Investigations Along the eCommerce User Journey

A NeuroIS Approach with fNIRS to Better Understand User Experience

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When I began my master studies in business information systems, I came in contact with the idea of measuring physiological reactions of users as a better means to assess emotional and spontaneous experiences. Since then I have committed myself to study this young but promising research field which only recently came to exist. Given that I am a person who loves creating visual design, and is fascinated by visual arts on the one hand, but that also loves to make even fuzzy concepts quantitatively measurable on the other hand, the investigation of psychophysiological user experiences as responses to visual website design provides a most interesting intersection for me. After having made first physiological measurements with electrocardiography and electrodermal activity paired with automated facial expression analysis during my master thesis, I was ready for the human brain as subject of study for my PhD.

While I talked about this topic with my supervisor Reinhard Schütte, he mentioned the works of his colleague Peter Kenning which fall into a similar research domain as the present thesis. Reinhard then established the research relationship with Peter Kenning that drew my attention to the fNIRS measurement method. Given that fNIRS is still rarely used in the IS field, I was able to conduct highly innovative IS research with it, building the basis for this thesis.

During the discussions about some of the included papers in this thesis, I have learned a lot from my colleagues and my co-authors. Not only about how to write a scientific article, but also to gain soft skills regarding how to work with different collaborators. At this point, I want to especially thank Reinhard for establishing the research relationship and getting me in touch with the beautiful method of fNIRS, as well as his steady support during my PhD studies, and his open mindset for different research topics. I believe that he has established a great variety of research fields at his chair for information systems, and the team is open-minded and multi-disciplinary. Without him and our team, I would not stand where I am now, and I will never forget that. Further thanks go to my co-authors included in this thesis, being Peter Kenning, René Riedl, Caspar Krampe, and Nadine Gier, who provided a lot of constructive feedback during our collaborations that helped me grow and conduct high-quality

research.

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Abstract

The identification and satisfaction of user needs in business-to-consumer ecommerce is crucial to elicit positive experiences and establish loyalty toward the business. One major interface to the consumer is the website of the business, which can impact the user and customer experience throughout the whole journey. Current approaches that aim to measure user experience (UX) and related constructs have significant shortcomings and are often not able to uncover spontaneous processes in website users. Related neuroIS research proposes that a great part of behavior is formed by these spontaneous processes and that the utilization of additional, neurophysiological measurements can help to uncover these processes and better understand user behavior. Therefore, and to address the shortcomings of common UX measurements in ecommerce, this cumulative thesis presents 6 essays along different UX phases being pre-use, during-use, and post-/repeated-use of the ecommerce website. As a means to assess the spontaneous, potentially unconscious processes, the neuroimaging method fNIRS is utilized in the included essays. Across all papers, several responses to website design factors across UX phases could be identified on the neural level. The complementing self-reported data could reveal these effects only to a certain degree. Consequently, this thesis shows the contribution of neuroimaging (fNIRS) to UX investigation on ecommerce websites to better understand users, which helps to optimize website design and thus, UX.

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List of Abbreviations

ACC	anterior cingulate cortex
ANOVA	analysis of variance
ANS	autonomic nervous system
AR-IRLS	autoregressive model with iteratively reweighted least squares
BA	Brodmann Area
BCI	brain computer interface
beta	regression coefficient
BOLD	blood-oxygen level dependent
CA	Cronbach's Alpha
CNS	central nervous system
COL	colorfulness
CX	customer experience
dfe	degrees of freedom
DIV	diversity
dlPFC	dorsolateral prefrontal cortex
dmPFC	dorsomedial prefrontal cortex
DPF	differential pathlength factor
ECG	Electrocardiography
EDA	Electrodermal Activity
EEG	Electroencephalography

FDR	false discovery rate
fMRI	functional Magnetic Resonance Imaging
fNIRS	functional Near-Infrared Spectroscopy
GLM	general linear model
GUI	graphical user interface
Hb	hemoglobin
HbO	oxygenated hemoglobin
HbR	deoxygenated hemoglobin
HCI	Human-Computer Interaction
hrf	hemodynamic response function
HSD	honest significance difference
HSH	hemisphere specific hypothesis
IS	Information Systems
LDD	long-distance detectors
LMMSE	Linear Minimum Mean Square Estimations
LQ	laterality quotient
MANOVA	multivariate analysis of variance
neuroIS	Neuro-Information-Systems
OFC	orbitofrontal cortex
PEOU	perceived ease of use
PFC	prefrontal cortex
PPF	partial pathlength factor
PU	perceived usefulness
PUI	purchase intention
rmANOVA	repeated-measures analysis of variance

rmMANOVA	repeated-measures multivariate analysis of variance
SDD	short-distance detectors
se	standard error
SIM	simplicity
SLR	structured literature review
TAM	Technology Acceptance Model
UI	user interface
UX	user experience
VisAWI	Visual Aesthetics of Website Inventory
vlPFC	ventrolateral prefrontal cortex
vmPFC	ventromedial prefrontal cortex

Chapter 1

Introduction

1.1. The Importance of Considering User Experience in eCommerce

Amazon was probably one of the first companies that revolutionized the way ecommerce[1] is done by putting the customer first and establishing a great variety in product assortment, short delivery times, and easy returns for orders. Especially the latter two are grand examples that user and customer[2] needs may include one thing above all: pleasant experiences (Hassenzahl and Tractinsky, 2006; Jordan, 2000; Lemon and Verhoef, 2016). Thus, vendors of successful websites seem to achieve a high level of pleasure and desirability in their customers by outperforming their expectations (Kuniavsky et al., 2012; Pucillo and Cascini, 2014). To reach this state of desirability and therefore, become customers' preferred website, an in-depth understanding of customers' experience is required. For instance, it may be assumed that a heavy focus on customer experience (CX), together with first-mover advantages helped Amazon gain the market power it has now. However, as the ecommerce market is much more established than it was back in the 1990s, the benefits of first-mover advantages may diminish. As a result, a focus on CX may become even more important for ecommerce companies to eventually foster loyalty in their customers (Kuniavsky et al., 2012).

As a result, more and more companies focus on achieving positive experiences through visual design of customer touch points as success factor (Alves et al., 2014). To identify potential means, companies are advised to take the whole customer journey in mind and identify critical factors of different touch points along the journey that impact the CX (Lim et al., 2015). In a recent review, it was found that customers prefer touch points that also fulfill functionality rather than primarily community-related touch points such as social media (Hallikainen et al., 2019). Among the touch points, brand-owned touch points such as the website are the most preferred interfaces to the ecommerce vendor (Hallikainen et al., 2019). This is supported in another study, which identified that the direct website visit and use is the most valuable marketing channel for a company, and should therefore be focused on

[1] Generally, there are different business-customer relationship models in ecommerce. The most common models are business-to-consumer (B2C), and business-to-business (B2B) (Deges, 2020; Mahadevan, 2000). This thesis focuses on the B2C ecommerce market and therefore, only refers to B2C when speaking about ecommerce.

[2] In this thesis, users are defined as human agents that interact with the website to achieve a specific goal. Therefore, their experiences are thought to be tightly connected to the characteristics of the website. Most of the website users are also customers of the website's vendor, however, customer experiences also go beyond the interaction with the website, and also involve company services such as delivery times, return policies, and service quality (Lee, Inman, et al., 2018).

to improve CX (Kakalejčík et al., 2020). As a result, the website [3] can be regarded as the most significant interface to customers in ecommerce, and should therefore be optimized in its design to meet users' expectations, and foster pleasurable user experiences (UXs) during website use. Especially when a company has yet to achieve a state of loyalty in its customers, website appeal is crucial because when it fails to appeal customers' first impressions as website users, they are most likely to abandon the website and search for alternatives (Kim and Fesenmaier, 2008). However, not only the first impression is crucial, companies can also loose customers along further use phases, if their expectations from first impressions are not met, and thus, their needs as website users are not satisfied during actual and repeated use (Lee and Ha, 2019; Thielsch, Blotenberg, et al., 2014; Thielsch, Engel, et al., 2015). Thus, a focus on UX and possible ways to assess it in order to improve it seems reasonable.

