p < 0.001$, indicating that both inductions led to a greater speed up in non-switch trials than podcast listening. The model also showed a three-way interaction between measurement point, switch factor and mindfulness, β = 68.20, *SE* = 5.63, $p < 0.001$, indicating that mindfulness was followed by a greater difference in RT between switch and non-switch trials compared to podcast listening and similarly for PMR, β = 116.26, *SE* = 6.72, $p < 0.001$, again indicating that compared to podcast listening, PMR was

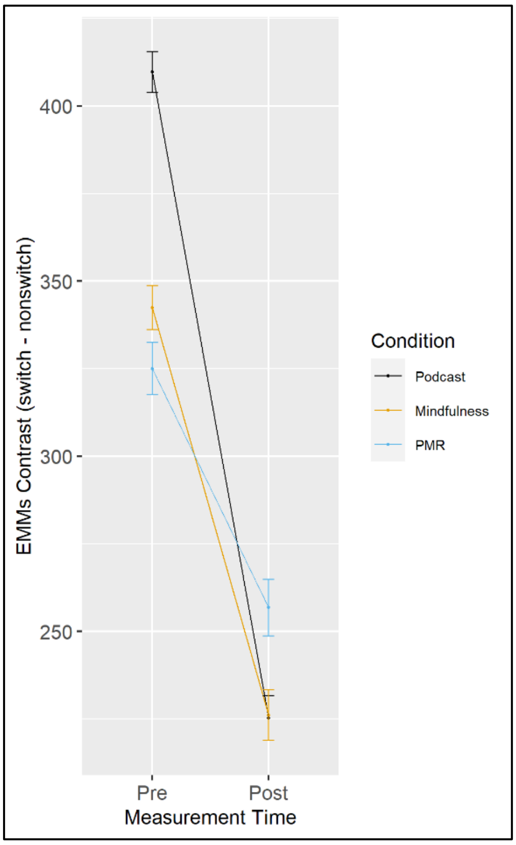

Figure 1.
Experiment 1: Switch Cost in RT During the Number-Letter Task

followed by a greater difference in RT between switch and non-switch trials. Figure 1 displays estimated marginal means contrasts for switch costs (EMM_{switch}- $EMM_{non\text{-}switch}$) resulting from the three-way interaction between measurement point, condition, and switch factor. Planned comparisons between conditions were calculated for pre-post differences in switch costs (see Table 1). Results show that podcast listening led to a larger decrease in switch costs from pre- to post-measurement than both mindfulness and PMR, whereas mindfulness resulted in a larger decrease in switch costs than PMR. Thus, the results indicate no effects of inductions on switching abilities beyond repeated testing, but an advantage for mindfulness compared to relaxation induction.

3.1.3.2 Accuracy.

The interaction model included a three-way interaction between measurement point, condition, and switch factor, as well as all two-way interactions containing these factors. The described model was compared to a set of restricted models. Likelihood ratio tests showed that the described model did not fit better than a model only including a two-way interaction between measurement point and condition, χ^2 (5) = 9.34, p = 0.096, but better than a main effects-only model, χ^2 (7) = 15.27, p = 0.033. Subsequently, comparing the two-way interaction model to the main effects-only model revealed a better fit for the latter, χ^2 (2) = 5.93, p = 0.051. Thus, there is no indication that response accuracy in task switching benefits from a short induction of a mindful state or a relaxation induction compared to repeated testing. The main effects-only model showed no significant main effects, all $p \geq$ 0.224.

3.1.4 Fidelity of Online Testing and Deliverance

Overall disturbance intensity was rated weak on average for all measurement points and practice sessions. Regarding possible distractions during RT measurements, 77.78% of participants at pre-measurement and 80.81% at post-measurement reported no distractions whatsoever (see Table 2). Most disturbances were either noise-related or interruptions by another person, while issues with the internet connection or other issues were less prominent. Other disturbances reported were mostly related to technical issues or technical distractions (e.g., a software pop-up notification appearing on the screen).

During the audio listening periods, 75.76% of participants at the first audio listening period, 76.77% at the second audio listening period, and 80.81% at the third audio listening period reported no distractions. Most disturbances fell into the category of noise, while interruptions by another person, issues with the internet connection and other issues were less prominent. Other disturbances during audio listening were mostly related to intrapersonal states or sensations as well as pets interrupting the practice.

Table 1

Experiment 1: Planned Comparisons of Switch Cost (RT) Reduction from Pre- to Post- Measurement during the Number-Letter Task

	Podcast - Mindfulness		Podcast - PMR		Mindfulness - PMR	
	T1 - T0: Estimate (SE)	*p*	*T1 - T0: Estimate (SE)*	*p*	*T1 - T0: Estimate (SE)*	*p*
Switch Cost (RT)	-68.2 (5.63)	**<0.001**	-116.3 (6.72)	**<0.001**	-48.1 (8.48)	**<0.001**

Note. T0 = pretest; T1 = posttest. P value adjustment: tukey method for comparing a family of 3 estimates.

Table 2

Experiment 1: Participants' Reports of Disctractions During Task Execution and Audio-Listening

	Experiment 1					
Disturbance Intensity	M_{t0}	SD_{t0}	M_{t1}	SD_{t1}	M_{t2}	SD_{t2}
(1 = weak to 4 = strong)	1.27	0.57	1.20	0.61	1.25	0.61

	Pre-Measurement		Second Audio Listening		Post-Measurement	
Distraction Categories	Audio Listening$_{t0}$	Task Execution$_{t0}$	Audio Listening	(No Task Execution)	Audio Listening$_{t1}$	Task Execution$_{t1}$
No Distractions	75.76%	77.78%	76.77%	-	80.81%	75.76%
Noise	12.12%	9.09%	10.10%	-	8.08%	10.10%
Interruption by a Person	7.07%	7.07%	6.06%	-	4.04%	10.10%
Internetconnection	4.04%	3.03%	5.05%	-	6.06%	5.05%
Other	4.04%	7.07%	4.04%	-	1.01%	1.01%

Note. t0 = Pre-measurement; t1 = Post-measurement. Items for possible distractions were not mutually exclusive, total percentages may exceed 100%.

3.1.5 Questionnaires

Results for the SRSI3s, PANAS, FFMQ, and experienced burden of the COVID-19 pandemic can be found in Appendix C, Table C.1 – Table C.12. Analysis for the SRSI3s scales revealed differences between groups in changes in basic relaxation from pre- to post- measurement. Planned comparisons showed that both mindfulness and PMR were higher for basic relaxation compared to podcast listening. Furthermore, the interaction between measurement point and condition was significant for quiet focus and awakening. Planned comparisons showed that both mindfulness and PMR led to greater increases in quiet focus and awakening compared to podcast listening. No differences in changes from pre- to post- measurement were found for transformation/transcendence and positive transcendent emotion. In conclusion, mindfulness as well as PMR led to greater increases in feelings of detachment and physical relaxation (basic relaxation) as well as in experiences of focus on the present moment and acceptance (quiet focus) compared to podcast listening, suggesting that both inductions were successful but also similar in inducing states of relaxation and focus.

As the results in Table 3 indicate, the interaction between measurement point and condition did not reach significance for PANAS scores, nor did the FFMQ show differences between groups at pre-measurement. Thus, analyses of RT and accuracy did not include covariates controlling for trait mindfulness or affective state. Participants rated their experienced burden and impairment due to the COVID-19 pandemic as moderate (work) and a lot (personal) on average, and this did not differ between experimental conditions.

3.2 Experiment 2

The described models for all executive functions assessed as well as questionnaires were identical to those described in Experiment 1. Full models can be found in Appendix B (Table B.7 – Table B.12).

3.2.1 Continuous Performance Test-II

As incorrect responses (i.e., responses to non-targets) were rare at pre- and post-measurement ($\leq$ 3.47% of all trials), only correct responses were included in the analysis (total data loss after cleaning: 5.11%).

3.2.1.1 Reaction Time.

A likelihood ratio test of the interaction model compared to a restricted main effects-only model showed that including the interaction did not lead to a significantly better fit, $\chi^2(2) = 1.29$, p =

0.525. As in Experiment 1, neither mindfulness nor PMR training improved inhibition RT performance from pre- to post-measurement beyond the effects of repeated testing.

The main effects-only model showed a main effect for the ISI of 1500 ms, β = 11.06, *SE* = 1.34, $p < 0.001$, and the ISI of 2000 ms, β = 21.32, *SE* = 1.27, $p < 0.001$, with larger RT for both longer ISIs in comparison to the ISI of 1000 ms, again replicating the effects regarding RT adaptation in correspondence with ISI duration. There was also a main effect for measurement point, β = -8.60, *SE* = 4.08, $p = 0.035$, indicating a decrease in RT from pre- to post-measurement. Furthermore, main effects were found for mindfulness, β = -26.73, *SE* = 6.15, $p < 0.001$, and PMR, β = -33.30, *SE* = 3.70, $p < 0.001$, indicating that both inductions were associated with lower RT compared to podcast listening.

3.2.1.2 Discriminability.

The interaction model for d' was compared to a restricted main effects-only model. Results showed that the interaction model did not fit better, $F(2, 356) = 0.68$, $p = 0.506$. The main effects-only model revealed no significant effects, all $p \geq 0.101$. Thus, inhibition accuracy was not improved by any training.

3.2.2 N-Back Task

Two participants (one from mindfulness and one from podcast listening) for which only data at pre-measurement was available were removed. One participant for which only 10.27% of trials remained after initial data cleaning was also removed from the analysis. Total data loss after cleaning: 7.40%.

3.2.2.1 Reaction Time.

The interaction model did not fit significantly better than a model without an interaction term, $\chi^2(2) = 0.52$, $p = 0.772$. Thus, neither mindfulness nor PMR led to beneficial decreases in updating latencies compared to a passive control condition. Accordingly, the main effects-only model will be reported.

The analysis showed a main effect for accuracy, β = -51.81, *SE* = 3.11, $p < 0.001$, with smaller RTs for correct than incorrect trials, and for target type, β = -34.41, *SE* = 2.62, $p < 0.001$, indicating shorter RTs for target compared to non-target trials. Furthermore, main effects were present for the n-back level 2-back, β = 103.32, *SE* = 2.29, $p < 0.001$, and 3-back, β = 118.39, *SE* = 2.37, $p < 0.001$, with RT larger for 2- and 3-back in comparison to 1-back trials, again replicating the effects of increasing task difficulty with greater *n*. Main effects were also present for measurement point, β = -103.31, *SE* = 3.42, $p < 0.001$, with RT decreasing from pre- to post-measurement, as well as for mindfulness, β = -

68.86, *SE* = 4.97, $p < 0.001$, and for PMR, β = -59.17, *SE* = 4.88, $p < 0.001$, with shorter RTs overall in both induction groups compared to podcast listening at both pre- and post-measurement.

3.2.2.2 Discriminability.

The model including the interaction term did not fit better than a restricted main effects-only model, $F(2,785) = 2.58$, $p = 0.076$. Thus, again as in Experiment 1, neither induction showed a beneficial effect on updating accuracy compared to a passive control condition. The main effects-only model showed a main effect for target type, β = -2.44, *SE* = 0.05, $p < 0.001$, indicating lower discriminability for target compared to non-target trials. All other main effects $p \geq 0.070$.

3.2.3 Number-Letter Task

Five participants (one from the mindfulness condition, two from PMR and two from podcast listening) for which only data at pre-measurement were available needed to be removed. One participant (PMR condition) with an average RT of 42ms was removed from the analysis. Total data loss: 7.25%.

3.2.3.1 Reaction Time.

The model including the three-way interaction between measurement point, condition and switch factor fit significantly better than a model with a two-way interaction between measurement point and condition, $\chi^2(5) = 45.28$ $p < 0.001$, and a main effects-only model, $\chi^2(7) = 45.50$, $p < 0.001$.

Simple effects were present for measurement point, β = -92.44, *SE* = 6.87, $p < 0.001$, indicating a decrease in RT from pre- to post-measurement for non-switch trials, and switch factor, β = 327.39, *SE* = 4.69, $p < 0.001$, with RT being slower for switch compared to non-switch trials at pre-measurement, replicating the effects of switch costs on response latencies that were also found in Experiment 1. A two-way interaction was present for measurement point and mindfulness, β = -20.77, *SE* = 9.12, $p = 0.023$, indicating a greater decrease in non-switch compared to switch trials for mindfulness compared to podcast listening. The two-way interaction between measurement point and PMR was nonsignificant, $p = 0.062$. A three-way interaction was found for measurement point, PMR and switch, β = 32.07, *SE* = 8.31, $p < 0.001$, indicating a greater difference in RT between switch and non-switch trials following PMR compared to podcast listening.

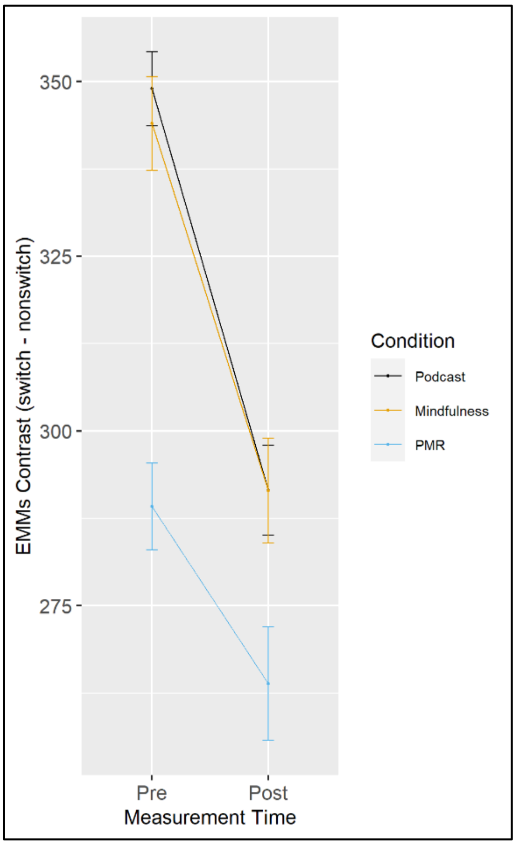

Figure 2.
Experiment 2: Switch Cost in RT During the Number-Letter Task

Figure 2 displays estimated marginal means contrasts for switch costs (EMM_{switch}- $EMM_{non\text{-}switch}$) resulting from the three-way interaction between measurement point, condition, and switch factor. Planned comparisons between conditions were calculated for pre-post differences in switch costs (see Table 4). The results show that PMR reduced switch costs to a lesser extent compared to mindfulness and podcast listening, while there was no difference in the decrease in switch costs between mindfulness and podcast listening. Thus, while the results again indicate no effects of inductions on switching abilities beyond repeated testing, a brief mindfulness training was again associated with an advantage in terms of switch cost reduction compared to a brief relaxation training.

3.2.3.2 Accuracy.

The model including the three-way interaction between measurement point, condition and switch factor was compared to a set of restricted models. The results show that the three-way interaction model fit better than a model including a two-way interaction between measurement point and condition, $\chi^2(5) = 19.75$, $p = 0.001$, and a main effects-only model, $\chi^2(7) = 20.58$, $p = 0.004$.

The three-way interaction model showed a simple effect for mindfulness, $\beta = -0.17$, $SE = 0.07$, $p = 0.015$, indicating overall lower accuracy for mindfulness compared to podcast listening. All two-way interactions including the measurement point factor were non-significant, $p \geq 0.078$, as were all three-way interactions, $p \geq 0.149$. Thus, response accuracy on a switching task was not affected by either induction.

Table 3

Experiment 1: Planned Comparisons of the SRSI3s from Pre- to Post- Measurement

	Podcast - Mindfulness		Podcast - PMR		Mindfulness - PMR	
	T1 - T0: Estimate (SE)	*p*	*T1 - T0: Estimate (SE)*	*p*	*T1 - T0: Estimate (SE)*	*p*
Basic Relaxation	-1.02 (0.32)	**0.005**	-1.23 (0.32)	**<0.001**	-0.21 (0.31)	0.778
Quiet Focus and Awakening	-0.77 (0.33)	**0.056**	-0.68 (0.33)	0.100	0.09 (0.32)	0.959

Note. T0 = pretest; T1 = posttest. P value adjustment: tukey method for comparing a family of 3 estimates.

Table 4

Experiment 2: Planned Comparisons of Switch Cost (RT) Reduction from Pre- to Post- Measurement during the Number-Letter Task

	Podcast - Mindfulness		Podcast - PMR		Mindfulness - PMR	
	T1 - T0: Estimate (SE)	*p*	*T1 - T0: Estimate (SE)*	*p*	*T1 - T0: Estimate (SE)*	*p*
Switch Cost (RT)	-4.91 (6.78)	0.749	-32.07 (8.31)	**<0.001**	-27.16 (10.79)	**0.032**

Note. T0 = pretest; T1 = posttest. P value adjustment: tukey method for comparing a family of 3 estimates.

3.2.4 Fidelity of Online Testing and Delivery

Overall disturbance intensity was rated as weak on average for all measurement points and all audio listening periods. Regarding possible distractions during RT measurements, 78.08% of participants at pre-measurement and 72.60% at post-measurement reported no distractions whatsoever (see Table 5). Most disturbances were noise related. Disturbances by another person, issues with the internet connection or other issues were less prominent. Other disturbances reported were mostly related to participants indicating fatigue.

Regarding the audio listening periods, 78.08% of participants at the first audio listening period, 75.34% at the second, 79.45% at the third and 75.34% of participants at the fourth audio listening reported no distractions. Most disturbances either fell into the category of distractions by another person or noise; issues with the internet connection or other distractions were less prominent. Other disturbances were mostly related to intrapersonal states or sensations as well as pets interrupting the practice.

3.2.5 Questionnaires

Analysis for the SRSI3s scales revealed no differences in changes from pre- to post-measurement between groups for any subscale. Results for the analyses of the SRSI3s, FFMQ, PANAS, and participants' experienced burden during the COVID-19 pandemic can be found in Appendix C, Table C.13 – Table C.24. No significant interaction effects were found for the PANAS scales, and the FFMQ showed no differences between groups at pre-measurement. Thus, no covariates for positive and negative affect or trait mindfulness were added into the models of RT and accuracy. Participants rated their experienced burden and impairment due to the COVID-19 pandemic as moderate (work) and between moderate and a lot (personal) on average, and this did not differ between experimental conditions.

Table 5

Experiment 2: Participants' Reports of Disctractions During Task Execution and Audio-Listening

	Experiment 2							
Disturbance Intensity (1 = weak to 4 = strong)	M_{t0}	SD_{t0}	M_{t1}	SD_{t1}	M_{t2}	SD_{t2}	M_{t3}	SD_{t3}
	1.25	0.49	1.19	0.49	1.22	0.58	1.23	0.51

	1st Audio Listening & Pre-Measurement		2nd Audio Listening		3rd Audio Listening		4th Audio Listening & Post-Measurement	
Distraction Categories	Audio Listening_{t0}	Task Execution_{t0}	Audio Listening	(No Task Execution)	Audio Listening	(No Task Execution)	Audio Listening_{t1}	Task Execution_{t1}
No Distractions	78.08%	78.08%	75.34%	-	79.45%	-	75.34%	72.60%
Noise	8.22%	12.33%	8.22%	-	8.22%	-	10.96%	13.70%
Interruption by a Person	12.33%	8.22%	10.96%	-	13.70%	-	8.22%	8.22%
Internetconnection	4.11%	0.00%	1.37%	-	1.37%	-	0.00%	0.00%
Other	2.74%	1.37%	4.11%	-	1.37%	-	5.48%	6.85%

Note. t0 = Pre-measurement; t1 = Post-measurement. Items for possible distractions were not mutually exclusive, total percentages may exceed 100%.

4 General Discussion and Conclusion

Cognitive models of mindfulness emphasize the role of attention regulation and executive functions during mindfulness practice and postulate that mindfulness trains these cognitive capacities (e.g., Bishop et al., 2004; Malinowski, 2013). Studies investigating the cognitive effects of mindfulness inductions and brief trainings have yielded mixed results for all attentional and executive functions for which the described models postulate effects. As outlined above, methodological differences between studies in the field, such as a lack of active or passive control conditions and high heterogeneity in the active controls used, make it difficult to integrate the current state of research. As a result, questions regarding mechanisms and the dose-response relation remain open. We aimed to address these issues in two ways. First, we contrasted effects of FAM with a relaxation technique to address the proposition that in early phases of mindfulness meditation, the practice does not produce specific states or effects (Fell et al., 2010; Vieth & von Stockhausen, 2022), but may induce relaxation, thereby freeing cognitive resources for improved attentional and executive functioning (Eysenck et al., 2007). Second, we increased the training length and number of training sessions from Experiment 1 to Experiment 2 while keeping other aspects of the research design constant. In doing so, we addressed the dose-response question by comparing the effects of a mindfulness induction with those of a brief mindfulness training. Our research questions were addressed in two randomized controlled double-blinded trials in a pre-post design with an active (relaxation induction, PMR) and passive control condition (podcast listening). We will discuss the results for identical tasks and associated cognitive functions from Experiment 1 and 2 jointly. Implications of the results for future research will be discussed below.

The results of both experiments showed that neither mindfulness nor PMR resulted in beneficial effects on response inhibition. This is in line with Polak (2009), who found no effects on Stroop interference compared to a relaxation induction and a passive control condition. However, our findings are in contrast with studies that did find improvement in measures of inhibition (Mrazek et al., 2012; Vieth & von Stockhausen, 2022; Wenk-Sormaz, 2005). Moreover, our results suggest no specific benefits of brief mindfulness practice for updating abilities. Similarly, previous studies showed no effects (Johnson et al., 2015), but also improvement stemming from both mindfulness and relaxation (Vieth & von Stockhausen, 2022) or improvement in only one of two updating tasks (Zeidan et al., 2010). Considering switching abilities, the increases in switching latencies and accuracy we found for mindfulness and relaxation did not go beyond the effects of repeated testing. However, switch costs decreased more strongly following mindfulness than relaxation in both experiments. These results (i.e., no benefit beyond repeated testing, but greater improvement for mindfulness compared to relaxation) are similar to those reported by Vieth & von Stockhausen (2022). Moreover, the finding of a lesser improvement in switching after mindfulness compared to podcast listening in Experiment 1 is in line with Wolff & Beste (2020), who found impaired switching after 15 minutes of FAM. The latter argue that increased focus following FAM may lead to rigid maintenance and shielding of current task goals, which in turn increases conflict between task sets. However, the results of Experiment 2 of the present study, Vieth & von Stockhausen (2022) and Jankowski & Holas (2020) do not suggest differences in switching abilities following FAM and passive control conditions. Still, the finding of greater improvement following mindfulness compared to relaxation in both experiments as well as in Vieth & von Stockhausen (2022) may provide initial evidence regarding differential effects of mindfulness and relaxation on task switching.

Our results contribute to findings in the field in that in two randomized controlled double-blinded trials, no specific benefit of mindfulness practice was found for any of the assessed executive functions of inhibition, updating and shifting. We also did not find specific benefits of relaxation practice, which was induced via an evidence-based technique and involved as thorough instructions as the mindfulness practice. In the following, we discuss possible factors in our study that might have affected its internal validity.

States of mindfulness and relaxation were assessed as a manipulation check with the SRSI3s. In Experiment 1, participants in the mindfulness as well as the relaxation condition reported increased scores in focus and relaxation from pre- to post-measurement, indicating that the practice had effects on the subjective experience of these states. However, in Experiment 2, which prolonged participants' practice duration and frequency, SRSI3s scores did not indicate changes in states of mindfulness and relaxation. It is therefore possible that trainings of the length investigated in our experiments do not lead to states which are sufficiently stable to reliably surface in subjective measures, let alone in the administered cognitive tests. This would also explain the broad spectrum of findings in the field, ranging from effects on cognition following single mindfulness sessions of only 8 minutes (Mrazek et al. 2012) to no specific benefits following inductions of 40 minutes (Vieth & von Stockhausen, 2022).

We administered all trainings and tests online, and it might be argued that the practice and testing conditions were too noisy to render systematic effects. However, as described above, we implemented several steps to secure fidelity by providing participants with thorough instructions about the necessary equipment and context for participation, sound checks for the audio listening, and verification of the fidelity of the online reaction time measurements and adherence to the audio instructions. We also assessed the frequency and quality of disturbances during practice and testing. A large majority of participants reported no disturbances at all, and the disturbances reported were rated to be of low impact for study participation. It therefore seems unlikely that our testing scheme was responsible for the lack of effects of mindfulness or relaxation practice on executive functions. In addition, analyses of the CPT-II, N-back Task and Number-Letter Task reliably replicated known effects of task characteristics (e.g., RT adaptation to prolonged ISIs during the CPT-II, increased RT with higher n-levels during the N-back Task, and RT switch costs for switch compared to non-switch trials during the Number-Letter Task). This also supports the claim that the tasks and testing were sufficiently sensitive to measure the respective executive function.

In summary, engaging in FAM three (Experiment 1) or four times (Experiment 2) across 5 days was not sufficient for mindfulness-specific improvements in inhibition, updating or task switching. The proposition that in the first stages of training, relaxation may yield similar effects as mindfulness cannot be rejected based on the present data. Previous studies suggest some parallels between effects (Fell et al., 2010; Vieth & von Stockhausen, 2022), and the manipulation check for Experiment 1 showed similar increases in focus and relaxation in both the mindfulness and the relaxation groups. It therefore seems worthwhile to pursue this question further and specify when the effects of both approaches, which have very different goals and use quite different means, begin to diversify. Based on our results, findings from other studies, and meta-analyses on the effects of brief mindfulness trainings, we would conclude that if short mindfulness inductions or very brief trainings have an effect, it may be too transient to surface reliably across tasks, laboratories, and variations in instruction length. A major question is therefore that of dose-response relations and underlying mechanisms. In the following section, we make some suggestions regarding how to proceed from these observations.

5 Limitations and Future Research

The present findings suggest that the cognitive benefits of mindfulness require longer periods of practice to unfold, and/or that the effects of short training periods are rather transient. In our experiments, we tried to address this issue of dose-response by increasing the practice time and frequency. However, the results suggest that our time window was still too short to assess longer-lasting, or more stable, benefits of the practice. Thus, the effects of FAM inductions may simply not cumulate, making an assessment before and after induction unsuitable to capture transient state benefits. Therefore, future studies may consider investigating the dose-response relationship for mindfulness meditation, attention, and executive functioning with experimental designs suitable for measuring transient states, such as ecological momentary assessments throughout participants' practice. For example, in an experience sampling study over 21 days of mindfulness-based home practice, Levi et al. (2021) reported no cumulative effects of the practice after completion of the 21-day training, but that the daily dose of meditation predicted state mindfulness, decentering, and emotional valence on a day-to-day basis. Similar designs utilizing experience sampling could also be beneficial for investigating the cognitive benefits of short mindfulness trainings. Assessing the transition from transient to more stable effects, which are reported after longer-term trainings and in respective reviews and meta-analyses (Másedas et al., 2020; Posner et al., 2015; Whitfield et al., 2021), would require longitudinal designs with additional measurement points between pre- and post-measurement.

Furthermore, as we have argued, future research in this field would benefit from a standardized approach regarding experimental design and methodology to allow for a better generalizability of results. We would suggest that such an approach include a baseline measurement to account for possible baseline differences within the respective sample, which need to be controlled for in order to establish the true effects of mindfulness inductions and brief trainings on attentional networks and executive functions (e.g., Leyland et al., 2019). Furthermore, the inclusion of passive control groups and random assignment to experimental conditions is recommended to control for effects of repeated testing (i.e., pretest sensitization effects, see for example Willson & Putnam, 1982; Kim & Willson, 2010). Regarding active control conditions, we chose to control for induced relaxation, as it is thought of as a by-product of mindfulness meditation training, especially in novices (Fell et al., 2010). Another promising active control condition is sham meditation, which accounts for expectancy effects that may affect results either positively or negatively (e.g., Prätzlich et al., 2015). For both active and passive control conditions, detailed instructions are necessary to control for variations between conditions within an experiment and for ease of comparison between studies. Additionally, assessing state mindfulness and relaxation as a manipulation check seems advisable to show that trainings had the intended effects and to assess possible differences or similarities between mindfulness and active control conditions such as relaxation or sham meditations.

Finally, our participant inclusion criteria regarding prior meditational experience excluded participants who had engaged in mindfulness practice within the last three months. While we would argue that continued practice is necessary to preserve any effects of mindfulness (e.g., Fell et al., 2010; Malinowski, 2013), future studies may consider longer periods of non-practice or the inclusion of naive participants only to control for a possible reactivation of prior mindfulness training effects.

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Appendix A

Supplementary Material Containing Instructions for the Mindfulness Meditation and Progressive Muscle Relaxation

Audio inductions were presented to the participants in German. Below are translated versions of the instructions.

Mindfulness Meditation

The mindfulness instructions focused on being present in and aware of the present moment, observing one's flow of breath without interfering with it, observing and letting go of thoughts and emotions that arise, and overall acceptance of the present moment.

Breathing Meditation Instructions

Sit down in a way that allows you to sit for a while in a well-balanced position. Straighten up slightly. Some people imagine a golden thread at the crown of their head that is pulling their head up.

(If you like,) close your eyes. If you tend to get sleepy, fixate on any point in the room in front of you.

Feel where your body is in contact with the chair, where it is supported and sustained.

1-minute pause

Now focus your attention on your breath. Breathe in and breathe out and be aware of this process of breathing. Become aware of your breath, where your body moves in the rhythm of your breath, and how. In the chest, in the stomach, or some other place?

2-minute pause

Feel the ever-changing sensations as the current of your breath flows in and out of the body.

3-minute pause

Allow your body to breathe with its own rhythm. You don't need to change or monitor anything. You are an observer of the processes that come naturally, from one moment to the next.

1-minute pause

Thoughts of all kinds may come to your mind. This is totally fine. Once you've taken note of this, simply direct your attention back to your breathing.

1-minute pause

If you are being critical of yourself, notice this and bring your attention back to your breathing. Be patient with yourself.

2-minute pause

Now take in the complete breathing process once again:

On the inhale, how breath flows in through the nose and lifts the chest and stomach.

On the exhale, how it flows out from the nose and then lowers the chest and belly and the pause after the exhale.

3-minute pause

Broaden your attention again to your whole body and to the space where you are sitting. Let your breath flow again without observing it.

2-minute pause

When you feel ready, open your eyes or let your gaze wander around the room. Be ready and awake for what is next in store for you.

Progressive Muscle Relaxation

Audio recordings of PMR were created by third parties; therefore, a full transcript of the recordings cannot be provided. An excerpt is presented below. During PMR, the participant is instructed to contract a specific muscle group (e.g., the upper thighs) for five to ten seconds during inhalation, and to let go of the tension during exhalation. The instructions start with rounds of contraction and release focused on the lower extremities and gradually progress upwards through the body. Between muscle groups, subjects are asked to take 10 to 20 seconds to relax and focus on changes in their physiological experience after releasing the tension.

Progressive Muscle Relaxation Instructions

Excerpt, for the right and left hand

Now focus your attention on your right arm. Now clench your right hand into a fist. Hold the tension for five seconds and pay attention to the feeling of tension, while the rest of the body is relaxed.

3-second pause

Now release again.

5-second pause

Observe how a pleasant relaxation spreads through your right hand.

Now move your attention to your left arm. Now clench your left hand into a fist. Hold the tension for five seconds, paying attention to the feeling of tension, while the rest of the body is relaxed.

3-second pause

Now release again.

5-second pause

Observe how a pleasant relaxation spreads through your left hand.

6-second pause

Notice how the muscles in the hands and arms loosen up and how the relaxation spreads. From the upper arms, to the forearms, to the fingertips. Both arms and both hands are now pleasantly relaxed and the muscles completely released.

Appendix B
Full Model Tabels

Table B.1

Experiment 1: Generalized Linear Mixed Models of RT During the Continuous Performance Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	404.55	2.43	399.79 – 409.31	**<0.001**
ISI_{1500}	6.87	1.01	4.88 – 8.85	**<0.001**
ISI_{2000}	14.87	1.02	12.88 – 16.86	**<0.001**
Time	-10.01	2.75	-15.39 – -4.62	**<0.001**
$Condition_{Mindfulness}$	5.22	2.35	0.61 – 9.83	**0.026**
$Condition_{PMR}$	-2.60	2.61	-7.70 – 2.51	0.319

Random Effects		*Model Specifications*	
τ_{00} Subject	451.45	Observations	65729
τ_{11} Subject : Time	648.70	Df Residuals	65719
ρ_{01} Subject	-0.51	Deviance	800583
N Subject	95	AIC	800603
		BIC	800694
		log-Likelihood	-400291

Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	404.32	3.56	397.34 – 411.31	**<0.001**
ISI_{1500}	6.85	1.07	4.75 – 8.94	**<0.001**
ISI_{2000}	14.87	1.10	12.71 – 17.03	**<0.001**
Time	-9.47	3.58	-16.48 – -2.45	**0.008**
$Condition_{Mindfulness}$	11.64	3.28	5.21 – 18.06	**<0.001**
$Condition_{PMR}$	2.22	3.53	-4.69 – 9.13	0.530
Time : $Condition_{Mindfulness}$	-21.91	4.13	-29.99 – -13.82	**<0.001**
Time : $Condition_{PMR}$	-15.91	3.16	-22.09 – -9.73	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	449.40	Observations	65729
τ_{11} Subject : Time	632.52	Df Residuals	65717
ρ_{01} Subject	-0.51	Deviance	800580
N Subject	95	AIC	800604
		BIC	800713
		log-Likelihood	-400290

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table B.2

Experiment 1: Linear Regressions of d' During the Continuous Performance Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	2.76	0.05	2.66 – 2.85	**<0.001**
ISI_{1500}	-0.15	0.08	-0.31 – 0.02	0.076
ISI_{2000}	-0.12	0.08	-0.29 – 0.04	0.137
Time	-0.09	0.07	-0.22 – 0.05	0.211
$Condition_{Mindfulness}$	0.01	0.09	-0.16 – 0.18	0.950
$Condition_{PMR}$	-0.04	0.09	-0.21 – 0.13	0.660
Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	2.77	0.05	2.67 – 2.86	**<0.001**
ISI_{1500}	-0.15	0.08	-0.31 – 0.02	0.082
ISI_{2000}	-0.13	0.08	-0.29 – 0.04	0.128
Time	-0.10	0.07	-0.23 – 0.04	0.160
$Condition_{Mindfulness}$	-0.18	0.12	-0.42 – 0.06	0.142
$Condition_{PMR}$	-0.10	0.12	-0.34 – 0.14	0.419
Time : $Condition_{Mindfulness}$	0.37	0.17	0.03 – 0.71	**0.031**
Time : $Condition_{PMR}$	0.12	0.17	-0.22 – 0.46	0.485

Note . P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table B.3

Experiment 1: Generalized Linear Mixed Model of RT During the N-Back Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	783.69	4.93	774.03 – 793.34	**<0.001**
Accuracy	-42.83	1.89	-46.53 – -39.13	**<0.001**
Target	-34.93	1.93	-38.72 – -31.14	**<0.001**
$Nback_{2back}$	118.23	1.90	114.51 – 121.94	**<0.001**
$Nback_{3back}$	123.51	1.95	119.69 – 127.32	**<0.001**
Time	-96.61	3.45	-103.38 – -89.84	**<0.001**
$Condition_{Mindfulness}$	10.55	8.69	-6.49 – 27.59	0.225
$Condition_{PMR}$	-9.58	3.40	-16.24 – -2.91	**0.005**
Random Effects			*Model Specifications*	
τ_{00} Subject	1439.29		Observations	63820
τ_{11} Subject : Time	1286.30		Df Residuals	63808
ρ_{01} Subject	-0.58		Deviance	870315
N Subject	95		AIC	870339
			BIC	870448
			log-Likelihood	-435158

Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	783.6	7.55	768.80 – 798.39	**<0.001**
Accuracy	-42.83	2.21	-47.16 – -38.50	**<0.001**
Target	-34.93	2.10	-39.04 – -30.82	**<0.001**
$Nback_{2back}$	118.23	1.86	114.59 – 121.87	**<0.001**
$Nback_{3back}$	123.51	1.96	119.67 – 127.34	**<0.001**
Time	-96.41	3.03	-102.36 – -90.46	**<0.001**
$Condition_{Mindfulness}$	13.11	3.00	7.23 – 18.98	**<0.001**
$Condition_{PMR}$	-7.17	3.88	-14.78 – 0.44	0.065
Time : $Condition_{Mindfulness}$	-4.48	4.18	-12.67 – 3.71	0.284
Time : $Condition_{PMR}$	-4.25	2.84	-9.82 – 1.32	0.135
Random Effects			*Model Specifications*	
τ_{00} Subject	1438.99		Observations	63820
τ_{11} Subject : Time	1286.24		Df Residuals	63806
ρ_{01} Subject	-0.57		Deviance	870315
N Subject	95		AIC	870343
			BIC	870470
			log-Likelihood	-435158

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table B.4

Experiment 1: Linear Regressions of d' During the N-Back Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.41	0.02	0.37 – 0.44	**<0.001**
Target	-2.43	0.04	-2.50 – -2.36	**<0.001**
$Nback_{2back}$	0.01	0.04	-0.07 – 0.10	0.746
$Nback_{3back}$	0.14	0.04	0.06 – 0.23	**0.001**
Time	0.04	0.04	-0.03 – 0.11	0.272
$Condition_{Mindfulness}$	-0.04	0.04	-0.13 – 0.04	0.313
$Condition_{PMR}$	0.04	0.04	-0.05 – 0.13	0.352

Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.41	0.02	0.37 – 0.44	**<0.001**
Target	-2.43	0.04	-2.50 – -2.36	**<0.001**
$Nback_{2back}$	0.01	0.04	-0.07 – 0.10	0.746
$Nback_{3back}$	0.14	0.04	0.06 – 0.23	**0.001**
Time	0.04	0.04	-0.03 – 0.11	0.274
$Condition_{Mindfulness}$	-0.04	0.04	-0.13 – 0.04	0.313
$Condition_{PMR}$	0.04	0.04	-0.05 – 0.13	0.352
Time : $Condition_{Mindfulness}$	-0.03	0.09	-0.20 – 0.14	0.750
Time : $Condition_{PMR}$	0.01	0.09	-0.16 – 0.19	0.873

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table B.5

Experiment 1: Generalized Linear Mixed Models of RT During the Number-Letter Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	1075.71	4.42	1067.06 – 1084.37	**<0.001**
Accuracy	-11.13	2.86	-16.74 – -5.52	**<0.001**
Switch	287.27	3.61	280.20 – 294.34	**<0.001**
Time	-168.01	5.25	-178.30 – -157.72	**<0.001**
$Condition_{Mindfulness}$	-55.93	4.84	-65.42 – -46.44	**<0.001**
$Condition_{PMR}$	-26.95	6.46	-39.61 – -14.29	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	10130.21	Observations	30017
τ_{11} Subject : Time	11366.25	Df Residuals	30007
ρ_{01} Subject	-0.64	Deviance	443514
N Subject	96	AIC	443534
		BIC	443617
		log-Likelihood	-221757

Two-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	1074.90	4.97	1065.15 – 1084.65	**<0.001**
Accuracy	-11.12	2.91	-16.83 – -5.41	**<0.001**
Switch	287.3	4.02	279.43 – 295.17	**<0.001**
Time	-166.77	7.62	-181.71 – -151.84	**<0.001**
$Condition_{Mindfulness}$	-60.49	6.24	-72.73 – -48.25	**<0.001**
$Condition_{PMR}$	-8.54	5.65	-19.60 – 2.53	0.131
Time : $Condition_{Mindfulness}$	7.73	9.94	-11.74 – 27.21	0.436
Time : $Condition_{PMR}$	-32.41	5.87	-43.91 – -20.91	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	10080.20	Observations	30017
τ_{11} Subject : Time	11277.54	Df Residuals	30005
ρ_{01} Subject	-0.64	Deviance	443513
N Subject	96	AIC	443537
		BIC	443637
		log-Likelihood	-221757

Three-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	1045.79	8.99	1028.16 – 1063.41	**<0.001**
Accuracy	-10.32	3.16	-16.52 – -4.12	**0.001**
Switch	359.09	5.07	349.16 – 369.01	**<0.001**
Time	-116.68	8.48	-133.31 – -100.06	**<0.001**
$Condition_{Mindfulness}$	-39.24	7.29	-53.52 – -24.95	**<0.001**
$Condition_{PMR}$	18.68	8.82	1.41 – 35.96	**0.034**
Time : Switch	-123.08	4.17	-131.25 – -114.90	**<0.001**
Time : $Condition_{Mindfulness}$	-15.02	6.10	-26.98 – -3.06	**0.014**
Time : $Condition_{PMR}$	-70.60	5.90	-82.15 – -59.04	**<0.001**
$Condition_{Mindfulness}$: Switch	-67.33	6.55	-80.17 – -54.50	**<0.001**
$Condition_{PMR}$: Switch	-84.70	5.87	-96.21 – -73.19	**<0.001**
Time : $Condition_{Mindfulness}$: Switch	68.20	5.63	57.16 – 79.24	**<0.001**
Time : $Condition_{PMR}$: Switch	116.26	6.72	103.10 – 129.43	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	9525.92	Observations	30017
τ_{11} Subject : Time	11072.38	Df Residuals	30000
ρ_{01} Subject	-0.61	Deviance	443379
N Subject	96	AIC	443413
		BIC	443554
		log-Likelihood	-221689

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table B.6

Experiment 1: Multilevel Logistic Regressions of Accuracy During the Number-Letter Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.02	0.02	-0.02 – 0.06	0.409
Switch	-0.03	0.02	-0.07 – 0.02	0.264
Time	-0.01	0.02	-0.05 – 0.04	0.675
$Condition_{Mindfulness}$	-0.01	0.03	-0.07 – 0.05	0.720
$Condition_{PMR}$	-0.03	0.03	-0.09 – 0.02	0.224
Two-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.02	0.02	-0.02 – 0.06	0.381
Switch	-0.03	0.02	-0.07 – 0.02	0.259
Time	-0.01	0.02	-0.06 – 0.03	0.622
$Condition_{Mindfulness}$	0.00	0.04	-0.07 – 0.08	0.903
$Condition_{PMR}$	-0.08	0.04	-0.16 – -0.00	**0.038**
Time : $Condition_{Mindfulness}$	-0.03	0.06	-0.14 – 0.08	0.596
Time : $Condition_{PMR}$	0.10	0.06	-0.01 – 0.21	0.085
Three-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.00	0.01	-0.02 – 0.02	0.921
Switch	-0.03	0.02	-0.07 – 0.02	0.236
Time	-0.01	0.02	-0.06 – 0.03	0.606
$Condition_{Mindfulness}$	-0.01	0.03	-0.07 – 0.05	0.725
$Condition_{PMR}$	-0.03	0.03	-0.09 – 0.02	0.236
Time : Switch	-0.06	0.05	-0.15 – 0.03	0.201
Time : $Condition_{Mindfulness}$	-0.03	0.06	-0.14 – 0.08	0.606
Time : $Condition_{PMR}$	0.10	0.06	-0.01 – 0.21	0.087
$Condition_{Mindfulness}$: Switch	0.01	0.06	-0.11 – 0.12	0.924
$Condition_{PMR}$: Switch	0.06	0.06	-0.05 – 0.17	0.274
Time : $Condition_{Mindfulness}$: Switcl	0.15	0.11	-0.08 – 0.37	0.201
Time : $Condition_{PMR}$: Switch	-0.12	0.11	-0.35 – 0.10	0.271

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: binomial (logit).