1.2. User Experience Research and Measurement

The approach to identify users' experiences along different use phases of a website is referred to as UX or user research (Hassenzahl and Tractinsky, 2006; Kuniavsky et al., 2012; Sauro and Lewis, 2012). Finding its origin and uprise as a buzzword in Human-Computer Interaction (HCI) literature at the turn of the 21st century, it has been marked by fuzzy conceptualizations in its beginnings (Bargas-Avila and Hornbæk, 2011; Law, Roto, et al., 2009). Eventually, UX is thought of as an umbrella term that aims to cover all experiences of users holistically (Zarour and Alharbi, 2017), and that aims at creating artefacts which are not only high in usability, but also pleasurable to use (Hassenzahl, 2013; Hassenzahl and Tractinsky, 2006; Jordan, 2000). In this vein, UX captures both users' perception (meaning sensory input and sense making of this input) of the artefact they interact with, as well as accompanying emotions that arise prior to, during, and after the artefact use (Minge and Thüring, 2018). Emotion, however, is a complex concept[4], and manifests itself not only in

[3] Both on desktop PCs and mobile devices, as customers often do not discriminate between desktop and mobile website but expect a consistent service across devices (Bilgihan et al., 2016). Literature on CX in ecommerce and m-commerce proposes that all aspects which are relevant for ecommerce are also relevant for m-commerce (Maity and Dass, 2014; Singh and Srivastava, 2019). However, for m-commerce, additional restrictions and factors appear due to the limited screen size, and attention constraints when used on the go (Maity and Dass, 2014). This thesis, however, focuses on desktop versions of websites, and as a result, the made statements can only be generalized to these website versions.

[4] Note that it is not the aim of this thesis to discuss the concept of emotion and the discourses in emotion research. For comprehensive overviews on how research on emotion as a concept and emotion theory has evolved over the years, the interested reader may have a look at Mandler (1979), Dixon (2012), Barrett (2016), and Scherer (2022).

subjective self-reports and behavior, but also in (neuro-)physiological processes, and motor expressions (Barrett, 2016; Kleinginna and Kleinginna, 1981; Larsen et al., 2008; Russell, 1980; Scherer, 2001). As a result, designing for positive UX in the end is designing artefacts that elicit pleasurable experiences (i.e., elicit positive emotion) (Hassenzahl and Tractinsky, 2006).

But how can we assess whether an interaction elicits pleasure and therefore, positive UX? Having elaborated that UX is a complex and dynamic concept, UX research has also been marked by a lack of empirical research in its beginnings (Bargas-Avila and Hornbæk, 2011; Law, Roto, et al., 2009; Robinson et al., 2018). Even in later years, the way how to measure UXs is still in debate, because there has been a lack of connecting the "what is measured" to "design choices", and thereby, a research model with dependent and independent variables was often not utilized (Law, Van Schaik, et al., 2014). Yet, such models would allow to generate actionable insights and make UX "improvable".

Related empirical UX research has therefore focused on using questionnaires, interviews, think aloud, observations, and performance measures to make UX measurable (Doherty and Doherty, 2018; Robinson et al., 2018; Zaki et al., 2021). In UX practice, large-scale A/B testing has also become an additional method to track users' clicking behavior, especially on websites[5] (King et al., 2017; Siroker and Koomen, 2013). However, because this method requires high amounts of data to lead to reliable results (Firmenich et al., 2019), it is less often applied in academia. While all of these methods provide first insights into users' behavior and evaluations, they have one thing in common: they only capture the outcomes of experiences, and not antecedent processes that give rise to an experience. These processes, however, would help us to better understand the link between design decision and experiential outcomes in the first place.

In this line, we argued that one essential characteristic of UX is that it comprises not only perception, but also emotion. One crucial characteristic that is often associated with emotion is that it is thought to happen spontaneously, and that it is an automatic and unconscious driver of decision making and behavior (Damasio, 1994; de Guinea and Markus, 2009; vom Brocke, Riedl, et al., 2013). While a part of UX and emotion is also subject to reflective judgment, the spontaneous part that is marked by automatic reactions can probably not be detected with self-reported or behavioral measures. The reason for this is that it is thought to comprise antecedent

[5]Grand examples on this are A/B testing practices by social media websites such as Facebook and Instagram (Xu et al., 2015)

processes that cannot be verbalized and deliberately reflected upon (Dimoka, Banker, et al., 2012; Zajonc, 1980). For instance, when asked after website use whether users enjoyed their interactions with the website, users can probably judge in how far they enjoyed it. If, however, they are then asked why they evaluate their experience the way they do, they often may not be able to give reasonable answers to that question (Zajonc, 1980). The reason for this can be explained by the assumption that a great part of behavior and decision-making lies outside of the "consciously" graspable domain, and can therefore not be articulated by means of language (Evans and Stanovich, 2013; Strack and Deutsch, 2004).

As a result, a continuous and passive[6] assessment of users' physiological reactions in addition to user behavior may help to provide more insights into these processes (Dimoka, Banker, et al., 2012). The field that deals with this idea in Information Systems (IS) has been coined Neuro-Information-Systems (neuroIS), and follows the assumption that especially neuroscience can "advance our knowledge of the complex interplay of IT and information processing, decision making and behavior" (Dimoka, Pavlou, et al., 2011b, p. 687). As a result, neuroIS[7] has been thought to help inform design decisions, evaluate designs, get a deeper understanding of the "why and how an IT artifact influences antecedents of behavior or actual behavior", and may even help to better predict user behavior (Riedl and Léger, 2016).

Unsurprisingly, the number of studies that employ additional physiological measures to complement the behavioral and self-report heavy literature has increased in recent years (Liapis et al., 2021; Zaki et al., 2021). Regarding the utilized measurement method, several studies have employed eye tracking for assessing user attention as response to visual aesthetics (for e.g., Pappas et al., 2018; Wang, Yang, et al., 2014), or to receive insights into instant emotional experience during technology use (Al-Wabil et al., 2010). Another applied method to receive insights into experienced emotion during website use is that of automated facial expression analyses (for e.g., Niforatos and Karapanos, 2015; Staiano et al., 2012; Tang et al., 2016; Yong, 2013). Electrodermal Activity (EDA) has shown to provide good indicators of stress and frustration (for e.g., Landowska and Miler, 2016), giving insights into user states. Similarly, several studies have also considered measuring heart rate and its variability as indicator for stress and frustration as responses to IT use (Zaki et al., 2021). All of these methods allow seamless physiological measurements that can provide us information about the current experiences of

[6]This means that the measurement does not interrupt the interaction between user and website in any way, because this would also disrupt the experience.
[7]Note that neuroIS will be introduced in more detail in Chapter 2 of this thesis.

users in terms of emotional valence and arousal because they assess physiological changes in the autonomic nervous system (ANS) (Mauss and Robinson, 2009; Riedl, Davis, and Hevner, 2014; Scherer, 2005). Which antecedent appraisal processes of the website's characteristics, and how the ANS activity is translated to behavioral intentions, however, may only be measurable through neural activity in the brain (Kreibig, 2010; Mauss and Robinson, 2009; Scherer, 2005).

Within the body of UX research that applies physiological measures, only a small part has used neuroimaging methods to receive insights into antecedent neural processes of UX constructs. The main reason for this might be that most neuroimaging methods are stationary, associated with high cost, and highly intolerable for movements of participants (i.e., functional Magnetic Resonance Imaging (fMRI), magnetoencephalography, post-iron emission) (Kenning, 2020; Pinti, Tachtsidis, et al., 2020). As we have stated before that UX measurement which aims to capture spontaneous, antecedent processes must be passive, it is highly questionable whether such stationary and restricting measurement methods are applicable to UX research. As a result, there is little to no research using these methods for UX assessment. However, there are also portable and less intrusive neuroimaging methods available that have potential for UX research (i.e., functional Near-Infrared Spectroscopy (fNIRS) and Electroencephalography (EEG)) (Kenning, 2020). In this line, several studies have used EEG as measurement method to assess neural activity as indicator for UX constructs (Federici et al., 2019; Stefancova et al., 2018; Zaki et al., 2021).

While EEG allows to explore electric potentials in the brain as direct reactions to stimulus perception, it also comes with several disadvantages. Significant problems are the localizing of the elicited neural responses spatially to brain areas, and artefacts in the data which can be caused by external electricity, head movements, facial expressions, or if mouse and keyboard are used (Kim, Seo, et al., 2017; Maior et al., 2015; Pinti, Tachtsidis, et al., 2020).[8] Next to EEG, a second portable and non-intrusive neuroimaging method has been introduced with fNIRS in the 1990s (Ferrari and Quaresima, 2012; Kenning, 2020). Given that this method has not been around as long as EEG (which was developed by Berger back in the 1920s) (Riedl and Léger, 2016), UX research that utilizes fNIRS as potential method is scarce (Hirshfield, Gulotta, et al., 2011; Pollmann, Vukelić, et al., 2016). Yet, fNIRS may offer high potential as it can overcome limitations of EEG and fMRI, especially with regards to movement artefacts (Kopton and Kenning, 2014; Pinti, Tachtsidis, et al., 2020). Therefore, this doctoral thesis investigates the potential of fNIRS as

[8]Please note that the neuroimaging methods are discussed in more detail later in sections 2.1.3. and 2.1.4.

measurement method for UX research of ecommerce websites.

1.3. Research Goal: Toward Neural Measures of User Experience

By utilizing fNIRS for UX research on ecommerce websites, this thesis in its cumulative form tackles two research gaps in current UX research that employs mobile neuroimaging methods. That is, of all the reviewed studies, the focus was to identify or distinguish emotional states of users by means of the neural activity (Federici et al., 2019; Pollmann, Vukelić, et al., 2016; Stefancova et al., 2018). While we have argued that especially emotional antecedents cannot be verbalized, we have also seen that neural activity, especially in prefrontal cortical areas, does not point to single responses (Kreibig, 2010). In this line, it represents a production of integrated responses of perception and emotion that may not be distinguishable in their single signals. Yet, these measurable integrated processes may be significant antecedents to UX constructs that can be assessed by self-reports such as perceived usefulness or aesthetics.

Although neuroIS research has been conducted in other contexts and has identified several antecedent processes to these constructs in the prefrontal cortex (PFC) (as is later introduced in section 2.1.2.), a systematic investigation on this in relation to UX measurement on ecommerce websites is missing so far. However, it is argued that "in order to be truly informative, physiological signals need to be linked to users' interaction experience aspects" (Liapis et al., 2021, p. 1). Therefore, the first research goal of this thesis is to:

> *Research goal 1: Identify potential neural correlates as antecedent processes to UX constructs on ecommerce websites.*

As we have outlined, first studies that utilized fNIRS for UX research already suggest its high potential for this domain. However, since research in this field is still scarce, the second research goal of this thesis is to:

> *Research goal 2: Evaluate the potential of adding fNIRS measurements to inform UX along different use phases on ecommerce websites.*

Thereby, research goal 1 provides the knowledge contribution of this thesis to the field of UX and neuroIS research on the role of the PFC in ecommerce website use. Research goal 2 shows the method-contribution in the sense of an innovative

measurement method for neuroIS and UX research (Krampe, Gier, et al., 2017; Nissen, Krampe, et al., 2019).

To address both research goals, the following chapter will first introduce the field of neuroIS research in more detail. After that, an overview of neuroIS findings of PFC activity in relation to IS constructs is presented. This is followed by the exploration of the three main used neuroimaging methods in neuroIS studies. Drawing on 6 rigor factors proposed by Riedl, Davis, and Hevner (2014), we then make an informed decision for fNIRS as an appropriate measurement method. After having explained the methodological approach[9] of this thesis, we will go over to the current state of research that investigates different stages of the user journey in ecommerce. From this review, we derive three main use phases with websites that can be used to map frequently measured UX constructs to these phases of the user journey.

As a result, we will derive the guiding framework in which the included publications of this cumulative thesis are mapped. After each of the included publications is presented for each use phase of the framework, we discuss the role of each investigated brain area across all included papers. This part of the discussion serves to satisfy research goal 1 of this thesis. After that, the main focus of each paper is reflected upon in the frame of the use phases and UX constructs, and implications for UX research are drawn regarding the potential of including fNIRS measures. This section of the discussion serves to fulfill research goal 2 of this thesis. Finally, the conducted work in this thesis is critically appraised, and a conclusion is drawn.

[9]Note that the term "methodological" in the English language can refer to both the study design and procedure defined by the applied method, as well as to the overarching methodology (see, for e.g., the Merriam-Webster Dictionary (https://www.merriam-webster.com/dictionary/methodological)).

Chapter 2

Methodological and Theoretical Approach

2.1. Methodological Approach

2.1.1. An Introduction to NeuroIS Research

As a successor of neuroeconomics[1], neuroIS has evolved as a subarea of the IS field that employs psychophysiological measurements to inform IS research (Dimoka, Pavlou, et al., 2007; Riedl, Davis, Banker, et al., 2017). The first paper that coined this term appeared in 2007 and defined neuroIS as the application of "cognitive neuroscience theories, methods, and tools in IS research" (Dimoka, Pavlou, et al., 2007, p. 1). In a more recent review of the field, the narrow scope of cognitive neuroscience was broadened, by defining neuroIS as a field of IS "that makes use of neuroscience and neurophysiological tools and knowledge to better understand the development, adoption, and impact of information and communication technologies" (Riedl, Fischer, et al., 2020, p. 13). As a result, not only the utilization of neuroimaging methods that measure responses in the central nervous system (CNS), but also the use of physiological measures such as Electrocardiography (ECG) or EDA that assess responses in the ANS are referred to as neuroIS research (Riedl, Davis, and Hevner, 2014).

Through the use of these (neuro-)physiological methods, three main domains of IS research are identified to which neuroIS can provide contributions (Dimoka, Banker, et al., 2012; Taylor et al., 2010). That is, i) the development and use of IT artefacts, ii) IS strategy and business outcomes, and iii) group works and decision support (Taylor et al., 2010). As this thesis deals with the investigation of user behavior to inform ecommerce website design, it can be placed into the first contribution domain. More precisely, Dimoka, Banker, et al. (2012) see opportunities for neuroIS in the first domain for "encouraging individual adoption and use of systems", "reducing information and cognitive load", and "encouraging online transactions by online consumers" (p. 683 ff). Given that especially neuroimaging methods can be used to assess neural correlates to constructs such as cognitive load, attention, stress, emotional processes, decision making, and trust/distrust[2] (Dimoka, Pavlou, et al., 2011b), they can help to better explain crucial antecedents to more complex IS constructs that are used to explain user experiences and behavior (Riedl and Léger, 2016). The main contribution that neuroimaging methods have is bound to the assumption that self-reported data requires conscious thought, which is not required for neuroimaging (Dimoka, Pavlou, et al., 2011b; Tams et al., 2014). As a

[1] Adding neuroscience theories and methods to the social sciences was pioneered by neuroeconomics (Dimoka, Pavlou, et al., 2007). Neuroeconomics is used as a referral to a combination of neuroscience and behavioral economics during the late 1990s/ early 2000s (Damasio, 2009; Glimcher et al., 2009).

[2] Note that the named constructs here partly overlap and that they are named here because they have been most frequently addressed in related neuroIS works (Riedl, Fischer, et al., 2020)

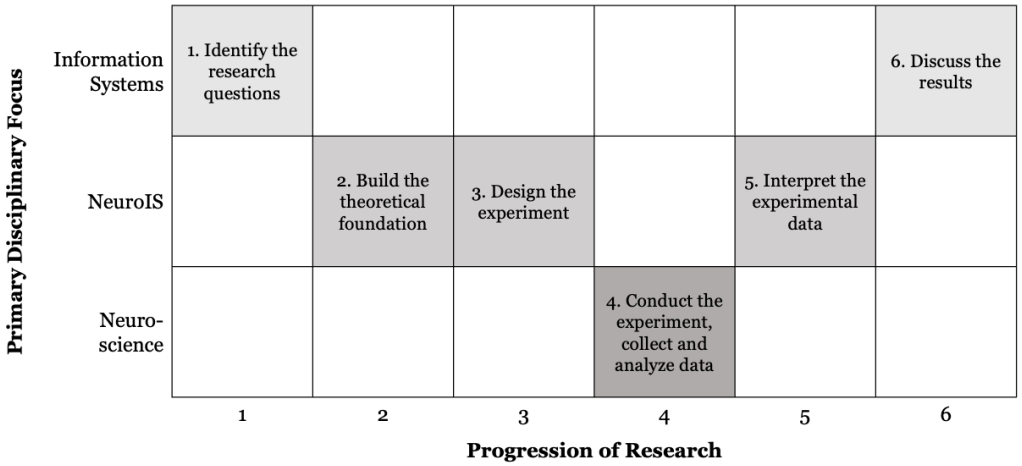


Figure 2.1. Procedure Model for NeuroIS Research

Note. Taken from vom Brocke and Liang (2014, p. 214)

result, also spontaneous, unconscious processes during website perception can be obtained that can help to better understand and explain the resulting user behavior (Riedl and Léger, 2016). This is supported in dual-processing theories, which state that behavior and behavioral intentions are much more driven by unconscious processes (i.e., system 1) rather than controlled and cognitively reflected upon processes (i.e., system 2) (Evans and Stanovich, 2013; Kahneman, 2011; vom Brocke, Riedl, et al., 2013). However, the utilization of neuroimaging methods should always be seen as a complement to self-reported data, and not as an alternative (Tams et al., 2014). The reason for this is that neural activation can often not be mapped one to one to a specific construct and therefore, it requires additional and contextual information to appropriately interpret neural results.