Table B.7

Experiment 2: Generalized Linear Mixed Models of RT During the Continuous Performance Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	402.01	5.30	391.62 – 412.40	**<0.001**
ISI_{1500}	11.06	1.34	8.44 – 13.69	**<0.001**
ISI_{2000}	21.32	1.27	18.84 – 23.81	**<0.001**
Time	-8.60	4.08	-16.61 – -0.60	**0.035**
$Condition_{Mindfulness}$	-26.73	6.15	-38.79 – -14.68	**<0.001**
$Condition_{PMR}$	-33.30	3.70	-40.56 – -26.05	**<0.001**
Random Effects			*Model Specifications*	
τ_{00} Subject	503.63		Observations	47801
τ_{11} Subject : Time	603.28		Df Residuals	47791
ρ_{01} Subject	-0.43		Deviance	581974
N Subject	69		AIC	581994
			BIC	582082
			log-Likelihood	-290987

Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	401.91	2.78	396.45 – 407.36	**<0.001**
ISI_{1500}	11.07	1.22	8.67 – 13.47	**<0.001**
ISI_{2000}	21.33	1.23	18.92 – 23.74	**<0.001**
Time	-8.98	3.83	-16.48 – -1.47	**0.019**
$Condition_{Mindfulness}$	-25.79	3.59	-32.84 – -18.75	**<0.001**
$Condition_{PMR}$	-32.31	3.50	-39.17 – -25.45	**<0.001**
Time : $Condition_{Mindfulness}$	-6.24	3.53	-13.15 – 0.67	0.077
Time : $Condition_{PMR}$	-4.63	3.10	-10.71 – 1.45	0.136
Random Effects			*Model Specifications*	
τ_{00} Subject	495.05		Observations	47801
τ_{11} Subject : Time	591.22		Df Residuals	47789
ρ_{01} Subject	-0.43		Deviance	581973
N Subject	69		AIC	581997
			BIC	582102
			log-Likelihood	-290986

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table B.8

Experiment 2: Linear Regressions of d' During the Continuous Performance Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	2.80	0.04	2.72 – 2.89	**<0.001**
ISI_{1500}	-0.14	0.10	-0.34 – 0.06	0.162
ISI_{2000}	-0.09	0.10	-0.29 – 0.10	0.348
Time	0.11	0.08	-0.05 – 0.28	0.172
$Condition_{Mindfulness}$	0.16	0.10	-0.03 – 0.36	0.101
$Condition_{PMR}$	-0.08	0.10	-0.27 – 0.12	0.458
Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	2.80	0.04	2.72 – 2.89	**<0.001**
ISI_{1500}	-0.14	0.10	-0.34 – 0.06	0.157
ISI_{2000}	-0.10	0.10	-0.29 – 0.10	0.340
Time	0.12	0.08	-0.05 – 0.28	0.160
$Condition_{Mindfulness}$	0.17	0.10	-0.03 – 0.36	0.097
$Condition_{PMR}$	-0.08	0.10	-0.27 – 0.12	0.457
Time : $Condition_{Mindfulness}$	0.23	0.20	-0.16 – 0.63	0.244
Time : $Condition_{PMR}$	0.10	0.20	-0.30 – 0.50	0.618

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table B.9

Experiment 2: Generalized Linear Mixed Models of RT During the N-Back Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	754.41	6.96	740.78 – 768.04	**<0.001**
Accuracy	-51.81	3.11	-57.92 – -45.71	**<0.001**
Target	-34.41	2.62	-39.55 – -29.27	**<0.001**
$Nback_{2back}$	103.32	2.29	98.82 – 107.81	**<0.001**
$Nback_{3back}$	118.39	2.37	113.74 – 123.05	**<0.001**
Time	-103.31	3.42	-110.00 – -96.61	**<0.001**
$Condition_{Mindfulness}$	-68.86	4.97	-78.60 – -59.11	**<0.001**
$Condition_{PMR}$	-59.16	4.88	-68.73 – -49.60	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	1495.22	Observations	44002
τ_{11} Subject : Time	1543.40	Df Residuals	43990
ρ_{01} Subject	-0.65	Deviance	594691
N Subject	66	AIC	594715
		BIC	594819
		log-Likelihood	-297345

Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	754.63	13.75	727.68 – 781.57	**<0.001**
Accuracy	-51.82	3.08	-57.86 – -45.79	**<0.001**
Target	-34.42	2.72	-39.74 – -29.10	**<0.001**
$Nback_{2back}$	103.32	2.22	98.96 – 107.67	**<0.001**
$Nback_{3back}$	118.39	2.35	113.77 – 123.00	**<0.001**
Time	-103.73	3.35	-110.29 – -97.16	**<0.001**
$Condition_{Mindfulness}$	-68.41	4.44	-77.12 – -59.71	**<0.001**
$Condition_{PMR}$	-46.29	4.53	-55.18 – -37.41	**<0.001**
Time : $Condition_{Mindfulness}$	-0.53	8.69	-17.56 – 16.51	0.952
Time : $Condition_{PMR}$	-20.33	5.29	-30.69 – -9.97	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	1485.73	Observations	44002
τ_{11} Subject : Time	1529.26	Df Residuals	43988
ρ_{01} Subject	-0.64	Deviance	594690
N Subject	66	AIC	594718
		BIC	594840
		log-Likelihood	-297345

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table B.10

Experiment 2: Linear Regressions of d' During the N-Back Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	1.58	0.04	1.50 – 1.66	**<0.001**
Target	-2.44	0.05	-2.53 – -2.35	**<0.001**
$Nback_{2back}$	0.00	0.06	-0.11 – 0.10	0.930
$Nback_{3back}$	0.10	0.06	-0.01 – 0.21	0.070
Time	0.07	0.05	-0.02 – 0.15	0.153
$Condition_{Mindfulness}$	0.08	0.06	-0.03 – 0.18	0.167
$Condition_{PMR}$	0.05	0.06	-0.06 – 0.16	0.352
Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	1.58	0.04	1.50 – 1.66	**<0.001**
Target	-2.44	0.05	-2.53 – -2.35	**<0.001**
$Nback_{2back}$	0.00	0.06	-0.11 – 0.10	0.930
$Nback_{3back}$	0.10	0.06	-0.01 – 0.21	0.069
Time	0.07	0.05	-0.02 – 0.16	0.144
$Condition_{Mindfulness}$	-0.05	0.08	-0.20 – 0.11	0.543
$Condition_{PMR}$	0.01	0.08	-0.15 – 0.16	0.915
Time : $Condition_{Mindfulness}$	0.25	0.11	0.03 – 0.46	**0.025**
Time : $Condition_{PMR}$	0.09	0.11	-0.13 – 0.31	0.435

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table B.11

Experiment 2: Generalized Linear Mixed Models of RT During the Number-Letter Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	903.05	6.78	889.76 – 916.34	**<0.001**
Accuracy	-1.15	3.52	-8.05 – 5.75	0.743
Switch	301.79	4.15	293.65 – 309.92	**<0.001**
Time	-104.13	7.68	-119.18 – -89.09	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$	-16.16	7.69	-31.23 – -1.10	**0.036**
$\text{Condition}_{\text{PMR}}$	-19.66	8.19	-35.71 – -3.60	**0.016**

Random Effects		*Model Specifications*	
τ_{00} Subject	3885.90	Observations	18582
τ_{11} Subject : Time	3717.15	Df Residuals	18572
ρ_{01} Subject	-0.62	Deviance	260861
N Subject	63	AIC	260881
		BIC	260959
		log-Likelihood	-130430

Two-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	903.26	8.86	885.89 – 920.62	**<0.001**
Accuracy	-1.15	3.94	-8.86 – 6.57	0.770
Switch	301.78	4.53	292.91 – 310.66	**<0.001**
Time	-104.37	8.80	-121.62 – -87.12	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$	-2.92	20.67	-43.43 – 37.60	0.888
$\text{Condition}_{\text{PMR}}$	-16.05	20.95	-57.11 – 25.00	0.443
Time : $\text{Condition}_{\text{Mindfulness}}$	-19.58	21.30	-61.34 – 22.17	0.358
Time : $\text{Condition}_{\text{PMR}}$	-5.40	21.61	-47.76 – 36.95	0.802

Random Effects		*Model Specifications*	
τ_{00} Subject	3886.75	Observations	18582
τ_{11} Subject : Time	3711.71	Df Residuals	18570
ρ_{01} Subject	-0.62	Deviance	260861
N Subject	63	AIC	260885
		BIC	260979
		log-Likelihood	-130430

Three-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	896.69	6.94	883.08 – 910.30	**<0.001**
Accuracy	-0.90	3.33	-7.42 – 5.62	0.787
Switch	327.39	4.69	318.20 – 336.58	**<0.001**
Time	-92.44	6.87	-105.90 – -78.98	**<0.001**
$\text{Condition}_{\text{Mindfulness}}$	-1.79	7.17	-15.85 – 12.27	0.803
$\text{Condition}_{\text{PMR}}$	-0.80	9.66	-19.72 – 18.13	0.934
Time : Switch	-45.12	5.72	-56.33 – -33.91	**<0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$	-20.77	9.12	-38.64 – -2.90	**0.023**
Time : $\text{Condition}_{\text{PMR}}$	-13.84	7.41	-28.36 – 0.69	0.062
$\text{Condition}_{\text{Mindfulness}}$: Switch	-4.98	5.92	-16.58 – 6.62	0.400
$\text{Condition}_{\text{PMR}}$: Switch	-59.78	5.90	-71.35 – -48.21	**<0.001**
Time : $\text{Condition}_{\text{Mindfulness}}$: Switch	4.91	6.78	-8.38 – 18.21	0.469
Time : $\text{Condition}_{\text{PMR}}$: Switch	32.07	8.31	15.78 – 48.36	**<0.001**

Random Effects		*Model Specifications*	
τ_{00} Subject	3866.38	Observations	18582
τ_{11} Subject : Time	3704.37	Df Residuals	18565
ρ_{01} Subject	-0.61	Deviance	260815
N Subject	63	AIC	260849
		BIC	260983
		log-Likelihood	-130408

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: inverse.gaussian (identity).

Table B.12

Experiment 2: Multilevel Logistic Regressions of Accuracy During the Number-Letter Task

Main Effects-Only Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.02	0.02	-0.03 – 0.07	0.371
Switch	-0.02	0.03	-0.08 – 0.03	0.459
Time	-0.02	0.03	-0.08 – 0.03	0.455
$Condition_{Mindfulness}$	0.03	0.03	-0.03 – 0.10	0.339
$Condition_{PMR}$	-0.02	0.03	-0.09 – 0.05	0.563
Two-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.02	0.02	-0.03 – 0.07	0.377
Switch	-0.02	0.03	-0.08 – 0.03	0.460
Time	-0.02	0.03	-0.08 – 0.03	0.466
$Condition_{Mindfulness}$	0.00	0.05	-0.09 – 0.10	0.974
$Condition_{PMR}$	-0.04	0.05	-0.13 – 0.06	0.453
Time : $Condition_{Mindfulness}$	0.06	0.07	-0.07 – 0.20	0.363
Time : $Condition_{PMR}$	0.03	0.07	-0.10 – 0.17	0.630
Three-Way Interaction Model	*Estimates*	*SE*	*95% CI*	*p*
(Intercept)	0.05	0.03	-0.01 – 0.10	0.109
Switch	-0.07	0.04	-0.15 – 0.01	0.089
Time	-0.07	0.04	-0.15 – 0.01	0.080
$Condition_{Mindfulness}$	-0.17	0.07	-0.30 – -0.03	**0.015**
$Condition_{PMR}$	-0.12	0.07	-0.25 – 0.02	0.096
Time : Switch	0.10	0.06	-0.01 – 0.21	0.078
Time : $Condition_{Mindfulness}$	0.16	0.10	-0.03 – 0.35	0.100
Time : $Condition_{PMR}$	0.01	0.10	-0.18 – 0.20	0.891
$Condition_{Mindfulness}$: Switch	0.34	0.10	0.15 – 0.53	**<0.001**
$Condition_{PMR}$: Switch	0.16	0.10	-0.03 – 0.35	0.108
Time : $Condition_{Mindfulness}$: Switcl	-0.20	0.14	-0.47 – 0.07	0.149
Time : $Condition_{PMR}$: Switch	0.04	0.14	-0.23 – 0.32	0.755

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method. Model fit by maximum likelihood (Laplace Approximation); family: binomial (logit).

Appendix C
Analyses of Questionnaires

Table C.1

Experiment 1: Linear Regressions of the SRSI3s Basic Relaxation Scale

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*LRT Test*		
								RSS	*F*	*p*
(Intercept)	2.95	0.07	2.82 – 3.08	**<0.001**						
Time	-0.48	0.07	-0.62 – -0.35	**<0.001**						
$Condition_{Mindfulness}$	-0.42	0.10	-0.62 – -0.23	**<0.001**						
$Condition_{PMR}$	0.22	0.09	0.03 – 0.41	**0.021**						
					192	0.273 / 0.262	188	163.5		
(Intercept)	2.95	0.07	2.82 – 3.08	**<0.001**						
Time	-0.47	0.07	-0.59 – -0.34	**<0.001**						
$Condition_{Mindfulness}$	-0.42	0.09	-0.61 – -0.24	**<0.001**						
$Condition_{PMR}$	0.22	0.09	0.04 – 0.40	**0.017**						
Time : $Condition_{Mindfulness}$	0.37	0.09	0.19 – 0.56	**<0.001**						
Time : $Condition_{PMR}$	-0.13	0.09	-0.31 – 0.05	0.141						
					192	0.332 / 0.314	186	150.33	8.14	**< 0.001**

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.2

Experiment 1: Linear Regressions of the SRSI3s Quiet Focus and Awakening Scale

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*LRT Test*		
								RSS	*F*	*p*
(Intercept)	2.99	0.07	2.86 – 3.12	**<0.001**						
Time	-0.30	0.07	-0.43 – -0.17	**<0.001**						
$Condition_{Mindfulness}$	-0.35	0.10	-0.54 – -0.15	**<0.001**						
$Condition_{PMR}$	0.19	0.09	0.00 – 0.37	**0.047**						
					192	0.148 / 0.134	188	161.62		
(Intercept)	2.99	0.07	2.86 – 3.12	**<0.001**						
Time	-0.29	0.07	-0.42 – -0.16	**<0.001**						
$Condition_{Mindfulness}$	-0.35	0.1	-0.54 – -0.16	**<0.001**						
$Condition_{PMR}$	0.19	0.09	0.00 – 0.37	**0.045**						
Time : $Condition_{Mindfulness}$	0.24	0.1	0.05 – 0.43	**<0.013**						
Time : $Condition_{PMR}$	-0.14	0.09	-0.33 – 0.04	0.128						
					192	0.176 / 0.154	186	156.30	3.16	**0.045**

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.3

Experiment 1: Linear Regressions of the SRSI3s Transformation/Transcendence Scale

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*LRT Test* *RSS*	*F*	*p*
(Intercept)	2.12	0.07	1.99 – 2.26	**<0.001**						
Time	-0.26	0.07	-0.39 – -0.12	**<0.001**						
$\text{Condition}_{\text{Mindfulness}}$	-0.13	0.10	-0.33 – 0.06	0.180						
$\text{Condition}_{\text{PMR}}$	0.13	0.10	-0.06 – 0.32	0.188						
					192	0.078 / 0.064	188	172.11		
(Intercept)	2.12	0.07	1.98 – 2.26	**<0.001**						
Time	-0.25	0.07	-0.39 – -0.11	**<0.001**						
$\text{Condition}_{\text{Mindfulness}}$	-0.13	0.10	-0.33 – 0.06	0.182						
$\text{Condition}_{\text{PMR}}$	0.13	0.10	-0.06 – 0.32	0.190						
Time : $\text{Condition}_{\text{Mindfulness}}$	0.08	0.10	-0.12 – 0.27	0.456						
Time : $\text{Condition}_{\text{PMR}}$	-0.06	0.10	10 -0.25 – 0.13	0.547						
					192	0.081 / 0.057	186	171.54	0.31	0.734

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.4

Experiment 1: Linear Regressions of the SRSI3s Positive Transcendent Emotion Scale

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*LRT Test* *RSS*	*F*	*p*
(Intercept)	3.38	0.08	3.22 – 3.55	**<0.001**						
Time	-0.12	0.08	-0.29 – 0.04	0.139						
$\text{Condition}_{\text{Mindfulness}}$	-0.33	0.12	-0.57 – -0.09	**0.007**						
$\text{Condition}_{\text{PMR}}$	0.26	0.12	0.03 – 0.50	**0.026**						
					192	0.053 / 0.038	188	254.88		
(Intercept)	3.38	0.08	3.21 – 3.55	**<0.001**						
Time	-0.12	0.08	-0.29 – 0.05	0.157						
$\text{Condition}_{\text{Mindfulness}}$	-0.33	0.12	-0.57 – -0.09	**0.007**						
$\text{Condition}_{\text{PMR}}$	0.26	0.12	0.03 – 0.50	**0.027**						
Time : $\text{Condition}_{\text{Mindfulness}}$	0.12	0.12	-0.12 – 0.36	0.328						
Time : $\text{Condition}_{\text{PMR}}$	-0.11	0.12	-0.35 – 0.12	0.339						
					192	0.059 / 0.034	186	253.20	0.62	0.540

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.5

Experiment 1: Linear Regressions of the PANAS PA Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	2.71	0.06	2.60 – 2.82	**<0.001**						
Time	0.02	0.06	-0.09 – 0.13	0.675						
Condition$_{Mindfulness}$	-0.13	0.08	-0.29 – 0.03	0.111						
Condition$_{PMR}$	0.14	0.08	-0.01 – 0.30	0.073						
					192	0.021 / 0.005	188	112.26		
(Intercept)	2.71	0.06	2.60 – 2.82	**<0.001**						
Time	0.03	0.06	-0.08 – 0.14	0.646						
Condition$_{Mindfulness}$	-0.13	0.08	-0.29 – 0.03	0.112						
Condition$_{PMR}$	0.14	0.08	-0.01 – 0.30	0.074						
Time : Condition$_{Mindfulness}$	0.06	0.08	-0.10 – 0.22	0.457						
Time : Condition$_{PMR}$	-0.08	0.08	-0.23 – 0.08	0.317						
					192	0.027 / 0.000	186	111.62	0.54	0.586

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.6

Experiment 1: Linear Regressions of the PANAS NA Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	1.92	0.05	1.83 – 2.01	**<0.001**						
Time	0.04	0.05	-0.06 – 0.13	0.422						
Condition$_{Mindfulness}$	0.05	0.07	-0.09 – 0.18	0.501						
Condition$_{PMR}$	-0.17	0.07	-0.30 – -0.04	**0.011**						
					192	0.040 / 0.025	188	80.62		
(Intercept)	1.92	0.05	1.83 – 2.01	**<0.001**						
Time	0.04	0.05	-0.06 – 0.13	0.444						
Condition$_{Mindfulness}$	0.05	0.07	-0.09 – 0.18	0.502						
Condition$_{PMR}$	-0.17	0.07	-0.30 – -0.04	**0.011**						
Time : Condition$_{Mindfulness}$	-0.04	0.07	-0.17 – 0.10	0.580						
Time : Condition$_{PMR}$	0.04	0.07	-0.09 – 0.17	0.541						
					192	0.043 / 0.017	186	80.43	0.22	0.799

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.7

Experiment 1: Linear Regression of the FFMQ Total Score at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.22	0.05	3.12 – 3.32	**<0.001**		
$Condition_{Mindfulness}$	0.01	0.07	-0.13 – 0.16	0.884		
$Condition_{PMR}$	0.03	0.07	-0.11 – 0.17	0.636		
					96	0.005 / -0.017

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.8

Experiment 1: Linear Regression of the FFMQ Observing Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.35	0.06	3.23 – 3.48	**<0.001**		
$Condition_{Mindfulness}$	0.09	0.09	-0.09 – 0.26	0.316		
$Condition_{PMR}$	0.00	0.09	-0.17 – 0.17	0.976		
					96	0.014 / -0.007

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence

Table C.9

Experiment 1: Linear Regression of the FFMQ Describing Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.42	0.09	3.25 – 3.59	**<0.001**		
$Condition_{Mindfulness}$	-0.04	0.12	-0.28 – 0.21	0.772		
$Condition_{PMR}$	0.12	0.12	-0.12 – 0.36	0.326		
					96	0.011 / -0.010

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence

Table C.10

Experiment 1: Linear Regression of the FFMQ Acting With Awareness Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.03	0.06	2.90 – 3.16	**<0.001**		
$Condition_{Mindfulness}$	-0.04	0.09	-0.22 – 0.15	0.686		
$Condition_{PMR}$	-0.04	0.09	-0.21 – 0.14	0.685		
					96	0.007 / -0.014

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence

Table C.11

Experiment 1: Linear Regression of the FFMQ Nonjudging of Inner Experience Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.49	0.09	3.31 – 3.67	**<0.001**		
$Condition_{Mindfulness}$	-0.02	0.13	-0.28 – 0.24	0.888		
$Condition_{PMR}$	0.03	0.13	-0.22 – 0.29	0.794		
					96	0.001 / -0.021

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence

Table C.12

Experiment 1: Linear Regression of the FFMQ Nonreactivity to Inner Experience Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	2.76	0.07	2.62 – 2.90	**<0.001**		
$Condition_{Mindfulness}$	0.06	0.10	-0.14 – 0.27	0.547		
$Condition_{PMR}$	0.06	0.10	-0.14 – 0.26	0.563		
					96	0.016 / -0.006

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence

Table C.13

Experiment 2: Linear Regressions of the SRSI3s Basic Relaxation Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	2.85	0.07	2.71 – 3.00	**<0.001**						
Time	-0.31	0.07	-0.46 – -0.17	**<0.001**						
$\text{Condition}_{\text{Mindfulness}}$	0.12	0.10	-0.08 – 0.32	0.242						
$\text{Condition}_{\text{PMR}}$	-0.08	0.10	-0.28 – 0.13	0.453						
					138	0.135 / 0.115	134	94.287		
(Intercept)	2.85	0.07	2.71 – 3.00	**<0.001**						
Time	-0.31	0.07	-0.46 – -0.17	**<0.001**						
$\text{Condition}_{\text{Mindfulness}}$	0.12	0.10	-0.08 – 0.32	0.245						
$\text{Condition}_{\text{PMR}}$	-0.08	0.10	-0.28 – 0.13	0.456						
Time : $\text{Condition}_{\text{Mindfulness}}$	0.02	0.10	-0.18 – 0.22	0.854						
Time : $\text{Condition}_{\text{PMR}}$	0.01	0.10	-0.19 – 0.22	0.908						
					138	0.135 / 0.103	132	94.222	0.046	0.9551

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.14

Experiment 2: Linear Regressions of the SRSI3s Quiet Focus and Awakening Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	2.99	0.06	2.87 – 3.12	**<0.001**						
Time	-0.20	0.06	-0.33 – -0.08	**0.002**						
$\text{Condition}_{\text{Mindfulness}}$	0.18	0.09	-0.00 – 0.35	0.050						
$\text{Condition}_{\text{PMR}}$	-0.12	0.09	-0.30 – 0.06	0.193						
					138	0.096 / 0.075	134	76		
(Intercept)	2.99	0.06	2.87 – 3.12	**<0.001**						
Time	-0.20	0.06	-0.33 – -0.07	**0.002**						
$\text{Condition}_{\text{Mindfulness}}$	0.18	0.09	-0.00 – 0.36	0.051						
$\text{Condition}_{\text{PMR}}$	-0.12	0.09	-0.30 – 0.06	0.195						
Time : $\text{Condition}_{\text{Mindfulness}}$	-0.07	0.09	-0.25 – 0.10	0.412						
Time : $\text{Condition}_{\text{PMR}}$	0.05	0.09	-0.13 – 0.24	0.557						
					138	0.101 / 0.067	132	75	0.36	0.699

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.15

Experiment 2: Linear Regressions of the SRSI3s Transformation/Transcendence Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	2.05	0.08	1.90 – 2.20	**<0.001**						
Time	-0.05	0.08	-0.20 – 0.10	0.535						
$Condition_{Mindfulness}$	0.17	0.11	-0.04 – 0.38	0.115						
$Condition_{PMR}$	-0.11	0.11	-0.33 – 0.10	0.300						
					138	0.022 / -0.000	134	106.22		
(Intercept)	2.05	0.08	1.90 – 2.20	**<0.001**						
Time	-0.05	0.08	-0.20 – 0.11	0.552						
$Condition_{Mindfulness}$	0.17	0.11	-0.04 – 0.38	0.117						
$Condition_{PMR}$	-0.11	0.11	-0.33 – 0.10	0.303						
Time : $Condition_{Mindfulness}$	-0.03	0.11	-0.24 – 0.18	0.797						
Time : $Condition_{PMR}$	0.09	0.11	-0.13 – 0.30	0.436						
					138	0.027 / -0.010	132	105.72	0.32	0.728

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.16

Experiment 2: Linear Regressions of the SRSI3s Positive Transcendent Emotion Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	3.67	0.09	3.49 – 3.86	**<0.001**						
Time	-0.01	0.09	-0.19 – 0.18	0.926						
$Condition_{Mindfulness}$	0.18	0.13	-0.08 – 0.44	0.170						
$Condition_{PMR}$	-0.13	0.13	-0.39 – 0.14	0.339						
					138	0.015 / -0.007	134	161.38		
(Intercept)	3.67	0.09	3.49 – 3.86	**<0.001**						
Time	0.00	0.09	-0.19 – 0.18	0.961						
$Condition_{Mindfulness}$	0.18	0.13	-0.08 – 0.44	0.171						
$Condition_{PMR}$	-0.13	0.13	-0.39 – 0.14	0.340						
Time : $Condition_{Mindfulness}$	-0.13	0.13	-0.39 – 0.13	0.312						
Time : $Condition_{PMR}$	0.15	0.13	-0.11 – 0.41	0.264						
					138	0.026 / -0.011	132	159.53	0.77	0.467

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.17

Experiment 2: Linear Regressions of the PANAS PA Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	2.30	0.06	2.19 – 2.42	**<0.001**						
Time	0.02	0.06	-0.10 – 0.14	0.762						
$\text{Condition}_{\text{Mindfulness}}$	0.03	0.08	-0.14 – 0.20	0.722						
$\text{Condition}_{\text{PMR}}$	-0.08	0.09	-0.25 – 0.09	0.347						
					138	0.007 / -0.015	134	66.113		
(Intercept)	2.30	0.06	2.18 – 2.42	**<0.001**						
Time	0.02	0.06	-0.10 – 0.14	0.755						
$\text{Condition}_{\text{Mindfulness}}$	0.03	0.08	-0.14 – 0.20	0.724						
$\text{Condition}_{\text{PMR}}$	-0.08	0.09	-0.25 – 0.09	0.350						
Time : $\text{Condition}_{\text{Mindfulness}}$	-0.04	0.08	-0.21 – 0.13	0.639						
Time : $\text{Condition}_{\text{PMR}}$	0.01	0.09	-0.16 – 0.18	0.922						
					138	0.009 / -0.028	132	65.99	0.12	0.884

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.18

Experiment 2: Linear Regressions of the PANAS NA Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	1.59	0.05	1.50 – 1.68	**<0.001**						
Time	0.06	0.05	-0.04 – 0.15	0.231						
$\text{Condition}_{\text{Mindfulness}}$	-0.08	0.06	-0.20 – 0.05	0.250						
$\text{Condition}_{\text{PMR}}$	0.11	0.07	-0.02 – 0.25	0.086						
					138	0.033 / 0.011	134	40		
(Intercept)	1.59	0.05	1.50 – 1.68	**<0.001**						
Time	0.05	0.05	-0.04 – 0.15	0.243						
$\text{Condition}_{\text{Mindfulness}}$	-0.08	0.07	-0.20 – 0.05	0.253						
$\text{Condition}_{\text{PMR}}$	0.11	0.07	-0.02 – 0.25	0.088						
Time : $\text{Condition}_{\text{Mindfulness}}$	0.03	0.07	-0.10 – 0.16	0.617						
Time : $\text{Condition}_{\text{PMR}}$	-0.04	0.07	-0.17 – 0.09	0.562						
					138	0.036 / -0.001	132	40	0.20	0.820

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.19

Experiment 2: Linear Regression of the FFMQ Total Score at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.29	0.06	3.17 – 3.42	**<0.001**		
$Condition_{Mindfulness}$	0.05	0.09	-0.13 – 0.22	0.580		
$Condition_{PMR}$	-0.03	0.09	-0.21 – 0.15	0.735		
					69	0.005 / -0.025

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table C.20

Experiment 2: Linear Regression of the FFMQ Observing Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.39	0.07	3.25 – 3.54	**<0.001**		
$Condition_{Mindfulness}$	0.09	0.10	-0.12 – 0.29	0.402		
$Condition_{PMR}$	0.05	0.1	-0.16 – 0.26	0.631		
					69	0.027 / -0.003

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals

Table C.21

Experiment 2: Linear Regression of the FFMQ Describing Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.48	0.09	3.31 – 3.65	**<0.001**		
$Condition_{Mindfulness}$	-0.06	0.12	-0.29 – 0.18	0.646		
$Condition_{PMR}$	-0.02	0.12	-0.27 – 0.22	0.855		
					69	0.007 / -0.023

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals

Table C.22

Experiment 2: Linear Regression of the FFMQ Acting With Awareness Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.23	0.08	3.06 – 3.39	**<0.001**		
$Condition_{Mindfulness}$	0.03	0.12	-0.21 – 0.26	0.807		
$Condition_{PMR}$	-0.23	0.12	-0.47 – 0.01	0.059		
					69	0.062 / 0.034

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals

Table C.23

Experiment 2: Linear Regression of the FFMQ Nonjudging of Inner Experience Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	3.54	0.11	3.32 – 3.77	**<0.001**		
$Condition_{Mindfulness}$	0.05	0.16	-0.27 – 0.36	0.769		
$Condition_{PMR}$	0.05	0.16	-0.27 – 0.38	0.736		
					69	0.006 / -0.024

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals

Table C.24

Experiment 2: Linear Regression of the FFMQ Nonreactivity to Inner Experience Scale at Pre-Measurement

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*
(Intercept)	2.76	0.08	2.61 – 2.92	**<0.001**		
$Condition_{Mindfulness}$	0.15	0.11	-0.07 – 0.36	0.177		
$Condition_{PMR}$	0.00	0.11	-0.22 – 0.22	0.984		
					69	0.037 / 0.008

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals

Effects of Mindfulness Meditation on Stereotype Expression in Two Randomized Controlled Double-Blinded Trials

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ABSTRACT

Models of stereotypes and discrimination propose the involvement of attentional control and executive functioning in successfully suppressing discriminatory behavior. A practice that has been shown to improve cognitive control even after short training durations is mindfulness meditation, and beneficial effects, even of short practice, on stereotype activation and the expression of discriminatory behavior have been reported.

In two randomized controlled double-blinded trials, the effects of short mindfulness trainings on the expression of stereotype-biased behavior were contrasted with relaxation trainings of equal length (progressive muscle relaxation; active control) and listening to podcasts (passive control). In Experiment 1, the effects of a short mindfulness induction (45 minutes in total) on stereotype expression were assessed with the Shooter Task. In Experiment 2, the Avoidance Task was utilized to assess the effects of a brief mindfulness training (80 minutes in total) on stereotype-biased behavior. Joined analyses of response latencies and accuracy by drift diffusion modeling showed that mindfulness increased the effect of stereotype bias on decision-making in both experiments. At the same time, relaxation resulted in a reduction of bias. Contrary to our hypothesis, the findings suggested that relaxation was beneficial for controlling stereotype-biased behavior, while the effects of short trainings in mindfulness were not. Implications for research in the field are discussed.

Keywords: state mindfulness; focused attention meditation; progressive muscle relaxation; cognitive control; stereotype bias; shooter bias

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Stereotypes are conceptualized as associations and beliefs about traits and qualities of members of a social group that influence thought and behavior towards the group (Greenwald & Banaji, 1995; Hilton & von Hippel, 1996). Research has shown that stereotypes already influence early perceptual processes – for example, the social category of race is processed within 200 ms of stimulus presentation (Kubota & Ito, 2017) – producing a readiness to perceive stereotype-consistent behaviors or characteristics (Fiske, 1998). Such preferred processing of stereotype-consistent information can subsequently bias decision-making and behavior. While stereotypes are part of basic categorization processes in the human mind that allow for efficient reduction of informational input from the environment, in the social domain, errors in this process in terms of overgeneralization and prejudice are very costly for stereotyped groups, for example resulting in poorer mental and physical health (e.g., Williams et al., 2019) or economic inequalities (e.g., Arrow, 1998). Therefore, the process of stereotyping and how to reduce its harmful effects received much attention in research.

Cognitive models of stereotyping distinguish between automatic and controlled processes (e.g., Devine, 1989; Dovidio et al., 1997; Devine & Sharp, 2009). Automatic processes are defined as the unintentional or spontaneous activation of a well-established set of associations or the pre-activation of motor-response sets for which no deliberate effort is required. For example, research has shown that behavior displayed by a Black person is more likely to be associated with threat compared to the same behavior displayed by a White person (Duncan, 1976) and that stereotypes lead to a readiness to perceive anger in Black compared to White faces (Hugenberg & Bodenhausen, 2003). Controlled processes, by contrast, are described as being intentional and more flexible, demanding attentional resources, and being limited by cognitive capacity. Cognitive depletion, for example, can reduce controlled but not automatic processes in stereotype tasks, increasing the likelihood of a stereotype-based response (Govorun & Payne, 2006). Dual-process models of stereotyping (e.g., Devine, 1989) propose that the difference between a biased and an unbiased response is not contingent on stereotypes being activated or not but rather depends on an individual's willingness and ability to control automatically activated associations, which is proposed to involve attentional (Posner & Peterson, 1990; Peterson & Posner, 2012) and executive control (Suchy, 2009; Miyake et al., 2000). Furthermore, Amodio (2014) outlined a control network of stereotype-based behavior, which is proposed to include monitoring of situational (social) cues, detecting conflict between a biased pre-activated behavioral tendency, and the individuals' goal-set to act without bias. If a conflict is detected, response inhibition of stereotype-biased behavior and the selection of alternative unbiased behavior are implemented. Accordingly, research on cognitive control in stereotype bias has highlighted the role of inhibitory control in bias expression (Bartholow et al., 2006; Correll et al., 2006; Payne, 2005). Also, conflict monitoring and detection have been shown to be associated with more controlled response behavior on tasks measuring stereotype-biased behavior (Amodio et al., 2004; Amodio et al., 2008;

Bartholow et al., 2012). Additionally, Ito et al. (2015) found that common executive function ability (i.e., the interplay of inhibition, working memory/updating and task switching) is negatively correlated with the expression of racial bias and positively correlated with controlled response behavior. Taken together, the models and studies described above highlight the role of attentional control and executive functioning in stereotype expression.

A practice that has been proposed to train attentional control and executive functions is mindfulness meditation (e.g., Colzato et al., 2016; Ostafin & Kassman, 2012; Wenk-Sormaz, 2005; Whitmarsh et al., 2013). Mindfulness can be described as a state of paying attention to and being fully aware of the present moment in a non-judgmental way (Kabat-Zinn, 1994). During a common mindfulness practice, the breathing meditation, the practitioner focuses their attention on the breath. In case of internal or external distractions, they return their attention to their breath. This process requires the constant monitoring and regulation of attentional resources while inhibiting irrelevant cognitive processes. Consequently, mindfulness practice has been found to enhance cognitive control abilities, even after short training durations (Cásedas et al., 2020; Chiesa et al., 2011; Lutz et al., 2008; Whitfield et al., 2021, but see Gill et al., 2020; Leyland et al., 2019) and has also been found to reduce expression of stereotypical bias. Lueke and Gibson (2015) utilized Implicit Association Tests (IATs) to examine automatic associations between a social category (in this study, race and age) and attributes of positive and negative valence, which were presented in stereotype congruent (e.g., Black face, tragic) or incongruent combinations (e.g., Black face, attractive). Following 10 minutes of mindfulness meditation, participants exhibited reduced automatic activation in racial and age bias compared to a passive control condition, while no differences between conditions in controlling biased responses were found. Moreover, employing a trust game with simulated interactions during which participants had to decide how much they would trust either a Black or a White partner to make a reciprocally beneficial money transaction, Lueke & Gibson (2016) showed that a 10-minute mindfulness meditation resulted in less differential treatment of Black compared to White partners compared to control conditions. Contrasting these findings is a study by Hunsinger et al. (2019), who investigated the effectiveness of an eight-week mindfulness-based resilience training for law enforcement officers in improving weapon identification on the Shooter Task. During the Shooter Task, participants are presented with Black or White targets holding either a gun or a non-harmful object. While the target's race is irrelevant to the participants' task of identifying the object as either a weapon or non-harmful, race has been shown to affect response behavior based on stereotypical associations of threat and Black people. Compared to a non-intervention control condition, the authors found no effects of mindfulness training on response latencies and behavior. However, the authors noted a lack of stereotype bias in response behavior at baseline, indicating that there might have been no stereotype bias in their sample that could have been affected by mindfulness training. Thus, while results by Lueke and Gibson (2015, 2016) suggest that mindfulness may modulate stereotype activation and bias expression, the results by Hunsinger et al. (2019) are less clear.

Therefore, the current study aimed to investigate the effects of enhanced cognitive control on stereotype bias expression via mindfulness meditation utilizing a short mindfulness induction (Experiment 1) and a brief training of mindfulness meditation (Experiment 2) in two randomized controlled double-blinded trials. As outlined above, we propose that the underlying mechanism of such an improvement would be enhanced attentional control/executive functioning by mindfulness meditation. We addressed challenges of research in the field by the following: In Experiment 1, the Shooter Task (Correll et al., 2002) was utilized to assess the effects of mindfulness training on stereotype-biased response behavior. During this task, participants are presented with photos of Black or White targets holding a gun or a non-threatening object (e.g., a phone) in their hand. Participants are asked to quickly make a shooting decision whenever a target holding a gun appears. Even though target race is irrelevant for task completion, results typically show the presence of a shooter bias, meaning that participants are faster and/or more accurate in their shooting decisions for armed Black compared to White targets and, conversely, are faster and/or more accurate in their decision to not shoot unarmed White compared to Black targets (e.g., Correll et al., 2007; Mekawi & Bresin, 2015; Plant & Peruche, 2005; Sadler et al., 2012). Modeling response behavior during the Shooter Task by means of drift diffusion modeling (DDM; Ratcliff, 1978; Ratcliff & Rouder, 1998) furthermore allowed us to investigate the influence of racial stereotypes on the process of decision-making, taking both response speed and accuracy into account. So far, studies utilizing the DDM to investigate decision-making during the Shooter Task have found facilitated evidence accumulation towards a correct response in stereotype congruent versus incongruent trials and that participants exhibit greater response control (i.e., trading speed for accuracy) to Black compared to White targets in an effort to control stereotype biased behavior (Correll et al., 2015; Johnson et al., 2018; Pleskac et al., 2018; Mayerl et al., 2019). These findings suggest that stereotypes directly influence the efficiency of information processing, as well as the amount of evidence required for making a decision, rather than facilitating motor-response preparation (e.g., Pleskac et al., 2018; but see Frenken et al., 2022), or eliciting an a-priori decision bias before information relevant for responding is processed (e.g., Pleskac et al., 2018; Johnson et al., 2017). We propose that training cognitive control abilities by mindfulness meditation could beneficially influence information processing during the Shooter Task by improving attentional monitoring and (re-) allocation of attentional resources to task-relevant information (i.e., identification of the object) as well as by improving inhibition of processing task-irrelevant information about target race. Such improvements are postulated to reduce or diminish the effects of stereotypes on response behavior. In Experiment 2, we utilized the Avoidance Task by Essien et al. (2017) to investigate whether the postulated effects translate to different discriminatory behavior. During the

Avoidance Task, participants are asked to avoid (rather than shoot) targets with knives (Turkish or German). Following the described shooter bias, Essien et al. found increased response speed in stereotype congruent (e.g., Turkish armed) compared to incongruent trials (e.g., German armed). The Avoidance Task was employed to increase the ecological validity of the scenario in a German sample by utilizing German and Turkish targets (the latter being a minority group in Germany that is stereotypically associated with threat or danger, Degner et al., 2007; Kahraman & Knoblich, 2000). Again, drift diffusion modeling was used to investigate underlying processes of decision-making. As results of Experiment 1 indicated a reduction in controlled responding for all conditions from pre- to post-measurement, Experiment 2 additionally assessed participants' motivation to control prejudiced behavior, which previously has been identified as affecting the willingness to exert cognitive control over activated stereotypes (e.g., Payne, 2005).

In both experiments, we utilized brief mindfulness training periods, which effectively isolate the direct effects of state mindfulness without confounding factors (e.g., longer training includes psycho-educational and motivational aspects). Since the dose-response relationship between mindfulness meditation and enhancement in cognitive control is still up for debate (e.g., Gill et al., 2020; Vieth & von Stockhausen, 2022a), we increased training frequency and total training duration from Experiment 1 to Experiment 2. We implemented a pre-post experimental design to assess the effects of short mindfulness trainings, contrasted by an active (induction of relaxation) and passive (podcast listening) control group. It was hypothesized that if improving cognitive control by mindfulness meditation is effective in reducing the expression of active stereotypes, such improvements may be reflected in processes of decision-making during both the Shooter and the Avoidance Task in the following ways: Enhanced cognitive control (i.e., enhanced conflict monitoring and successful (re-) allocation of attentional resources to task-relevant information) should decrease the impact of task-irrelevant information of target race or ethnicity in information processing. Furthermore, increased controlled responding (speed-accuracy tradeoffs) could indicate participants' effort to exert cognitive control over biased information processing. How these improvements would be reflected in the parameters of the DDM will be outlined below.

1 Methods

1.1 Participants

The samples consisted of 96 participants in Experiment 1 (74 female, 1 non-binary, M_{age} = 23.5, SD_{age} = 5.43) and 69 participants in Experiment 2 (57 female, 1 non-binary, M_{age} = 22.0, SD_{age} = 5.62). Recruitment was done through social and university internal message boards for research participation. Participants meeting the inclusion criteria of being older than 17 and not having practiced mindfulness or any other form of meditation regularly during the last three months were contacted by e-mail to set up dates for online participation. Participants received access to the online research environment via a link sent by e-mail at the date they had chosen for their first measurement point. The e-mail also included further information about participation in online research (appropriate environment for participation from home and technical requirements). The link directed participants to a page with written information about methods and testing included in the experiment, data protection standards and research ethics. Participants could begin with the first measurement point after agreeing to participate and data storage. The current standards of the General Data Protection Regulation of the European Union (GDPR 2016/679) were met for data collection, storage and anonymization. The local university's ethical commission of the Department of Psychology approved the experiment.

1.2 Assessment of Stereotype Activation and Expression

Reaction-time tasks were programmed with OpenSesame (Mathôt et al., 2012; version 3.3.11) and presented using a JATOS interface (Lange et al., 2015; version 03.06.2001). Participants were instructed to wear headphones for noise reduction and informed that access to reaction-time tasks was restricted to desktop computers only (this included laptop computers used as desktops), as responses were recorded via participants' keyboards.

1.2.1 Shooter Task

The Shooter Task was developed by Correll et al. (2002) to investigate the effect of race on shooting decisions. During the task, participants are presented with images of Black or White men who either hold a gun or a non-threatening object, for example, a cell phone or a wallet. Each time the participant is presented with a person on the computer screen, they must quickly decide whether the person is holding a gun or a non-threatening object and indicate their decision by button press[1]. Stimulus material and design were adopted from Correll et al. (2002). Each trial began with a fixation point, followed by a random number of background images (ranging between one to four, showing landscapes of American cities) with random duration (500 to 1000ms). Following, the target was superimposed on another randomly selected background image. Targets were presented in various positions (standing or crouching). Response behavior was awarded or punished following a pay-off matrix. A hit (deciding to shoot a target with a gun) earned 10 points, and a correct rejection (deciding

[1] While in the original task by Correll et al. (2002) participants are asked to indicate a 'shooting decision' by button press, we decided to instruct participants to simply indicate the presence or absence of a gun by pressing a respective key. In our experiment we assessed non-police, German sample. Germany has very strict gun laws and most citizens are very unlikely to ever be in contact with a gun, let alone the decision to shoot another human being.

not to shoot a target holding a non-threatening object) earned 5 points. A false alarm (falsely deciding to shoot an unarmed target) led to a deduction of 20 points, and a miss (falsely deciding not to shoot an armed target) resulted in a loss of 40 points. The payoff matrix is used to emphasize a possible threat, with the strongest punishment (-40 points) in case of missing an armed target. Furthermore, a timeout penalty (subtracting 10 if participants failed to respond within 850 ms after target presentation) reinforced timely responding. Participants were instructed to respond as accurately and as quickly as possible.

Participants were instructed to place their left and right index finger on the ‘A’ and ‘L’ keys and indicate target identification of either a non-threatening object or a gun, respectively, for each trial. A session consisted of three practice trials and a single block of 80 trials. Each combination of target race (Black, White) and object condition (gun or no gun) was represented with 20 trials. Participants were instructed to fixate on the fixation cross at the beginning of trials and were informed that they would score based on their performance. The total task duration was approximately 10 minutes.