When researchers plan to conduct a neuroIS experiment, there are several factors to be considered. To guide researchers, vom Brocke and Liang (2014) have suggested a procedure model for conducting neuroIS research (Figure 2.1). In their model, they propose that the research questions should be identified within the IS domain, because IS provides the application field and therewith, the motivation and relevance for neuroIS. At the core of neuroIS comes then the theoretical foundations in which neuroscience constructs need to be mapped to IS constructs. This is typically done by means of a framework or theory that allows to connect neuroscience to IS constructs. The overarching theory can be either from the IS or the neuroscience field, or from other cognate disciplines. The experiment itself, including data collection and analysis, then falls into the domain of neuroscience as it requires using neuroscientific practices for neuroimaging methods. The interpretation of the obtained neuroscientific results, however, is then to be put in relation to IS

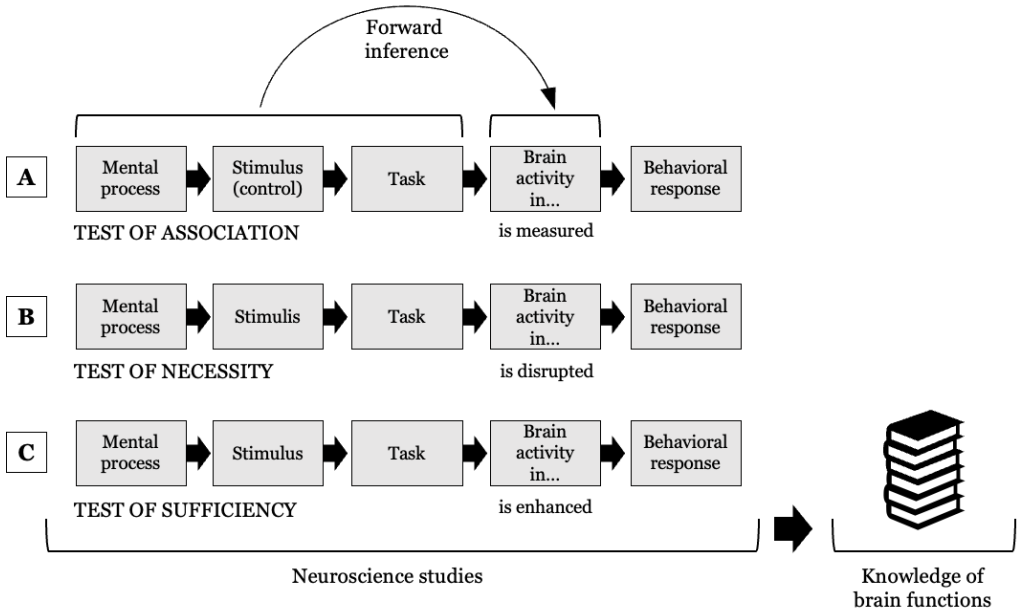


Figure 2.2. Knowledge Production in NeuroIS Research

Note. Taken from Riedl, Davis, Banker, et al. (2017, p. 5)

constructs again because they provide the frame within which the neural results can be interpreted. Therefore, this part falls into the domain of neuroIS. Finally, discussing the results and their interpretations mainly falls into the field of IS, as IS knowledge is to be extended through neuroscience data, methods or knowledge.

We may take a closer look at how knowledge is normally generated out of neuroscientific results. In accordance to cognitive neuroscience, knowledge from neural results is typically formed by means of forward inference which means that conclusions are drawn from stimuli (and the triggered mental processes) to brain activation[3] (Riedl, Davis, Banker, et al., 2017). Generally, there are three strategies with which such conclusions can be made. As depicted in Figure 2.2, brain activity as a reaction to set stimuli may be (A) measured, (B) disrupted, or (C) enhanced. This is done to identify specific brain areas and their (A) association with, (B) necessity for, or (C) sufficiency for processing the presented stimuli (Riedl, Davis, Banker, et al., 2017). Given that neuroIS research in the domain of ecommerce websites is still scarce as elaborated in the introduction and further discussed in Section 2.2, this thesis will use approach (A), and mainly focuses on identifying the association

[3]In contrast to this, one of the biggest concerns in neuroscience and neuroIS research is reverse inference "by which the engagement of a particular cognitive process is inferred from the activation of a particular brain region. Such inferences are not deductively valid, but can still provide some information." (Poldrack, 2006, p. 59). Therefore, reverse inference should only be carefully applied and always be seen in the frame of the mental process and the given task setting of the study (Hutzler, 2014).

between website designs, evaluations of these designs, neural processes as responses to perceiving these designs, and the resulting user behavior. To do this, each of the included papers will investigate neuroscientific literature for general processes that may be related to the IS-relevant stimulus under investigation (i.e., the ecommerce website) (Riedl, Davis, Banker, et al., 2017).

In the definition of neuroIS presented at the beginning of this chapter, both an investigation of the CNS and ANS have been identified to be referred to as neuroIS research. Although ANS activity can also be investigated to draw conclusions about UX on ecommerce websites, a focus on CNS activity may be more reasonable for the given research goal as elaborated in the following. The CNS normally includes the brain and spinal cord and receives input from the peripheral nervous system, which can be divided into the somatic nervous system that comprises skeletal muscles (e.g., facial expressions), and the ANS which comprises smooth muscles and glands (Larsen et al., 2008; Riedl, Davis, and Hevner, 2014). The main purpose of the ANS is to restore the body (parasympathetic) and to prepare for action (sympathetic), which is required to guarantee survival (Larsen et al., 2008; Riedl, Davis, and Hevner, 2014). While the idea of physiological reactions to IS stimuli comprises all nervous systems, the CNS receives input from the other nervous systems and acts like a central controlling hub that guides decision making and behavior (Berntson et al., 2016; Larsen et al., 2008; Levine et al., 2016; Salzman and Fusi, 2010). For instance, measuring ANS activity through EDA can be used to obtain the level of arousal in a user as a reaction to IT system use (Boucsein, 2012; Chanel et al., 2011; Healey, 2015). This arousal may be a result of high cognitive load, emotional stimulation, or physical activity (Tullis and Albert, 2013). When looking at the neural activation, the arousal measured through EDA is also found in brain areas, however, depending on the main source of arousal, a different brain area may be activated. Thus, neuroimaging can help to better classify whether the measured arousal in ANS is due to cognitive, emotional, and/or motor processes.

Therefore, although the stimulation of different website designs might also be measurable through ANS activity, the coordinated processing, reflection, and decision-making happens in the brain (Critchley, 2009). Within the brain, the neural structure that coordinates decision-making processes and receives input from other brain regions is the prefrontal cortex (PFC) (Carlén, 2017; Salzman and Fusi, 2010). Several theories in cognitive neuroscience and neuroeconomics further demonstrate the crucial role of the PFC for perception, evaluation, judgment, and decision making (e.g., Bechara and Damasio, 2005; Bechara, Damasio, and Damasio, 2000; Burgess et al., 2007; Damasio, 1994; Deppe et al., 2005; Koechlin et al., 1999; Krampe,

Gier, et al., 2018). As outlined in the introduction, the focus of this thesis lies on the evaluation of ecommerce websites that have specific attributes, and how this evaluation is processed so that it results in certain self-reports and behavioral intentions. As a result, measurements in this thesis will focus on assessing neural activity in the PFC as a neural mechanism to perceiving, using, and deciding for different ecommerce websites.