1.2.2 Avoidance Task

The Avoidance Task by Essien et al. (2017) is an adaptation of the shooter bias paradigm to investigate the effect of target ethnicity on approach-avoidance behavior. During the task, participants are presented with images of German or Turkish men holding a silver or black knife or a non-threatening object (silver digital camera, aluminum thermos, black wallet, or black cell phone). Stimulus material and design were adopted from Essien et al. (2017). Background images consist of German cities and show empty streets with sidewalks on both sides of the streets. Half of the targets are superimposed on the left and half on the right sidewalk, with target position counterbalanced for object type and target ethnicity. The general task procedure, trial sequence and pay-off matrix were adopted from the Shooter Task as described above; however, the response indication for the Avoidance Task differs. Participants are instructed to place their left and right index finger on the ‘A’ and ‘L’ keys, respectively, and are told that their own position in a trial (i.e., left or right sidewalk) is always identical to the position of the target. Participants are instructed to quickly decide whether the person is holding a knife or a non-threatening object and indicate their decision to either avoid the target by changing to the other side of the street (i.e., pressing the opposite-side key) or to approach the target by staying on the same streetside (i.e., pressing the same-side key). For example, if an armed target appeared on the left side of the street, participants would correctly indicate to avoid the target by pressing the right (‘L’) key.

A session consisted of 20 practice trials and a single block of 80 trials. Each combination of target ethnicity and target object was represented with 20 trials. Participants were instructed to fixate on a fixation cross in the center of the screen at the beginning of trials and were informed that they would score based on their performance. The total task duration was approximately 10 minutes.

1.3 Questionnaires

The Positive and Negative Affect Schedule (PANAS; Watson et al., 1988; German version: Breyer & Bluemke, 2016) was used to assess possible influences of mood (Van Steenbergen et al., 2010) on attentional and executive control. The PANAS measures positive and negative affective states on two scales and consists of 20 items. Positive and negative affective states are assessed with ten items each. Participants are to indicate how well each affective state (e.g., "scared") applies to them currently on a 5-point Likert-type scale.

Experiment 2 additionally included a scale measuring motivation to act without prejudice (Motivation zu vorurteilsfreiem Verhalten, MVV; Banse & Gawronski, 2003). The MVV is a one-factorial scale measuring aspects of the motivation to control prejudiced behavior with 16 items. Participants have to indicate how well a statement applies to them on a 5-point Likert-type scale (e.g.*, "If I have thoughts or emotions that discriminate others, I keep them to myself*.").

Sociodemographic questions included participants' age, gender, marital status, education, employment, and the number of people in the household. Experienced impairment due to the COVID-19 pandemic (work/personal) and experienced burden due to the COVID-19 pandemic (work/personal) were assessed to control for possible effects on induction effectiveness. Furthermore, prior experience with mindfulness and related meditation practices and relaxation training was assessed.

Additional questionnaires included in the procedure but not reported here were the Five-Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006; German Version: Michalak et al., 2016), the Smith Relaxation States Inventory 3s (SRSI3s; Smith, 2020; German version: Vieth et al., 2020), the state anxiety scale of the State-Trait-Anxiety Inventory (STAI; Spielberger et al., 1970; German Version: Grimm, 2009) and the HEXACO scales emotionality, openness to experience and agreeableness of the short version of the HEXACO Personality Inventory (HEXACO-60; Ashton & Lee, 2007; German Version: Moshagen et al., 2014). Furthermore, both experiments included the assessment of the executive functions of inhibition (Continuous Performance Task-II, Conners, 2000; Conners et al., 2003), updating (N-Back Task, Kirchner, 1958), and task switching (Number-Letter Task, Rogers & Monsell, 1995; Suchy, 2009) results of which are reported elsewhere (Vieth & von Stockhausen, 2022b).

1.4 Sound- and Fidelity-Checks for Online Research

Before induction or podcast deliverance, participants were presented with a sound check (in which they had to identify an animal noise correctly) to ensure that they could hear audio inductions correctly and adjust the audio volume before audio delivery. Participation could only continue if the sound-check was successful. Otherwise, participants were instructed to get in touch with the experimenter to resolve technical issues and continue participating. Once the sound-check was completed, participants were instructed in writing to, if possible, conduct the experiment in a separate room, in which induction, as well as testing, could be performed in silence and without disturbances. Furthermore, participants received information about appropriate sitting posture and the usage of headphones for noise reduction. After participants agreed to have read and confirmed adherence to these instructions, they could start the induction (breathing meditation or PMR) or podcast by pressing a play button.

We assessed participants' compliance by collecting data on whether all audio files were played to completion and informed participants that they would only receive total compensation for participation if all audio instructions and tasks, and questionnaires were completed. Otherwise, participants received partial credit. Participants who did not complete all audio files (i.e., did not receive the total training dosage) were excluded from the final sample. Questions regarding participants' ability to follow audio instructions and the occurrence of disturbances during participation (noise, interruption by another person, issues with internet connection, or other) were added to each measurement point to ensure the quality of data collection. If distractions occurred, participants were asked to rate overall disturbance intensity on a 4-point Likert-type scale (weak to strong). To ensure that participants would execute RT measures correctly, they were guided with written information prior to every RT task, asked to follow task-specific instructions considering taking breaks and received reminders between RT tasks regarding sitting posture, the height of the computer screen, participating in a distraction-free environment as well as using headphones for noise reduction.

1.5 Research Design

Both experiments were 3 (mindfulness, PMR or podcast listening) x 2 (measurement point) experimental designs. Mindfulness meditation was the experimental condition, PMR was the active control condition and listening to podcasts was the passive control condition. PMR was selected as a mind-body practice that could plausibly be administered at the same length and frequency as mindfulness, but that is not supposed to improve cognitive control. Podcast listening was selected as a passive control condition to keep participants active without any practice involved, therefore controlling for overall engagement and effects of repeated testing. All participants were given the same information about participating in a concentration training and were unaware of different experimental conditions. Participants were randomly assigned to an experimental condition within the online experimental environment. Accordingly, both experiments reported qualify as randomized controlled double-blinded research designs. Deliverance of inductions (or podcast listening) was three times during Experiment 1 (after pre-measurement, between pre- and post-measurement, and before post-measurement) and four times during Experiment 2 (as in Experiment 1 plus one additional session between pre- and post-measurement).

1.5.1 Experimental Conditions

In both experiments, repeated deliverance of inductions was done so that participants could become familiar with the respective practice and postulated short-term effects of the inductions would surface at post-measurement. Deliverance was done via pre-recorded audio files. During Experiment 1, three doses of mindfulness, relaxation, or podcast listening were delivered on different days within five days. Inductions and podcasts were delivered in increasing lengths (10, 15 and 20 minutes). Variations in induction length were achieved by shortening a 20-minute recording to 10- and 15-minute versions, keeping inductions as standardized as possible, and avoiding variations in speaker voice or speaking rate. During Experiment 2, four doses of equal length (20 minutes) were delivered within five days. This was done to achieve a longer total training duration which qualified as a brief training (compared to a short induction in Experiment 1) while keeping the delivery timeframe constant.

1.5.2 Audio-Instructions

Mindfulness instructions focused on being aware of the present moment with an accepting and non-judgmental attitude and observing the in- and outflow of the breath. Furthermore, instructions included noticing and letting go of thoughts and emotions that may occur during the practice (more detailed information for both mindfulness and PMR instructions can be found in Appendix A). Mindfulness instructions were recorded by speakers (both male and female) trained by the authors to deliver meditation inductions with a calm voice and appropriate intonation.

During PMR (Jacobson, 1938), practitioners are instructed to tense a muscle group (e.g., the upper thighs) for five to ten seconds with the inhale and to release the tension with the exhale. A PMR session usually starts with the lower extremities and gradually progresses upwards through the body, leaving ten to twenty seconds of focus on the changes in physiological experience between muscle groups. PMR recordings were provided by two experienced trainers (male and female; Bödeker, 2013; Kristenich, 2017). To ensure a clear distinction between mindfulness and relaxation inductions, mindfulness instructions excluded phrases implying or directly instructing relaxation. Likewise, PMR recordings were adjusted so they did not include mindfulness-related phrasings (e.g., instructions of acceptance of the present experience).

Four podcasts concerning historical sites and unique landscapes were utilized in both experiments. To ensure the adequacy of utilizing the podcasts in a passive control condition, they were pretested for not eliciting strong positive or negative emotional reactions (levels of arousal and valence were assessed) and evoking medium levels of interest and engagement. In both experiments, podcasts were presented randomly with the constraint that participants would not be presented with the same podcast twice.

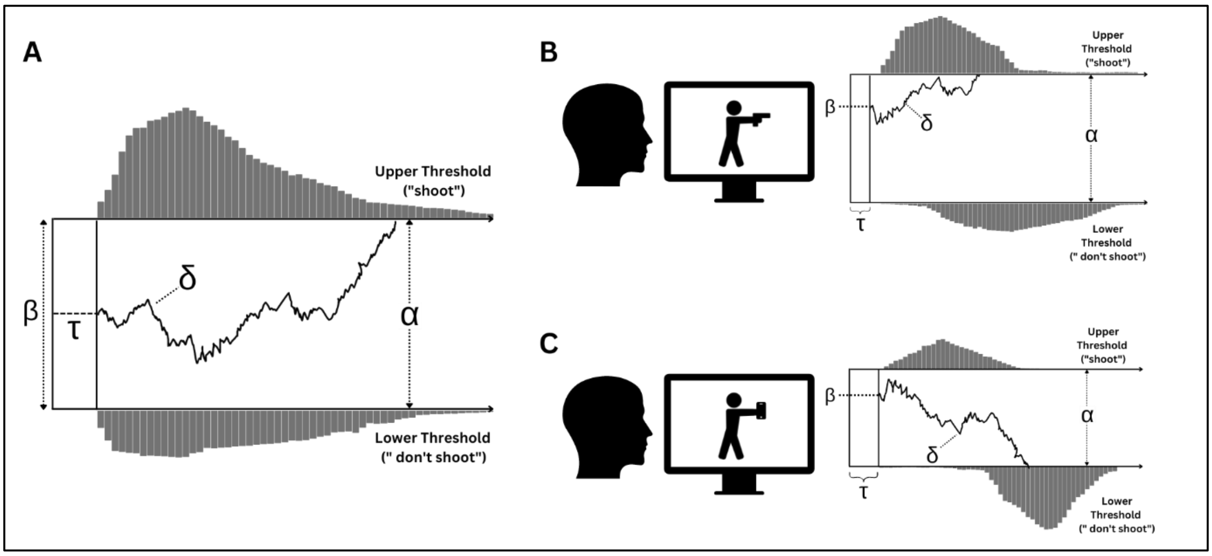
1.6 Procedure

A general outline will be given as the procedure was similar in both experiments. Variations between Experiments 1 and 2 will be commented on where relevant. On their day of participation, participants were greeted in writing and provided with the written informed consent form, which included information on how to get in touch with the authors in case of questions regarding research participation. After reading the form and giving their consent, the first experimental session started with questions regarding sociodemographic variables followed by questionnaires and reaction-time tasks in the following order: SRSI3s, CPT-II, STAI, PANAS, N-back Task, FFMQ-D, Number-Letter Task, HEXACO-60 subscales, Shooter Task (Experiment 1) or Avoidance Task (Experiment 2). As described above, manipulation checks and assessments of compliance and fidelity were placed throughout the experiment. Sequences of questionnaires and tests were the same across experiments, points of measurement and participants. Participants were allowed to take self-paced breaks between questionnaires and tasks. After completing the pre-measurement, participants were asked to execute the sound-check and presented with the first audio induction (breathing meditation or PMR) or a podcast. After the first experimental session was completed, participants were thanked and informed that they would receive an invitation to the second session via e-mail. The second session (and third session in Experiment 2) took place within the same week and only consisted of the second induction or podcast listening. The last session began with a practice of mindfulness or PMR, or podcast listening and ended with the post-assessment of all tasks and questionnaires (finishing tasks and questionnaires took about 90 minutes). After study completion, participants were debriefed about the purpose of the study and different experimental conditions, thanked, and received course credit.

2 Statistical Analyzes

Drift diffusion models (Ratcliff, 1978; Ratcliff & Rouder, 1998) describe binary decision-making during a speeded task as a process of continuous evidence accumulation (see Figure 1A): For each trial of a given task, information from the stimulus is extracted and evidence for a decision accumulates (delta, drift rate) until a threshold (alpha) for one of two decision is met. Additionally, the DDM accounts for an individual's initial bias for one of the two decisions at the beginning of evidence accumulation (beta; start point) and for reaction time components unrelated to decision making (e.g., motor components or basal stimulus processing; non-decision time, tau). We used Bayesian hierarchical DDMs, which estimate posterior distributions using Markov Chain Monte Carlo (MCMC) simulations (Vandekerckhove et al., 2011).

Figure 1.
Representation of the Drift Diffusion Model.



Our models were adapted from previous work in which drift diffusion models for the shooter bias paradigm were utilized (Johnson et al., 2017; Pleskac et al., 2018), drawing parameters from distributions on individual and condition levels. Separate models were run for conditions at pre- and post-measurement. A specification of the estimated parameters and their interpretation can be found in Table 1. How stereotype bias affects decision-making during the Shooter Task is depicted will be outlined in the following.

Higher delta values reflect stronger evidence for the respective decision, while values closer to zero reflect ambiguous evidence interpretation or guessing. Accordingly, delta may be interpreted as a measure of perceptual sensitivity or task difficulty and has been shown to be affected by stimulus discriminability, with lower values of delta for stimuli that are harder to discriminate (Pleskac et al., 2018; Lerche & Voss, 2019; Voss et al., 2004). Thus, higher absolute levels of delta generally reflect more efficient information processing for a correct decision, and improvements in cognitive control following mindfulness could be reflected in greater improvements compared to both control conditions. Stereotype bias has been shown to facilitate information processing in that evidence for the correct decision accrues more efficiently. For example, Pleskac et al. (2018) showed facilitation of evidence accumulation for the correct decision in stereotype congruent (i.e., Black armed or White unarmed) versus incongruent trials (i.e., Black unarmed or White armed) across several experiments (see also Correll et al., 2015; Johnson et al., 2018; Mayerl et al., 2019). Suppose a Black target is depicted with a gun in Figure 1B (stereotype congruent) and a phone in Figure 1C (stereotype incongruent). Evidence accumulation for the correct shoot decision in XB is facilitated by stereotype bias (i.e., delta is steeper). In contrast, evidence accumulation for the correct decision not to shoot is not (i.e., greater fluctuation in delta between the thresholds in either direction). On the level of response behavior, this would be characterized by shorter response time and greater accuracy in stereotype congruent compared to incongruent trials. Since target race represents a task-irrelevant category during the Shooter Task, improving cognitive control by mindfulness should enhance attention allocation to task-relevant information and diminish the effect of task-irrelevant information and, therefore, the effect of stereotype bias on information processing towards a correct response. Delta was modeled separately for all combinations of target race and object type

Table 1
Parameters of the Drift Diffusion Model

Parameter	Specification
Threshold separation (α)	Separation of decision thresholds, with $0 < \alpha$. Larger values reflect more accurate but slower decisions (i.e., speed-accuracy tradeoff). Modeled separately for target ethnicity.
Relative start point (β)	Location of starting point for evidence accumulation relative to thresholds, with $0 < \beta < 1$. Values of $\beta > .5$ indicate a bias to "Shoot" and vice versa. Modeled separately for target ethnicity.
Drift rate (δ)	Quality of extracted evidence in favor of a response, with $-\infty < \delta < \infty$. Negative values reflect stronger evidence in favor of "Do not Shoot" and vice versa. Higher absolute values reflect more efficient processing. Modeled separately for target ethnicity x object type.
Non-decision time (τ)	Includes the time spent encoding the stimulus, executing a response, and any other contaminant pre- and post-decisional processes, with $0 < \tau$. Modeled separately for target ethnicity x object type.

The larger the threshold separation of the responses, the more evidence is required on a given trial to reach a decision. Alpha thus reflects response caution or a speed-accuracy trade-off; for example, shifting participants' motivation to respond more accurately can lead to increased threshold separation (Lerche & Voss, 2019; Voss et al., 2004). Conversely, restricting the response window during the Shooter Task has been shown to motivate fast responding, resulting in lower alpha values (Pleskac et al., 2018). Furthermore, studies have reported larger alpha for Black compared to White targets (Frenken et al., 2022; Johnson et al., 2018; Pleskac et al., 2018), interpreted as heightened response caution (i.e., more controlled responding) for Black targets reflecting an attempt to counteract racial bias during the Shooter Task. As depicted in Figure 1B, heightened threshold separation increases the distance between the starting point and the threshold for either decision. Thus, larger levels of evidence need to be accumulated for either decision, reflected in slower but more accurate responses. In Figure 1C, lower threshold separation decreases the distance between the decision boundaries; accordingly, less evidence for either decision must be accrued, reflected in faster but more error-prone responses. Thus, heightened cognitive control following mindfulness could lead to increased response thresholds. This means that participants would trade response speed for accuracy and that more information would be accumulated before a decision threshold is reached. Alpha was modeled for Black and White targets separately.

Values of beta greater than 0.5 shift the start point of evidence accumulation closer to the threshold for a shoot response and thus reflect an initial bias to "shoot", irrespective of the presented target information. Reversely, beta values smaller than 0.5 reflect an initial bias to "not shoot", as evidence accumulation starts closer to the "do not shoot" threshold. In case of a decision bias, responses for the threshold closer to the start point will occur more frequently and faster, as the process of evidence accumulation (delta) will reach the threshold more frequently. As during the Shooter Task, a pay-off matrix with a relatively greater reward for correctly detecting a gun and relatively greater punishment for not detecting a gun is used, an initial shooting bias has been found (Johnson et al., 2018; Pleskac, 2018; but see Correll et al., 2015), which is in line with studies reporting modulations of initial bias by response reward (Lerche & Voss, 2019; Voss et al., 2004). Thus, as depicted in Figure 1B and 1C, an initial bias for shooting will bias the subsequent evidence accumulation process in that the threshold for making a "shoot" decision is reached faster and more frequently. In gun trials (Figure 1B), such a bias will facilitate a correct response, while in non-gun trials (Figure 1C), incorrect responses will occur fast and more frequently and evidence accumulation for the correct decision of not shooting will be prolonged. Beta was estimated for Black and White targets separately. Since beta reflects a response bias prior to the accumulation of evidence for either decision (i.e., prior to information processing), target race is unlikely to affect an initial bias (e.g., Pleskac et al., 2018).

The parameter tau provides an estimation of the duration of processes not related to decision-making during each trial (e.g., stimulus encoding and motor processes related to response execution). It has been shown that increasing the complexity of the motor response on a given task can increase tau (Voss et al., 2004; Lerche & Voss, 2019). A robust finding for the Shooter Task is that non-decision time is shorter for gun compared to non-gun trials (Correll et al., 2015; Johnson et al., 2018; Pleskac et al., 2018), which has been attributed to a faster encoding of the relatively uniform category of gun stimuli compared to the broader category of non-gun stimuli (e.g., phones, soda cans, wallets) presented in the task. In Figure 1B, tau is depicted as smaller for a gun trial compared to longer non-decision time in a non-gun trial (Figure 1C). As can be seen, the total response time on a given trial is affected by the length of processes unrelated to decision-making. Heightened cognitive control following mindfulness could lead to longer non-decision time by increasing motor-response inhibition. However, since tau encompasses several processes, an interpretation of underlying causes for changes in tau can only be speculative. Tau was modeled separately for all combinations of target race and object type.

Modeling decision-making during the Avoidance Task was based on the same DDM approach. Specifications of priors, JAGS and R Code for model estimation can be found in Appendix B. MCMC chain convergence was assessed by the potential scale reduction factor, chain resolution by effective sample sizes and Monte Carlo standard errors. Diagnostic plots for obtained condition-level parameters can be found in Appendix C. Individual parameters were extracted for further analysis through repeated-measures analyses of variance (ANOVA) with an added error term to account for subject-dependent variance. The Kenward-Roger approximation was utilized to account for heightened levels of kurtosis in the distributions of the dependent measures (Arnau et al., 2014a & 2014b). Planned comparisons between conditions were done by estimated marginal mean (EMM) contrasts. For p-value adjustment, the Tukey method was selected.

Data were modeled in R (R Core Team, 2020; version 4.0.2). EMMs were calculated with the emmeans package (Lenth, 2020; version 1.4.8.), and figures of results were obtained using the ggplot2 package (Wickham, 2016; 3.3.6). HDDMs were estimated using MCMC sampling via the rjags (Plummer, 2019; version 4.10) and runjags package (Denwood, 2016; version 2.0.4-6) with the Wiener module extension (Wabersich & Vandekerckhove, 2014).

3 Results Experiment 1

The results section will present analyses relevant to our hypotheses (i.e., effects of measurement point, which reflect effects of practice and repeated testing and interactions between measurement point and condition, which reflect differential effects of training). Separate analyses of all DDM parameters will be provided. Furthermore, difference scores were calculated for parameters to assess a possible influence of stereotype bias or target race. A rationale will be given in the following.

To investigate stereotype bias in drift rate (i.e., stereotypic drift rate, $\text{Delta}_{\text{stereotypic}}$), we utilized the calculation of difference scores from Correll et al. (2015) (i.e., $\text{Delta}_{\text{stereotypic}} = [\text{Delta}_{\text{Black armed}} - \text{Delta}_{\text{White armed}}] - [\text{Delta}_{\text{Black unarmed}} - \text{Delta}_{\text{White unarmed}}]$). Positive values of stereotypic drift rate indicate a positive effect of stereotype congruency on evidence accumulation (i.e., more efficient decision-making for congruent compared to incongruent trials). The same strategy was utilized to assess the influence of stereotype bias in non-decision time ($Tau_{stereotypic}$), for which positive values indicate prolonged tau for congruent compared to incongruent trials. For threshold separation (alpha) and initial bias (beta), difference scores ($Alpha_{Black} - Alpha_{White}$; $Beta_{Black} - Beta_{White}$) were calculated to assess differences in the processes by target race, with positive values reflecting greater threshold separation or greater “shoot” bias for Black compared to White targets respectively. While following previous findings, no effects of target race or stereotype bias on beta or tau were postulated, and few studies have investigated the effects of repeated testing or interventions on decision-making during the Shooter Task. Therefore, we decided to investigate possible changes related to stereotypes in the respective parameters. Prior to modeling, reaction times smaller than 100 ms were removed. This resulted in a data loss of 0.97%. Only significant effects with $p \leq 0.05$ are reported. For planned comparisons, absolute t values will be provided for ease of interpretation.

3.1 Drift Rates

The ANOVAs for all combinations of race and object revealed a main effect for measurement point and an interaction between measurement point and condition (see Table 2). The results are displayed in Figure 2.

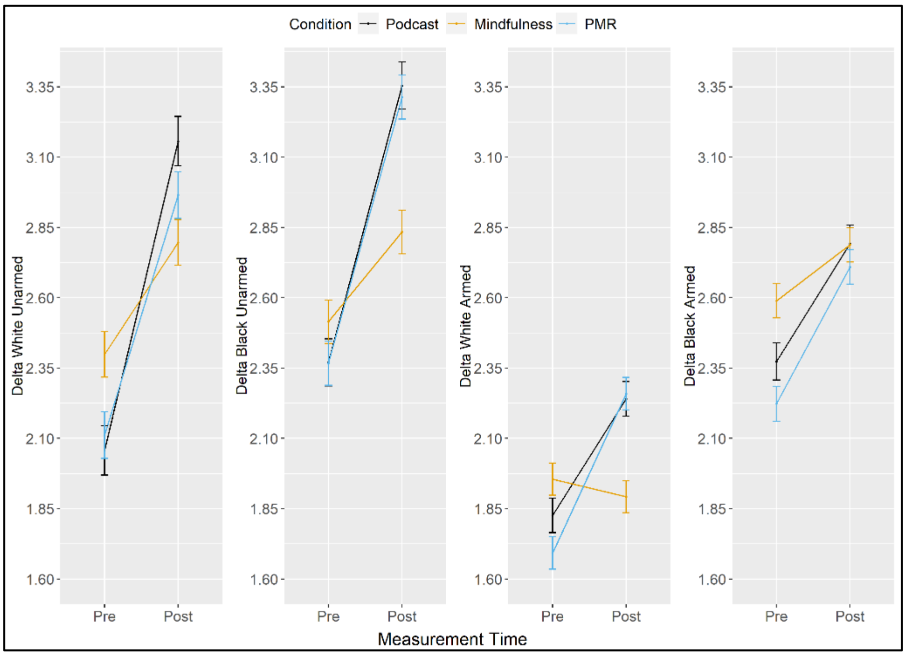


Figure 2.
Experiment 1: Drift Rates from Pre- to Post-Measurement.

Planned comparisons of EMM contrasts (EMM_{t1}- EMM_{t0}) between groups for delta in White unarmed trials indicated a lesser improvement in evidence accumulation following mindfulness compared to PMR, $t(93) = 3.29$, $p = 0.004$, and to podcast listening, $t(93) = 4.89$, $p < 0.001$ (PMR vs. podcast listening, $t < 1$). For delta in Black unarmed trials, planned comparisons again revealed a lesser increase in the rate of evidence accumulation following mindfulness compared to both PMR, $t(93) = 4.80$, $p < 0.001$, and podcast listening, $t(93) = 4.92$, $p < 0.001$ (PMR vs. podcast listening, $t < 1$). Planned comparisons for delta in White armed trials showed that mindfulness was followed by a reduction in evidence accumulation compared to both PMR, $t(93) = 6.56$, $p < 0.001$, and podcast listening, $t(93) = 4.81$, $p < 0.001$, (PMR vs. podcast listening, $t < 2$, $p = 0.288$). Planned comparisons for delta in Black armed trials showed that mindfulness improved evidence accumulation to a lesser degree compared to PMR, $t(93) = 2.84$, $p = 0.014$, while a comparison between mindfulness and podcast indicated no difference in improvement, $t(93) = 2.11$, $p = 0.094$, (PMR vs. podcast listening, $t < 1$). In summary, except for a reduction in evidence accumulation following mindfulness in White armed target trials, conditions improved evidence accumulation for all race by object combinations. However, podcast listening and PMR showed greater evidence accumulation improvements compared to mindfulness meditation. Thus, while it was postulated that improved cognitive control following mindfulness would lead to enhanced processing of task-relevant information, which should have resulted in facilitated accumulation of evidence for correct responses, mindfulness exhibited the least overall improvement in evidence accumulation. In comparison, PMR and podcast listening lead to similarly greater improvements.

An ANOVA with stereotypic drift rate as the dependent variable indicated an interaction between measurement point and condition (see Table 3). Planned comparisons (EMM_{t1}- EMM_{t0}) between groups showed that mindfulness was followed by an increase in the effect of stereotype bias on evidence accumulation compared to PMR, who exhibited a decrease, $t(93) = 3.16$, $p = 0.006$ (other contrasts, t's < 2, p's ≥ .198). The results are displayed in Figure 3. Concluding, the reduction in evidence accumulation for stereotype incongruent armed targets following mindfulness led to an increase in stereotypic drift rate. Thus, the increased effect of stereotype bias on evidence accumulation does not reflect an increase in the effect of stereotype congruency, but rather a lack of similar improvement in a stereotype-incongruent condition following mindfulness. In contrast, PMR increased in stereotype-incongruent compared to congruent armed trials to a greater extent, and this led to a reduction in stereotypic drift rate. However, planned comparisons for mindfulness and podcast listening, and PMR and podcast listening, were non-significant, limiting the differentiation of the respective changes from the effects of repeated testing.

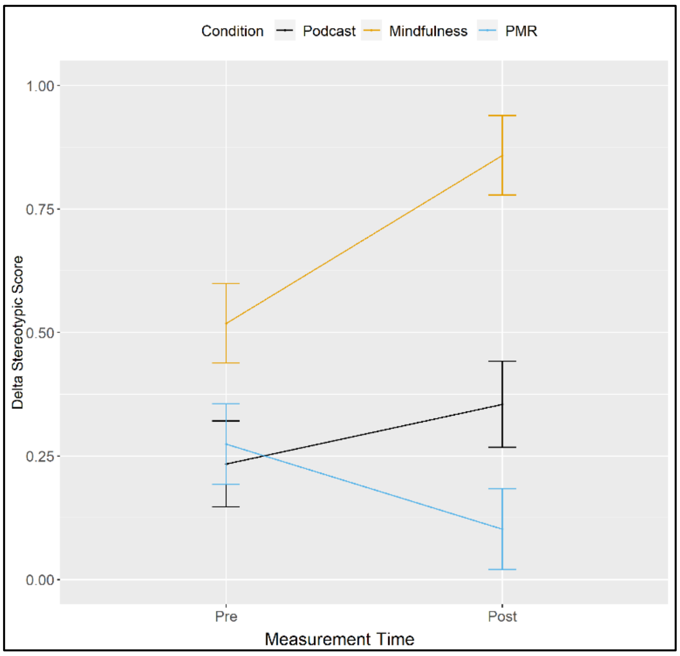


Figure 3.
Experiment 1: Stereotypic Drift Rate from Pre- to Post-Measurement.

Table 2

Experiment 1: Mixed ANOVAs for the DDM Parameters in the Shooter Task

	Sum of Squares	df	Mean Square	*F*	*p*
Delta White unarmed					
Measurement Point	29.36	1	29.36	182.42	**<.001**
Condition	0.10	2	0.05	0.31	0.731
Measurement Point x Condition	4.04	2	2.02	12.55	**0.015**
Delta Black unarmed					
Measurement Point	26.85	1	26.85	187.93	**<.001**
Condition	0.75	2	0.37	2.61	0.079
Measurement Point x Condition	4.58	2	2.29	16.02	**0.001**
Delta White armed					
Measurement Point	4.48	1	4.48	58.16	**<.001**
Condition	0.20	2	0.10	1.31	0.274
Measurement Point x Condition	3.59	2	1.80	23.33	**<.001**
Delta Black armed					
Measurement Point	6.48	1	6.48	75.67	**<.001**
Condition	0.86	2	0.43	5.05	**0.008**
Measurement Point x Condition	0.76	2	0.38	4.42	**0.015**
Alpha White					
Measurement Point	0.72	1	0.72	139.29	**<.001**
Condition	0.27	2	0.14	26.24	**<.001**
Measurement Point x Condition	0.05	2	0.02	4.43	**0.015**
Alpha Black					
Measurement Point	1.49	1	1.49	144.23	**<.001**
Condition	0.26	2	0.13	12.79	**0.012**
Measurement Point x Condition	0.03	2	0.01	1.23	0.297
Beta White					
Measurement Point	0.03	1	0.03	20.68	**0.016**
Condition	0.03	2	0.01	8.80	**<.001**
Measurement Point x Condition	0.02	2	0.01	5.44	**0.006**
Beta Black					
Measurement Point	0.00	1	0.00	0.89	0.347
Condition	0.01	2	0.01	4.08	**0.020**
Measurement Point x Condition	0.06	2	0.03	24.93	**<.001**
Tau White unarmed					
Measurement Point	0.25	1	0.25	86.39	**<.001**
Condition	0.09	2	0.05	16.23	**<.001**
Measurement Point x Condition	0.09	2	0.04	14.76	**0.003**
Tau Black unarmed					
Measurement Point	0.32	1	0.32	99.86	**<.001**
Condition	0.02	2	0.01	3.73	**0.028**
Measurement Point x Condition	0.03	2	0.02	5.47	**0.006**
Tau White armed					
Measurement Point	0.16	1	0.16	65.69	**<.001**
Condition	0.01	2	0.01	2.60	0.080
Measurement Point x Condition	0.06	2	0.03	12.44	**0.016**
Tau Black armed					
Measurement Point	0.17	1	0.17	80.83	**<.001**
Condition	0.03	2	0.01	6.56	**0.002**
Measurement Point x Condition	0.08	2	0.04	19.81	**<.001**

3.2 Threshold Separation

The parameter alpha reflects the level of evidence required to reach a decision threshold, i.e., the quantity of information for an individual to enable a "shoot" or "do not shoot" response on a given trial. Separate analyses were performed for alpha in White and Black trials; EMMs are displayed in Figure 4.

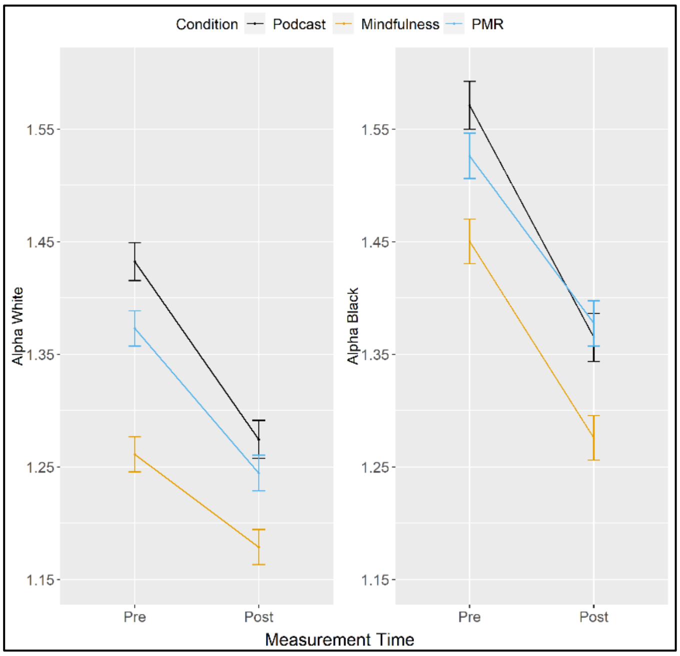


Figure 4.
Experiment 1: Threshold Separation from Pre- to Post-Measurement.

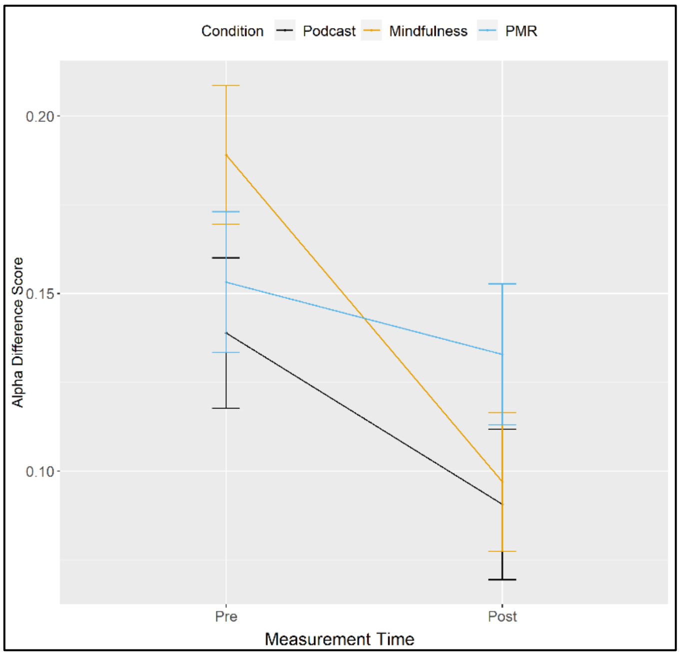


Figure 5.
Experiment 1: Difference Score for Threshold Separation from Pre- to Post-Measurement.

The ANOVA analyzing alpha for White targets indicated a main effect for measurement point and an interaction between measurement point and condition (see Table 2). Planned comparisons (EMM_{t1}-EMM_{t0}) between conditions showed that mindfulness exhibited a lesser decrease in evidence required for decision-making compared to podcast listening, $t(93) = 2.93$, $p = 0.012$, (other contrast's, t's < 2, p's ≥ 0.159). The ANOVA analyzing alpha for Black targets revealed a main effect for measurement point (see Table 2), indicating that all conditions decreased the amount of evidence required for decision-making from pre- to post-measurement.

Analysis of alpha indicated that for both Black and White targets, all conditions decreased the amount of evidence required for decision-making, reflecting a trade-off for less accurate but faster decision-making from pre- to post-measurement. For Black targets, podcast listening decreased to a greater extent than mindfulness, but no further comparisons reached significance. The overall decrease in alpha indicates faster but more error-prone responding, which may be an effect of repeated testing (i.e., adaptation to the restricted response-time window). An ANOVA for the difference score revealed a main effect of measurement point but no interaction between measurement point and condition (see Table 3), indicating that as participants decreased controlled responding from pre- to post-measurement, they also decreased the effect of target race on threshold separation (see Figure 5).

Table 3

Experiment 1: Mixed ANOVAs for the DDM Difference Scores in the Shooter Task

	Sum of Squares	df	Mean Square	*F*	*p*
Delta Stereotypic					
Measurement Point	0.44	1	0.44	2.01	0.159
Condition	9.28	2	4.64	21.07	**<.001**
Measurement Point x Condition	2.21	2	1.11	5.02	**0.008**
Alpha Difference Score					
Measurement Point	0.14	1	0.14	11.73	**<.001**
Condition	0.03	2	0.01	1.13	0.328
Measurement Point x Condition	0.04	2	0.02	1.88	0.159
Beta Difference Score					
Measurement Point	0.02	1	0.02	7.50	**0.007**
Condition	0.00	2	0.00	0.74	0.482
Measurement Point x Condition	0.09	2	0.04	16.32	**<.001**
Tau Difference Score					
Measurement Point	0.00	1	0.00	0.65	0.421
Condition	0.12	2	0.06	11.39	**0.038**
Measurement Point x Condition	0.12	2	0.06	11.78	**0.028**

3.3 Initial Bias

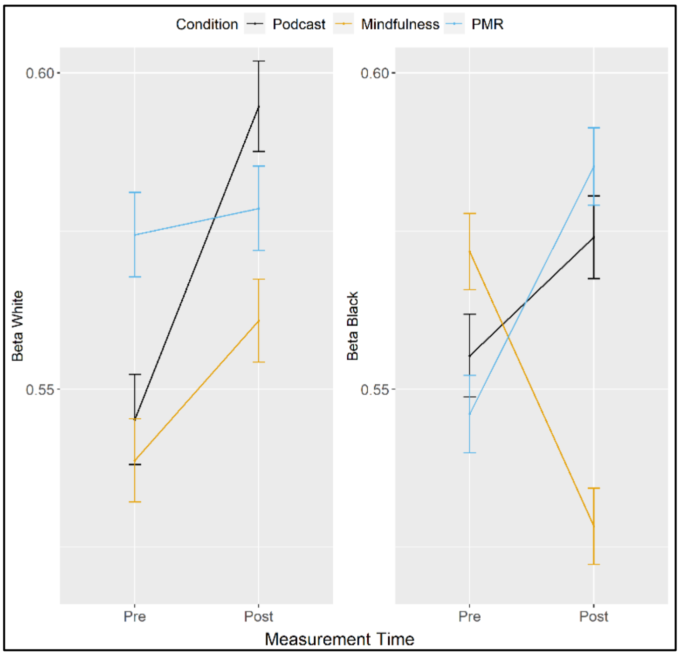


Figure 6.

Experiment 1: Initial Bias from Pre- to Post-Measurement.

The parameter beta describes the participants' initial bias for one of the two choices. Values below 0.5 indicate a bias for "do not shoot" while values above 0.5 indicate a bias for "shoot" decisions. Beta was estimated separately for White and Black targets; EMMs are displayed in Figure 6.

The ANOVA for White targets indicated a main effect for measurement point and an interaction between measurement point and condition (see Table 2). Planned comparisons of EMM contrasts (EMM_{t1}- EMM_{t0}) between conditions showed that the increase in shoot bias following podcast listening was greater compared to PMR, $t(93) = 3.29$, $p = 0.004$ (other contrasts t's ≤ 2, p's ≥ .118).

The ANOVA analyzing beta for Black targets revealed an interaction between measurement point by condition (see Table 2). Planned comparisons (EMM_{t1}- EMM_{t0}) between conditions revealed that while mindfulness decreased a "shoot" bias for Black targets compared to PMR, $t(93) = 6.78$, $p <$ 0.001, and podcast listening, $t(93) = 4.94$, $p < 0.001$, both PMR and podcast listening exhibited similar increases in "shoot" bias, $t < 2$, $p = 0.247$.

Analysis of initial bias indicated differential effects for Black compared to White targets. While for White targets, all conditions exhibited an increase in initial "shoot" bias (which would be expected given the pay-off matrix of the Shooter Task), mindfulness was followed by a decrease in "shoot" bias for Black targets compared to increases for both control conditions. Influences of target race on beta within and between conditions were assessed with an ANOVA for beta difference score. Results indicated a main effect of measurement point and an interaction between measurement point and condition (see Table 3). Planned comparisons between conditions indicated an increase for PMR compared to a decrease following mindfulness, $t(93) = 5.64$, $p < 0.001$, and podcast listening, $t(93) = 3.54$, $p = 0.002$ (mindfulness vs. podcast listening, $t < 2$, $p = 0.148$). However, values at pre- and post-measurement were close to zero (see Figure 7). Thus, as expected, given previous research, the effect of target race on initial bias was marginal.

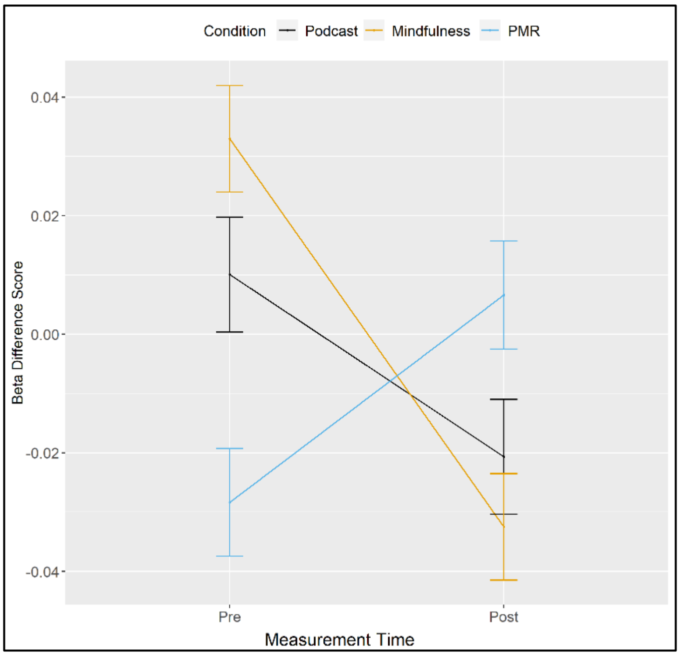


Figure 7.
Experiment 1: Difference Score for Initial Bias from Pre- to Post-Measurement.

3.4 Non-Decision Time

The parameter tau reflects response components that are unrelated to decision-making. Values are displayed in milliseconds. Tau was estimated separately for all combinations of ethnicity and object type. EMMs are displayed in Figure 8.

The ANOVAs for all combinations of race and object revealed a main effect for measurement point and an interaction between measurement point and condition (see Table 2). Planned comparisons (EMM_{t1}- EMM_{t0}) between conditions for White unarmed targets revealed a smaller increase in non-decision time following mindfulness compared to PMR, $t(93) = 3.48$, $p = 0.002$, as well as podcast listening, $t(93) = 5.32$, $p < 0.001$, (PMR vs. podcast listening, $t < 2$, $p = 0.133$). Planned comparisons between conditions for Black unarmed targets revealed a greater increase in non-

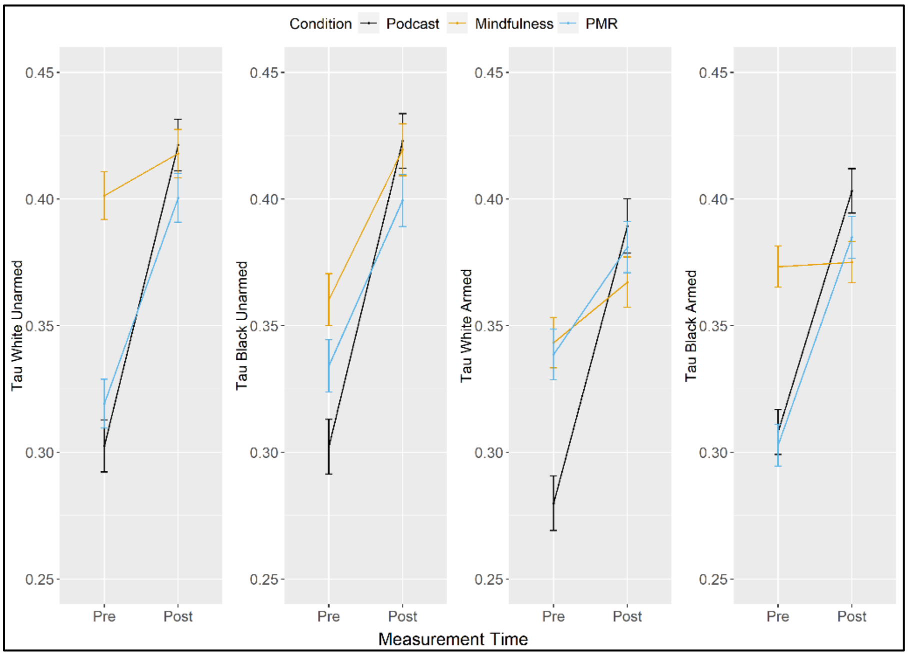


Figure 8.
Experiment 1: Non-Decision Time from Pre- to Post-Measurement.

decision time following podcast listening compared to both mindfulness, $t(93) = 3.04$, $p = 0.008$, and PMR, $t(93) = 2.72$, $p = 0.021$, (mindfulness vs. PMR, $t < 1$). Planned comparisons for White armed targets showed that podcast listening exhibited a greater increase in non-decision time compared to both mindfulness, $t(93) = 4.80$, $p < 0.001$, and PMR, $t(93) = 3.73$, $p < 0.001$, (mindfulness vs. PMR, $t = 1$). Finally, planned comparisons for Black armed targets showed that mindfulness increased in non-decision time for Black armed targets to a lesser extent compared to PMR, $t(93) = 5.07$, $p < 0.001$, and podcast listening, $t(93) = 5.70$, $p < 0.001$, (PMR vs. podcast listening, $t < 1$).

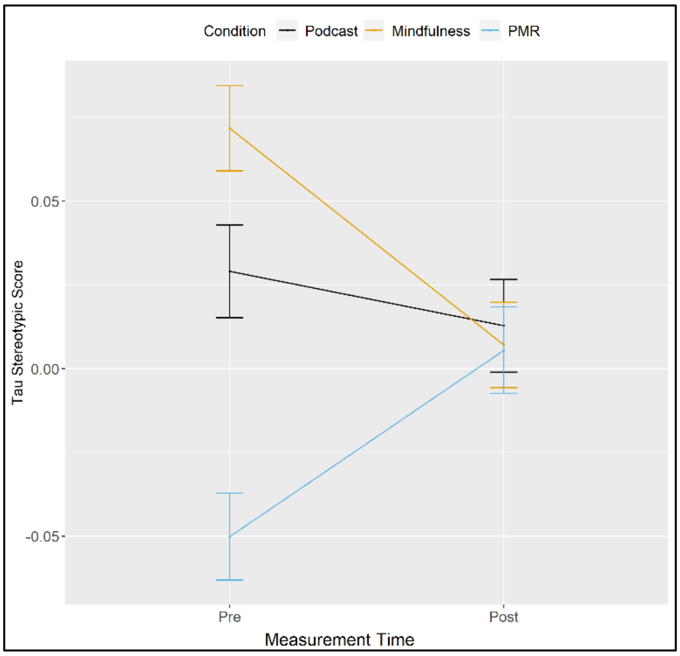


Figure 9.
Experiment 1: Stereotypic Non-Decision Time from Pre- to Post-Measurement.

Overall, mindfulness was followed by lesser increases in non-decision time in White unarmed and Black armed trials (i.e., stereotype congruent) compared to PMR and podcast listening, which showed similar increases. For Black unarmed and White armed (i.e., stereotype incongruent) targets, increases following mindfulness and PMR were similar, compared to greater increases following podcast listening. Estimating the effect of stereotype bias on tau showed an interaction between measurement point and condition (see Table 3). Planned comparisons between conditions indicated an increase in non-decision time for stereotype congruent trials for PMR compared to a decrease following mindfulness, $t(93) = 4.83$, $p < 0.001$, and podcast listening, $t(93) = 2.77$, $p = 0.018$, (mindfulness vs. podcast listening,

$t < 2$, $p = 0.150$). Similar to the findings in initial bias (beta), deviations from zero were small (see Figure 9); thus, there was no substantial effect of stereotype bias from pre- to post-measurement in accordance with previous studies.

3.5 Positive and Negative Affect

The analysis of variance for PANAS scores showed no effect of measurement point by condition (see Appendix D). Thus, PANAS scores were not included as covariates in the analyses reported above.

4 Results Experiment 2

Three participants needed to be removed due to recording failure. Prior to modeling, reaction times smaller than 100 ms were removed, resulting in 0.91% of data loss.

4.1 Drift Rate

Separate ANOVAs for German and Turkish unarmed as well as German and Turkish armed targets were performed. The results are displayed in Figure 10.

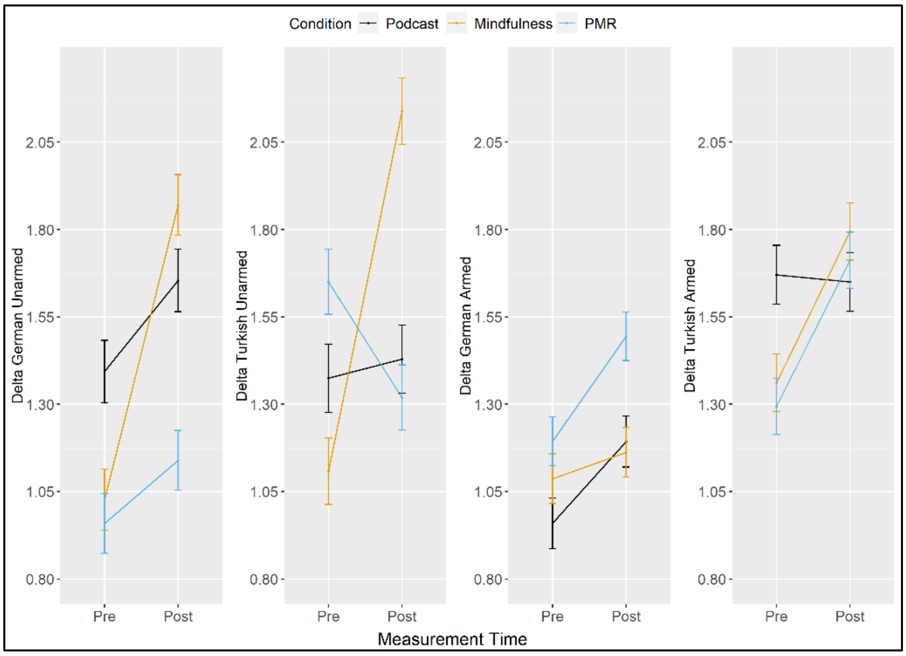


Figure 10.
Experiment 2: Drift Rates from Pre- to Post-Measurement

The ANOVAs analyzing delta for German and Turkish unarmed targets as well as for Turkish armed targets revealed a main effect for measurement point and an interaction between measurement point and condition (see Table 4). Planned comparisons (EMM_{t1}-EMM_{t0}) between conditions for German unarmed targets showed a greater improvement in evidence accumulation following mindfulness compared to both PMR, $t(63) = 5.56$, $p < 0.001$, and podcast listening, $t(63) = 4.78$, $p < 0.001$, (PMR vs. podcast, $t < 1$). Planned comparisons for Turkish unarmed targets showed that the improvement in evidence accumulation following mindfulness was greater compared to podcast listening, $t(63) = 7.74$, $p < 0.001$, and differed from PMR, who exhibited a decrease in evidence accumulation, $t(63) =$

11.06, $p < 0.001$, and accordingly also differed from podcast listening, $t(63) = 3.10$, $p = 0.008$. Planned comparisons for Turkish armed targets showed that compared to podcast listening, mindfulness, $t(63) = 3.31$, $p = 0.004$, as well as PMR, $t(63) = 3.24$, $p = 0.005$, led to greater improvements in evidence accumulation, (mindfulness vs. PMR, $t = 0.11$, $p < 0.994$). The ANOVA analyzing delta for German armed targets indicated a main effect for measurement point (see Table 4); all conditions increased in evidence accumulation from pre- to post-measurement.

In summary, for both German and Turkish unarmed targets, mindfulness outperformed PMR and podcast listening in increasing evidence accumulation for the correct response. For Turkish armed targets, mindfulness and PMR led to similar improvements compared to lesser improvements following podcast listening. All conditions improved evidence accumulation in German armed trials from pre- to post-measurement. Compared to Experiment 1, podcast listening exhibited lesser increases in evidence accumulation from pre- to post-measurement, which may be explained by greater task difficulty (i.e., greater variations in target stimuli affecting discriminability as well as response keys depending on target location leading to greater difficulty in response selection). PMR similarly improved to a lesser degree. Greater improvements in evidence accumulation following mindfulness may indicate that a brief mindfulness training increased cognitive control for responding in accordance with task demands compared to PMR and podcast listening. As can be seen in Figure 10, and similar to Experiment 1, mindfulness again exhibited the smallest increase in evidence accumulation for stereotype incongruent (i.e., Turkish) armed targets compared to all other trial conditions.

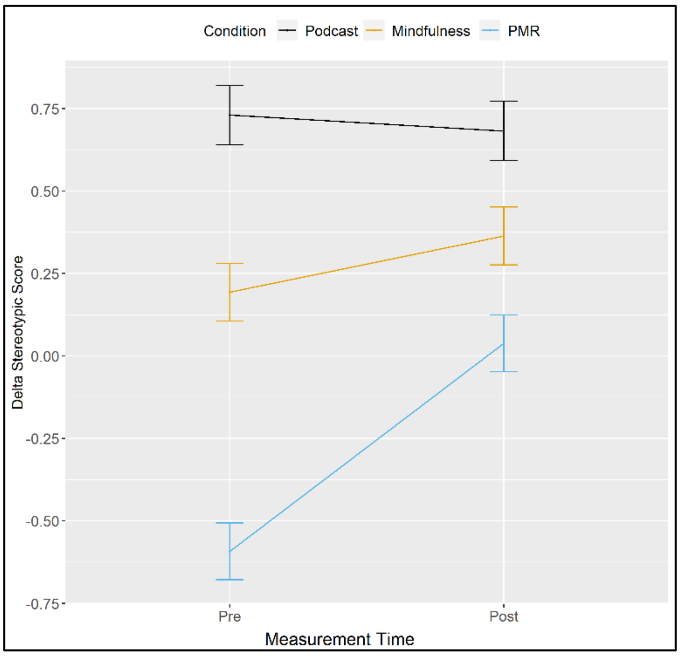


Figure 11.
Experiment 2: Stereotypic Drift Rate from Pre- to Post-Measurement.

An ANOVA for stereotypic drift rate was performed to assess if changes in evidence accumulation depended on stereotype bias. Results indicated a main effect for measurement point and an interaction between measurement point and condition (see Table 5). Planned comparisons between conditions revealed differential effects for PMR, which reduced the effect of a counter-stereotype bias (i.e., more efficient evidence accumulation for incongruent compared to congruent trials) on evidence accumulation compared to mindfulness, who exhibited an increase in stereotype bias, $t(63) = 2.80$, $p = 0.018$, and podcast listening, who exhibited the highest effect of stereotype congruency but no pre-post change, $t(63) = 4.08$, $p = 0.001$, (mindfulness vs. podcast listening, t = 1.30, p = 0.401). The results are displayed in Figure 11. Like in Experiment 1, increases in stereotypic drift rate following mindfulness did not reflect increases in the effect of stereotype congruency but lesser improvement in evidence accumulation in the stereotype incongruent armed target condition. Furthermore, while PMR started with a counter-stereotypic bias at pre-measurement, the training was again followed by a reduction in bias. As can be seen in Figure 10, this was based on a reduction of efficient evidence accumulation in stereotype-incongruent unarmed trials.

4.2 Threshold Separation

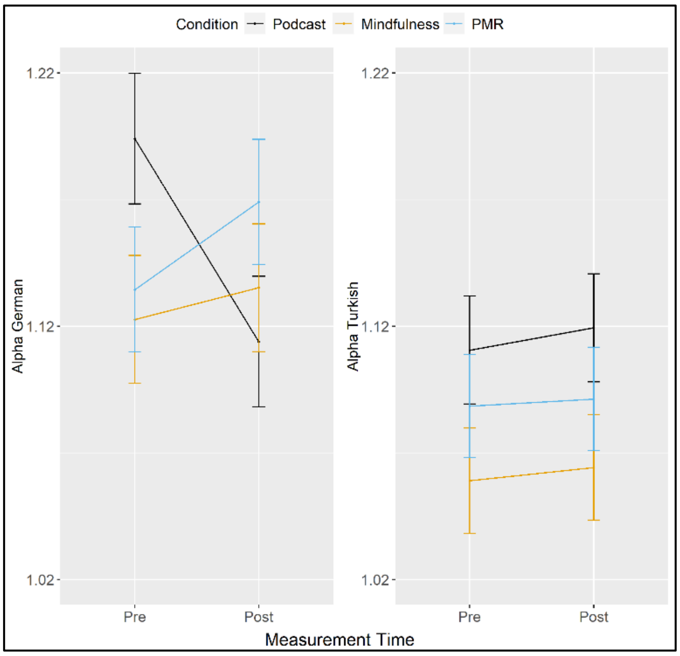


Figure 12.
Experiment 2: Threshold Separation from Pre- to Post-Measurement.

Separate analyses were performed for alpha in German and Turkish trials, EMMs are displayed in Figure 12.

The ANOVA analyzing alpha for German targets indicated an interaction between measurement point and condition. Planned comparisons of EMM contrasts (EMM_{t1}- EMM_{t0}) between conditions showed that podcast listening was followed by a decrease in threshold separation for German targets compared to both mindfulness, $t(63) = 2.36$, $p = 0.055$; and PMR, $t(63) = 2.96$, $p = 0.012$, who exhibited a similar increase, $t < 1$. The ANOVA analyzing alpha for Turkish targets revealed no main effect for measurement point and no interaction between measurement point and condition (see Table 4), indicating no changes in threshold separation for Turkish targets from pre- to post-measurement.

In summary, podcast listening decreased in threshold separation for German targets from pre- to post-measurement, indicating that podcast listening was followed by less accurate but faster responses in German trials. At the same time, an increase in controlled responding was present following a brief mindfulness and relaxation training. The analysis of threshold separation for Turkish targets indicated no changes from pre- to post-measurement. An ANOVA for the alpha difference score revealed an interaction between measurement point and condition (see Table 5). Planned contrasts between conditions showed that podcast listening decreased the difference in threshold separation

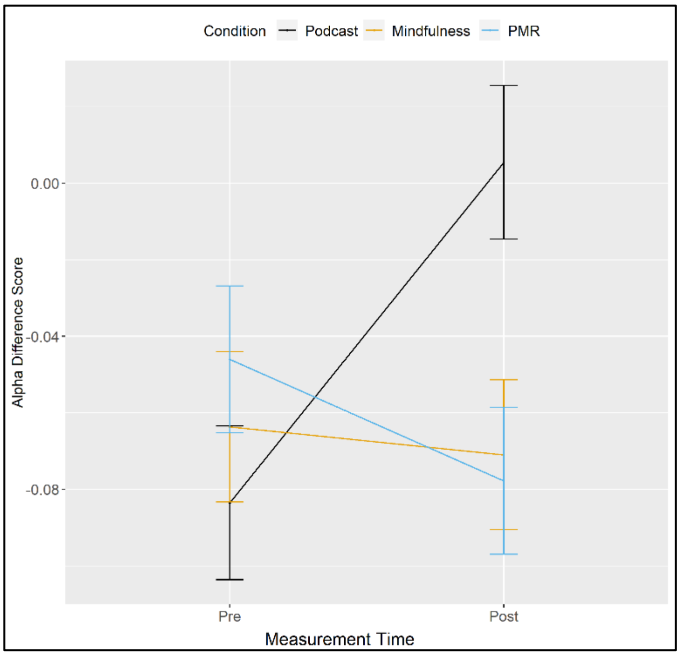


Figure 13.
Experiment 2: Difference Score for Threshold Separation from Pre- to Post-Measurement.

for German and Turkish targets compared to mindfulness, *t*(63) = 2.42, *p* = 0.047, as well as PMR, *t*(63) = 3.07, *p* = 0.009, which were followed by similar increases in threshold separation for German compared to Turkish targets, t < 1. The deviation from zero was small for all conditions (see Figure 13), indicating no substantial effect of target ethnicity on response caution during the Avoidance Task compared to the Shooter task.

4.3 Initial Bias

Separate analyses were performed for beta in German and Turkish targets, EMMs are displayed in Figure 14. Both ANOVAs for German and Turkish targets indicated a main effect of measurement point and an interaction between measurement point and condition, see Table 4.

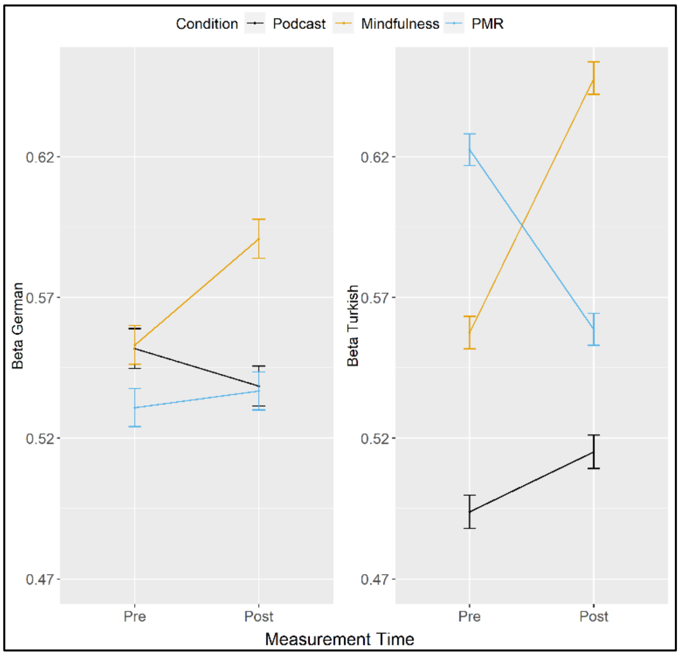


Figure 14.
Experiment 2: Initial Bias from Pre- to Post-Measurement.

Planned comparisons for beta in German trials showed that the increase in "avoid" bias following mindfulness was greater compared to the increase following PMR, *t*(63) = 2.99, *p* = 0.011, and differed from podcast listening who decreased, *t*(63)= 4.69, *p* < 0.001 (PMR vs. podcast listening, *t* < 2, *p* = 0.181). Planned comparisons for beta in Turkish trials revealed that PMR was followed by a decrease compared to mindfulness, *t*(63) = 14.89, *p* < 0.001, and podcast listening, *t*(63) = 8.12, *p* < 0.001, which exhibited an increase in "avoid" bias for Turkish targets, which was greater following mindfulness compared to podcast listening, *t*(63) = 6.52, *p* < 0.001.

Table 4

Experiment 2: Mixed ANOVAs for the DDM Parameters in the Avoidance Task

	Sum of Squares	df	Mean Square	*F*	*p*
Delta German unarmed					
Measurement Point	6.04	1	6.04	75.52	**<.001**
Condition	1.82	2	0.91	11.40	**<.001**
Measurement Point x Condition	2.90	2	1.45	18.11	**<.001**
Delta Turkish unarmed					
Measurement Point	2.08	1	2.08	24.37	**<.001**
Condition	0.29	2	0.15	1.73	0.186
Measurement Point x Condition	10.99	2	5.50	64.46	**<.001**
Delta German armed					
Measurement Point	1.36	1	1.36	19.80	**<.001**
Condition	0.82	2	0.41	5.98	**0.004**
Measurement Point x Condition	0.30	2	0.15	2.16	0.123
Delta Turkish armed					
Measurement Point	2.53	1	2.53	25.14	**<.001**
Condition	0.28	2	0.14	1.38	0.260
Measurement Point x Condition	1.42	2	0.71	7.08	**0.002**
Alpha German					
Measurement Point	0.00	1	0.00	0.48	0.490
Condition	0.01	2	0.00	0.43	0.655
Measurement Point x Condition	0.08	2	0.04	4.85	**0.011**
Alpha Turkish					
Measurement Point	0.00	1	0.00	0.31	0.582
Condition	0.01	2	0.01	1.96	0.150
Measurement Point x Condition	0.00	2	0.00	0.03	0.971
Beta German					
Measurement Point	0.00	1	0.00	5.31	**0.025**
Condition	0.01	2	0.01	11.70	**<.001**
Measurement Point x Condition	0.01	2	0.01	11.29	**<.001**
Beta Turkish					
Measurement Point	0.01	1	0.01	13.88	**<.001**
Condition	0.17	2	0.09	141.86	**<.001**
Measurement Point x Condition	0.13	2	0.07	111.44	**<.001**
Tau German unarmed					
Measurement Point	0.05	1	0.05	11.13	**0.001**
Condition	0.02	2	0.01	1.58	0.215
Measurement Point x Condition	0.06	2	0.03	6.28	**0.003**
Tau Turkish unarmed					
Measurement Point	0.01	1	0.01	7.06	**0.010**
Condition	0.00	2	0.00	0.31	0.735
Measurement Point x Condition	0.03	2	0.02	11.93	**<.001**
Tau German armed					
Measurement Point	0.01	1	0.01	2.36	0.130
Condition	0.01	2	0.01	1.70	0.190
Measurement Point x Condition	0.00	2	0.00	0.01	0.992
Tau Turkish armed					
Measurement Point	0.00	1	0.00	0.16	0.690
Condition	0.02	2	0.01	3.24	**0.046**
Measurement Point x Condition	0.04	2	0.02	7.72	**0.001**

Table 5

Experiment 2: Mixed ANOVAs for the DDM Difference Scores in the Avoidance Task

	Sum of Squares	df	Mean Square	*F*	*p*
Delta Stereotypic					
Measurement Point	2.07	1	2.07	13.66	**<.001**
Condition	17.43	2	8.72	57.43	**<.001**
Measurement Point x Condition	2.66	2	1.33	8.77	**<.001**
Alpha Difference Score					
Measurement Point	0.01	1	0.01	1.08	0.304
Condition	0.02	2	0.01	1.14	0.326
Measurement Point x Condition	0.09	2	0.04	5.20	**0.008**
Beta Difference Score					
Measurement Point	0.00	1	0.00	1.19	0.279
Condition	0.13	2	0.06	67.11	**<.001**
Measurement Point x Condition	0.10	2	0.05	52.54	**<.001**
Tau Difference Score					
Measurement Point	0.16	1	0.16	36.13	**<.001**
Condition	0.01	2	0.00	0.65	0.525
Measurement Point x Condition	0.08	2	0.04	9.28	**<.001**

A brief mindfulness training was followed by an increase in initial avoidance bias for both German and Turkish targets, which is in accordance with greater response reward and punishment for correct and incorrect "avoid" decisions, respectively (i.e., response manipulation by the pay-off matrix). A short training in relaxation and podcast listening exhibited no change in initial bias for German targets. At the same time, PMR decreased, and podcast listening increased an initial avoidance bias for Turkish targets.

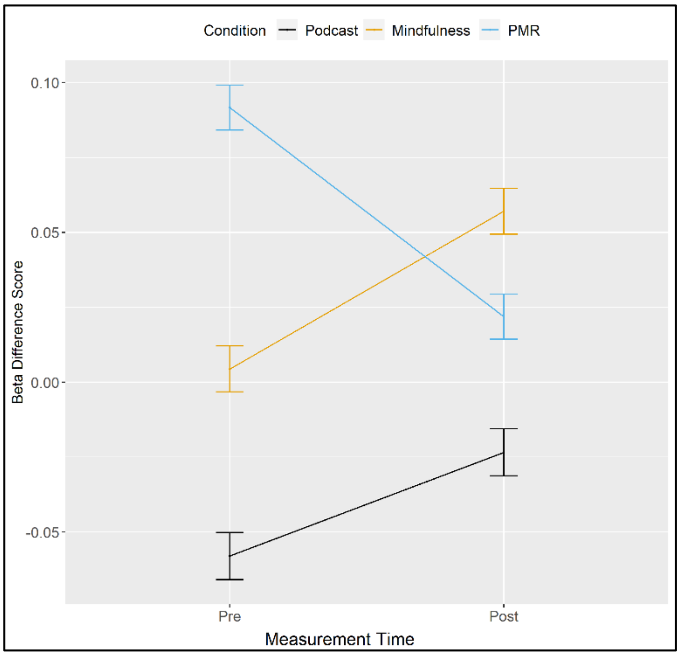


Figure 15.

Experiment 2: Difference Score for Initial Bias from Pre- to Post-Measurement.

An ANOVA with beta difference score as the dependent variable revealed an interaction between measurement point and condition (see Table 5). Planned comparisons between conditions indicated a decrease in the effect of target ethnicity for PMR compared to increased following mindfulness, $t(63) = 9.48$, $p < 0.001$, and podcast listening, $t(63) = 7.99$, $p < 0.001$, (mindfulness vs. podcast listening, $t < 2$, $p = 0.364$). As in Experiment 1, deviations from zero for the beta difference score were small at pre- and post-measurement (see Figure 15), suggesting that the effect of target ethnicity on initial bias is marginal in the Avoidance Task as well.

4.4 Non-decision Time

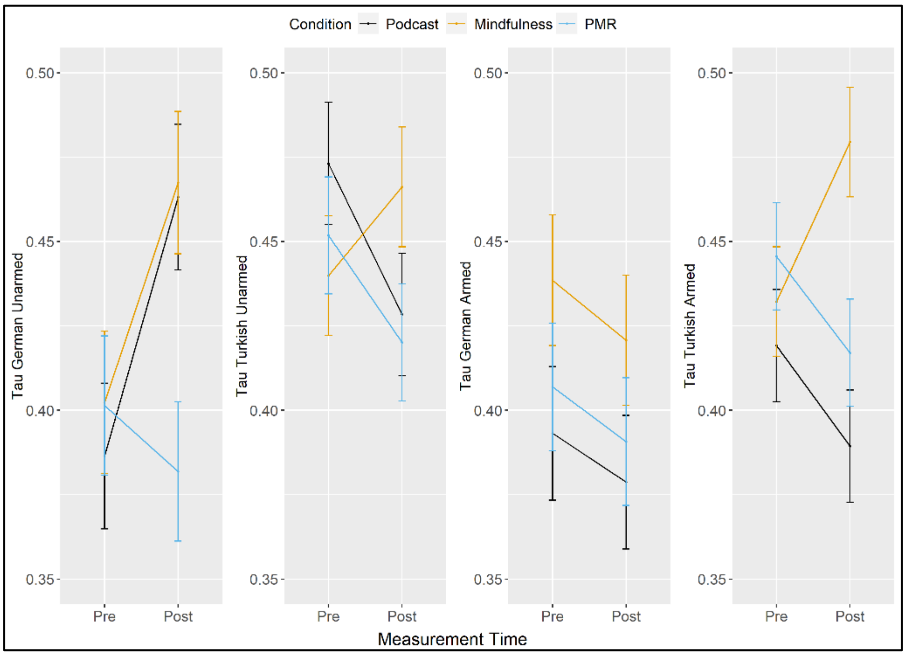


Figure 16.
Experiment 2: Non-Decision Time from Pre- to Post-Measurement.

Four separate analyses were performed for tau. EMMs are displayed in Figure 16. The ANOVA analyzing tau for German unarmed targets indicated a main effect for measurement point and an interaction between measurement point and condition (see Table 4). Planned comparisons of EMM contrasts (EMM_{t1}- EMM_{t0}) between conditions indicated that PMR was followed by a decrease in non-decision time, compared to mindfulness, $t(63) = 2.86$, $p = 0.016$, as well as podcast listening, $t(63) = 3.21$, $p = 0.006$, who exhibited similar increases, $t < 1$. The ANOVA analyzing tau for Turkish unarmed targets revealed a main effect for measurement point and an interaction between measurement point and condition (see Table 4). Planned comparisons revealed that mindfulness was followed by an increase in non-decision time, compared to PMR, $t(63) = 3.81$, $p < 0.001$, and podcast listening, $t(63) = 4.55$, $p < 0.001$, who exhibited a similar reduction, $t < 1$. The ANOVA analyzing tau for German armed targets revealed no main effect for measurement point and no interaction for measurement point by condition (see Table 4). The ANOVA analyzing tau for Turkish armed targets indicated an interaction between measurement point and condition (see Table 4). Planned comparisons between conditions indicated that mindfulness was followed by an increase in non-decision time compared to PMR, $t(63) = 3.42$, $p = 0.003$, and podcast listening, $t(63) = 3.39$, $p = 0.003$, who both similarly decreased, $t < 1$.

In summary, a brief mindfulness training was followed by an increase in non-decision time in all trial conditions except for German armed targets, in which no condition exhibited any pre- to post-changes. Contrary, PMR was followed by decreases in non-decision time for German unarmed, Turkish unarmed, and Turkish armed targets. Following podcast listening, an increase in non-decision time for German unarmed targets was found. In contrast, podcast listening led to decreases in non-decision time following German and Turkish armed targets. This pattern of pre-post changes between conditions showed differences compared to Experiment 1. First, for non-decision time in the Shooter Task, similarities between a short mindfulness induction and PMR were present in stereotype-incongruent trials. In Experiment 2, there were no similarities in the change of non-decision time for a brief mindfulness training and a brief relaxation training, indicating differential effects of the trainings. Also, non-decision times were overall longer in the Avoidance compared to the Shooter Task. This may be due to the more complex response instructions for the Avoidance Task (i.e., which button indicates an avoid or approach response changes according to which side of the street the target person appears).

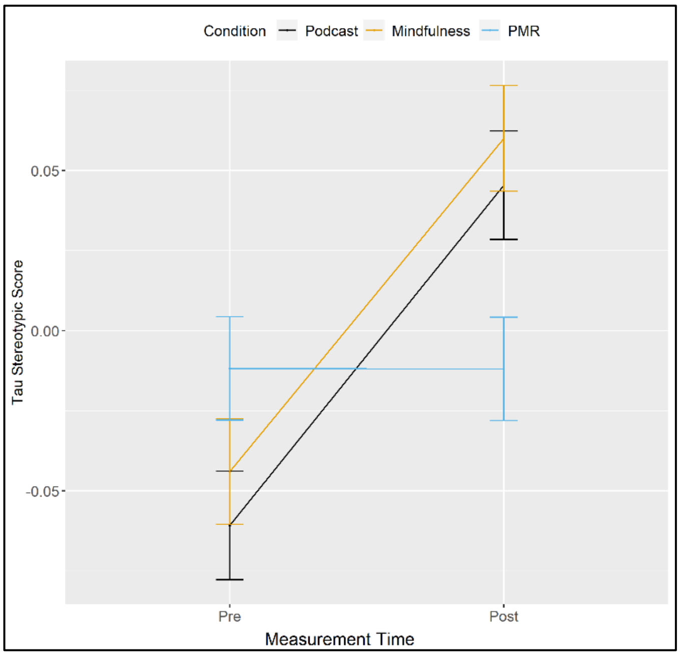


Figure 17.
Experiment 2: Stereotypic Non-Decision Time from Pre- to Post-Measurement

Estimating the effect of stereotype bias on tau indicated a main effect for measurement point and an interaction between measurement point and condition (see Table 5). Planned comparisons between conditions indicated no change following PMR compared to mindfulness, $t(63) = 3.69$, $p = 0.001$, and podcast listening, $t(63) = 3.72$, $p = 0.001$, who increased non-decision time (mindfulness vs. podcast listening, $t < 1$). However, similar to the results in Experiment 1, deviations from zero were small for $Tau_{stereotypic}$, suggesting that as for the Shooter Task, effects of stereotype bias on processes reflected in non-decision time during the Avoidance Task were not substantial (e.g., no effect of stereotype on motor-response preparation or inhibition).

4.5 Positive and Negative Affect

As in Experiment 1, the interaction between measurement point and condition did not reach significance for PANAS scores, all *p*'s > 0.05 (see Appendix D). Accordingly, analyses did not include covariates controlling for affective states.

4.6 Motivation to Control Prejudice

A correlational analysis was performed between the MVV score and separate threshold separations and drift rates and their respective difference scores to examine a possible relationship between threshold separation, drift rate, and motivation to control prejudice. However, no significant relationship between MVV score and any of the variables of interest was found, all *ps*' > 0.05, suggesting that motivation to control prejudice did not affect threshold separation or evidence accumulation during the Avoidance Task. Accordingly, analyses did not include covariates controlling for motivation to control prejudice.

5 Discussion

Social-cognitive models of stereotyping have proposed that while stereotypes and related pre-activated motor responses are activated automatically and unintentionally, initiation of non-prejudiced behavior requires intentional activation of cognitive control (Amodio, 2004; Devine, 1989; Dovidio et al., 1997; Devine & Sharp, 2009). Correspondingly, studies have shown the involvement of attention control and executive functioning in successful behavioral suppression of activated stereotypes (e.g., Bartholow et al. 2006; Correll et al., 2006; Ito et al., 2015; Payne, 2005). The investigation of processes of decision-making underlying stereotype expression has shown that stereotype bias can affect information processing in the following ways (Johnson et al., 2018; Pleskac et al., 2018; Mayerl et al., 2019): evidence for a correct response accumulates more efficiently in stereotype congruent compared to incongruent trials, leading to accelerated response speed and heightened accuracy. Also, greater controlled responding has been reported for Black compared to White targets, characterized by more accurate but slower responses, which has been interpreted as reflecting a motivation to control stereotype-biased responding. Therefore, the present paper investigated if training cognitive control by mindfulness meditation would lead to less stereotype-biased information processing and more controlled responding in the Shooter and the Avoidance Tasks. Previous findings have indicated that even short inductions of a mindful state effectively decrease racial stereotype activation and bias expression (Lueke & Gibson, 2015 & 2016). However, studies utilizing longer training durations have reported no effects of mindfulness on racial stereotype expression (Hunsinger et al., 2019).

In Experiment 1, the effects of a short mindfulness induction on the decision process during the Shooter Task were contrasted with the effects of a short relaxation induction and a passive podcast listening condition. In Experiment 2, we increased the training length and the number of training sessions to address the question of dose-response relations for mindfulness trainings and cognitive control (e.g., Gill et al., 2020; Vieth & von Stockhausen, 2022a). Furthermore, the Avoidance Task was utilized to address the generalizability of the effects reported for the Shooter Task (e.g., Pleskac et al., 2018) and to increase the ecological validity of the scenario in a German sample. Decision behavior was modeled with drift diffusion models, which jointly take into account response times and responses. Results for effects on the expression of stereotype bias and decision-making processes will be discussed for both experiments.

5.1 Effects of Mindfulness on Stereotype Bias

We postulated that enhanced cognitive control following mindfulness training would improve the processing of task-relevant information (i.e., object type) while disregarding task-irrelevant information (i.e., target race or ethnicity). Such an improvement would reduce the effect of stereotype bias on evidence accumulation (drift rate; delta) during the Shooter and the Avoidance Task, meaning that evidence accumulation for correct decisions would not be facilitated in stereotype congruent compared to incongruent trials. For the Shooter Task in Experiment 1, stereotypic drift rates ($Delta_{stereotypic}$) at pre-measurement indicated the presence of a stereotype bias for all conditions, reflecting that evidence for a correct decision accumulated more efficiently for stereotype congruent compared to incongruent trials and thus replicating previous findings of stereotype bias affecting the process of information accumulation (Correll et al., 2015; Johnson et al., 2018; Pleskac et al., 2018; Mayerl et al., 2019). Contrary to our hypothesis, the effect of stereotype bias on evidence accumulation increased following mindfulness, while a decrease was found following PMR. Pre-post changes for podcast listening did not differ significantly from mindfulness or PMR. For the Avoidance task in Experiment 2, podcast listening and mindfulness exhibited stereotype-biased evidence accumulation at pre-measurement. At the same time, PMR displayed a counter-stereotypic bias (i.e., evidence for stereotype-incongruent trials accrued more efficiently compared to incongruent trials). Similar counter-stereotype bias effects as following PMR have also been reported in previous tasks (e.g., James et al., 2016; Peck et al., 2021). For the Avoidance Task, this reflects an interaction between target ethnicity and object type, nevertheless. Overall, these findings replicate an effect of stereotype bias on decision-making and response behavior during the Avoidance Task (Essien et al., 2017). Similar to the Shooter Task, mindfulness was followed by an increased stereotypic drift rate compared to both control conditions. The passive control condition exhibited no pre-post changes in stereotypic drift rate, while relaxation training reduced a counter-stereotypic drift rate. In summary, these results suggest that short trainings in relaxation, but not mindfulness, were beneficial for reducing the effect of stereotype bias on response behavior in the Shooter and the Avoidance Task. While our hypothesis of enhanced cognitive control following mindfulness meditation leading to less biased decision-making was thus not confirmed, the differential findings for mindfulness compared to PMR suggest differential mechanisms of short trainings in mindfulness mediation and relaxation, which has been a point of discussion in the mindfulness literature (Fell et al., 2010; Vieth & von Stockhausen, 2022a).

For threshold separation (i.e., the amount of evidence required for decision making; alpha), we proposed that greater cognitive control may lead to increased controlled responding (i.e., longer reaction times and less error-prone responding) for Black or Turkish targets. In line with previous studies (Frenken et al., 2022; Johnson et al., 2018; Pleskac et al., 2018), results for the Shooter Task indicated that all conditions exhibited higher controlled responding for Black compared to White targets at pre-measurement. Differences in threshold separation for Black compared to White targets decreased for all conditions from pre- to post-measurement, indicating that repeated testing reduced the effect of target race on response style across conditions. For the Avoidance Task, effects on target ethnicity on threshold separation were non-substantial. For both tasks, there was no correlation between threshold separation and self-reported motivation to control prejudice. For the Shooter Task, this finding contrasts with previous interpretations of heightened controlled responding indicating an effort to control stereotype-biased behavior for Black targets (e.g., Pleskac et al., 2018).

For initial bias (starting point; beta) and non-decision time (all processes taking place before and after the decision process; tau), previous studies have provided no evidence for an effect of stereotype during the Shooter Task (Correll et al., 2015; Johnson et al., 2018; Pleskac, 2018; Mayerl et al., 2019). Confirmingly, the present results indicated no effect of target race or ethnicity on initial bias or non-decision time in the Shooter and Avoidance Task.

5.2 Effects of Mindfulness on Decision Making

Overall, changes in the decision-making process for the Shooter Task were indicative of lesser improvements following mindfulness compared to PMR and podcast listening: Evidence for correct decisions accrued less efficiently following mindfulness compared to the control conditions. Combined with the reduced amounts of evidence required for making a decision found in all groups, mindfulness was followed by faster but also more error-prone responding compared to the control conditions (i.e., higher fluctuations in drift rate indicate greater ambiguity and more error-proneness in evidence accumulation; lower thresholds reduce the amount of evidence required for decision making, which goes along with decreased reaction time and increased error-proneness). In comparison, greater efficiency in evidence accumulation following PMR and podcast listening combined with decreased thresholds for decision-making resulted in faster but comparably less error-prone responding (i.e., while lower thresholds indicate faster but more error-prone responding, steeper drift rates decrease the likelihood of reaching the incorrect response threshold). Findings for initial bias showed overall adaptation to response rewards by the pay-off matrix, but mindfulness exhibited a decrease in initial bias for Black targets. The difference score for initial bias ($Beta_{Black}$ – $Beta_{White}$) showed no substantial effect of race, and previous studies have similarly reported no effects of target race on initial bias. Accordingly, the reduction in “shoot” bias for Black targets following mindfulness may be generally interpreted as unbeneficial for increasing response reward (i.e., reducing a “shoot” bias goes against the reward pattern of the pay-off matrix). In comparison, both PMR and podcast listening increased an initial “shoot” bias in all targets in accordance with the manipulation by the pay-off matrix. Considering the results for non-decision time, mindfulness exhibited the least increases compared to both controls (congruent trials) or podcast listening (incongruent trials). Because non-decision time reflects several processes (e.g., stimulus encoding and motor-response preparation), a clear-cut interpretation of these results is difficult. However, in combination with the findings of faster but more error-prone responding following mindfulness, we would argue that lesser increases in non-decision time following mindfulness are in line with more impulsive responding compared to both controls.

In contrast, results for the Avoidance Task indicated greater improvements in decision-making following mindfulness compared to podcast listening and at least partially greater improvements compared to PMR. Regarding the efficiency of evidence accumulation, mindfulness exhibited greater improvement compared to both controls (for unarmed targets) and podcast listening (for armed targets). Furthermore, mindfulness and PMR increased the response threshold for German targets and exhibited no change for Turkish targets. Thus, mindfulness and PMR exhibited increased accuracy and response time, indicative of (more) controlled responding, and this was even more pronounced for mindfulness compared to PMR in unarmed targets (i.e., drift rates are steeper, reflecting faster and more accurate responding; high response thresholds reflect slower and less error-prone responding). Contrary, podcast listening was followed by lesser improvements in evidence accumulation and decreased threshold separation for German but not Turkish targets. For German targets, decision-making following podcast listening was thus faster but comparably more error-prone. For Turkish targets, decision-making may have been comparably slower but with no pre-post change in accuracy. Regarding initial bias, mindfulness increased an initial „avoid“ bias for all targets, indicating beneficial adaptation to reward manipulation by the pay-off matrix. The changes following PMR and podcast listening indicated less beneficial adaptations (PMR decreased an initial "avoid" bias for Turkish targets while an increase followed podcast listening; both conditions exhibited no change in German trials). For non-decision time, mindfulness was followed by increases in processes unrelated to decision-making. In comparison, PMR was followed by decreases in non-decision time. Given that PMR indicated similar improvements in decision-making as mindfulness, the differential changes in non-decision time are difficult to interpret. Considering that mindfulness led to greater efficiency in evidence accumulation in some trial conditions compared to PMR, reductions in non-decision time following PMR versus increases in non-decision time following mindfulness might indicate longer stimulus processing prior to decision-making in mindfulness, and this may have affected subsequent information processing favorably. For podcast listening, changes in non-decision time were similarly unclear, as non-decision time increased for German armed targets while it decreased for Turkish unarmed and armed targets. Considering the lesser improvement in evidence accumulation following podcast listening and a reduction in threshold separation for German targets, increased non-decision time for German armed targets may indicate difficulty in response preparation following lesser quality and quantity in information processing. For Turkish targets, podcast listening required more information for decision-making (i.e., greater threshold separation in comparison to German targets), which may indicate that response preparation could have been facilitated by greater information uptake.

6 Conclusion

Concluding, the presented results suggest partially shared, partially differential effects of short trainings in mindfulness and relaxation. Regarding general improvements in decision-making, a short mindfulness induction seemed to impair beneficial improvements in the Shooter Task from pre- to post-measurement compared to relaxation and the passive control condition. For the Avoidance Task, brief mindfulness and relaxation trainings were similarly beneficial compared to lesser improvements for the passive control condition. However, a direct comparison of training effects is limited by the fact that two conceptually similar but still different tasks were employed (differences in stimuli and social groups utilized and additional spatial aspect of responding in the Avoidance compared to the Shooter Task). Regarding the effects of stereotype bias, in both the Shooter and Avoidance Task, short trainings in PMR resulted in reduced effects of stereotype bias on evidence accumulation. Contrary to our hypothesis, mindfulness increased the effect of stereotype bias on evidence accumulation in both tasks. Separate analyses of drift rates suggested that for mindfulness, increased effects of stereotype bias were based on lesser improvement in stereotype incongruent (White or German armed) trials, which indicates that mindfulness was followed by comparably higher ambiguity in evidence accumulation (reflected in slower and more error-prone responses) in trials with heightened response conflict (i.e., target race or ethnicity was incongruent with the presence of a harmful object). For PMR, results of the Shooter Task indicated that a decrease in the effect of stereotype bias in response behavior was based on greater improvements in stereotype incongruent (White) armed targets, thus comparably lesser ambiguity in information processing along with faster and more accurate responding. For the Avoidance Task, in which PMR displayed counter-stereotypic bias at pre-measurement, the reduction of this bias was based on a reduction in evidence accumulation in stereotype incongruent (Turkish) unarmed trials. While a counter-stereotype bias was unexpected, these results still imply that task performance at post-measurement following PMR was less dependent on associations between target ethnicity and object type. Thus, all changes in the effect of stereotype bias were explained by respective changes in incongruent but not congruent trials, suggesting that mindfulness and PMR differentially affected information processing under conditions that induced response conflict. However, why these effects only emerged in either armed or unarmed incongruent trials is unclear.