2.1.2. The Role of the Prefrontal Cortex in NeuroIS Research

To get an overview of existing neuroIS knowledge about the association between PFC activity and IS constructs, we have reviewed work published in leading IS journals (as defined by the AIS Basket of Eight)[4], as well as in eight major HCI journals that were identified in a literature review by Gurcan et al. (2021)[5]. We searched the title, abstract, and keywords with the search string *""neuroIS" OR "neuroimag*" OR "neural correlate*""* without any further restrictions to the search. The papers were filtered based on two criteria: whether activation was found in the PFC, and whether they are concerned with user reactions to IT artefacts. Figure 2.3 graphically summarizes the identified constructs categorized after the neural sub-areas of the PFC (a detailed overview of the reviewed studies can be seen in Appendix.1).

As some studies did not further distinguish subareas within the PFC, we included them as overall PFC constructs without further localization. In these studies, activation in the PFC has been related to positive UX during smartphone use to accomplish three tasks: purchasing a movie ticket, finding a bus route in maps, and posting a selfie on social media (Ding, Cao, et al., 2020). More precisely, the authors identified that interaction with less interruptions, which was also rated higher in UX scales, resulted in higher PFC engagement (Ding, Cao, et al., 2020). The idea of general PFC activation pointing to higher user engagement has also been confirmed in the area of gaming (Ding, Hu, et al., 2018; Li, Jiang, et al., 2014). This correlation with positive UX and engagement may be a result of attention and cognitive processes related to the interaction. For instance, Léger et al. (2014) found that with the help of EEG and eye tracking, three processes related to the decision whether to open an

[4]The AIS Basket of Eight comprises the following journals: European Journal of Information Systems, Information Systems Journal, Information Systems Research, Journal of AIS, Journal of Information Technology, Journal of MIS, Journal of Strategic Information Systems, MIS Quarterly. For more information see https://aisnet.org/page/SeniorScholarBasket.

[5]The identified journals are: Computers in Human Behavior, International Journal of Human Computer Studies, Ergonomics, Journal of Neural Engineering, Interacting with Computers, Lecture Notes in Computer Science, IEEE Transactions on Neural Systems and Rehabilitation Engineering, International Journal of Human Computer Interaction

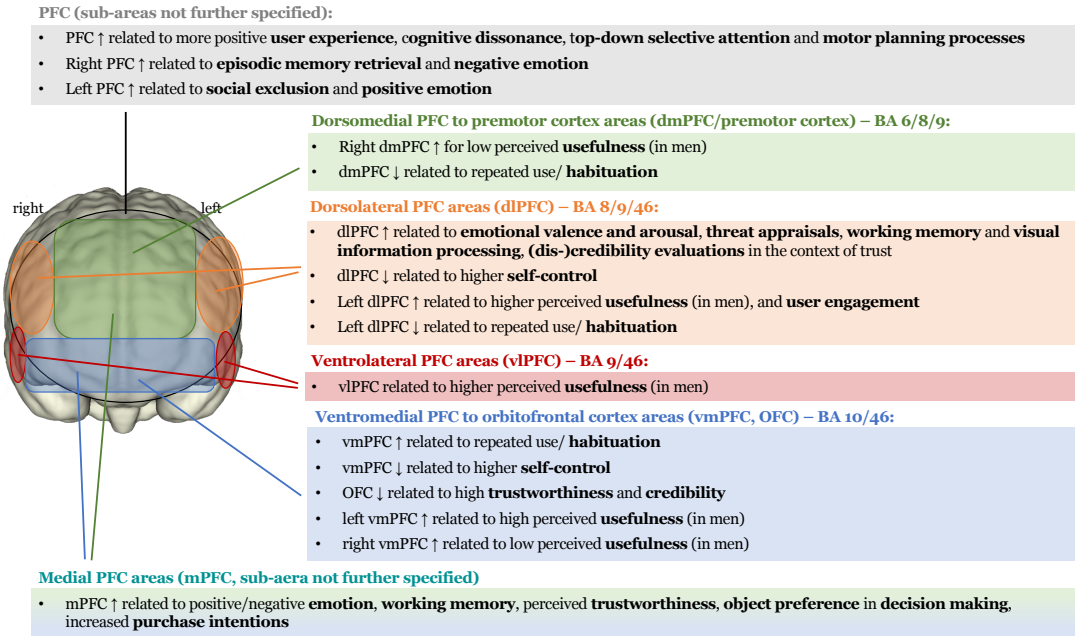


Figure 2.3. Identified Constructs in IS and HCI Research Related to PFC Activation

Note. PFC = prefrontal cortex, BA = Brodmann Areas, ↑ = neural activation, ↓ = neural deactivation

email after notification or to ignore the email, are found in the PFC: the attentional reaction to, the cognitive processing of, and the active motor planing on whether to approach or avoid the email. Interestingly, also in cases of active decision making where the received information is in conflict with one's own beliefs, as in the case of fake news, seems to elicit PFC activation, too (Moravec et al., 2019). As a result, a general activation of the PFC region may give hints to the level of user engagement with an ecommerce website, including the attention resources, cognitive load, and decision-making processes, which can help to draw conclusions regarding the users' UX.

However, there is not just the PFC as whole brain region to be considered. Some studies have distinguished between whether they have identified activation on the left or the right hemisphere of the PFC. In accordance with the hemisphere specific hypothesis (HSH), two ecommerce studies have argued for the left PFC being involved in positive emotion, while the right PFC is related to negative emotional processing (Gregor et al., 2014; Kuan et al., 2014). However, such lateralization should be treated with caution as it may not be universally valid. For instance, left PFC activation has also been identified in cases of social exclusion (Lai et al., 2016), which is normally regarded as negative emotional experience and therewith, in contradiction to HSH. Furthermore, the right PFC has also been found involved in

task-related episodic memory retrieval (Dong and Jeong, 2018). This finding does not directly contradict with the HSH, however, it points to the involvement of the right PFC in different processes. As a result, a mere consideration of just "the PFC" or a discrimination between the left and right hemisphere of the PFC might not be sufficient. According to its structures and functions, the PFC can be subdivided into its lateral and medial parts, as well as dorsal and ventral parts (Carlén, 2017; Ridderinkhof et al., 2004).

The lateral regions (dorsolateral and ventrolateral PFC (dlPFC and vlPFC, respectively)) have been associated with processes related to emotional valence and arousal (including threat) (Bandara et al., 2018; Warkentin et al., 2016), thereby supporting the prior proposal that emotional information is processed in the PFC. The dlPFC has, however, also been identified in contexts of credibility and trust judgments of ecommerce websites where both cognitive and emotional processes are involved (Dimoka, 2010). Similarly, processes which are thought to be of more cognitive nature such as self-control (Hu, West, et al., 2015), working memory, and visual information processing (Clemente et al., 2014), and habituation (Vance et al., 2018), seem to be processed in the dlPFC or at least impact the neural activity of the dlPFC. In our own works, the dlPFC and vlPFC have also been related to high versus low perceived usefulness of ecommerce websites (Nissen and Krampe, 2021), which is discussed further in the discussion section of this thesis, and only included here for the purpose of completeness of the literature review.

The medial PFC regions (dorsomedial PFC (dmPFC) and ventromedial PFC/ orbitofrontal cortex (vmPFC/OFC)) have also been identified involved in the processing of emotional valence and arousal in general (Bandara et al., 2018). In line with positive emotional stimuli, there have been associations of medial PFC activation with perceived trustworthiness (Dimoka, 2010; Riedl, Mohr, et al., 2014), the preference for objects during a decision making task (Luu and Chau, 2009), and increased purchase intentions (Grosenick et al., 2008). All three associations point to a positive UX and approach intentions towards a website. However, medial PFC activation also seems to incorporate cognitive processes such as working memory (De Guinea et al., 2014), habituation (Anderson et al., 2016; Vance et al., 2018), and cognitive self-control that prevents impulsive buying decisions (Hu, West, et al., 2015). Analogous to activation of the lateral PFC regions, our work identified that both the dmPFC and vmPFC may play a role in the evaluation of usefulness of an ecommerce website (Nissen and Krampe, 2021).