Our results differ from Lueke & Gibson's (2015) findings of reduced automatic stereotype associations on race and age IATs following 10 minutes of FAM Furthermore, Lueke and Gibson (2016) reported less biased treatment of Black compared to White players in a trust game. These differential findings may be related to differences in the paradigms utilized. In comparison to the IAT, which requires that participants shift between a concept (e.g., ethnicity) and an attribute (e.g., valence) categorization task, the Shooter and Avoidance Task do not require such shifts between task sets (i.e., in every trial, the task is to identify the target object). Relatedly, Ito et al. (2015) have shown that for the Shooter Task, greater control over bias expression was predicted by common executive functioning ability, while for the IAT, bias control was predicted specifically by shifting ability (for a discussion of the involvement of task switching in IAT performance, see for example Klauer et al., 2010). Furthermore, while both tasks in the present paper imply that a physical threat needs to be avoided (by shooting or avoiding an armed target), the trust game utilized by Lueke and Gibson (2016) implies that a monetary gain can be optimized based on the trustworthiness of a counterpart, thereby not inducing a situation of danger or threat. Nevertheless, based on Lueke and Gibson's findings, the involvement of cognitive control in the expression or suppression of stereotype-biased behavior (e.g., Amodio, 2014; Bartholow et al., 2012; Payne, 2005) and beneficial effects of mindfulness meditation on cognitive control (for a review, see Chiesa et al., 2011) we would have expected to find improvements in unbiased decision-making and responding following mindfulness training. Furthermore, if the training dosages in the present study were insufficient in increasing cognitive control following mindfulness, we would have expected to find no change in the effect of stereotype bias on decision-making but not an increased effect of stereotype bias. Relatedly, we would not have expected to find improved suppression of stereotype-biased behavior following induced relaxation by PMR. These findings may suggest that processes outside of cognitive control resulted in beneficial improvements following relaxation trainings. However, based on the present data, no definitive interpretation of underlying mechanisms for this effect can be made.

7 Limitations and Future Research

Implementing the experiments in an online research environment required careful checks regarding the fidelity of training delivery, testing and participants' compliance. As described above, we assured fidelity by providing thorough instructions about necessary equipment and an adequate environment for participation, sound checks prior to audio delivery of inductions and podcast listening and requested written agreements to adherence to instructions. Also, the frequency and severity of disturbances were assessed. A more detailed description of the results of these checks is reported in Vieth & von Stockhausen (2022b). Overall, most participants reported no disturbances during testing and audio delivery, and disturbances reported were rated to be of low impact on study participation. Therefore, online testing and audio delivery implementation seemed to have been of sufficient quality.

To our knowledge, this study is the first to apply drift diffusion modeling to the Avoidance Task. Based on theoretical considerations and for direct comparability of the results of both experiments, we utilized the same HDDMs for the Shooter and the Avoidance Task. The results generally suggested that processes of decision-making in the Avoidance Task were well reflected by the parametrization (i.e., an avoidance bias could be replicated; effects on bias expression following mindfulness and PMR emerged similarly across tasks). Still, assessing how well the model accounts for the data by conducting posterior predictive checks in future studies would be advisable. Furthermore, estimating models in which parameters vary differently by trial conditions (e.g., allowing threshold separation to vary as a function of object type) and comparing model fits could be done to further assess the adequacy of the model for the Avoidance Task (for a discussion of variations in parameter estimation for the Shooter Task see Pleskac et al., 2018).

For the Shooter Task, we decided to instruct participants to indicate the presence or absence of a gun instead of asking participants to indicate a "shooting decision" as in the original task by Correll et al. (2002). While we thus adapted instructions to improve the external validity of the task in a German sample, this may have affected the comparability of our results to studies utilizing the original instructions. However, since effects of stereotype activation on response behavior can also be found in the Weapon Identification Task (e.g., Payne, 2001), which similarly instructs participants to identify objects as a tool or a weapon, we would argue that the internal validity of the task was not threatened.

The present experiments were parts of two studies that also assessed the executive functions of inhibition, updating/working memory and task switching. The analyses of the effects of short mindfulness trainings on separate executive functions did not reveal significant improvements following short training periods of mindfulness meditation (Vieth & von Stockhausen, 2022b). However, there is evidence that while mindfulness trainings may not lead to domain-specific improvements in executive functions, overall executive control abilities across separate domains are improved (Cásedas et al., 2020; Whitfield et al., 2021), and common executive ability has been shown to reduce stereotype bias expression (Ito et al., 2015). Future research may implement designs suitable for latent variable analysis to assess whether short mindfulness trainings may lead to domain-general improvements in EFs and to investigate if such an improvement affects successful stereotype bias control in response behavior.

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Appendix A

Supplementary Material Containing Instructions for the Mindfulness Meditation and Progressive Muscle Relaxation

Inductions were read to the participants in German. Below are translated versions of the instructions.

Mindfulness Meditation

The mindfulness instructions focused on being present in and aware of the present moment, observing one's flow of breath without interfering with it, observing and letting go of thoughts and emotions that arise, and overall acceptance of the present moment.

Breathing Meditation Instructions

Sit down in a way that allows you to sit for a while in a well-balanced position. Straighten up slightly. Some people imagine a golden thread at the crown of their head that is pulling their head up.

(If you like,) close your eyes. If you tend to get sleepy, fixate on any point in the room in front of you.

Feel where your body is in contact with the chair, where it is supported and sustained.

1-minute pause

Now focus your attention on your breath. Breathe in and breathe out and be aware of this process of breathing. Become aware of your breath, where your body moves in the rhythm of your breath, and how. In the chest, in the stomach, or some other place?

2-minute pause

Feel the ever-changing sensations as the current of your breath flows in and out of the body.

3-minute pause

Allow your body to breathe with its own rhythm. You don't need to change or monitor anything. You are an observer of the processes that come naturally, from one moment to the next.

1-minute pause

Thoughts of all kinds may come to your mind. This is totally fine. Once you've taken note of this, simply direct your attention back to your breathing.

1-minute pause

If you are being critical of yourself, notice this and bring your attention back to your breathing. Be patient with yourself.

2-minute pause

Now take in the complete breathing process once again:

On the inhale, how breath flows in through the nose and lifts the chest and stomach.

On the exhale, how it flows out from the nose and then lowers the chest and belly and the pause after the exhale.

3-minute pause

Broaden your attention again to your whole body and to the space where you are sitting. Let your breath flow again without observing it.

2-minute pause

When you feel ready, open your eyes or let your gaze wander around the room. Be ready and awake for what is next in store for you.

Progressive Muscle Relaxation

During PMR, the participant is instructed to contract a specific muscle group (e.g. the upper thighs) for five to ten seconds during inhalation, and to let go of the tension during exhalation. The instructions start with rounds of contraction and release focused on the lower extremities and gradually progress upwards through the body. Between muscle groups, subjects are asked to take ten to 20 seconds for relaxation and to focus on changes in their physiological experience when releasing the tension.

Progressive Muscle Relaxation Instructions

Notes

Tension: 5 seconds.

Pause between steps: 10 seconds.

Introduction

Tighten each muscle of your body one by one for about 5 seconds, not too much but just until you feel a slight stretch, and hold the tension. Then release the tension without moving around much. Next, consciously pay attention to the feeling of relaxation for about 10 seconds.

If you don't feel the relaxation the first time, repeat it again. While tensing each muscle, try to keep all other muscles as relaxed as possible. Concentrate solely on the particular muscle group you are tensing.

Posture

Sit up straight. Your head is straight between your shoulders and your legs are together. Your arms are resting on your thighs.

Your feet are firmly on the floor.

Unless you find it uncomfortable, close your eyes. If you become slightly drowsy, fixate on a point about 2m in front of you on the floor.

Now take a few deep breaths and let your body become loose and pleasantly heavy. Take your time here.

1. Now clench your right hand into a fist and tighten it. Count slowly from 1 to 5... and release the tension. Now enjoy the feeling of relaxation.
2. Now clench your left hand into a fist, count slowly from 1 to 5....and then relax again.
3. Now tense your forearm muscles by reaching up your hands. Your forearms should remain on your thighs. Hold the tension... and relax again. Feel the relaxation.
4. Now tense your forearm muscles by bending your elbows with open hands. Hold the tension... and relax again.
5. Now crunch up your forehead. While doing so, open your eyes wide. Raise your eyebrows so that your forehead becomes wrinkled, hold the tension... and relax again. If you like, close your eyes again. Continue breathing calmly and relaxed. Enjoy the feeling of relaxation.
6. Now draw your eyebrows together so that a vertical frown line appears on your forehead. Hold the tension...and relax again.
7. Now close your eyes more firmly and count slowly from 1 to 5.... hold the tension...and relax again. Continue to breathe in a relaxed manner.
8. Now press your lips together without clenching your teeth. Hold the tension...and relax again.
9. Now press your tongue against the roof of your mouth. Hold the tension...and relax again. Let your tongue lie loosely in your mouth. Your breath is flowing calmly and relaxed.
10. Now clench your teeth, hold the tension... and relax again. Enjoy the feeling of relaxation.
11. Now tilt your head down to your right shoulder. Hold the tension...and relax again.
12. Now tilt your head down to your left shoulder. Hold the tension... and relax again. Breathe calmly and relaxed.
13. Now pull your shoulders up to your ears. Hold the tension...and relax again.

14. Now press your shoulder blades together towards the back of your spine. Hold the tension... and relax again.

15. Now inhale deeply so that your chest expands. Hold your chest like this and continue breathing lightly. Hold the tension. Then let your chest collapse .... and relax again. Breathe calmly and relaxed once again.

16. Now push your stomach out and hold it for a moment while continuing to breathe. Hold the tension. Then pull your stomach in... And relax again.

17. Now tense the muscles in your buttocks. Hold the tension... and relax again.

18. Now tense your thighs by pressing your heels into the floor and lifting your toes off the floor. Hold the tension...and relax again.

19. Tense your calves by pressing your feet down onto the floor. Not too hard. Hold the tension... and relax again.

20. Inhale again in a completely relaxed way... and exhale... Repeat this five times... When you feel ready, slowly open your eyes.

Appendix B

Model Specification and R Code for the Drift Diffusion Model

Figure B1

Model Specification of Drift Diffusion Models for the Shooter and Avoidance Task

```
model {
  #likelihood function
  for (t in 1:nTrials) {
  y[t] ~ dwiener(alpha[Cond1[t], subject[t]],
    tau[Cond2[t], subject[t]],
    beta[Cond1[t], subject[t]],
    delta[Cond2[t], subject[t]])
  }
  for (s in 1:nSubjects) {
    for (c1 in 1:nCond1) {
      alpha[c1, s]  ~ dnorm(muAlpha[c1], precAlpha) T(.1, 5)
      beta[c1, s] ~ dnorm(muBeta[c1], precBeta) T(.1, .9)
    }
    for (c2 in 1:nCond2) {
      tau[c2, s] ~ dnorm(muTau[c2], precTau) T(.0001, 1)
      delta[c2, s] ~ dnorm(muDelta[c2], precDelta) T(-5, 5)
    }
  }
  #priors
  precAlpha ~ dgamma(.001, .001)
  precBeta ~ dgamma(.001, .001)
  precTau ~ dgamma(.001, .001)
  precDelta ~ dgamma(.001, .001)
  for (c1 in 1:nCond1){
    muAlpha[c1]  ~ dunif(.1, 5)
    muBeta[c1] ~ dunif(.1, .9)
  }
  for (c2 in 1:nCond2){
    muTau[c2] ~ dunif(.0001, 1)
    muDelta[c2] ~ dunif(-5, 5)
  }
}
```

Note. y = response times in seconds, negative for unarmed and positive for armed target trials; nTrials = number of observations; Cond1 = vector indicating target race/ethnicity; nCond1 = number of within-subject conditions for target race/ethnicity; Cond2 = vector indicating target race/ethnicity and object type; nCond2 = number of within-subject conditions for target race/ethnicity and object type; subject = vector indicating participant for each trial; nSubjects = number of participants

Figure B2

Example Specification of Initials and Modeling in R Statistics

```
#initial values
initfunction <- function(chain){
  return(list(
    muAlpha = runif(nRace, .2, 4.9), #threshold mean
    muBeta = runif(nRace, .15, .85), #start point mean
    muTau = runif(nRaceObject, .01, .05), #non-decision time mean
    muDelta = runif(nRaceObject, -4.9, 4.9), #drift rate mean
    precAlpha = runif(1, .01, 100), #threshold precision
    precBeta = runif(1, .01, 100), #start point precision
    precTau = runif(1, .01, 100), #non-decision precision
    precDelta = runif(1, .01, 100), #drift rate precision
    .RNG.name = "lecuyer::RngStream",
    .RNG.seed = sample.int(1e10, 1, replace = F)))
}

#list of parameters to be monitored
parameters <- c("muAlpha", "muBeta", "muTau", "muDelta", #condition means
                "precAlpha", "precBeta", "precTau", "precDelta", #condition precisions
                "alpha", "beta", "tau", "delta", "deviance") #individual means and deviance

nUseSteps = 20000 #number of iterations
nChains = 4 #number of chains (one per processor)

#Run the model in runjags
startTime = proc.time()
jagsModel_mind_post <- run.jags(method = "parallel",
                               model = "model.txt",
                               monitor = parameters,
                               data = datalist,
                               inits = initfunction,
                               n.chains = nChains,
                               adapt = 1000, #sampler adaptation
                               burnin = 1000, #burn in period
                               sample = ceiling(nUseSteps/nChains),
                               thin = 5, #thin if high autocorrelation
                               modules = c("wiener", "lecuyer"),
                               summarise = F,
                               plots = F)
stopTime = proc.time()
elapsedTime = stopTime - startTime
show(elapsedTime/60)
```

Appendix C

Model Diagnostics for Drift Diffusion Models

MCMC chain convergence was assessed with the potential scale reduction factor (PSRF). All point estimates of the PSRF for condition and individual level parameters = 1, the multivariate PSRF for each model was < 1.2, indicating full convergence for all parameters. MCMC autocorrelation was assessed by effective sample sizes (ESSs). Most ESS values were ≥ 10.000, indicating accurate and stable estimates of the posterior distribution, but a few ESS were < 10.000. Since we extracted posterior means for further frequentist analyses and ESS ≥ 10.000 are especially recommended when working with 95% highest density intervals (see Kruschke, 2014), this was not a concern. Relatedly, Monte Carlo standard errors (MCSE) were ≤ 0.01, indicating stable posterior mean estimations for all parameters.

Condition level parameters will be presented for all models estimated. See table C1 for a legend of parameter names and trial conditions.

Table C1
Parameter Estimates and Respective Trial Conditions

Parameter		Shooter Task	Avoidance Task
muAlpha[1]	muBeta[1]	White targets	German targets
muAlpha[2]	muBeta[2]	Black targets	Turkish targets
muDelta[1]	muTau[1]	White unarmed targets	German unarmed targets
muDelta[2]	muTau[2]	Black unarmed targets	Turkish unarmed targets
muDelta[3]	muTau[3]	White armed targets	German armed targets
muDelta[4]	muTau[4]	Black armed targets	Turkish armed targets

Figure C1

Experiment 1: Model Diagnostics for the Drift Diffusion Model for the Mindfulness Condition at Pre-Measurement (Shooter Task)

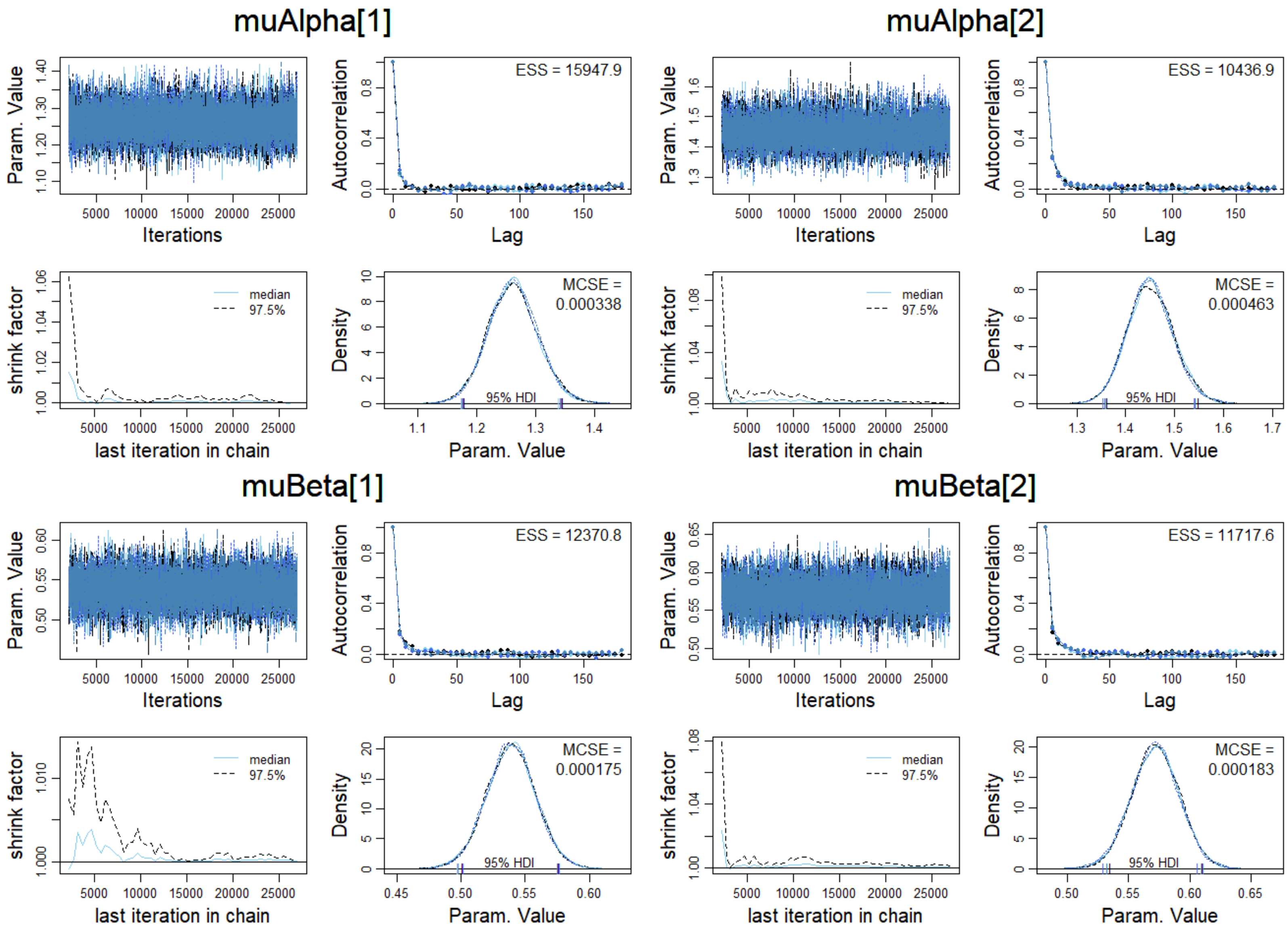

Figure C1
(continued)

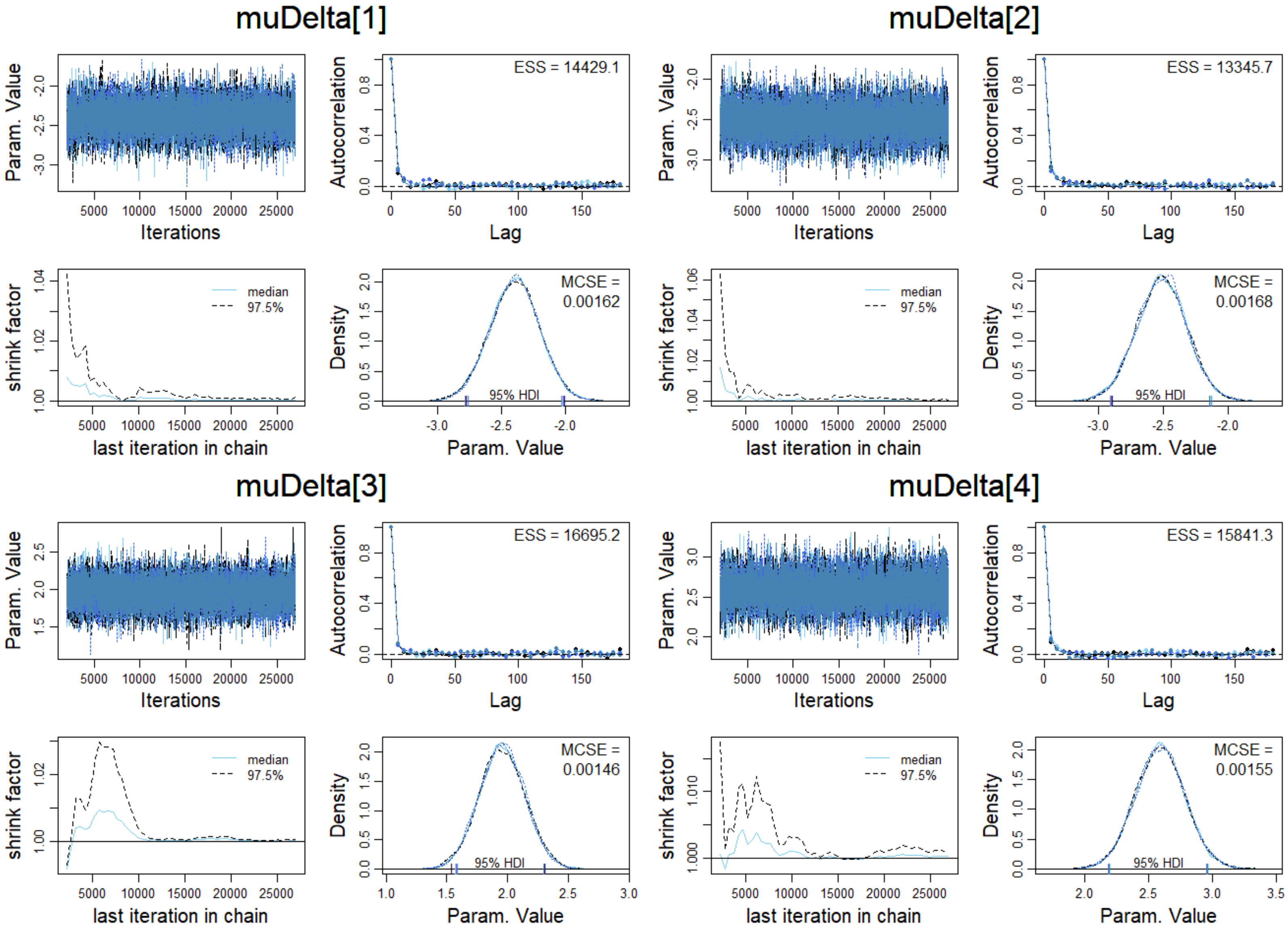

Figure C1
(continued)

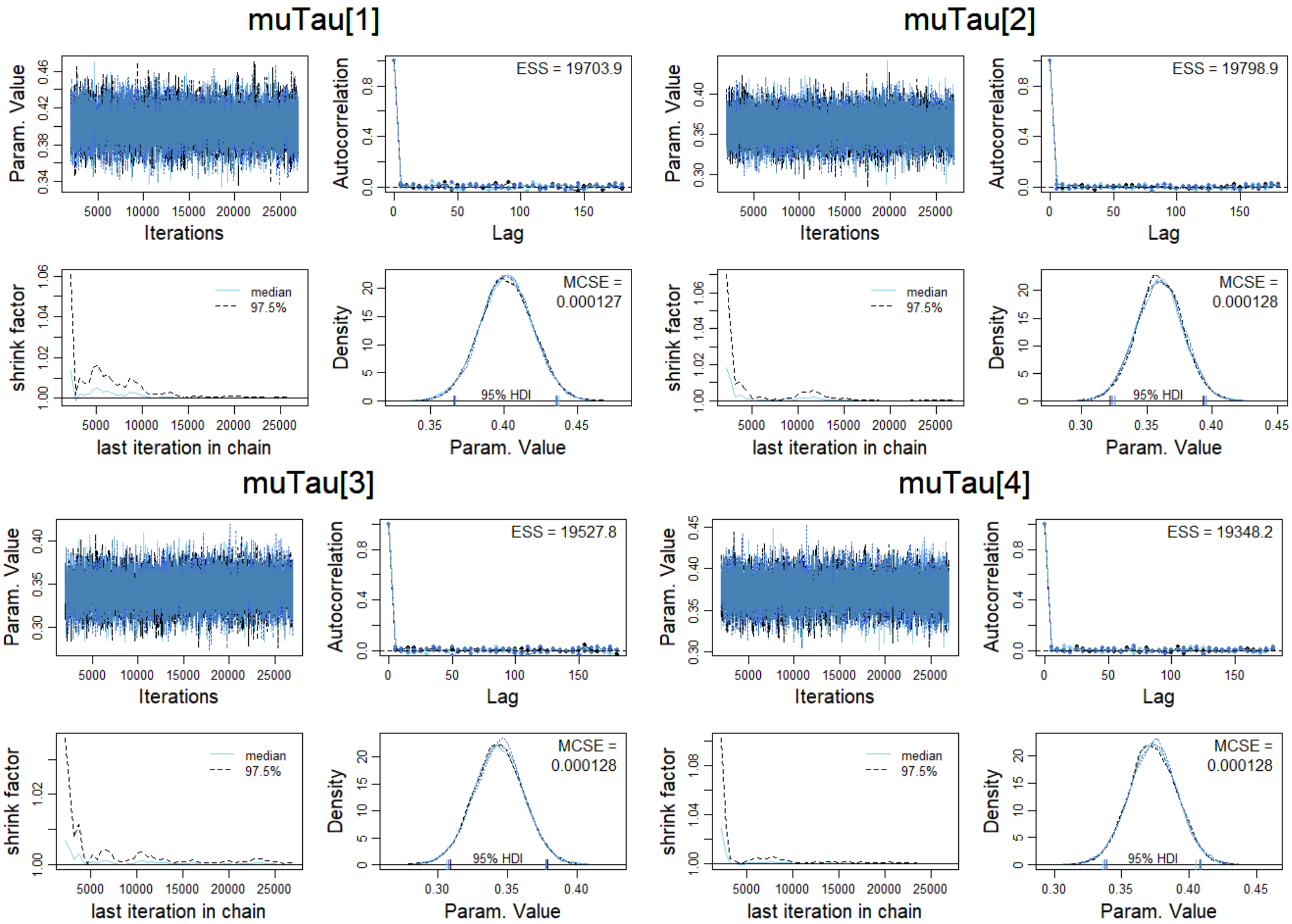

Figure C2

Experiment 1: Model Diagnostics for the Drift Diffusion Model for the Mindfulness Condition at Post-Measurement (Shooter Task)

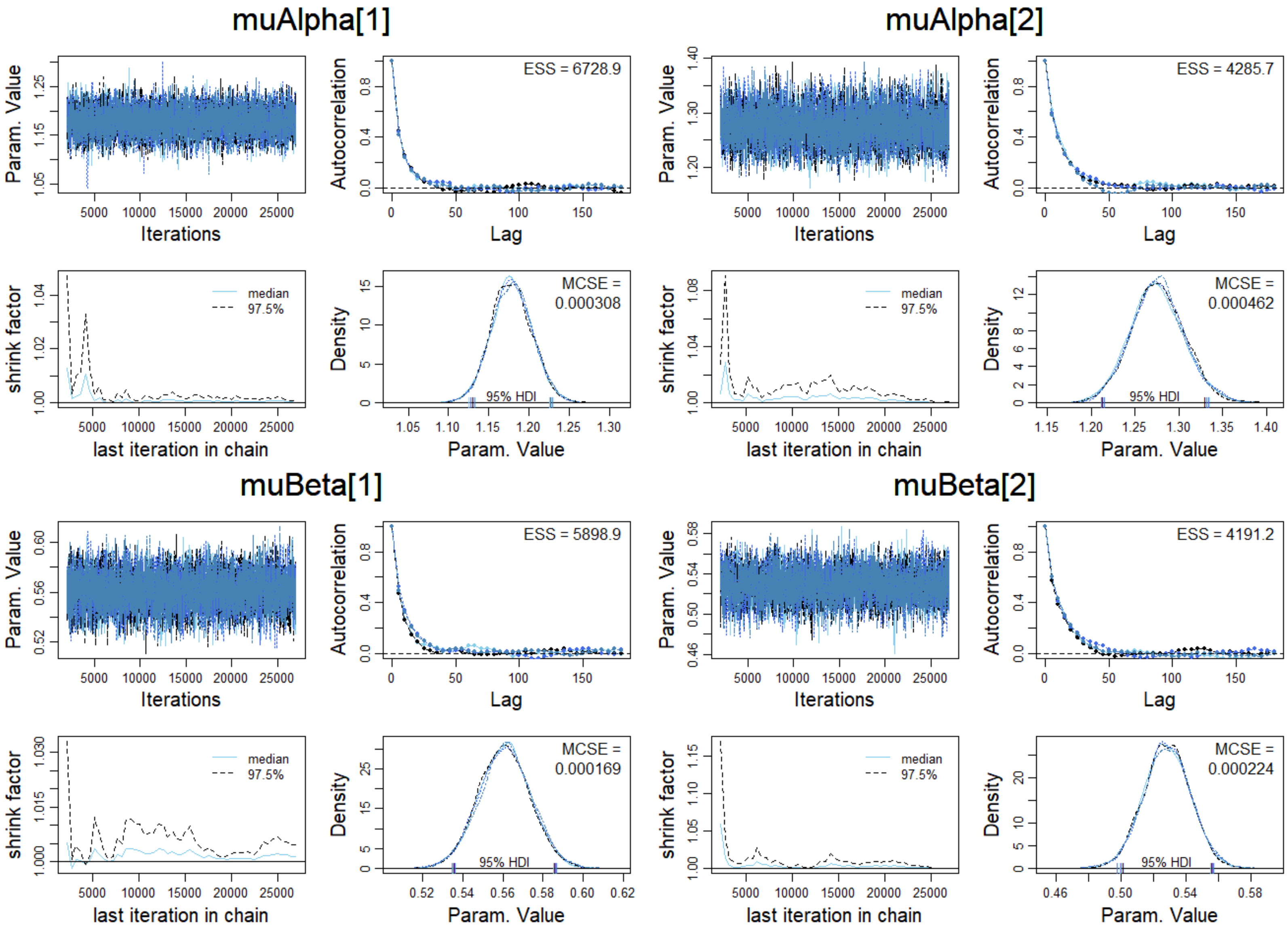

Figure C2
(continued)

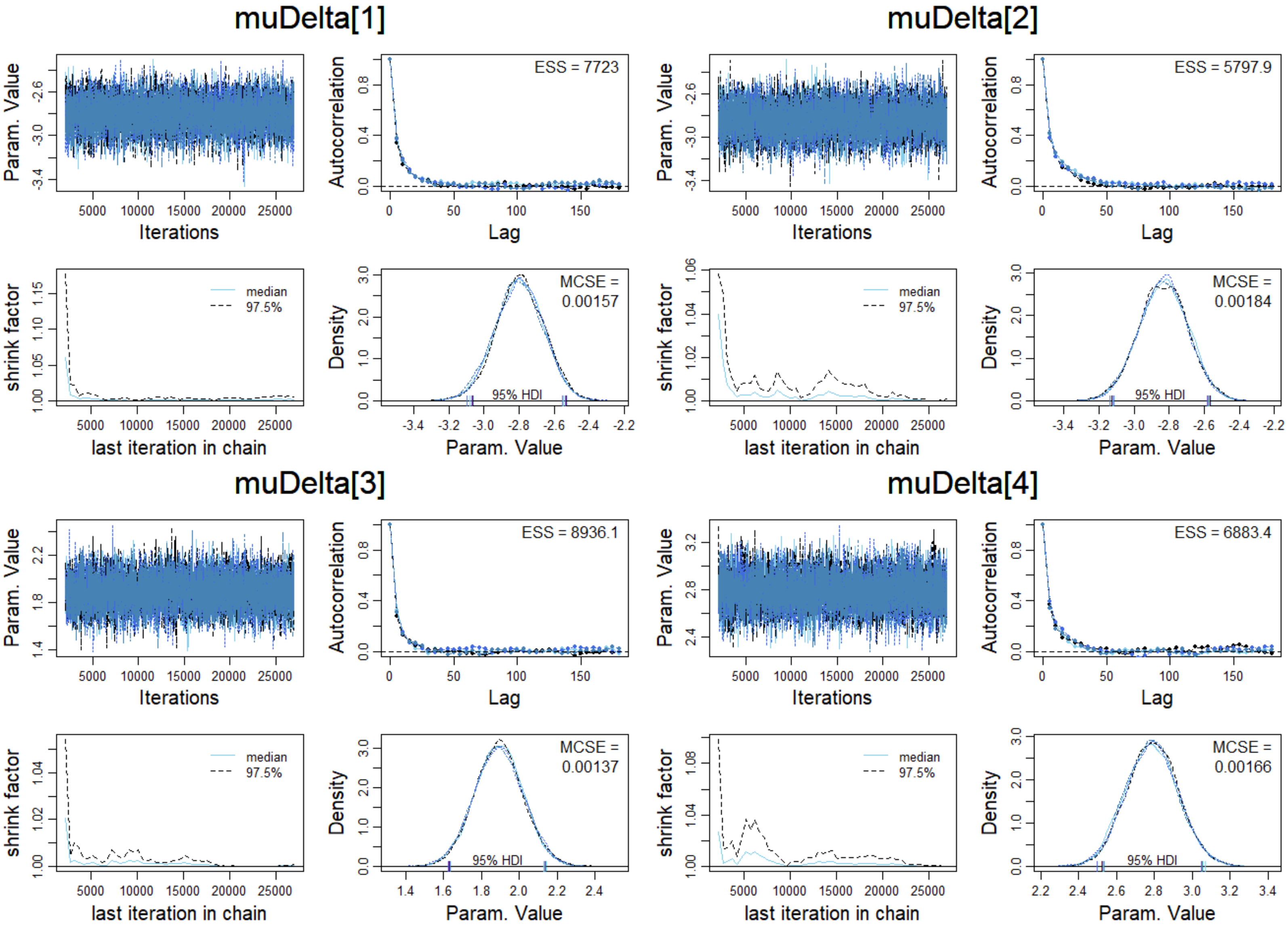

Figure C2
(continued)

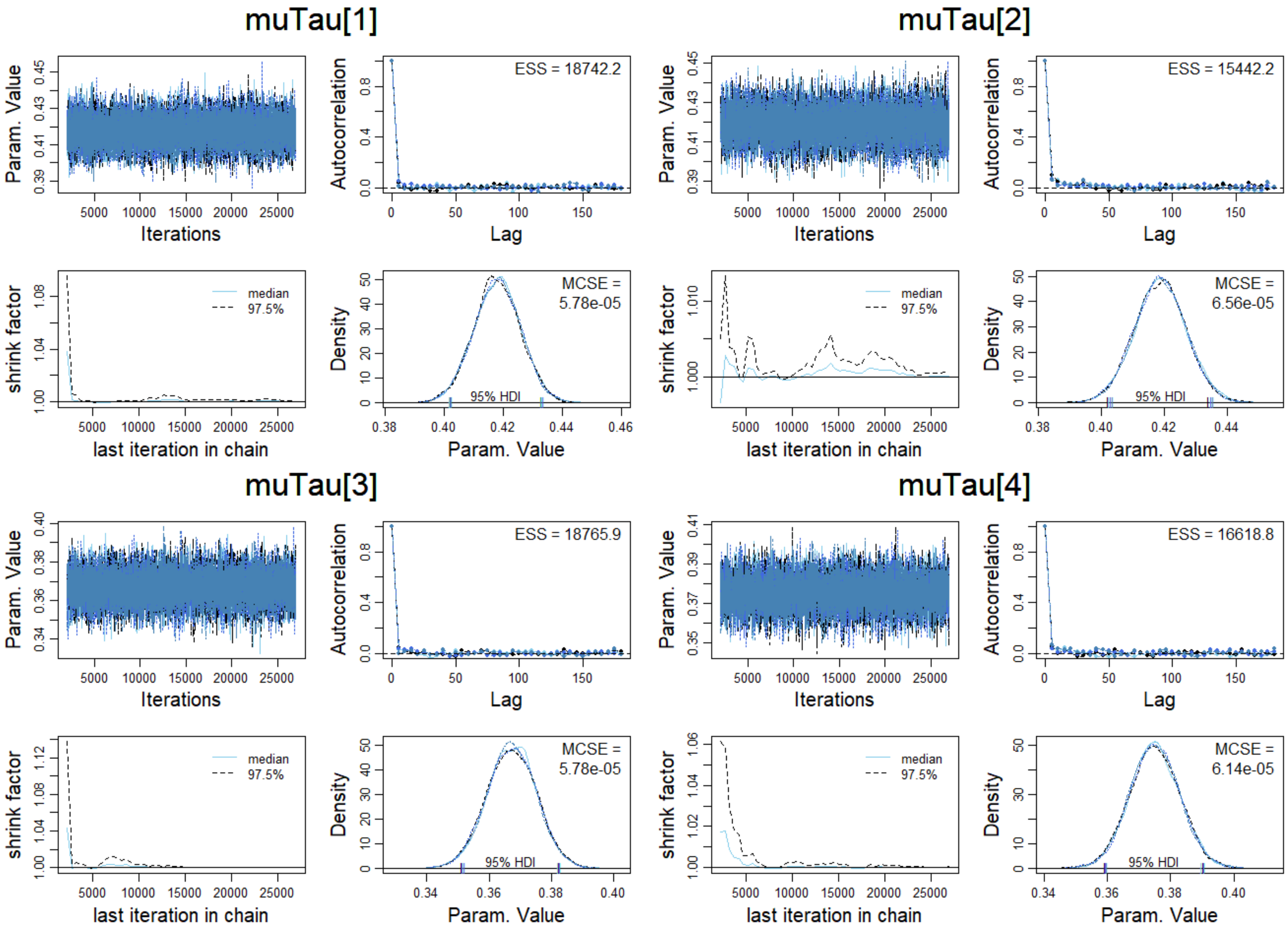

Figure C3

Experiment 1: Model Diagnostics for the Drift Diffusion Model for the PMR Condition at Pre-Measurement (Shooter Task)

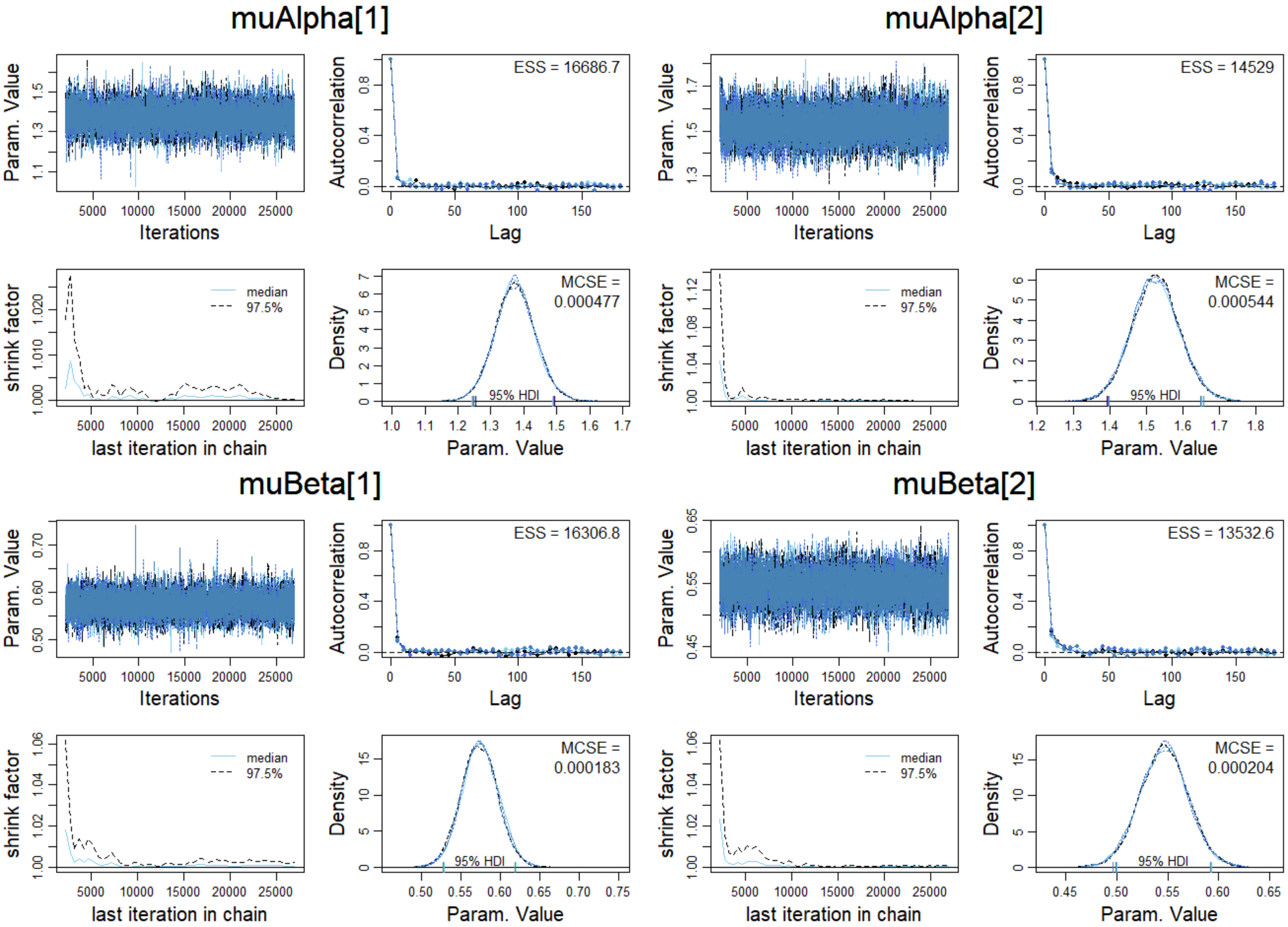

Figure C3
(continued)

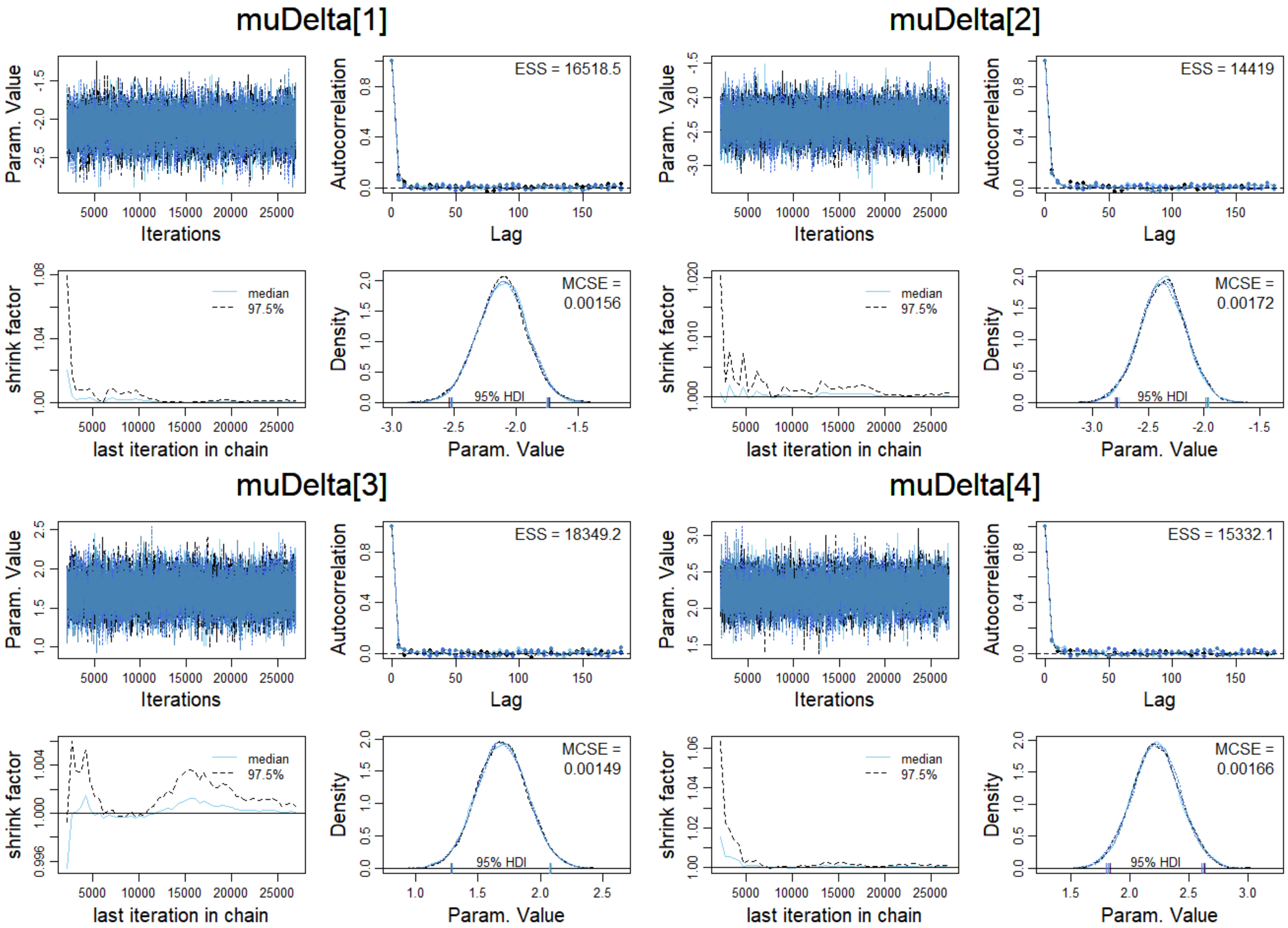

Figure C3

(continued)

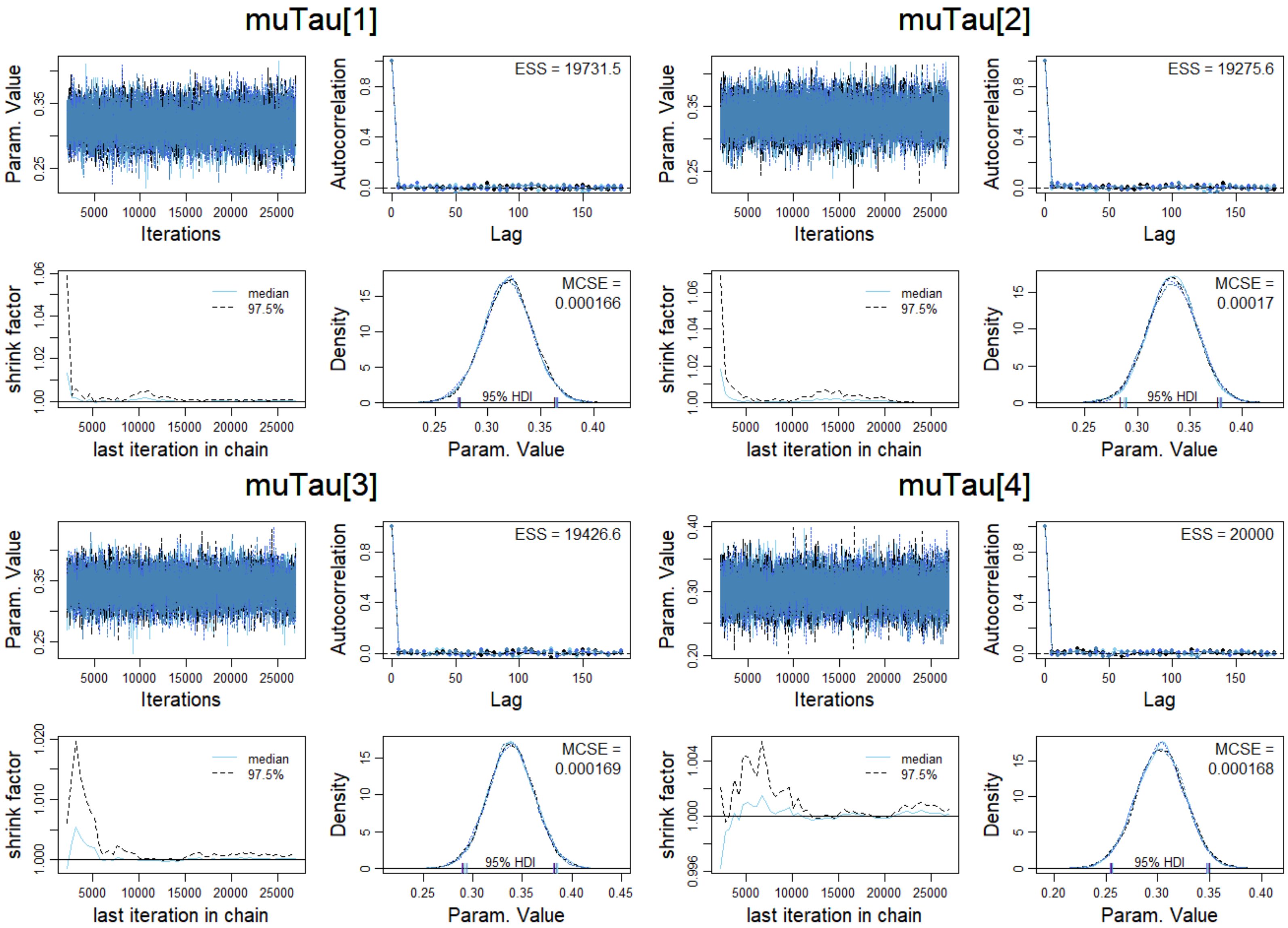

Figure C4

Experiment 1: Model Diagnostics for the Drift Diffusion Model for the PMR Condition at Post-Measurement (Shooter Task)

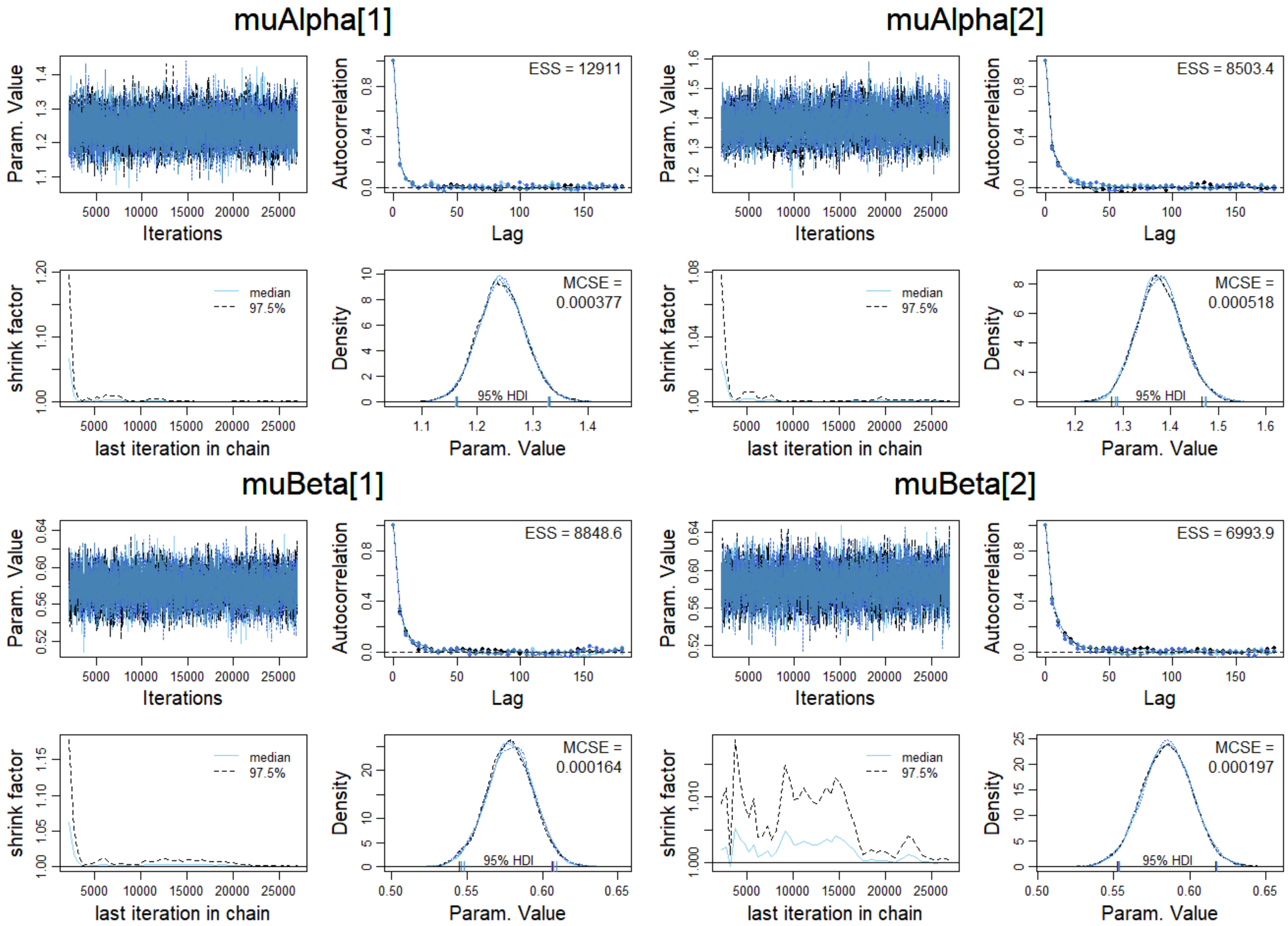

Figure C4
(continued)

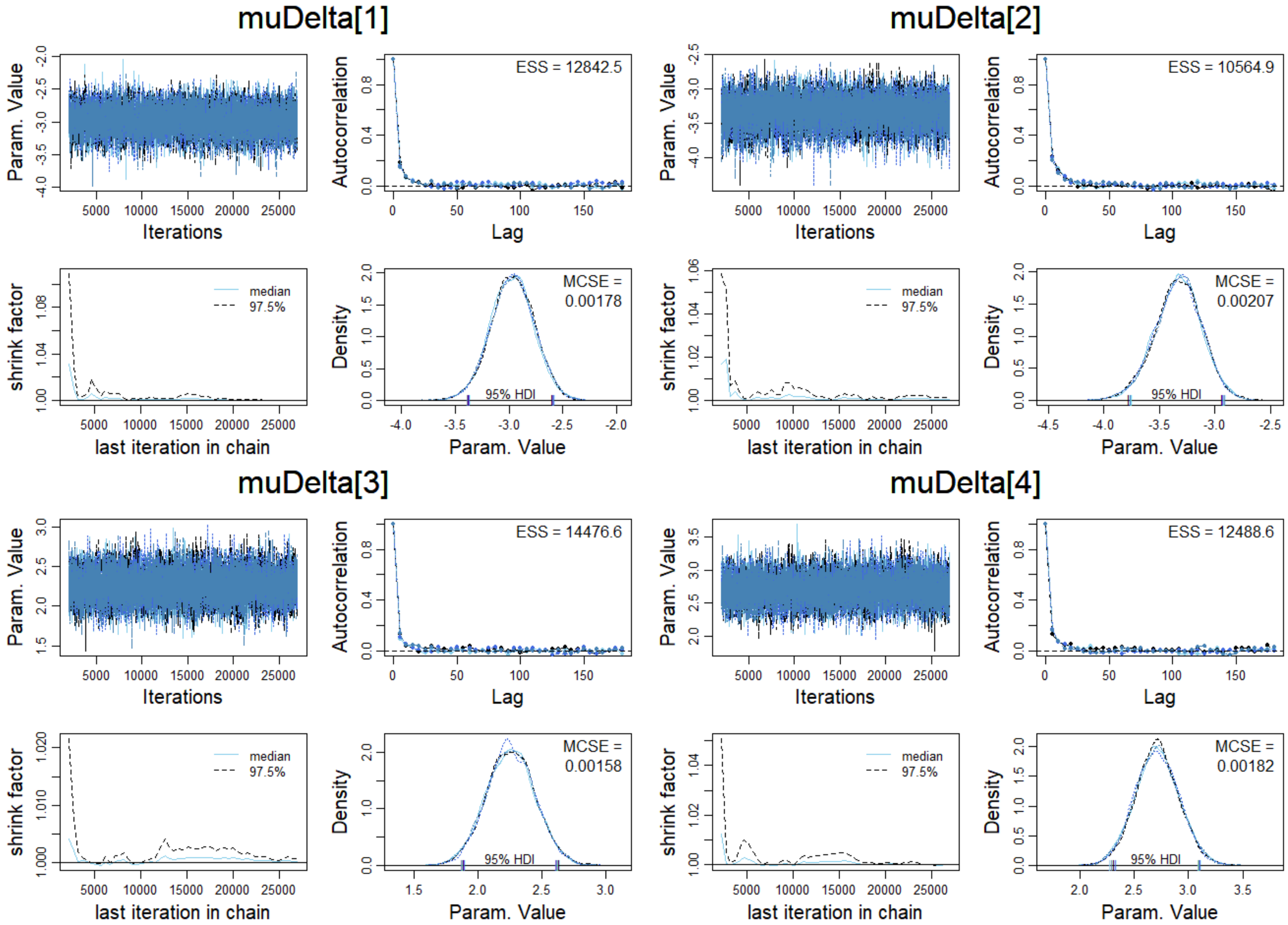

Figure C4

(continued)

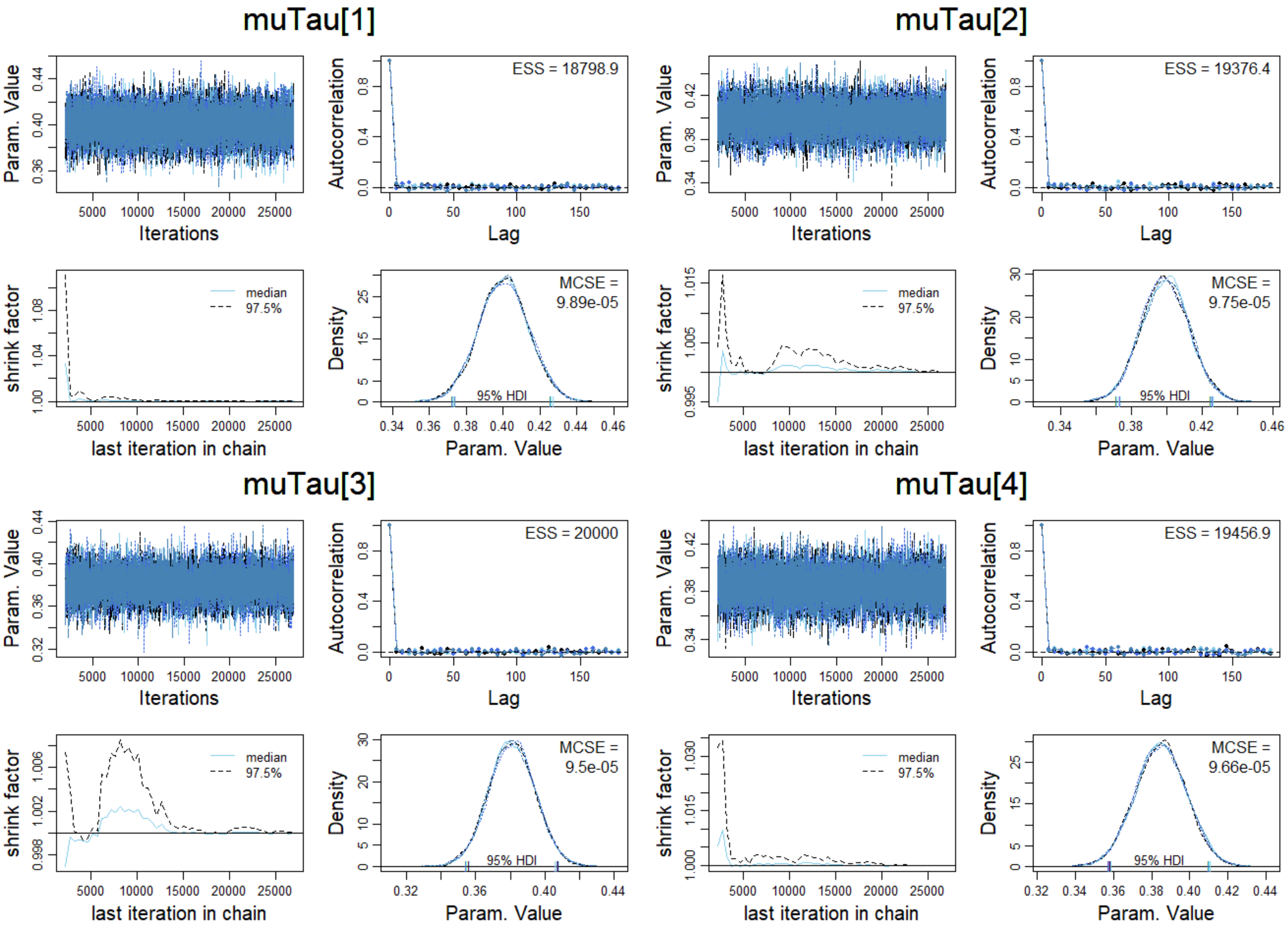

Figure C5

Experiment 1: Model Diagnostics for the Drift Diffusion Model for the Podcast Listening Condition at Pre-Measurement (Shooter Task)

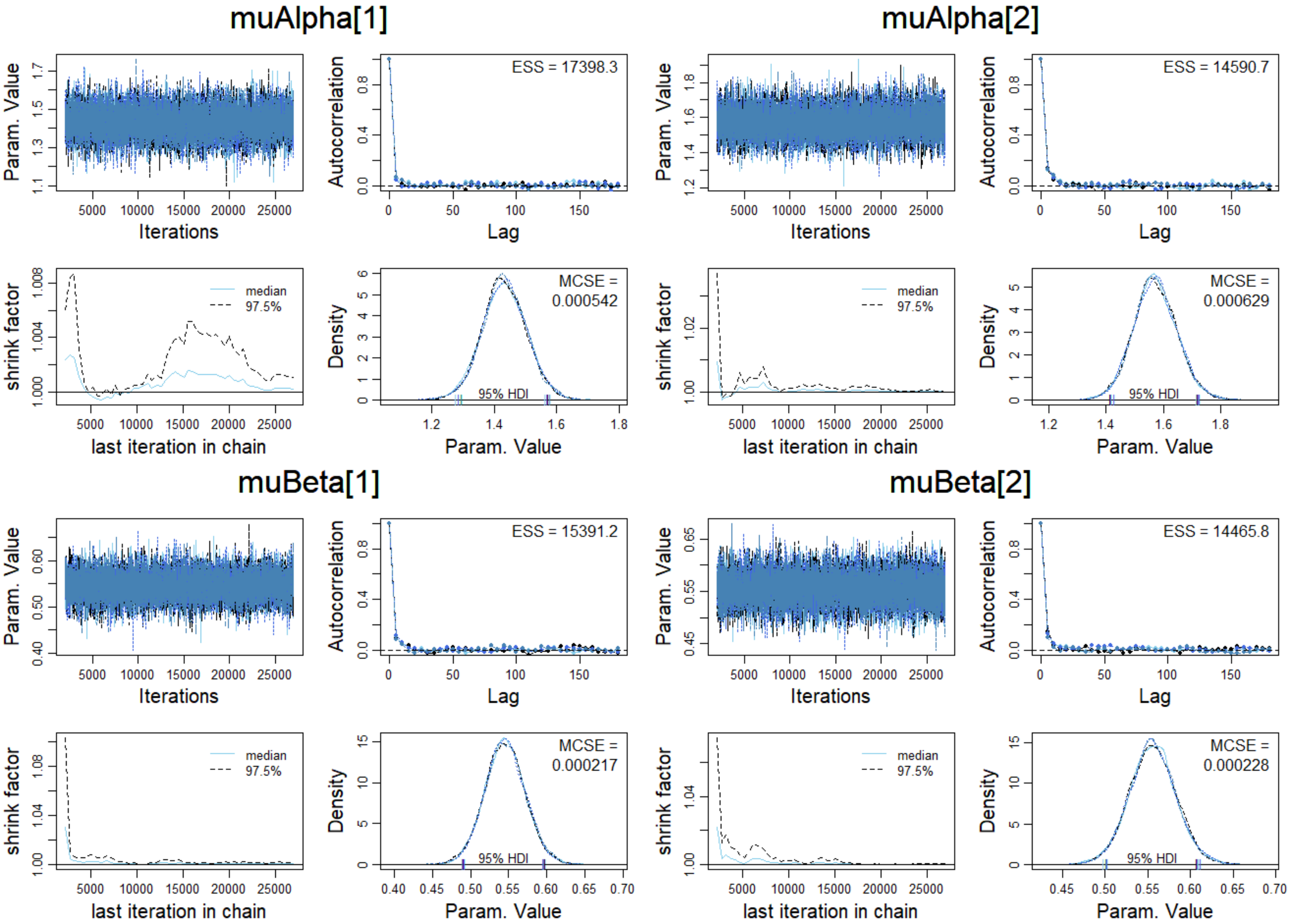

Figure C5
(continued)

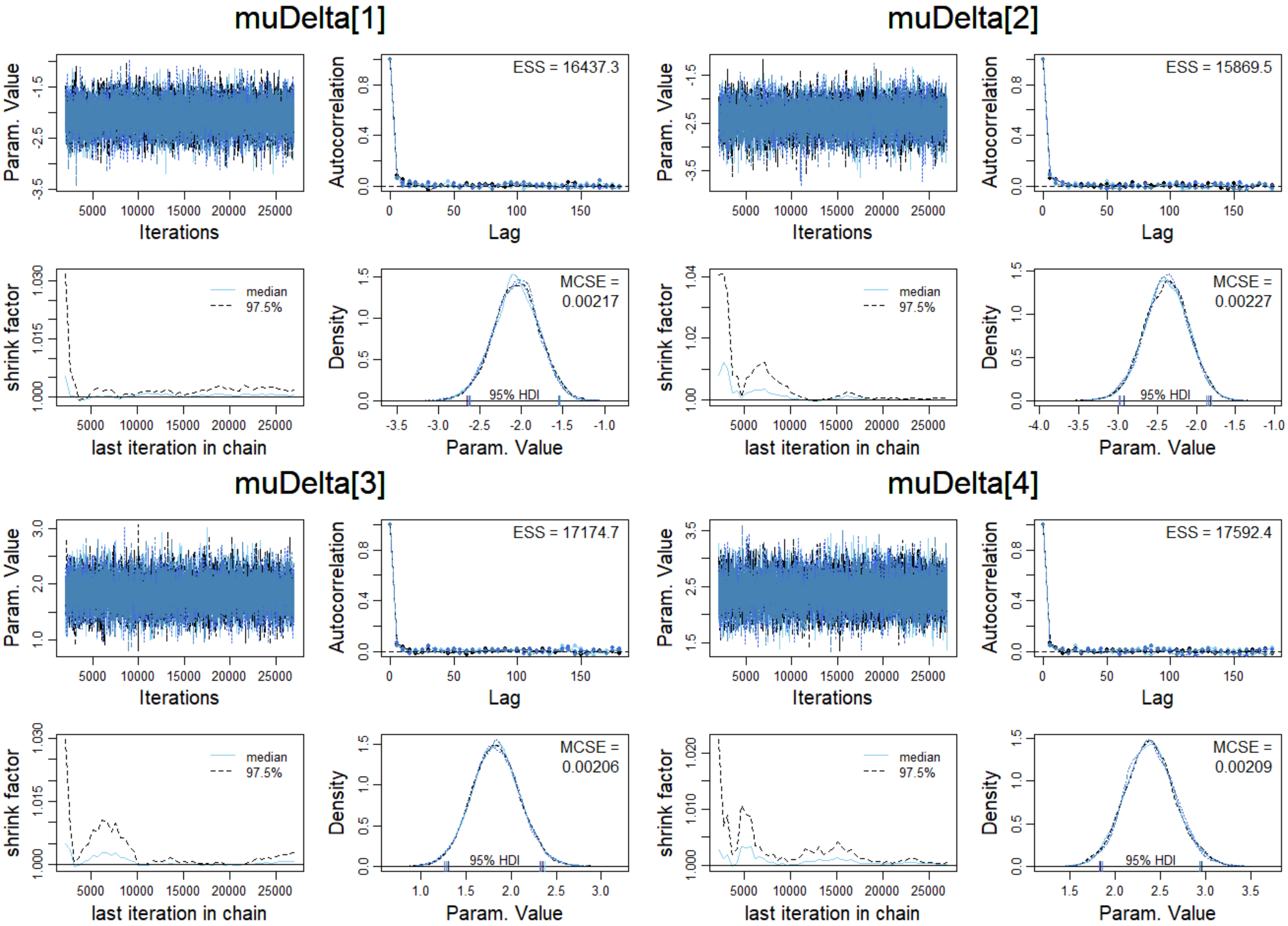

Figure C5
(continued)

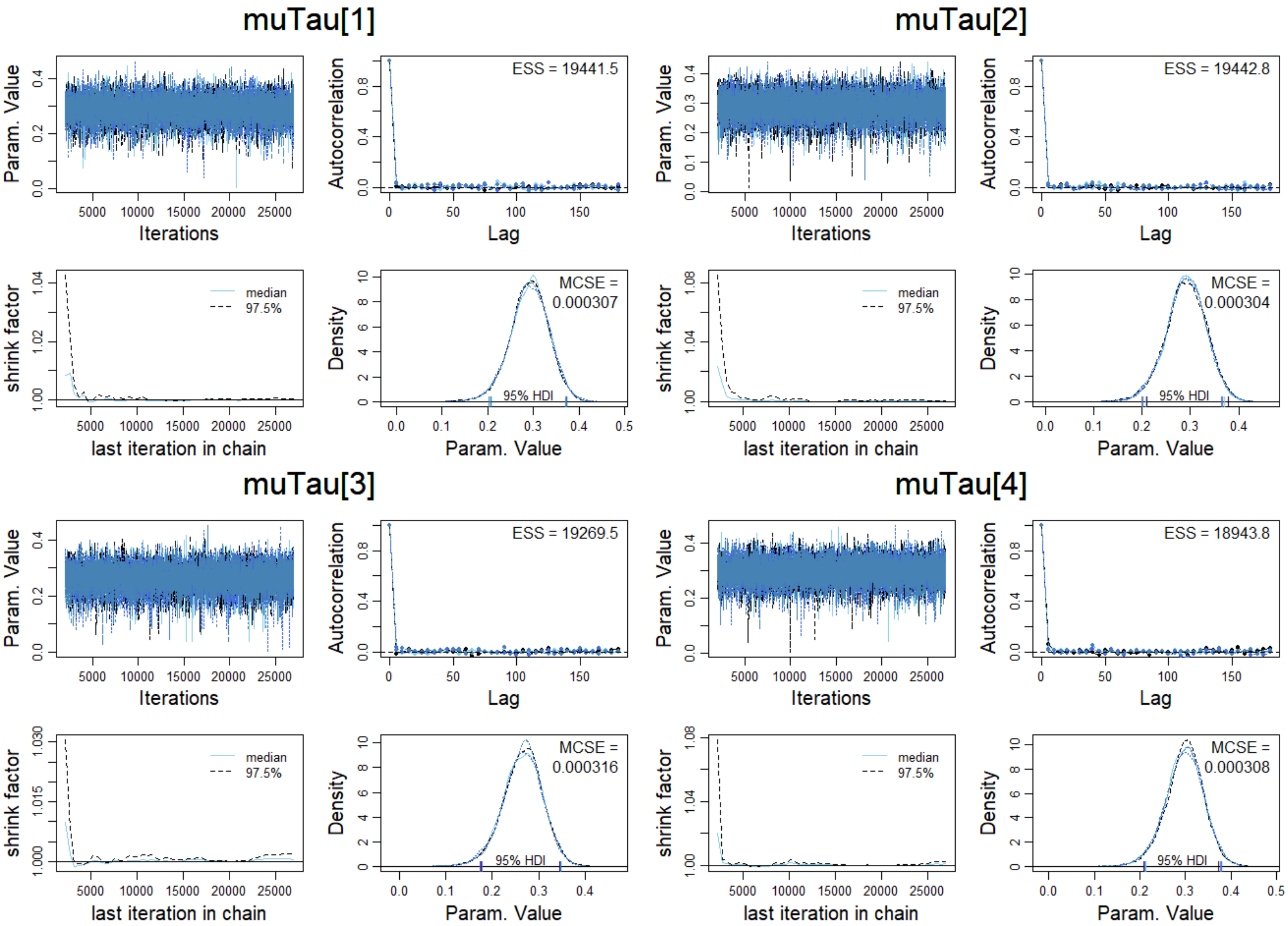

Figure C6

Experiment 1: Model Diagnostics for the Drift Diffusion Model for the Podcast Listening Condition at Post-Measurement (Shooter Task)

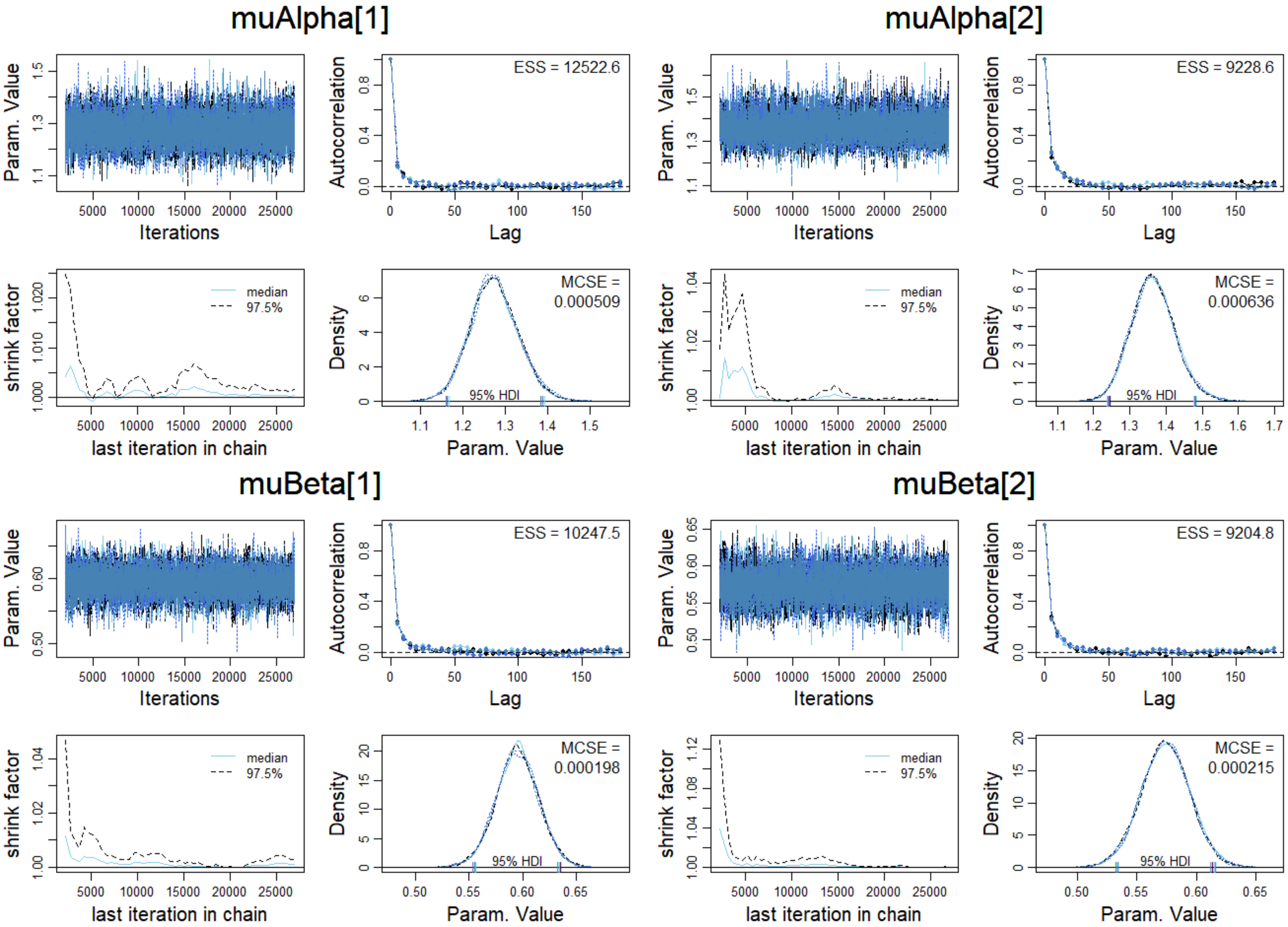

Figure C6
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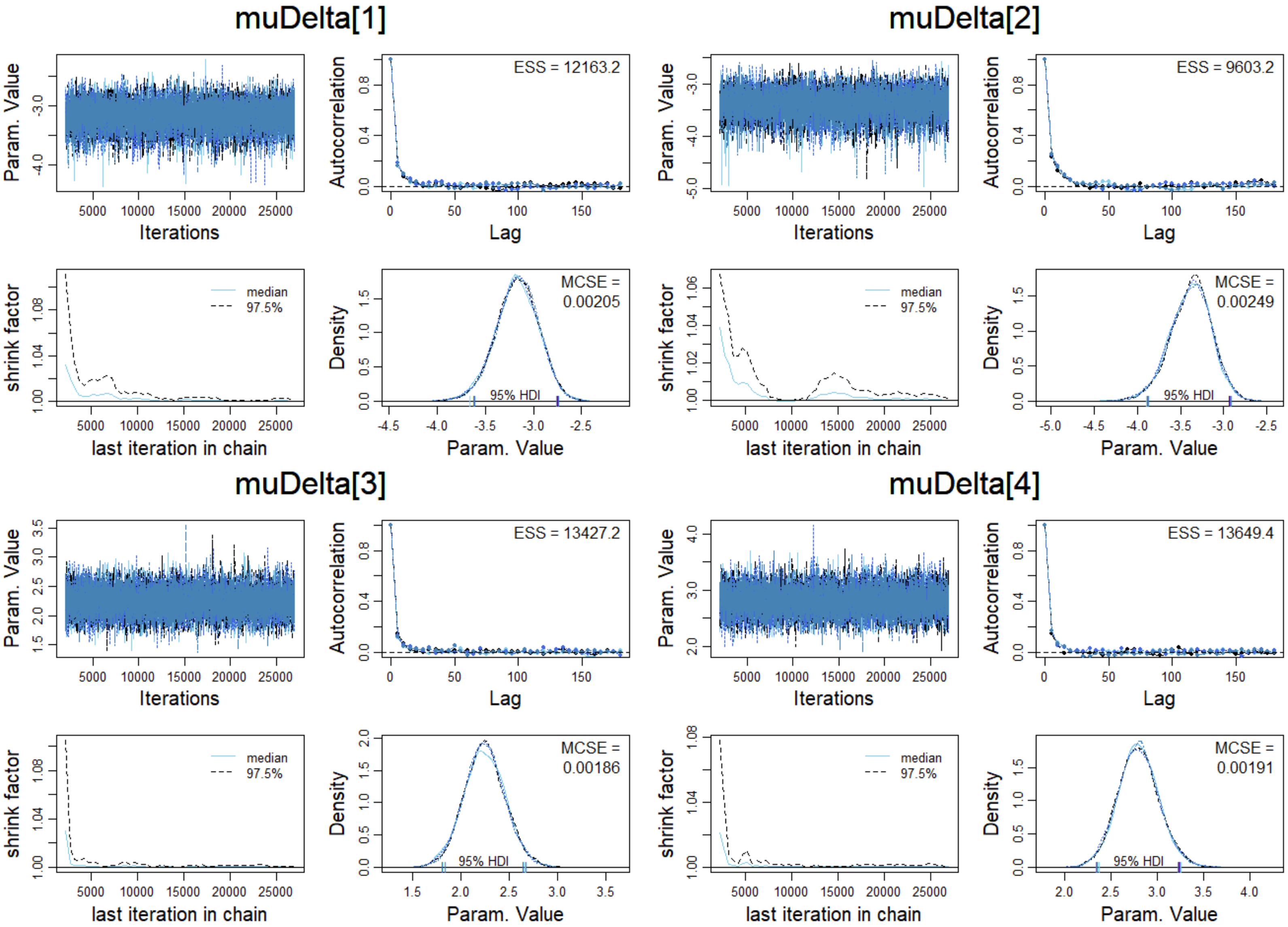

Figure C6
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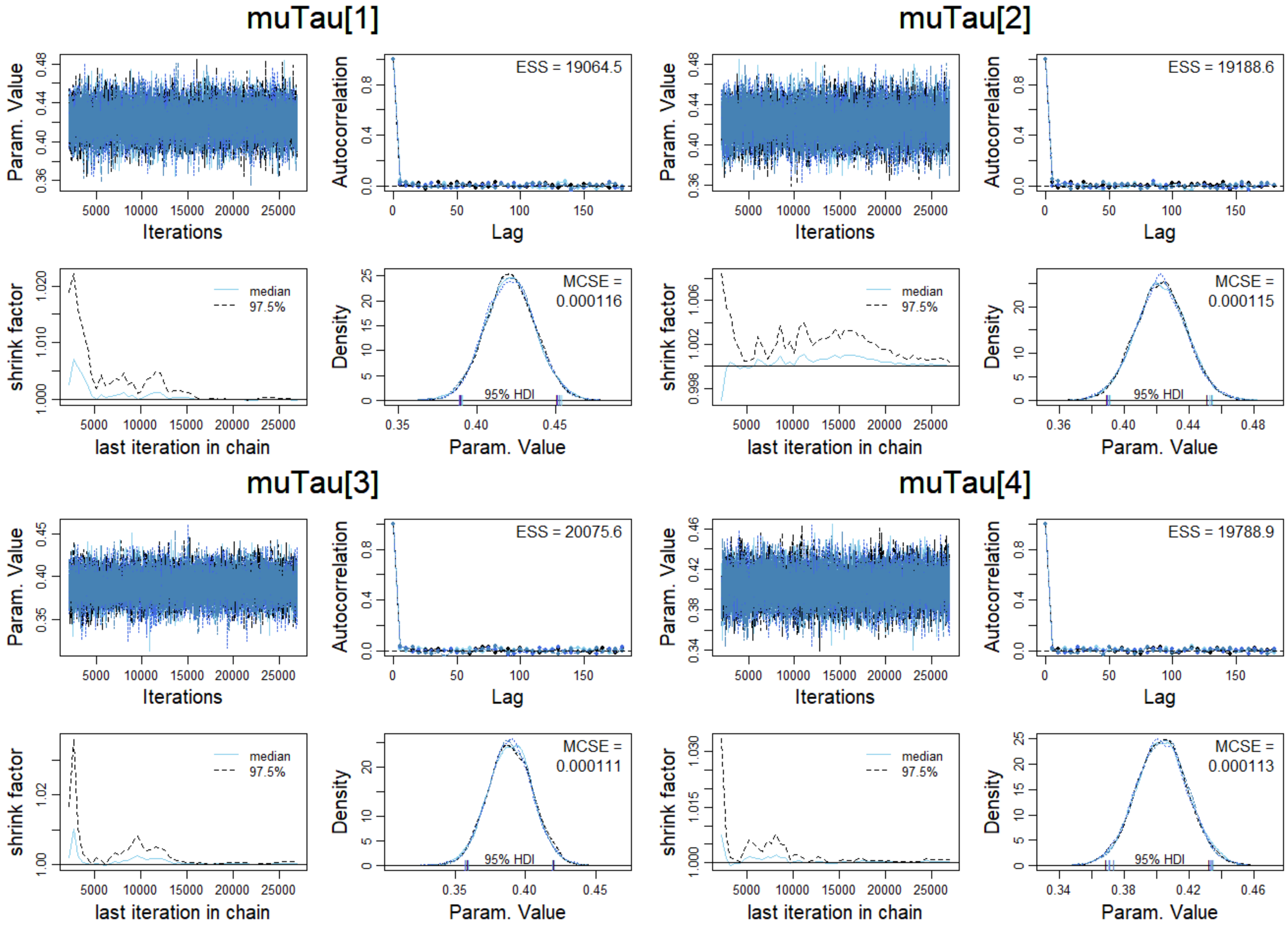

Figure C7

Experiment 2: Model Diagnostics for the Drift Diffusion Model for the Mindfulness Condition at Pre-Measurement (Avoidance Task)

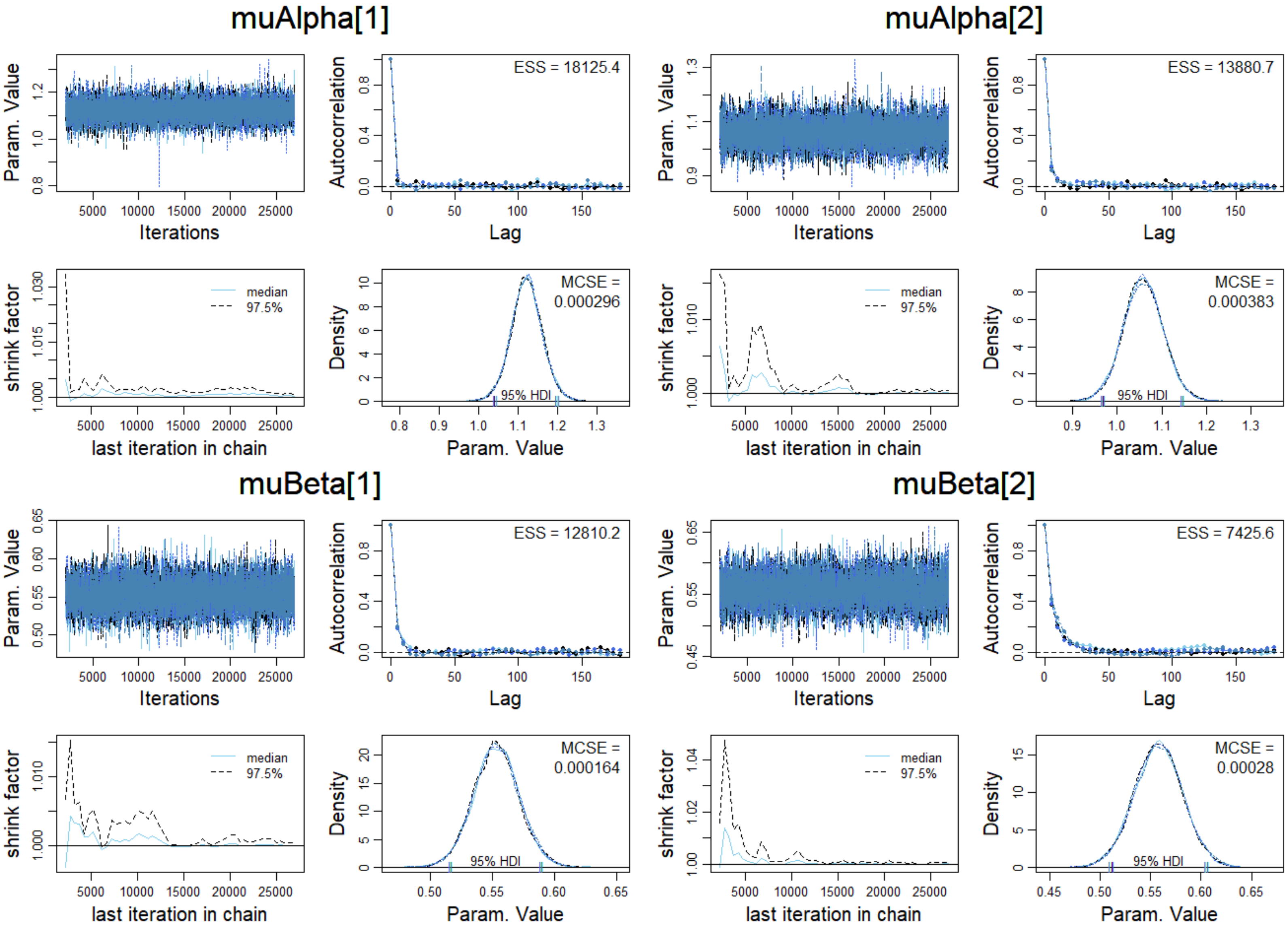

Figure C7
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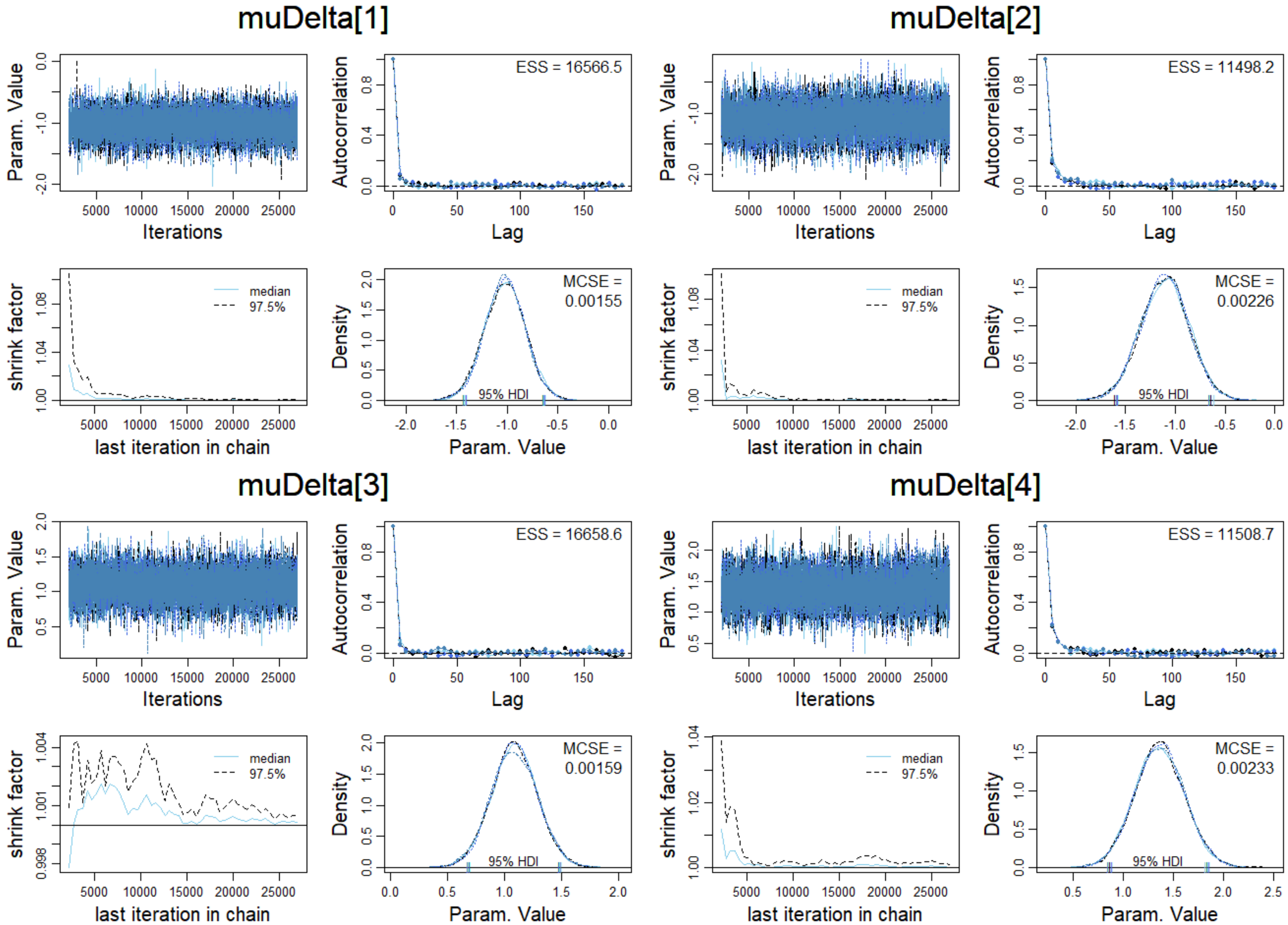