Although not having the claim to be complete, this brief overview reveals

the PFC's association to several relevant constructs for an UX investigation on ecommerce websites. Furthermore, it also shows that there is no direct one-to-one relationship between regions of the PFC and IS constructs, and that the involvement of brain regions seems to be dependent on the context of the study. Especially when also considering the summarized findings of this review in Figure 2.3, it can be seen that some study results also contradict one another for some constructs. For instance, while Ding, Cao, et al. (2020) found increased PFC activation as an indicator for positive UX, both Gregor et al. (2014) and Kuan et al. (2014) identified the right PFC activated in relation to negative emotion. As a result, further research is required to advance our knowledge of the involvement of PFC regions in the interaction with an IT artefact such as ecommerce websites. In this line, and as was shown that the PFC is not just one black box brain region but actually consists of several sub-areas which serve different functionality (Carlén, 2017), a more detailed view at this brain region for the context of ecommerce website processing seems reasonable.

To further investigate this matter, however, the informed selection of a neuroimaging method is required. Therefore, we were also interested in the utilized methods with which the neural activity was measured in the frame of the structured literature review (details are also listed in Appendix.1). Results show that almost half of the reviewed studies used EEG as their neuroimaging method (45%). This is followed by 32% of the studies using fMRI, and only 23% used fNIRS[6]. Consequently, all three of these methods are capable of measuring PFC activity, however, each method has its advantages and disadvantages.

2.1.3. Comparing Commonly Applied Neuroimaging Methods in NeuroIS

Generally[7], there is the assumption that neural activation is associated with i) electric potentials that are sent by firing neurons in the brain instantly after stimulus onset, and ii) an increased transportation of oxygen through the blood to the recruited brain areas (Riedl and Léger, 2016). Both of these physiological events allow for measurement methods to assess the neural activity that results from the set stimuli in an experiment. While EEG measures the electrical activity described in i) (Müller-Putz et al., 2015; Pernet et al., 2020; St. Louis et al., 2016), both fMRI and fNIRS measure the amount of oxygen and its changes in the blood described in ii) (Gore, 2003; Huppert et al., 2006; Sato et al., 2013; Soares et al., 2016). As a result from assessing different physiological phenomena, and further due to the characteristics of the measurement

[6]From this, one paper was authored by me and is also included in this thesis.

[7]Please note that parts of the contents in this section can also be found in short forms in the included manuscripts of this thesis that utilize fNIRS.

Methods	**fNIRS**	**fMRI**	**EEG**
Physiological signal	HbO, HbR	BOLD (HbO, HbR)	electric potentials
Spatial resolution	20-30mm	0.3mm voxels	50-90mm
Penetration depth	cortical areas	whole head	cortical areas
Temporal sampling rates	up to 10 Hz	1-3 Hz	over 1,000 Hz
Robustness to motion	very good	limited	limited
Sounds	silent	noisy	silent
Portability	yes, for portable systems	none	yes, for portable systems
Cost	comparatively low	high	comparatively low

Table 2.1. Technical Specifications of fNIRS, fMRI, and EEG

Note. Adapted from Pinti, Tachtsidis, et al. (2020, p. 15)

methods, different advantages and disadvantages can be found for each. The following Table 2.1 summarizes the characteristics of each method.

We can see that fMRI is the only method in this comparison which allows a whole-head image with high spatial resolution. However, it comes with the significant downside of high environmental noise caused by the MRI-scanner, artificial measurements due to the fixation of participants in the scanner, high costs per participant, and low temporal resolution (Kopton and Kenning, 2014; Krampe, Gier, et al., 2017; Pinti, Tachtsidis, et al., 2020). Because the fixation of participants has often been found a significant limitation of fMRI measurements (Kemp et al., 2015), several works have considered mobile measurements to increase ecological validity of their findings. Both fNIRS and EEG offer the opportunity for mobile measurements which is necessary for IS and HCI research as participants would typically sit at a desk, for e.g., when using IT artefacts (Riedl, Mohr, et al., 2014).

Among the mobile neuroimaging methods, EEG has shown to have the highest temporal resolution, is silent, and can be applied non-invasively (Müller-Putz et al., 2015; Pinti, Tachtsidis, et al., 2020; Riedl, Minas, et al., 2020). However, EEG comes with significant problems of localizing the elicited neural responses spatially to brain areas, and is prone to artefacts caused by external electricity, head movements, facial expressions, or if mouse and keyboard are used (Kim, Seo, et al., 2017; Maior et al., 2015; Pinti, Tachtsidis, et al., 2020). Therefore, EEG is especially applicable if rapid, time-critical reactions to stimuli should be assessed. It might not be a reasonable choice if general decision-making processes are investigated that do not underlie a time-critical onset (which is faster than approximately 5 seconds), and that are to be ascribed spatially to brain areas (Pinti, Tachtsidis, et al., 2020).

The mobile method of fNIRS offers a valuable approach, because it comes with

Advantages of fNIRS compared to fMRI:	**Disadvantages of fNIRS compared to fMRI:**
better temporal resolution	lower spatial resolution
tolerance to motion artifacts	only surface measurements on cortical levels
can be used for natural, mobile measurements	impossible to gain structural images and anatomical information
more participant friendly, because can be applied in naturalistic tasks	dark and thick hair negatively impacts data quality
higher feasibility for multi-modal measurements with EEG	lack of standardization in data analysis
Advantages of fNIRS compared to EEG:	**Disadvantages of fNIRS compared to EEG:**
better spatial resolution	lower temporal resolution
tolerance to motion artifacts	cannot capture electric potentials
possibility to monitor and	lesser standardization in data analysis
dry measurements result in higher quality data	

Table 2.2. Advantages and Disadvantages of fNIRS compared to fMRI and EEG

higher spatial resolution than EEG (although lower than that of fMRI) (Hirshfield, Chauncey, et al., 2009; Irani et al., 2007; Kim, Seo, et al., 2017). Further, compared to the other introduced methods, one major advantage of fNIRS lies in its robustness against movement artefacts, especially those which may appear due to head movements, and due to mouse and keyboard use during measurements (Cui, Baker, et al., 2015; Girouard et al., 2010; Kim, Seo, et al., 2017; Maior et al., 2015). Although it is limited in its temporal resolution compared to EEG, and in its spatial resolution compared to fMRI, its advantage to get a “best of both” measurement, and its robustness to artefacts makes it a favorable measurement method (Kopton and Kenning, 2014), especially for HCI research. The advantages and disadvantages of fNIRS compared to fMRI and EEG are summarized in the following Table 2.2.

2.1.4. Rigor in NeuroIS and Selecting the Neuroimaging Method

To make an informed selection for one of these methods, we further draw on six factors for rigorous neuroIS research proposed by Riedl, Davis, and Hevner (2014).[8] The first factor to be considered is *reliability*, which "refers to the proportion of a measurement’s total variance that is due to random error, rather than true variance of the underlying construct" (Bhattacherjee, 2012; Riedl, Davis, and Hevner, 2014, p. x). In the context of conducting neuroIS research, the question to be asked is "how stable measures are in repeated measurements across studies?". This results in typical experimental paradigms using a number of repetitions of the included stimuli in order to achieve reliable data within one study to avoid that the found

[8]Note that the described factors here are not unique for neuroIS research, but they pose general rigor factors for (quantitative) research in IS and social sciences. In this chapter, however, we will apply them especially for the context for neuroIS.

effects are due to random error. The number of required repetitions, however, varies depending on the neuroimaging method used. If the paradigm is programmed with care, and the technical specifications of the used method are appropriate for the brain regions of interest[9], all three of the neuroimaging methods offer high reliability (Ferrari and Quaresima, 2012; Riedl, Davis, and Hevner, 2014; Riedl, Minas, et al., 2020). Therefore, reliability is not the discriminating factor to choose one of the neuroimaging methods over another.

Validity refers to the "extent to which a measurement instrument measures the construct that it purports to measure" (Riedl, Davis, and Hevner, 2014, p. xiv). While content, construct, and ecological validity are crucial factors for IS research in general (Cook et al., 1979; Oates, 2006; Straub and Gefen, 2004), instrument validity is especially important for the selection of an appropriate measurement method in neuroIS (Riedl, Davis, and Hevner, 2014). In correspondence with the study design and knowledge production process explained in section 2.1.1, the identification of an appropriate measurement method requires reviewing related neuroIS and neuroscience literature through which brain areas of interest are to be defined (Riedl, Davis, Banker, et al., 2017; Riedl, Davis, and Hevner, 2014). Therefore, the prior section has introduced related neuroIS research and also investigated the employed measurement methods. Based on the findings from our literature review, all three neuroimaging methods are generally valid to investigate constructs related to the evaluation of and decision-making on ecommerce websites, by being able to measure neural activity in the PFC.