Figure C7

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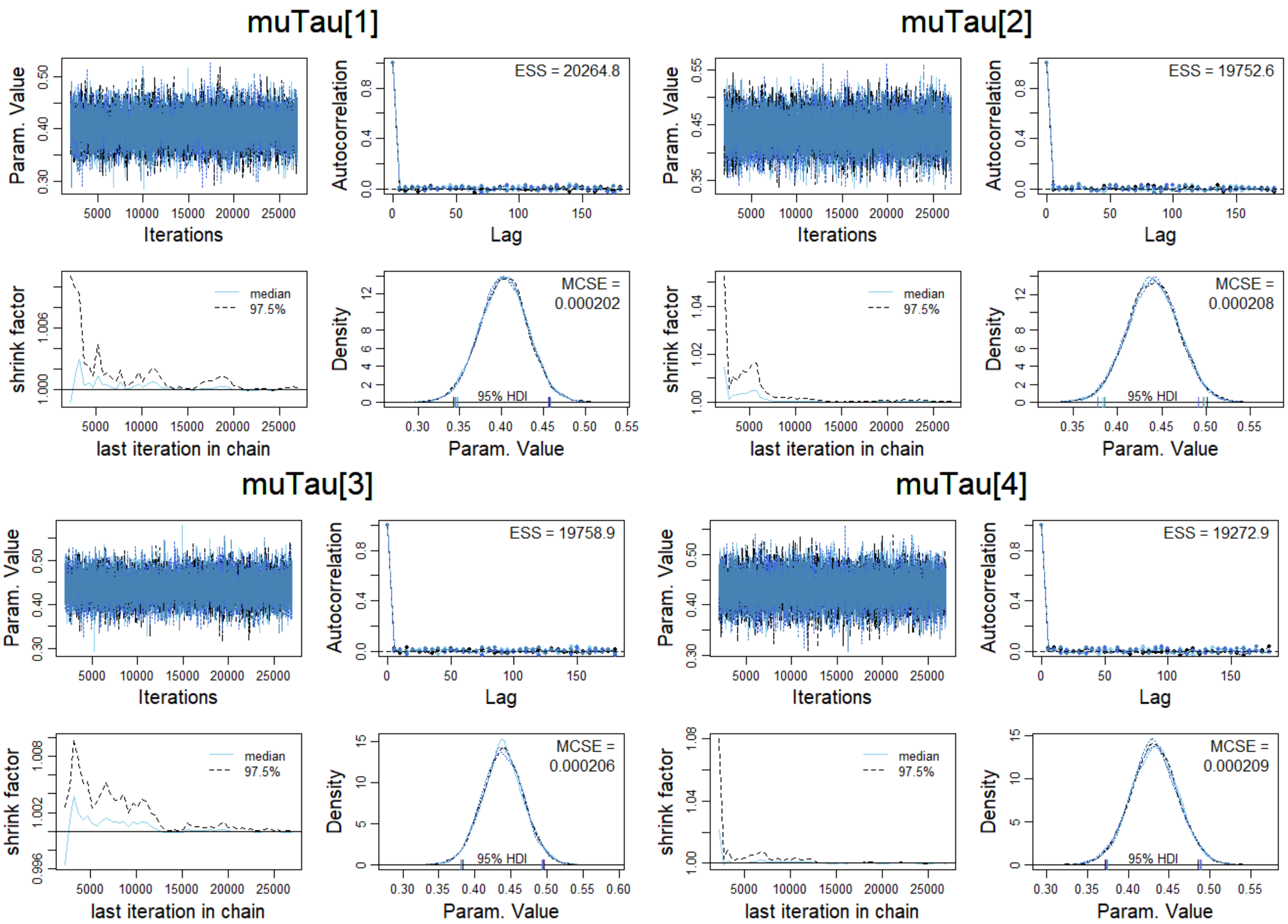

Figure C8

Experiment 2: Model Diagnostics for the Drift Diffusion Model for the Mindfulness Condition at Post-Measurement (Avoidance Task)

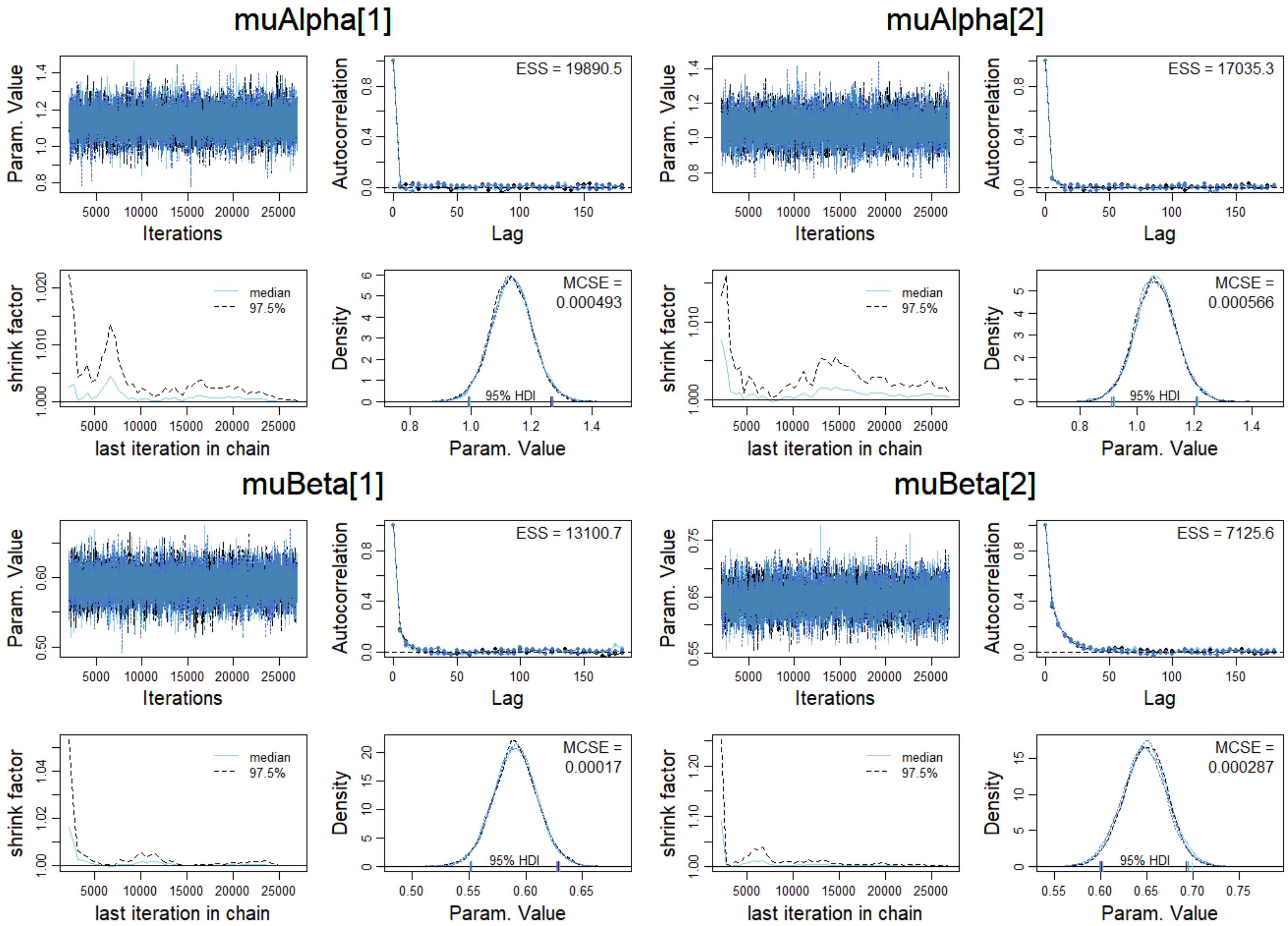

Figure C8

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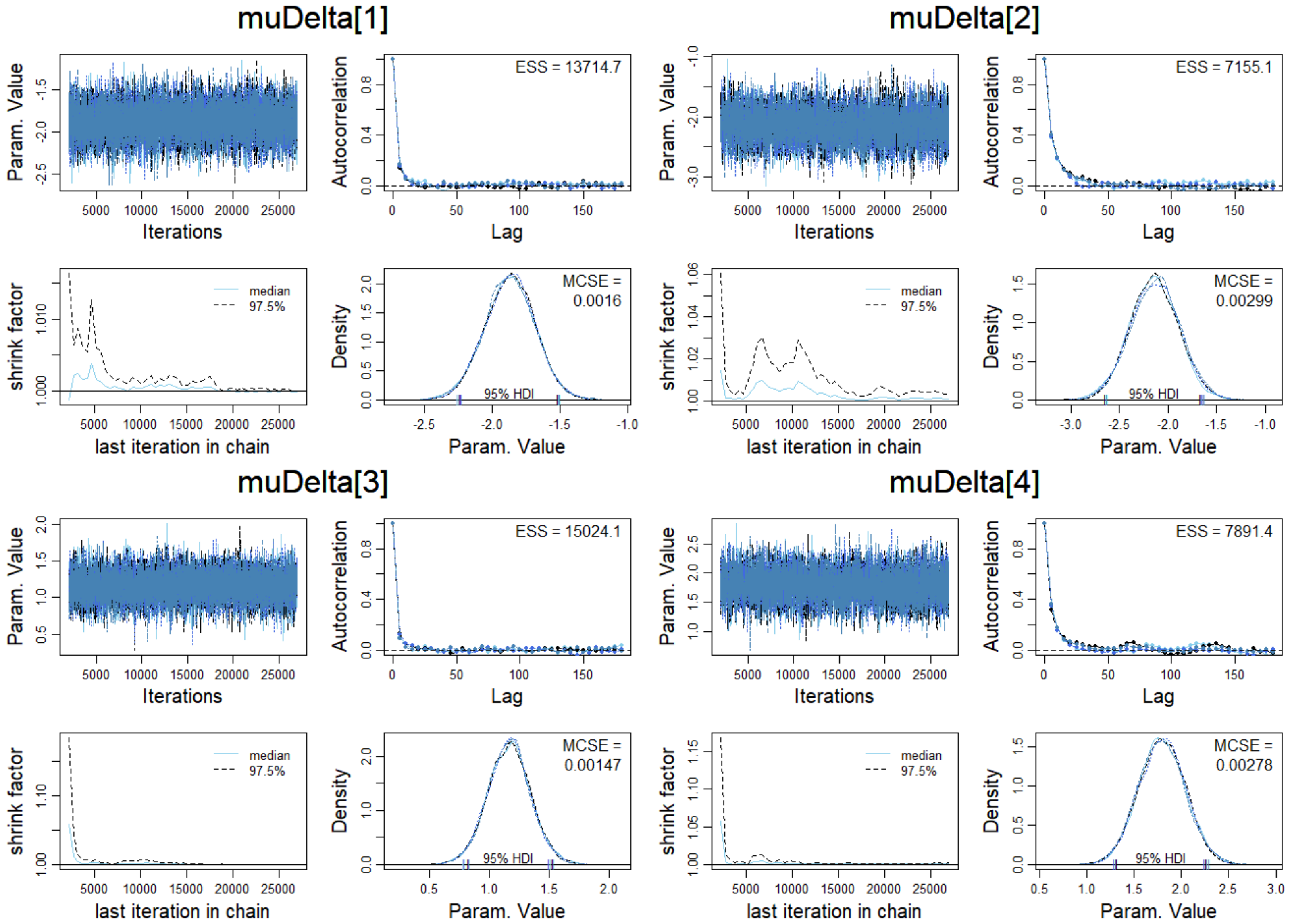

Figure C8

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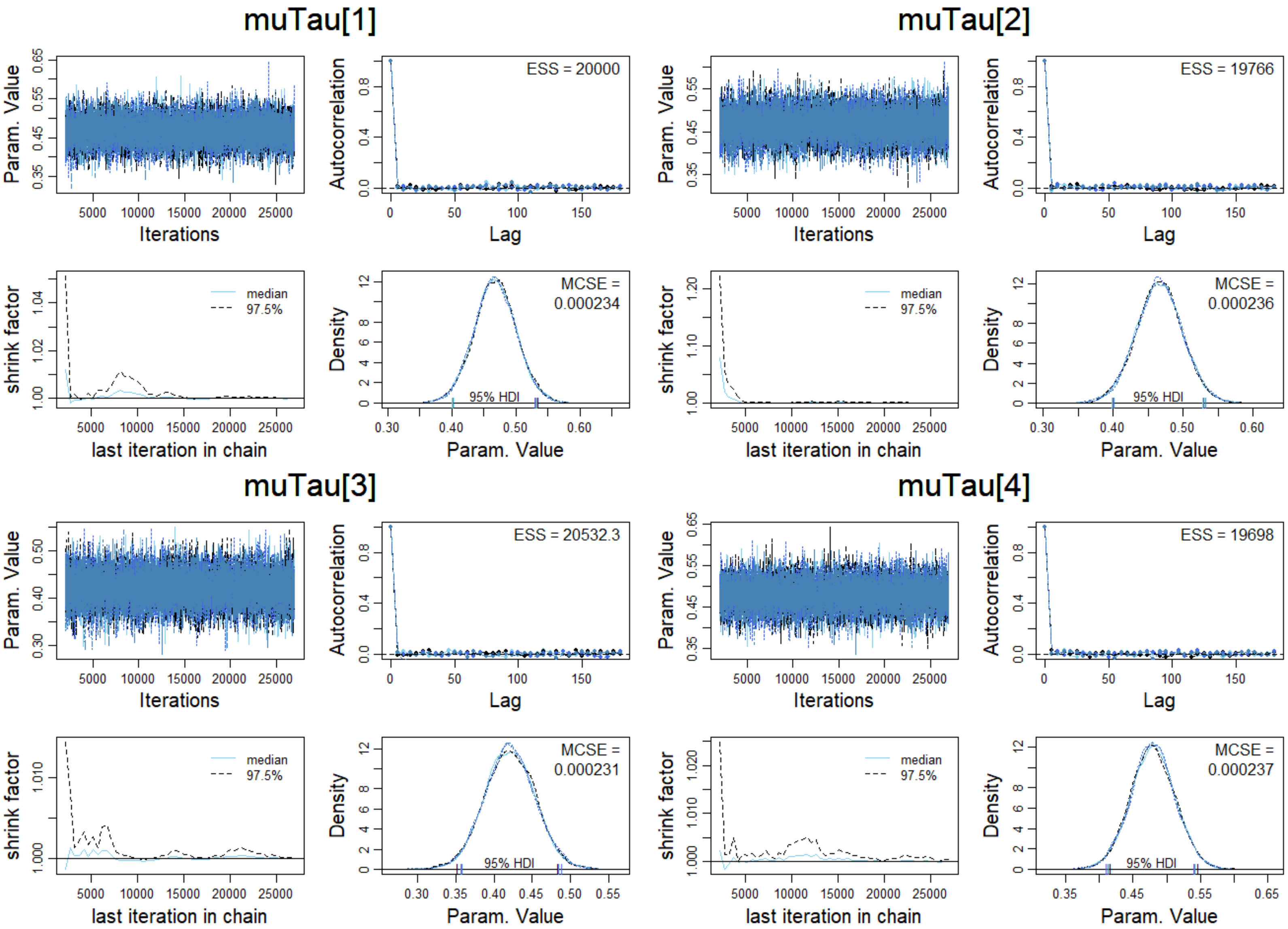

Figure C9

Experiment 2: Model Diagnostics for the Drift Diffusion Model for the PMR Condition at Pre-Measurement (Avoidance Task)

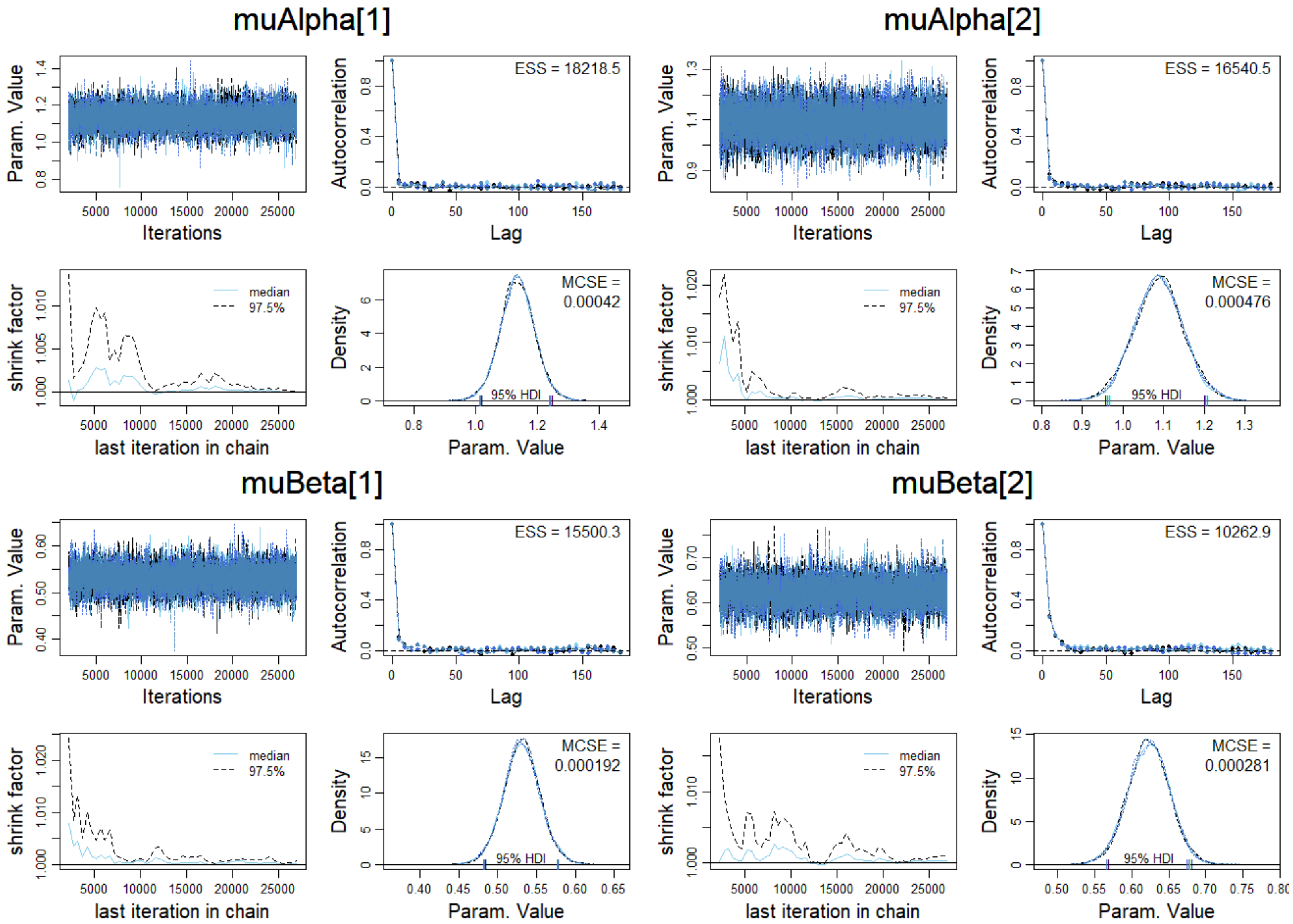

Figure C9
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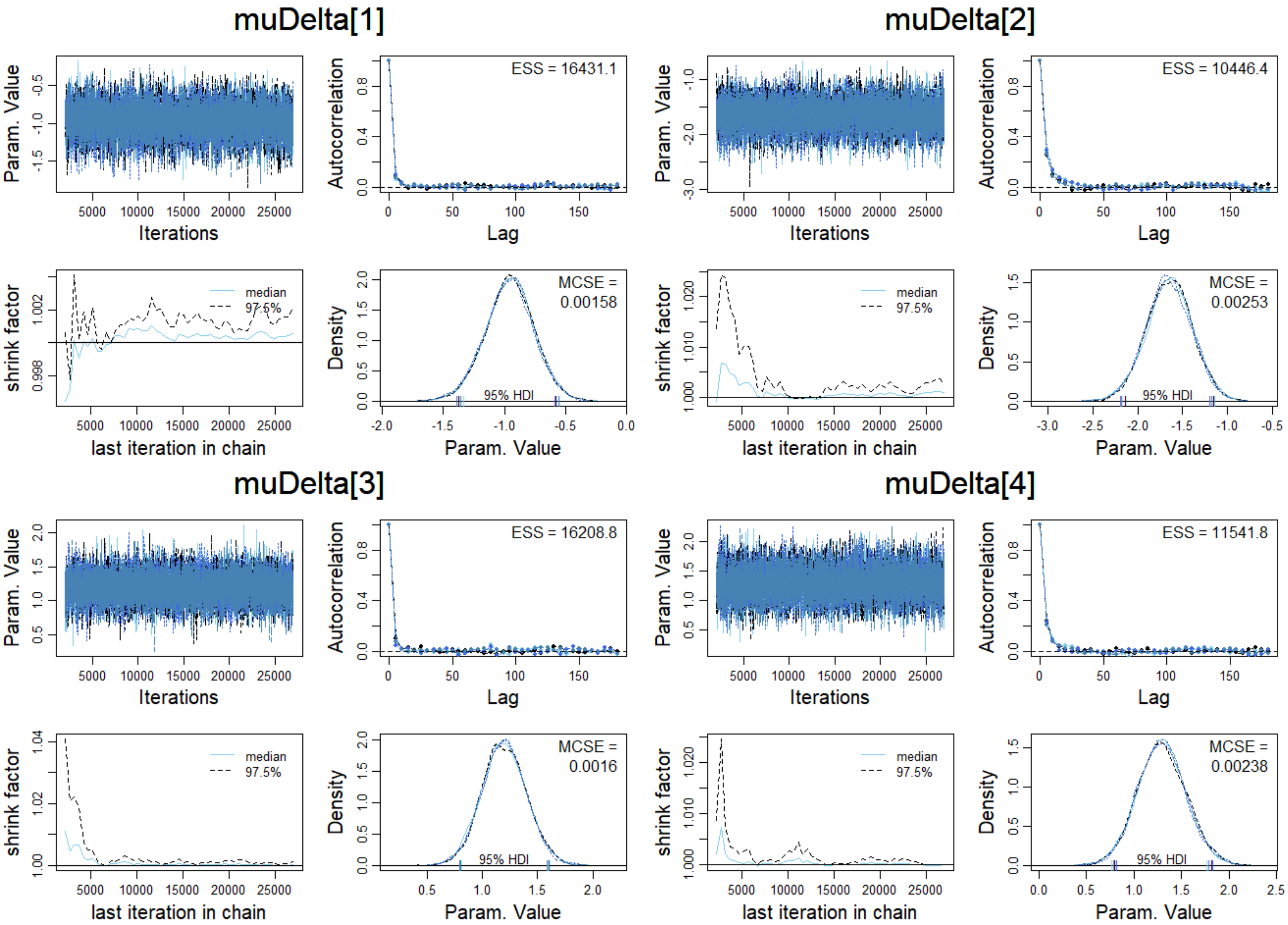

Figure C9
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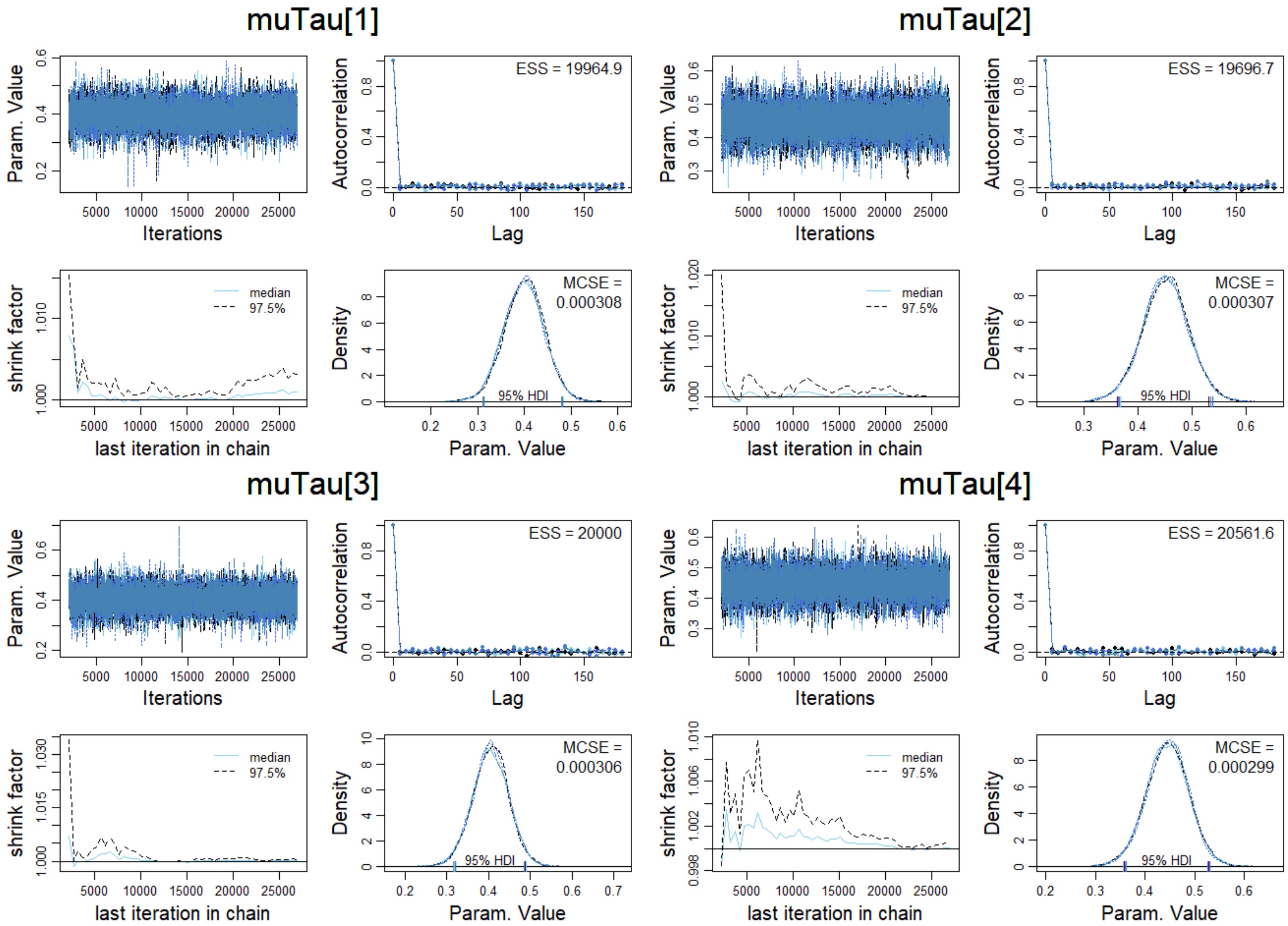

Figure C10

Experiment 2: Model Diagnostics for the Drift Diffusion Model for the PMR Condition at Post-Measurement (Avoidance Task)

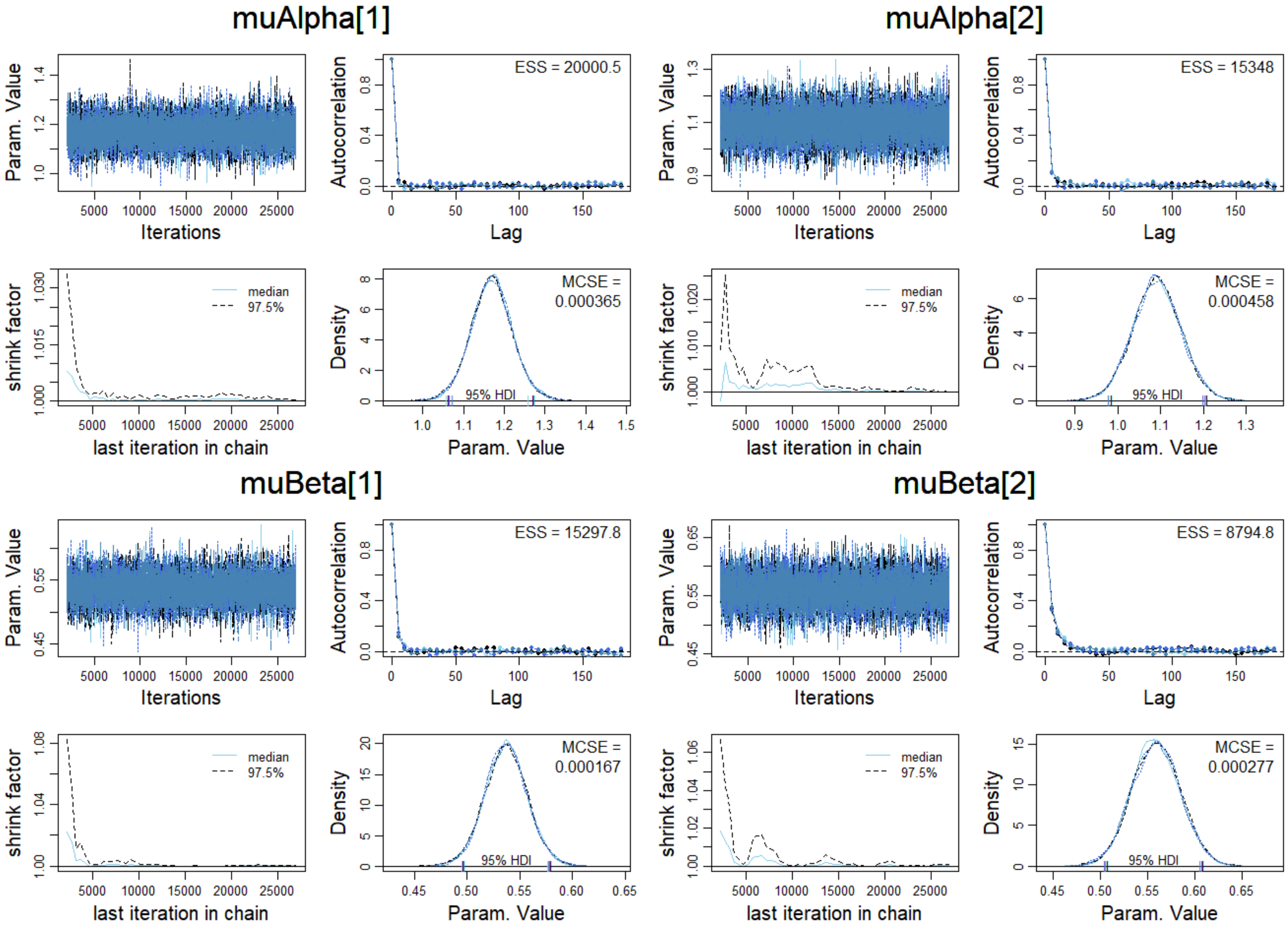

Figure C10
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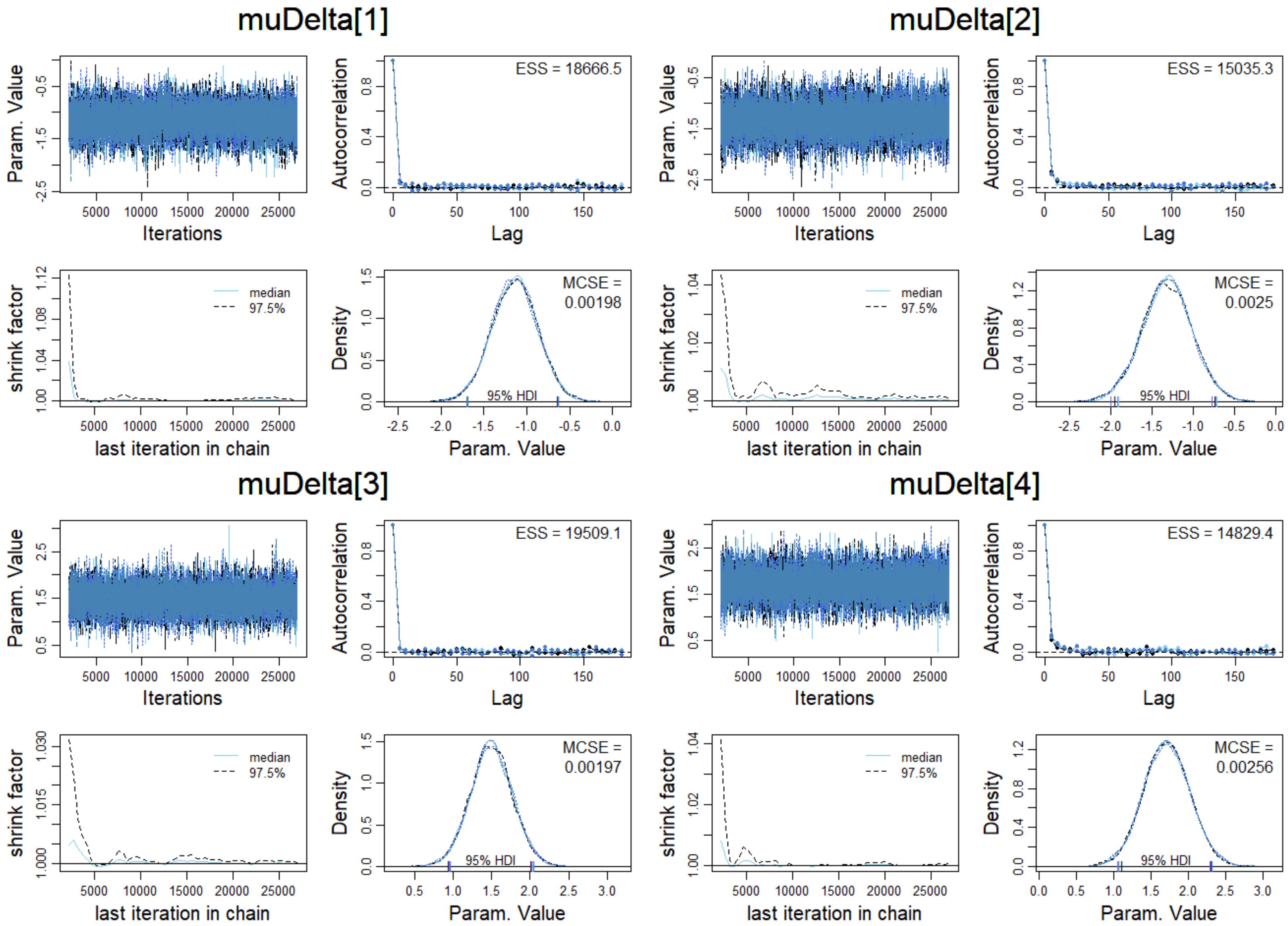

Figure C10
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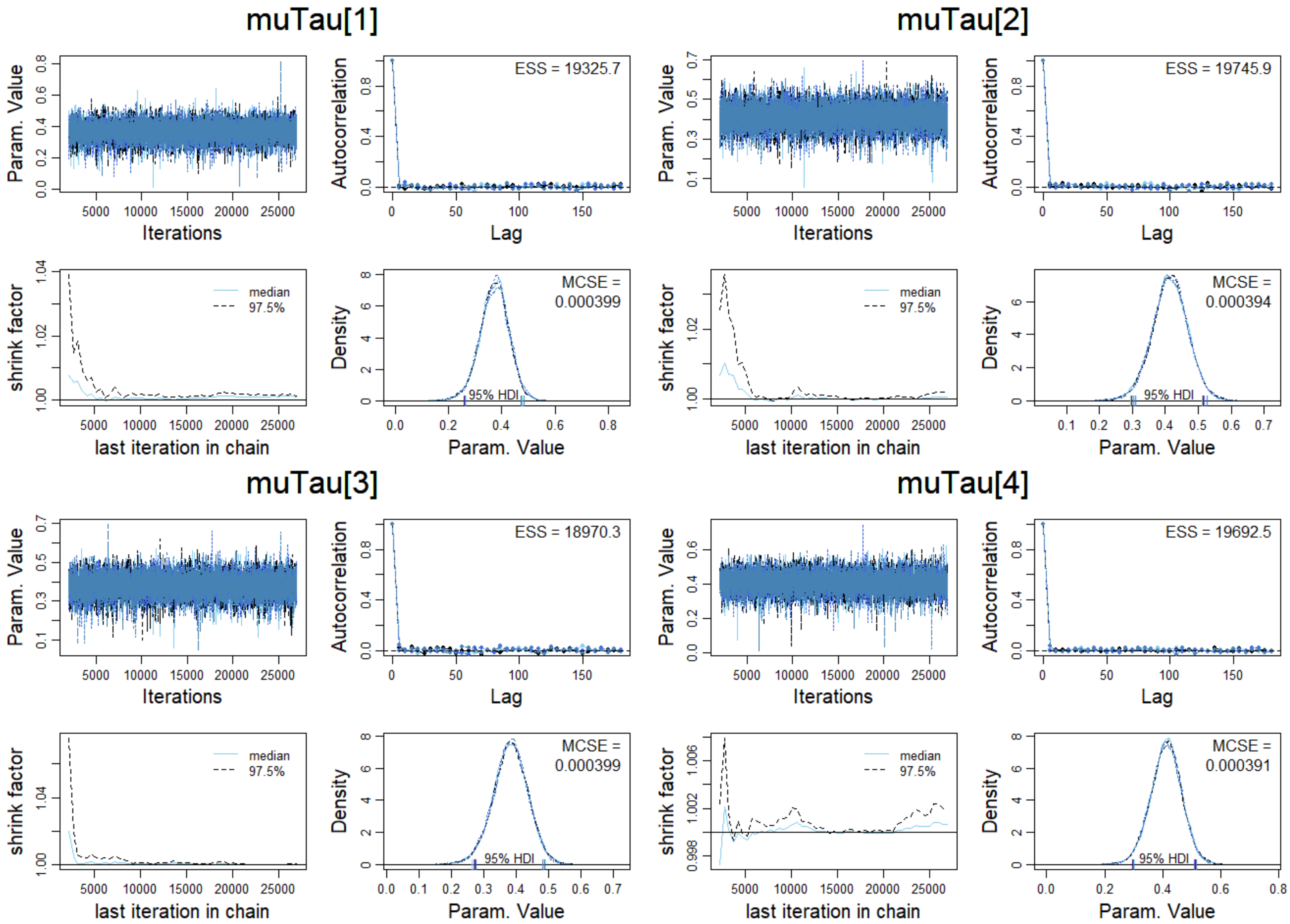

Figure C11

Experiment 2: Model Diagnostics for the Drift Diffusion Model for the Podcast Listening Condition at Pre-Measurement (Avoidance Task)

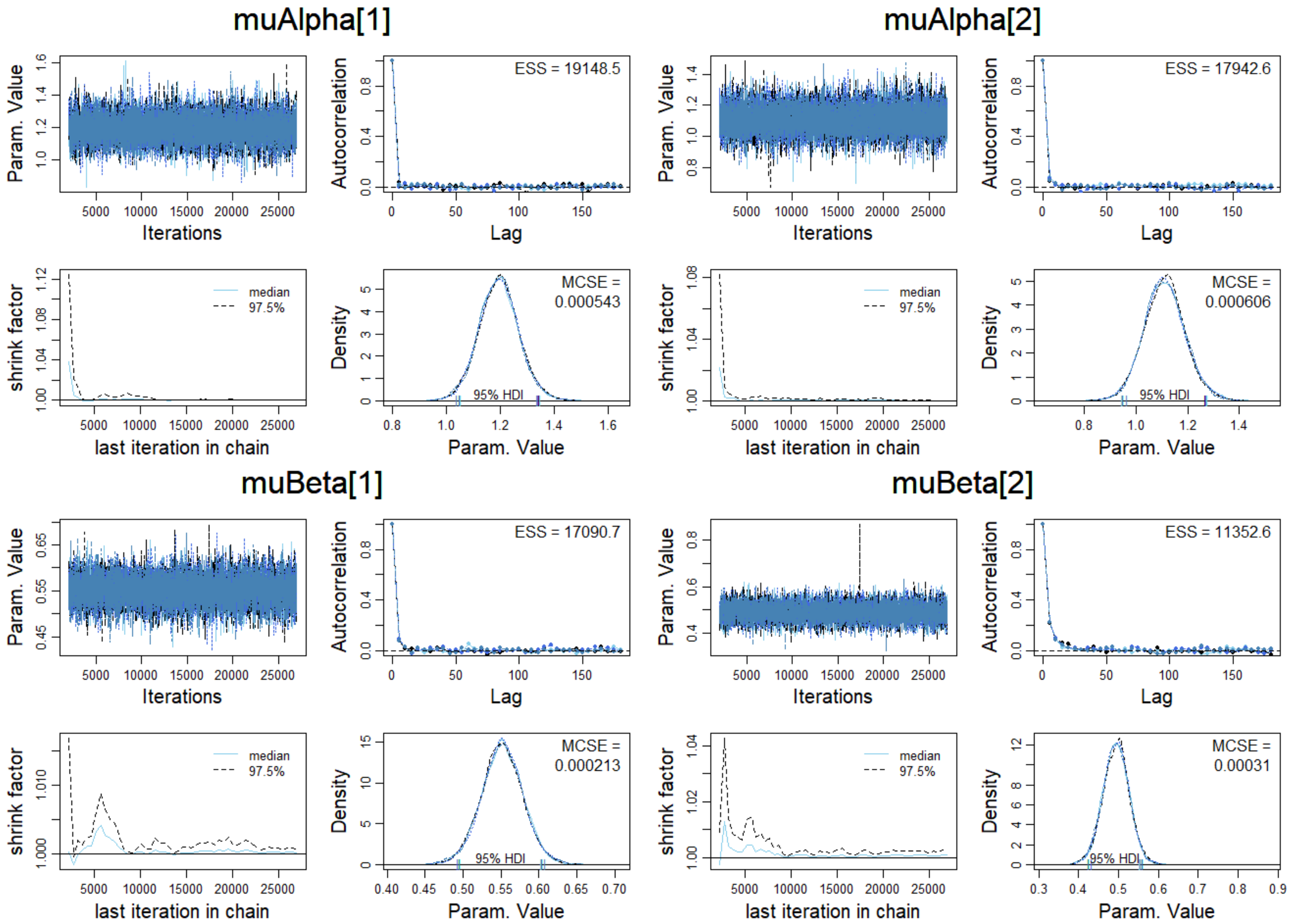

Figure C11
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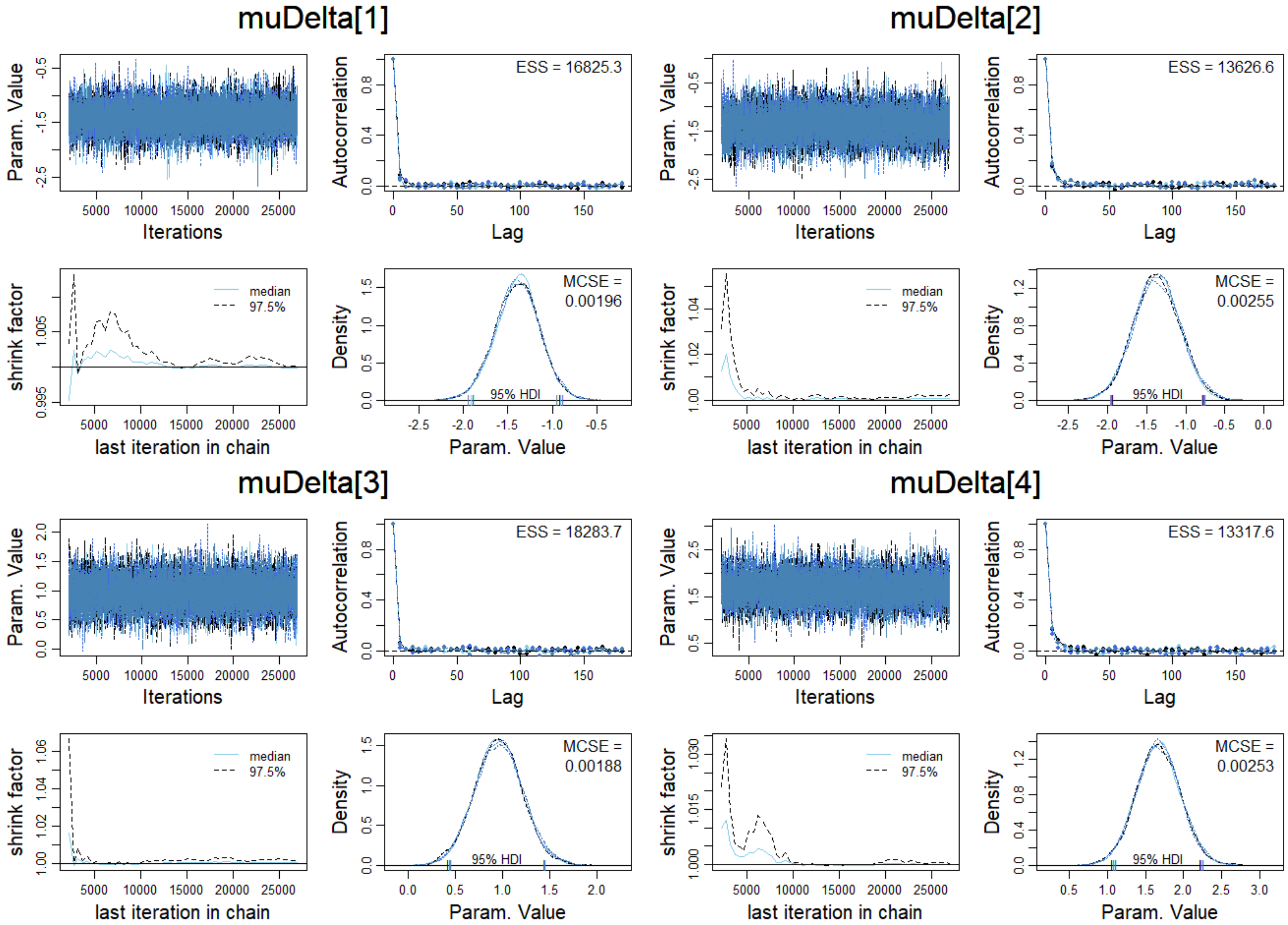

Figure C11

(continued)

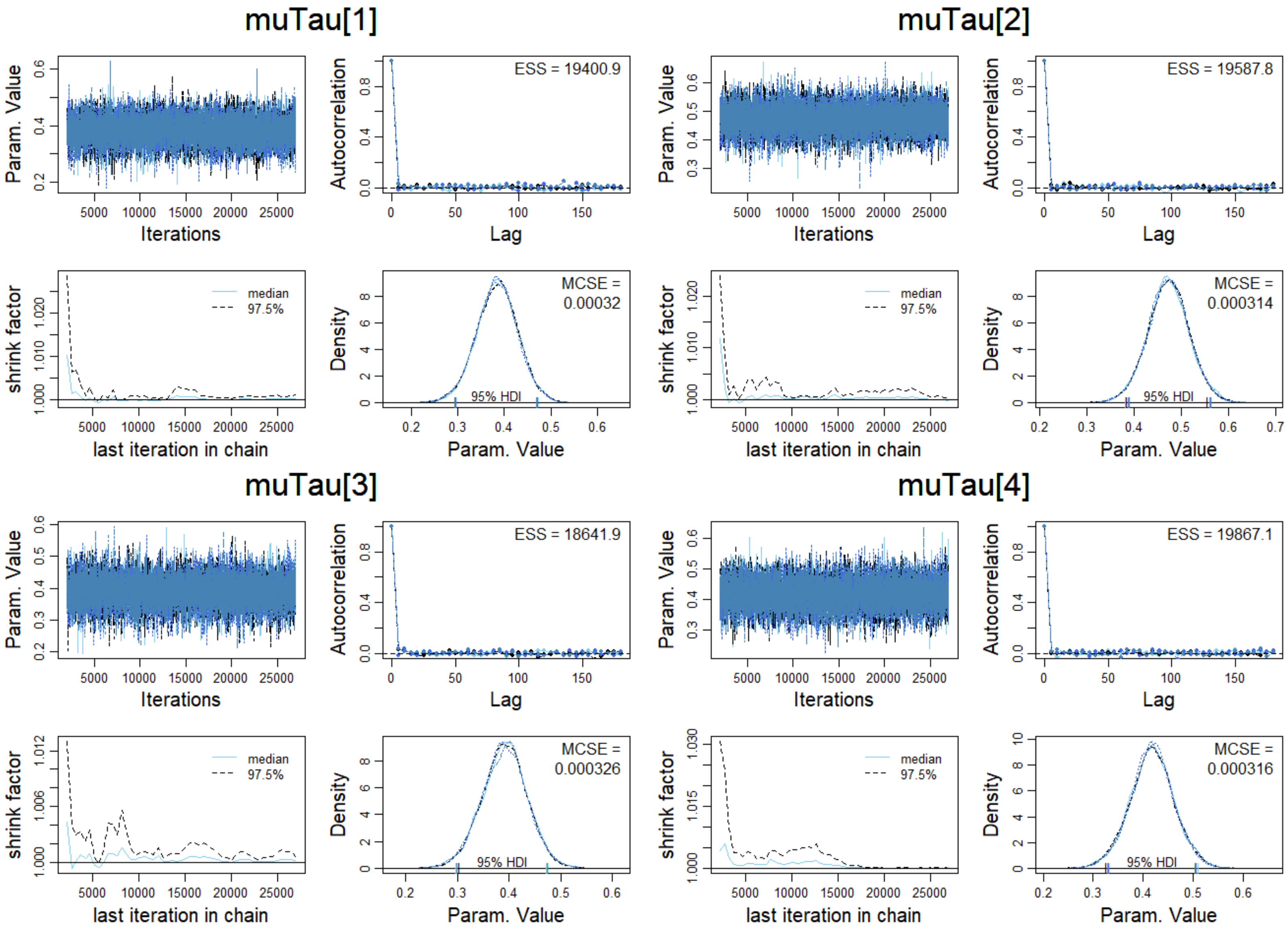

Figure C12

Experiment 2: Model Diagnostics for the Drift Diffusion Model for the Podcast Listening Condition at Post-Measurement (Avoidance Task)

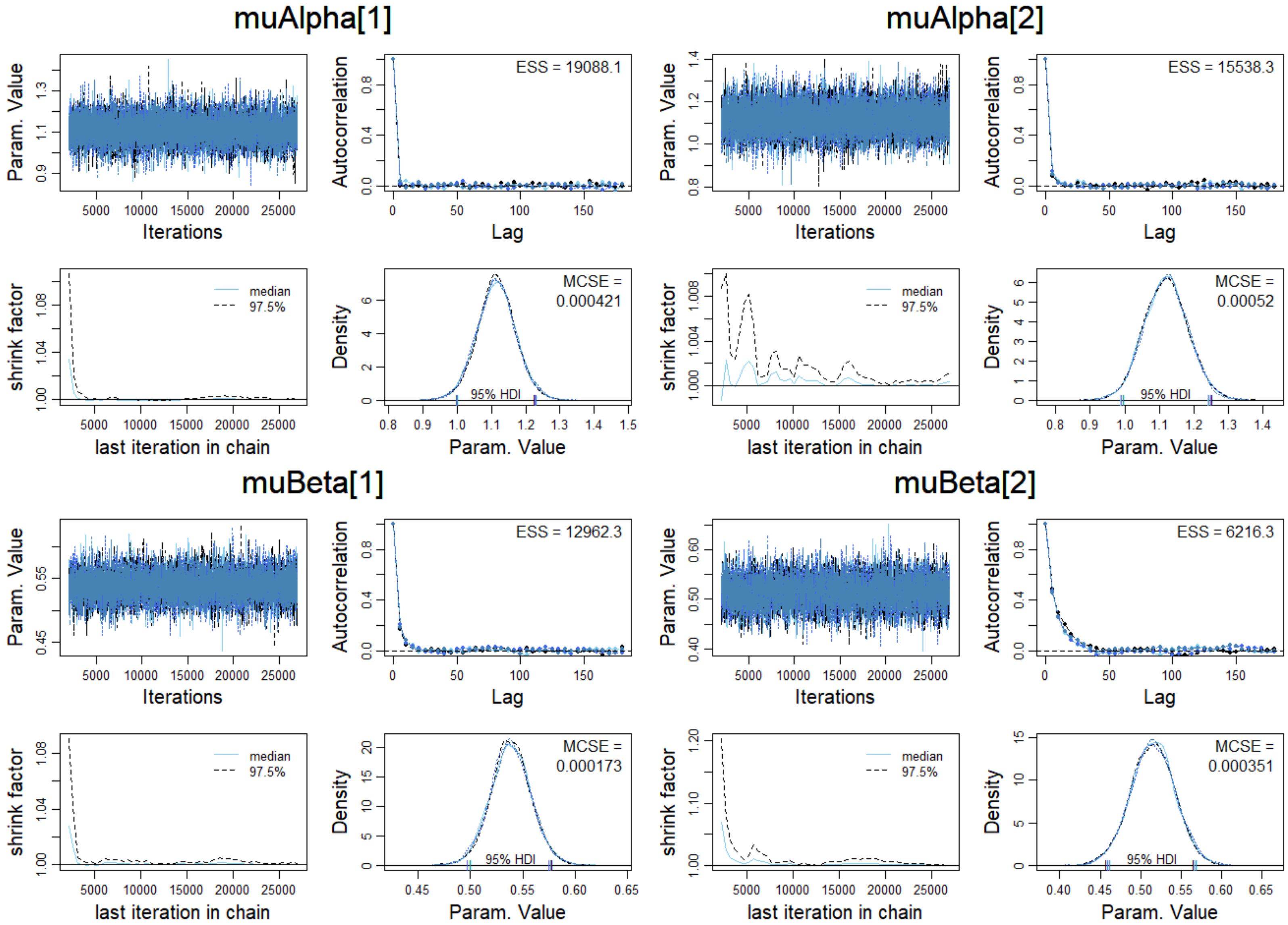

Figure C12

(continued)

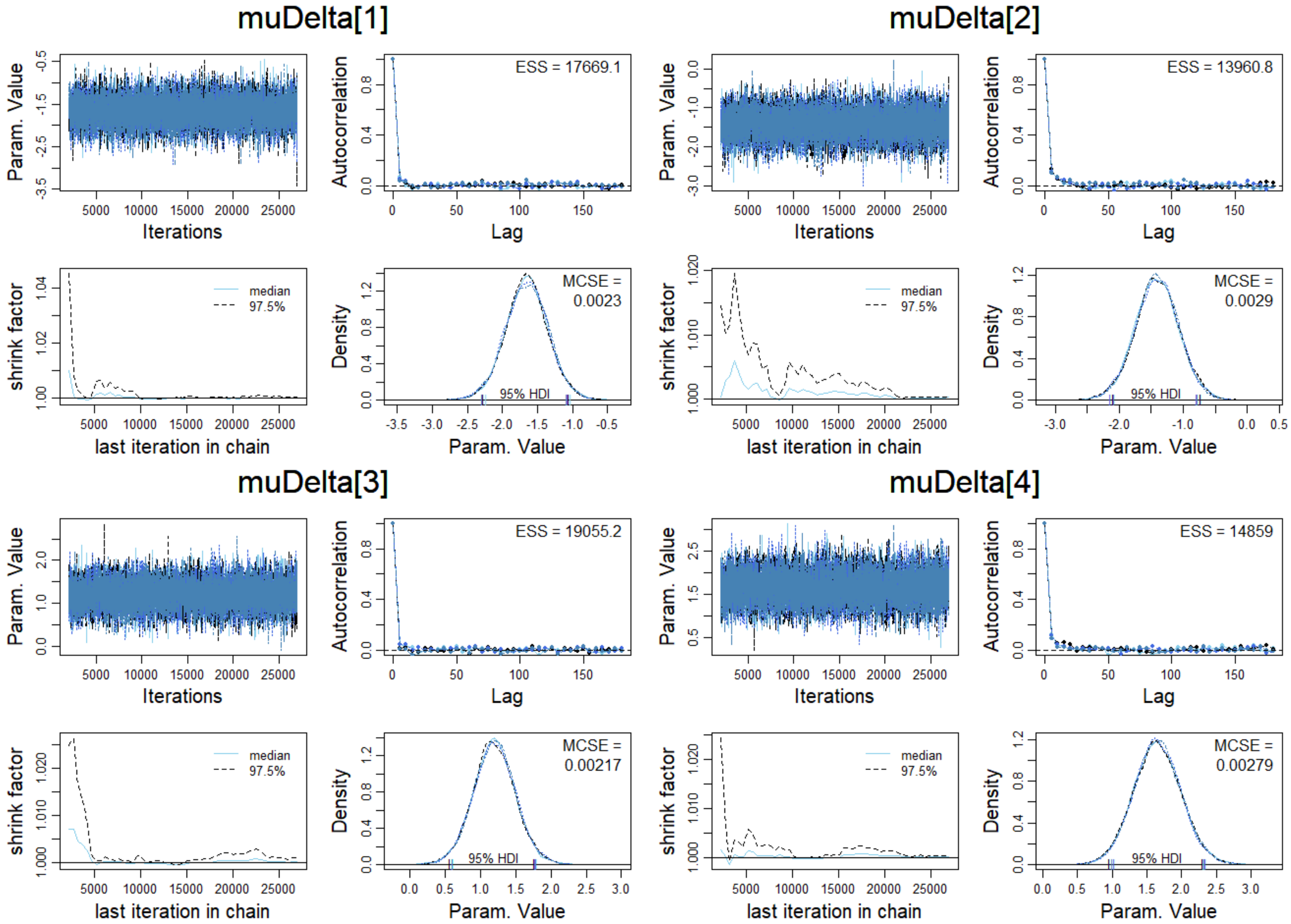

Figure C12
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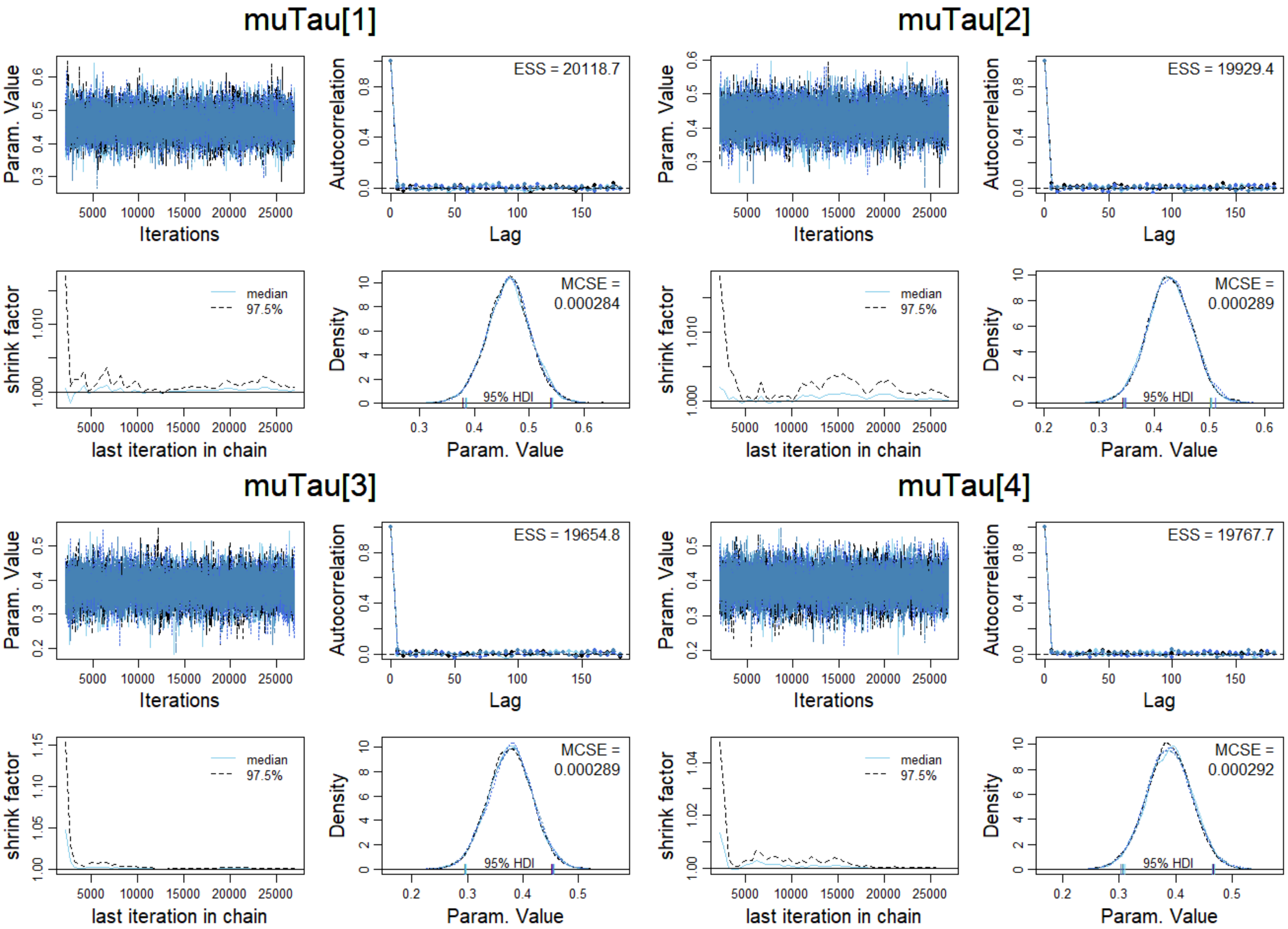

Appendix D

Analyses of Positive and Negative Affect With the PANAS

Table D1

Experiment 1: Linear Regressions of the PANAS PA Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	2.71	0.06	2.60 – 2.82	**<0.001**						
Time	0.02	0.06	-0.09 – 0.13	0.675						
Condition$_{Mindfulness}$	-0.13	0.08	-0.29 – 0.03	0.111						
Condition$_{PMR}$	0.14	0.08	-0.01 – 0.30	0.073						
					192	0.021 / 0.005	188	112.26		
(Intercept)	2.71	0.06	2.60 – 2.82	**<0.001**						
Time	0.03	0.06	-0.08 – 0.14	0.646						
Condition$_{Mindfulness}$	-0.13	0.08	-0.29 – 0.03	0.112						
Condition$_{PMR}$	0.14	0.08	-0.01 – 0.30	0.074						
Time : Condition$_{Mindfulness}$	0.06	0.08	-0.10 – 0.22	0.457						
Time : Condition$_{PMR}$	-0.08	0.08	-0.23 – 0.08	0.317						
					192	0.027 / 0.000	186	111.62	0.54	0.586

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table D2

Experiment 1: Linear Regressions of the PANAS NA Scale

								LRT Test		
Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*RSS*	*F*	*p*
(Intercept)	1.92	0.05	1.83 – 2.01	**<0.001**						
Time	0.04	0.05	-0.06 – 0.13	0.422						
Condition$_{Mindfulness}$	0.05	0.07	-0.09 – 0.18	0.501						
Condition$_{PMR}$	-0.17	0.07	-0.30 – -0.04	**0.011**						
					192	0.040 / 0.025	188	80.62		
(Intercept)	1.92	0.05	1.83 – 2.01	**<0.001**						
Time	0.04	0.05	-0.06 – 0.13	0.444						
Condition$_{Mindfulness}$	0.05	0.07	-0.09 – 0.18	0.502						
Condition$_{PMR}$	-0.17	0.07	-0.30 – -0.04	**0.011**						
Time : Condition$_{Mindfulness}$	-0.04	0.07	-0.17 – 0.10	0.580						
Time : Condition$_{PMR}$	0.04	0.07	-0.09 – 0.17	0.541						
					192	0.043 / 0.017	186	80.43	0.22	0.799

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table D3

Experiment 2: Linear Regressions of the PANAS PA Scale

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*LRT Test* *RSS*	*F*	*p*
(Intercept)	2.30	0.06	2.19 – 2.42	**<0.001**						
Time	0.02	0.06	-0.10 – 0.14	0.762						
$Condition_{Mindfulness}$	0.03	0.08	-0.14 – 0.20	0.722						
$Condition_{PMR}$	-0.08	0.09	-0.25 – 0.09	0.347						
					138	0.007 / -0.015	134	66.113		
(Intercept)	2.30	0.06	2.18 – 2.42	**<0.001**						
Time	0.02	0.06	-0.10 – 0.14	0.755						
$Condition_{Mindfulness}$	0.03	0.08	-0.14 – 0.20	0.724						
$Condition_{PMR}$	-0.08	0.09	-0.25 – 0.09	0.350						
Time : $Condition_{Mindfulness}$	-0.04	0.08	-0.21 – 0.13	0.639						
Time : $Condition_{PMR}$	0.01	0.09	-0.16 – 0.18	0.922						
					138	0.009 / -0.028	132	65.99	0.12	0.884

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Table D4

Experiment 2: Linear Regressions of the PANAS NA Scale

Predictor	*Estimates*	*SE*	*95% CI*	*p*	*Observations*	*R2 / R2 adjusted*	*Res. df*	*LRT Test* *RSS*	*F*	*p*
(Intercept)	1.59	0.05	1.50 – 1.68	**<0.001**						
Time	0.06	0.05	-0.04 – 0.15	0.231						
$Condition_{Mindfulness}$	-0.08	0.06	-0.20 – 0.05	0.250						
$Condition_{PMR}$	0.11	0.07	-0.02 – 0.25	0.086						
					138	0.033 / 0.011	134	40		
(Intercept)	1.59	0.05	1.50 – 1.68	**<0.001**						
Time	0.05	0.05	-0.04 – 0.15	0.243						
$Condition_{Mindfulness}$	-0.08	0.07	-0.20 – 0.05	0.253						
$Condition_{PMR}$	0.11	0.07	-0.02 – 0.25	0.088						
Time : $Condition_{Mindfulness}$	0.03	0.07	-0.10 – 0.16	0.617						
Time : $Condition_{PMR}$	-0.04	0.07	-0.17 – 0.09	0.562						
					138	0.036 / -0.001	132	40	0.20	0.820

Note. P-values for fixed effects were calculated using Satterthwaites approximations. Confidence Intervals have been calculated using the Wald method.

Discussion

The present dissertation investigated the effects of short mindfulness inductions on cognitive control and the expression of discriminatory behavior. Cognitive models consider attentional and executive control as fundamental mechanisms for initiating, maintaining as well as improving a mindful state (Bishop et al., 2004; Hölzel et al., 2011; Jankowski & Holas, 2014; Kang et al., 2013; Malinowski, 2013; Shapiro et al., 2006). Furthermore, these improvements in cognitive control are postulated to form the basis for later changes in the perspective on the self, as well as changes in self-regulation and constructive behavioral modifications. While models propose that repeated and prolonged practice is necessary to achieve stable improvements in cognitive control and mindfulness-specific states, the dose-response relationship is still up to debate, or more specifically, what an initial starting point for postulated improvements in cognitive control might be (Fell et al., 2010; Lutz et al., 2015). It has been proposed that novices initially focus on practicing to inhibit distractions to maintain the meditative state (Lutz et al., 2015), and while such improvements have been reported in studies utilizing short inductions (Leyland et al., 2019; Norris et al., 2018; first experiment), the current state of research is inconclusive (Gill et al., 2020; Larson et al., 2013; Leyland et al., 2019).

Furthermore, Fell et al. (2010) proposed that brain states following the initial stages of mindfulness training are unspecific and obtainable through other practices, such as relaxation training. This raises the question of whether the initial stages of mindfulness training improve cognitive control functions or indirectly improve cognitive control by induced relaxation (Eysenck et al., 2007). While there is evidence for beneficial effects of short FAM inductions compared to relaxation on inhibitory control (Mrazek et al., 2012; Wenk-Sormaz, 2005), the present state of research is insufficient to conclude that effects in early mindfulness training can be distinguished from relaxation (Baer, 2006; Chiesa et al., 2011; Shapiro et al., 2006).

Three empirical studies were presented to examine the dose-response relation between short mindfulness trainings and cognitive control. The first two studies examined the effects of short FAM trainings with increasing frequency and duration on the attentional networks (Petersen & Posner, 2012; Posner & Petersen, 1990) and the executive functions of set formation, maintenance and shifting (Suchy, 2009; Miyake et al., 2000). To investigate whether the effects of initial mindfulness training are specific or whether a first mechanism of mindfulness could be the reduction of dysfunctional tension by induced relaxation, short trainings in FAM were contrasted with PMR. The third study investigated the effects of short FAM trainings on the expression of discriminatory behavior. In line with models of control of stereotype-biased behavior (Amodio, 2014; Devine, 1989; Dovidio et al., 1997; Devine & Sharp, 2009) and previous findings by Lueke and Gibson (2015; 2016), it was postulated that improvements in cognitive control following short mindfulness trainings would enhance the suppression of otherwise stereotype-biased behavior. A summary of the presented studies and a discussion of the results will be given in the following.

In Study 1 (Vieth & von Stockhausen, 2022a), a short FAM induction of 2 x 20 minutes was compared to the effects of a PMR induction of equal length in a randomized controlled trial. Listening to podcasts was selected as a passive control condition to control for the effects of repeated testing. Separate reaction time tasks were utilized to assess the attentional networks (alerting, orienting and executive attention) and executive functions of cognitive inhibition, updating and task-switching. Results suggested that updating and executive attention exhibited similar improvements following mindfulness and PMR compared to the passive control condition, while the alerting and orienting networks were not affected by either induction. The findings for inhibition did not indicate that a short mindfulness induction outperformed relaxation, and while effects on task switching were differential, they were not beneficial for both practices. While mindfulness improved inhibition latencies compared to both PMR and podcast listening, PMR improved measures of response quality (i.e., discriminability was improved following PMR compared to podcast listening, and errors of omission were reduced compared to both mindfulness and podcast listening). For task switching, mindfulness led to greater improvements in switch costs from pre- to post-measurement compared to detrimental effects on task switching following PMR. However, mindfulness did not outperform the passive control condition. The conclusions of the first study were: First, short trainings in mindfulness meditation can produce beneficial effects on cognitive control, namely on executive attention, updating and inhibition. Second, it could not be concluded that these effects were mindfulness specific, as relaxation led to comparable improvements in updating and executive attention.

Two subsequent randomized controlled double-blinded trials were performed and presented in Study 2 (Vieth & von Stockhausen, 2022b). Training frequency and duration were increased to assess whether mindfulness-specific effects would unfold after more extended practice compared to the first study. Again, the executive functions of updating, inhibition and task switching were assessed with separate reaction time tasks. Furthermore, states of relaxation and mindfulness were assessed with self-report measures as a manipulation check. Results from a short induction (Experiment 1, 45 minutes across three sessions) and a brief mindfulness training (Experiment 2, 80 minutes across four sessions) showed no improvements in cognitive inhibition or updating following mindfulness and PMR. Effects for task-switching showed greater improvements for mindfulness compared to PMR, but these were also not beyond effects of repeated testing in both experiments. Taken together, the proposition that relaxation may yield similar effects as mindfulness in initial training stages could not be rejected nor confirmed based on the present data. Support for similar mental states was provided by self-report in Experiment 1, which showed similar increases in the subjective experience of focus and relaxation following mindfulness and PMR. The strength of evidence for such similar improvement was limited by the fact that in Experiment 2, which employed prolonged practice duration and frequency, self-report did not indicate changes in the subjective experience of mindful or relaxed states for either training. Therefore, and considering the contrasting findings of improvements following shorter training duration in Study 1, it was discussed that effects following short mindfulness trainings of the administered length and frequency might not be stable enough to emerge in pre-post designs reliably and therefore did not reliably present themselves in the tasks utilized.

Whether mechanisms underlying similar improvements in updating and executive attention following mindfulness and relaxation in Study 1 are alike cannot be concluded based on the present data. Furthermore, no definite conclusions can be made regarding what such a shared mechanism would be. Improvements in updating/working memory and executive attention by relaxation and mindfulness may have resulted from improved state relaxation (freeing up resources for cognitive performance; Eysenck et al., 2007). This would be in line with the notion that relaxation is considered a by-product of mindfulness meditation (Fell et al., 2010; Hölzel et al., 2011; Tang et al., 2015). While the amount of practice in the initial stages of mindfulness training may be insufficient to evoke beneficial effects on cognitive control, improved state relaxation may already surface following a short practice. In support of this reasoning were findings of increased state relaxation following both mindfulness and PMR in Experiment 1 of Study 2, while no improvements in executive functioning were found. Furthermore, self-reported focus increased following both practices. Following Lutz et al.'s classification of phenomenological experiences (2015), it may be argued that PMR and FAM practice evoke a similar attentional focus. During PMR, attention is voluntarily allocated to observing the contraction and relaxation of muscle groups, meaning that while the attentional focus is repeatedly shifted during PMR, it is directed to successive narrow focal points. While both practices thus evoke a narrow attentional focus, the phenomenological experience of the practices will differ in other aspects: Compared to FAM, maintaining attention to the task during PMR would arguably be less effortful, as PMR involves proprioceptive feedback through repeatedly constricting and relaxing muscles. Relatedly, novice partitioners will experience a greater sense of stability and clarity during PMR compared to initial FAM practice (i.e., it requires less effort to sustain attention to the task and accordingly, the experience will be more stable and clearer). In summary, while the scope of attentional focus is similar, comparing the phenomenological states of the practices highlights several differences between the practices, which according to Lutz et al. (2015) should result in different cognitive states. Whether inductions in mindfulness and PMR thus similarly improved updating and executive attention by induced relaxation or whether they differ in mechanisms at play cannot be concluded. Moreover, improvements in updating could not be replicated in Study 2, limiting the strength of evidence for such beneficial effects of the practices.

Differential effects for mindfulness and PMR were found for cognitive inhibition in Study 1. Mindfulness improved inhibition latency, while improved inhibition response quality was found following PMR. The differential findings in Study 1 did not reliably emerge across studies, limiting the strength of evidence regarding differential improvement in cognitive inhibition following short FAM and PMR practice. Effects on task switching were also differential for mindfulness and PMR and emerged across studies and experiments (i.e., no effects beyond repeated testing but greater improvement for mindfulness compared to PMR). Based on their findings, Wolff & Beste (2020) suggested that increased attentional focus following FAM meditation may lead to rigid maintenance of task goals and therefore impedes switching between task sets. However, except for Experiment 1 in Study 2, the effects of mindfulness were not detrimental, just not beyond repeated testing. As described above, during PMR, the attentional focus is also narrow but shifts between body parts (i.e., while the attentional focus is narrow, attention is not sustained on a fixed focal point but frequently disengaged and re-allocated). In line with Wolff and Beste's reasoning, switching between task sets would not be expected to be impeded following PMR, but PMR resulted in the least improvements compared to mindfulness and podcast listening across experiments and studies. Why relaxation training impaired improvement for task switching compared to repeated practice and whether this effect would persist following longer training durations would require more research.

In Study 2, with increased training dosages, no effects beyond repeated testing were found. We would have expected to at least reproduce improvements for updating and inhibition if the effects of short mindfulness trainings are stable and unfold over practice time. It was discussed that pre-post designs might not be suitable for investigating relatively transient improvements in initial mindfulness practice, as an experience sampling study by Levi et al. (2021) showed that effects following short training dosages did not cumulate over time but increased same-day self-report measures of state mindfulness. It should also be considered that while variations in the research designs of Study 1 and Study 2 were kept minimal, specific alterations had to be made to adapt the design to the online delivery of training and testing. The possible impact of these adaptations regarding differential results for Studies 1 and 2 will be discussed in the limitations.

Taken together, the results of Study 1 were indicative of similar improvements in updating and executive attention following mindfulness and PMR. Differential effects of the practices emerged for inhibition and switching, but they either did not support superior effects for mindfulness or beneficial effects beyond repeated testing. No improvements in executive functions following mindfulness and PMR were found in Study 2. Therefore, the study provided no evidence of whether the trainings would result in differential or similar benefits. Overall, these partly similar, partly differential findings for mindfulness and PMR were insufficient to reject or confirm the proposition that the initial stages of mindfulness practice lead to unspecific improvements (Fell et al., 2010). Still, the findings highlight that prolonged practice is paramount for stable and specific effects to unfold (Bishop et al., 2004; Jankowski & Holas, 2014; Malinowski, 2013). Differential effects of mindfulness and PMR would be expected to emerge after longer training dosages, as prolonged mindfulness practice is proposed to lead to mindfulness-specific states with high generalizability and transfer on attentional and executive control (Fell et al., 2010; Posner et al., 2015). Furthermore, the direct observation of one's mental state while maintaining an open-minded and accepting attitude in mindfulness practice is proposed to improve meta-cognition and self-regulation given sufficient practice (Bishop et al., 2004; Hölzel et al., 2011; Jankowski & Holas, 2014; Kang et al., 2013; Shapiro et al., 2006). On the contrary, while PMR is an effective method for inducing relaxation (Manzoni et al., 2008; McCallie et al., 2006; Toussaint et al., 2021), even prolonged practice is not expected nor designed to improve cognitive control or meta-cognition.

The aim of Study 3 (Vieth & von Stockhausen, 2022c) was to investigate whether short trainings in FAM are beneficial for reducing stereotype-biased behavior. To this end, the experimental designs of Study 2 included two reaction time tasks for assessing the effect of stereotype bias on response behavior (Shooter Task by Correll et al., 2002; Avoidance Task by Essien et al., 2017). Joined analyses of response latency and accuracy by drift diffusion modeling (Ratcliff, 1978; Ratcliff & Rouder, 1998) suggested that the effect of stereotype bias on evidence accumulation for decision-making was increased following an induction and a brief training in mindfulness meditation compared to PMR and listening to podcasts, which was contrary to our hypothesis. Unexpectedly, trainings in PMR reduced the effect of stereotype bias on evidence accumulation. Furthermore, differential effects of training dosages for mindfulness were found: In Experiment 1, a short mindfulness induction was followed by the least improvements in decision-making and resulted in higher ambiguity in information processing and more error-prone responding compared to both control conditions. In Experiment 2, a brief mindfulness training led to greater or equal improvements than relaxation in evidence accumulation for correct decisions and enhanced controlled responding. Thus, both inductions showed beneficial effects compared to repeated testing (podcast listening). These improvements may indicate that the training dosage delivered in Experiment 2 was sufficient in increasing cognitive control capacities necessary for overall improved task performance compared to a short induction in Experiment 1. However, this interpretation is limited by using conceptually similar but different tasks (i.e., social groups contrasted, stimuli utilized for threat induction and spatial aspects of responding in the Avoidance Task). Despite these general improvements in decision-making for mindfulness in the Avoidance Task, and just like in the Shooter Task, an increased effect of stereotype bias on the efficiency of information processing following mindfulness was found. Analyses of evidence accumulation for separate trial conditions showed that increased stereotype bias following mindfulness was based on greater ambiguity in information processing for stereotype-incongruent armed trials in both experiments. This indicates that mindfulness, compared to PMR and podcast listening, was followed by reduced performance (i.e., slower decisions and a higher percentage of errors) in trials that elicited high response conflict due to stereotype incongruency. The reduced effect of stereotype bias following relaxation was reversely based on comparably greater improvement in evidence accumulation for stereotype-incongruent armed (Experiment 1) or stereotype-incongruent unarmed trials (Experiment 2). Why this was the case and why incongruency effects were only present in certain trial conditions (i.e., either armed or unarmed) is unclear, but generally suggests differential effects of short mindfulness and relaxation trainings on heightened response conflict elicited by stereotype incongruency. In summary, our results were not in line with the findings by Lueke & Gibson (2015 & 2016), who reported reduced stereotype activation and expression of stereotype bias following short FAMs. Differences between paradigms utilized in Study 3 hinder a direct comparison of the results. Improvements in stereotype suppression following PMR but impairment following mindfulness suggest differentiable effects of the practices, but more research is needed to understand the underlying mechanisms at play.

Conclusion

Relating the presented findings to the aims of this dissertation, the following conclusions can be drawn. Regarding the dose-response relationship between initial phases of mindfulness training and postulated improvements in attentional and executive control, results of Studies 1 and 2 suggest that beneficial effects of short mindfulness trainings are transient and require prolonged practice to stabilize. Results of Study 3 were partially indicative of improvements in cognitive control following a brief mindfulness training but may also suggest impairment of control in situations with heightened response conflict. Regarding the specificity of the effects of short mindfulness trainings, partial evidence for differential effects compared to relaxation was found in Studies 1 and 3. However, the overall picture of the findings was too ambiguous to reach a conclusion about the (un-)specificity of effects in initial mindfulness practice. Regarding effects of short mindfulness trainings on the expression of stereotype bias, mindfulness increased the effect of bias on decision-making across two experiments, while PMR decreased the effect. These findings were unexpected and inconsistent with theoretical considerations and empirical findings. Therefore, replication and further investigation of underlying mechanisms would be desirable.

Limitations and Future Research

The presented experiments utilized convenience samples which mainly consisted of psychology students at the University of Duisburg-Essen. These relatively homogenous samples (e.g., age, education and socio-economic status) restrict the generalizability of the results. Therefore, replicating the results in more diverse samples would be desirable.

Participation was not restricted to complete novices of mindfulness practice but controlled for endured practice (i.e., no regular practice within the last three months prior to participation), which would be essential for persistent effects of mindfulness practice (e.g., Fell et al., 2010; Malinowski, 2013). Future studies may decide to restrict participation to individuals without prior meditational experience.

Due to restrictions during the COVID-19 pandemic, inductions and testing in Studies 2 and 3 were conducted online. Remote participation poses a challenge to controlling if participants carefully adhere to instructions for inductions and testing. Checks of feasibility and compliance suggested that the delivery of interventions was carried out without complications and that participants complied with instructions for training and testing. Still, Study 1 (i.e., in a laboratory setting) showed improvements in cognitive control for both mindfulness and PMR, while increased training length and frequency in Study 2 did not produce effects beyond repeated testing. Task-specific characteristics (e.g., increased difficulty by greater n in the N-back Task or increased reaction time for switch trials in the Number-Letter Task) also emerged in Study 2, indicating that tasks and testing were sensitive to assess executive functions remotely. Furthermore, online testing in Study 2 also led to beneficial adjustments in the research design: In Study 1, the experimenter read mindfulness and PMR instructions aloud, which increased the variability of induction presentation within induction delivery as between inductions and podcast listening. In Study 2, inductions and podcast listening were presented with audio files. Thus, greater standardization of the experimental manipulations was achieved. Furthermore, the randomized assignment of participants to experimental conditions was implemented in the online research environment, resulting in a double-blinded, randomized controlled experimental design. The lack of such designs has been a point of discussion in mindfulness research (e.g., Vago et al., 2019).

The results of impaired control of stereotype bias following mindfulness in Study 3 were unexpected, but they appeared across experiments and tasks. This suggests similar decision-making processes for the Shooter and the Avoidance Task. Still, using one of the two tasks to replicate the results and further investigate of dose-response effects of mindfulness training on stereotype expression would be desirable.

Furthermore, results in Study 3 suggested differential effects of mindfulness and PMR on trials with heightened response conflict. Future studies may directly investigate the underlying mechanisms of effects on response conflict following mindfulness and PMR during the Shooter or Avoidance Task. For example, Larson et al. (2013) showed that a brief mindfulness training decreased ERPs indicative of conscious processing or awareness of errors in a flanker task compared to a passive control condition (but no behavioral differences emerged between conditions). Related to our findings, models of stereotypes and discriminatory behavior and empirical studies have highlighted the necessity of conflict monitoring and detection to control otherwise stereotype-biased behavior (e.g., Amodio et al., 2004; Amodio et al., 2008; Bartholow et al., 2012). Investigating whether there is a relationship between the awareness of erroneous stereotype-congruent responses and impaired control of stereotype expression following short FAM trainings may deepen the understanding of the presented results.

Further measurements of the attentional networks and executive functions assessed in Studies 1 and 2 should be included in future research. For example, Gallant (2016) discussed that FAM specifically trains the detection and inhibition of cognitive distractions and may therefore improve cognitive inhibition. Such improvement may not translate to inhibition of prepotent motor responses, assessed with the CPT-II (utilized in the presented studies). Future research may employ Stroop tasks (Eriksen & Eriksen, 1974) which have been shown to be a valid assessment of cognitive inhibition (e.g., Hung et al., 2018) and have been previously utilized in mindfulness research (e.g., Wenk-Sormaz, 2005).

As discussed, it may be that effects following short trainings are not reliably measurable in pre-post designs because effects following brief training periods are not stable enough (Levi et al., 2021). Therefore, future studies may utilize experience sampling designs to assess transient improvements in cognitive control during initial mindfulness training phases on a day-to-day basis (Davidson & Dahl, 2018). While the feasibility of such designs for the assessment of cognitive control with well-established tasks may be limited by practical concerns (i.e., participants being willing and able to perform extensive testing daily), recent progress in the field of gamified assessments of cognitive control on mobile devices may provide a promising and valid alternative (e.g., Song & Park, 2020).

Future research may also incorporate psychophysiological measures of relaxation (e.g., heart rate variability) or electroencephalographic recordings to assess markers of state relaxation and attention. For example, Lumma et al. (2015) compared the cardiovascular effects and experienced effort of a breathing meditation (FAM), a loving-kindness meditation (during which feelings of love, warmth and compassion are practiced by generating and maintaining mental imagery) and an observing-thought meditation (OMM). They found that loving-kindness and observing-thought meditation were associated with heightened physiological arousal and experienced effort compared to FAM. Similar comparisons of FAM and PMR practice may further deepen the understanding of the underlying mechanism in the initial phases of mindfulness practice.

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