Further, the factor of *sensitivity* "is a property of a measure that describes how well it differentiates values along the continuum inherent in a construct. Because a measure, by definition, must be capable of assuming at least two values, minimal sensitivity is given when two states of a construct can be discriminated." (Riedl, Davis, and Hevner, 2014, p. xvii). Riedl et al. further claim that this factor should be considered in neuroIS in the sense that the selected measurement method should be able to discriminate at least two states of a construct (high, low). As was seen in the literature review of the prior section, all of the included neuroimaging methods are able to distinguish high and low states of relevant constructs for the cognitive and emotional processing of an ecommerce website. Further, the actual sensitivity of the neuroimaging methods to specific constructs for defined IT stimuli (such as ecommerce websites) might be highly dependent on the aim of the study, as well as on the statistical methods that are used to analyze the data (Wager, Keller, et al., 2005).

[9]This mainly depends on the Tesla of the fMRI scanner, or on the number and placement of optodes for EEG and fNIRS.

For instance, when immediate reactions within milliseconds are to be investigated, EEG needs to be selected as method. If, however, the focus is more on the spatial identification of activated brain areas during decision making, either fNIRS or fMRI are to be selected.

While it is important that the measurement method can distinguish different levels of the included constructs, it is also of interest that it captures the target construct and distinguishes it from related constructs (i.e., *diagnosticity*) (Riedl, Davis, and Hevner, 2014). Generally, there is no direct one-to-one relationship between brain signals and included constructs[10] (Dimoka, Pavlou, et al., 2011b), and thus, we would argue that this factor is the most difficult to assess for neuroIS research. In neuroscience research, some specific brain data have been mapped to distinct neural structures or frequency bands in EEG, however, it has to be kept in mind that brain areas always work as a network (Carlén, 2017; Cela-Conde, Garcia-Prieto, et al., 2013). Due to the limited research on user evaluations of ecommerce websites and the related constructs, we cannot make clear statements about the diagnosticity ability of the different neuroimaging methods. Rather, the level of diagnosticity may need to be considered for each study individually and even then, it might be difficult to precisely assess it (Riedl, Davis, and Hevner, 2014). First approaches to this are studies that deal with the development of brain computer interfaces (BCIs) where neural data is processed and interpreted in a way that it can be used as input for the interaction with a system (see e.g., Hirshfield, Bobko, Barelka, Sommer, et al., 2019 or Cao et al., 2014). To reliably do this, a high level of sensitivity and diagnosticity are required. Nevertheless, the increasing addition of machine learning algorithms in neural data processing may further improve the diagnosticity because more complex patterns may become observable.

One of the claims that neuroeconomics and neuroIS research made in its beginnings was that it potentially captures *objective* data that does not underlie social biases (Dimoka, Banker, et al., 2012; Riedl, Davis, and Hevner, 2014). While this claim holds true to a certain degree, it needs to be treated with caution, especially for measurements on the PFC. The reason for this is that PFC activity involves both conscious and unconscious processes, and therefore, a part of the observed neural activity in our studies is due to the cultural and social context, the included self-reported scales, as well as the physiological attributes of the included stimuli (this is discussed in more detail for the context of color processing on websites in Paper 1). As a result, Riedl, Davis, and Hevner (2014) argue that objectivity of neuroIS studies should rather be evaluated in the sense of the *replicability* of the study. For

[10] As becomes evident in the results of the prior section, see Figure 2.3.

all three of the neuroimaging methods, replicability is generally given and depends on the degree of detail with which the study design and the data analysis steps are described. Therefore, there are several methodological papers in neuroscience that discuss guidelines on how to report the study design, as well as data pre-processing steps, and data analysis to foster replicability of results (for fNIRS procedures see, e.g., Hocke et al., 2018; Pinti, Scholkmann, et al., 2019; Tachtsidis and Scholkmann, 2016).

Finally, *intrusiveness* "indicates the extent to which a measurement instrument interferes with an ongoing task, which thereby distorts the investigated construct" (Riedl, Davis, and Hevner, 2014, p. xxvi). Further, Riedl et al. differentiate 3 types of intrusiveness for psychophysiological methods being 1) degree of movement freedom, 2) degree of natural position, and 3) degree of invasiveness to the physical body of the participant. The level of intrusiveness is especially high for fMRI, as it requires participants to lie down in the scanner and reduce movement to a minimum (Kemp et al., 2015; Kenning, 2014; Zurawicki, 2010). As a result, measurements with fMRI hardly reflect the typical HCI environment where users sit at a desk or on their couch (Riedl, Davis, and Hevner, 2014). Therefore, the utilization of mobile measurements that allow participants to perceive and use websites in a natural position is reasonable. Both EEG and fNIRS allow for such measurements, as both offer the same degree of movement freedom and natural position (Hirshfield, Chauncey, et al., 2009; Pinti, Tachtsidis, et al., 2020). However, the EEG signal is much more prone to movement artefacts than the fNIRS signal (Kim, Seo, et al., 2017; Maior et al., 2015; Pinti, Tachtsidis, et al., 2020), and therefore, the offered degree of movement freedom may be higher for fNIRS. Finally, both fNIRS and EEG require optodes to be placed on the head of participants which leads to a similar level of invasiveness[11]. Yet, EEG often requires the use of conductive gel under the optodes while fNIRS can be done through dry measures. Consequently, the invasiveness of fNIRS can be evaluated as a little lower than that of EEG.

As a result of this brief presentation of rigor factors for neuroIS research, and the characteristics of the three presented neuroimaging methods, the following papers will use fNIRS as method. The reason for this is that while all neuroimaging methods offer sufficient reliability and validity if used with care, the ecological validity through lower intrusiveness advocates to use a mobile neuroimaging method. Given that EEG is primarily used when reactions within milliseconds are to be obtained (Müller-Putz et al., 2015; Pinti, Tachtsidis, et al., 2020), and the brain

[11]Note that as fMRI does not require the placement of sensors on the human body, the factor of invasiveness is not applied to fMRI in this comparison.

area, from which these reactions came, is not of first interest, the decision falls on fNIRS. Supporting this, and as discussed in the prior paragraph, fNIRS also has the advantage of a higher robustness against movement artefacts when compared to EEG. Against this background, we deem fNIRS to be an appropriate neuroimaging method to gain insights into users' processing of and decision-making on ecommerce websites. To further narrow down the aspects of the websites, and to identify crucial constructs for users' decision-making in ecommerce, the following section introduces related literature in this domain.

2.2. Related Literature

To get an overview of the state of the art literature on stages of CX and UX on ecommerce websites, two structured literature reviews (SLRs) have been conducted to get an impression of *(i)* how UX and CX are currently investigated in the frame of ecommerce websites, and *(ii)* which UX constructs are typically employed and should therefore be investigated by means of fNIRS in this thesis. From this, a framework is derived that provides the structure for the included manuscripts in this cumulative thesis.

2.2.1. User Experience Phases on eCommerce Websites

As we have stated in our introduction, companies aim at generating positive UX on their ecommerce website to foster re-use intentions and loyalty (Bilgihan, 2016; Gregor et al., 2014). Therefore, we may take a broader look at users also as customers from the website. While UX is usually only directed toward the website as a "product", CX also relates to the service of the vendor (Lee, Inman, et al., 2018). Therefore, the UXs along the whole customer journey can be referred to as CX (Märtin et al., 2021). Yet, the differences between UX and CX are becoming closer, making UX and CX less distinguishable in several cases for ecommerce websites (Lee, Ka-hyun Lee, et al., 2018; Solis, 2015).

As a result, phases in the UX and CX might overlap, when only the touchpoint of the ecommerce website is considered. The similarity is also reflected in the common definitions of UX and CX. While CX aims at "a customer's cognitive, emotional, behavioral, sensorial, and social [processes and responses] during the customer's entire purchase journey" (Lemon and Verhoef, 2016), UX "includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use" (ISO 9241-210 cited after Pohlmeyer, 2011). Based on these definitions, we can

derive that both comprise emotional and cognitive evaluations during different phases that are went through. According to Lemon and Verhoef (2016), the CX journey can be differentiated in the phases pre-purchase, purchase, and post-purchase. The phase differentiation according to the customer journey proposed by Lemon and Verhoef (2016) was selected in this thesis as it is still the most influential work on CX (Tueanrat et al., 2021b), and therefore serves as an appropriate orientation for CX phases. Similarly, UX per our definition comprises a phase prior to use, during use, and after use - which becomes visible not only in the presented ISO definition, but is present in several models of UX as well (Karapanos et al., 2009; Minge, 2008; Pohlmeyer, 2011; von Saucken and Gomez, 2014). In line with these, the after use phase eventually appears not as a one reflection after the first use, but may reflect repetitive uses over time that eventually lead to loyalty (see for e.g., Pohlmeyer, 2011). However, as the two concepts of UX and CX target a different object of interest (making website interaction pleasant (UX) vs. making the purchase process pleasant (CX)), they are investigated in more detail in the following.

As the roles of user and customer overlap for ecommerce websites, the proposed phases of CX and UX may also partly overlap, which becomes especially transparent when looking at common constructs that are measured in the three phases of each. To identify these, a SLR was conducted on the web of knowledge[12] on November 30th in 2021 with the goal to identify commonly utilized constructs in the CX phases pre-purchase, purchase, and post-purchase as suggested by Lemon and Verhoef (2016). We used the search string: *("user journey" OR "customer journey" OR "touch point*" OR touchpoint* OR "purchase journey" OR "user stage*") AND (website* OR e-commerce OR ecommerce OR "web site" OR "online shop*" OR "online retail*" OR e-shop OR "online commerce")* in the title, abstracts, and keywords fields of potential papers. This resulted in an initial sample of 84 papers which were further filtered based on their abstracts. Papers were only further included in the literature set if they focused on either different phases of UX or CX, or if they focused on different touchpoints of ecommerce customers. As a result of this filtering step, 24 papers were read as full-texts to further look at the conceptualization of CX stages and the investigated website attributes within these stages. Unfortunately, only 6 papers survived this filtering step.

The following Table 2.3 summarizes the identified constructs and user activities from the conducted SLR for each of the CX phases. Generally, the pre-purchase phase can be characterized through website exploration (Cortinas et al., 2019), during which the perceived information is processed, and the website's ease of use and

[12]see http://webofknowledge.com/

convenience, usefulness (including product information), usability, and perceived risk and trust of the retailer is assessed (among others) (Kawaf and Tagg, 2017; Klaus, 2013; Kotni, 2017; Mu and Zhang, 2021). In this phase, also the visual design and elicited pleasure during the interaction with the website is thought to be most influential (Tueanrat et al., 2021a). During the purchase phase, the focus shifts more to the actual transaction process rather than the exploration of the website. The focus of attention lies now on the product presence (Klaus, 2013), transaction effort (Kotni, 2017), and purchase button (Cortinas et al., 2019). However, most of the constructs which influence CX during pre-purchase still persist during the purchase phase, being trust (Klaus, 2013), convenience and pleasure (Tueanrat et al., 2021a), and the convenience of search for and information found for products, as well as the brand reputation (Mu and Zhang, 2021). The post-purchase phase is assumed to have less effect on the CX (Tueanrat et al., 2021a), and can be positively influenced by the delivery and return policies, loyalty programs, and positive word of mouth when the purchase experience was positive (Kawaf and Tagg, 2017; Klaus, 2013; Kotni, 2017; Mu and Zhang, 2021).

Authors	**Pre-Purchase**	**Purchase**	**Post-Purchase**
Klaus (2013)	context familiarity, product presence, usability, interactivity, trust	product presence, usability, interactivity, social presence, value for money, communication, trust	communication, trust
Kotni (2017)	product and price information, product range (breadth and depth), convenience	transaction effort, availability, security, website design, shopping experience, checkout time	delivery, return policy, customer services, loyalty benefits

Authors	Pre-Purchase	Purchase	Post-Purchase
Kawaf and Tagg (2017)	information processing, perceived ease of use, perceived usefulness, perceived benefits, perceived control, skill, trust propensity, perceived risk, enjoyment, ease of location of website, hedonic and utilitarian features, personalization, social interactions, multi-device compatibility	actual shopping experience (emotion/ cognition)	satisfaction, repeat purchase, positive word of mouth, brand engagement
Cortinas et al. (2019)	most time consuming is the exploration of purchase options, header, and navigation (website exploration)	focus on purchase button, less focus on header, menu and products	attention is more likely to shift back to website exploration
Tueanrat et al. (2021a)	convenience and pleasure are most influential attributes, high price sensitivity, speed of exploration, ease of navigation, personalization, information content, navigation structure, graphic design	convenience and pleasure are most influential	Has less effect on the overall online shopping experience
Mu and Zhang (2021)	search, product information, price information, product ratings, type of sellers, competing brands, seller marketing capability, brand reputation	search, product information, price information, product ratings, type of sellers, competing brands, seller marketing capability, brand reputation	choice whether to leave a positive or negative review, if at all

Table 2.3. Frequently Used Constructs in the CX Phases

What becomes visible from this overview is that there are different foci in the studies. For instance, Kawaf and Tagg (2017), Klaus (2013), and Tueanrat et al.

(2021a) focused more on constructs perceived by the customer as a user of the website, while the work by Kotni (2017) focused more on the customer role by putting the product in the center of their study. Furthermore, we also see that a distinction between these three phases may not be possible, because there are several website-related constructs which are of importance during pre-purchase and purchase phase. Furthermore, when looking at the utilized constructs of usability and trust (Klaus, 2013), website design (Kotni, 2017), perceived ease of use and usefulness (among others) (Kawaf and Tagg, 2017), attention focus on different website elements (Cortinas et al., 2019), and pleasure (among others) (Tueanrat et al., 2021a), it is supported that a great part of CX is triggered by the website design and evaluations of the website use. Therefore, a focus on the different use phases defined by UX and how these map to the purchase phases from CX may be more reasonable to derive a framework for this thesis.

When looking at the UX phases, the pre-use phase also falls clearly in the pre-purchase phase and describes the immediate first impression of the website prior to the first click of the user. The use-phase of the website then falls into both the pre-purchase, and the purchase phase. In cases where customers want to look at the status of their order, it also falls into the post-purchase phase. Further, the post-use phase can also happen in all three purchase phases, as the customer might have decided to not make a purchase at all (use and post-use in pre-purchase phase), to make a purchase and then close the website (use and post-use in pre- and purchase phase), or to make a purchase and look at the status of the delivery (use and post-use in post-purchase phase). As the focus of this thesis is to assess the experience of the user as positive influence factor on their behavior, a closer look at the different use phases and commonly utilized constructs in these phases seems to be reasonable.

2.2.2. Use Phases and Constructs on eCommerce Websites

To identify common investigated constructs in the UX use phases, a second SLR was conducted on November 30th 2021 on the web of knowledge database. We searched the same fields as in the first search, namely abstract, title, and keywords of papers with the following search string: *("first impression*" OR "first use" OR "repeated use") AND (website* OR e-commerce OR ecommerce OR "web site" OR "online shop*" OR "online retail" OR e-shop OR "online commerce").*[13] This resulted in an initial set of 73 articles. Similar to the first literature search, we went

[13]Note the term "use" was excluded from the search string because it resulted in too many (31,257) irrelevant articles.

through all abstracts of the papers and filtered all papers out that did not look at ecommerce websites and UX or CX concepts (e.g., perceived aesthetics, usefulness, usability, purchase intention). As a result of this screening process, a set of 21 articles remained. After more narrow analyses based on full-text reads, a final set of 19 papers are considered to identify commonly applied constructs in related literature in each of the user journey phases of UX.

In line with the prior presented definition of UX, literature results were structure into "pre-use", "during use", and a "post-/repeated-use" phase. Repeated-use is conceptualized here as an addition to the post-use phase, because pre-use and use phases determine whether users are willing to re-use the website after post-use. With regular repeated-use, it also has to be noted that users may enter a stage of identification where an (emotional) attachment to the website is established by high familiarity with the website (Gregor et al., 2014; Karapanos et al., 2009; Sénécal et al., 2015). As a result, the expectations and evaluations in the pre-use and during-use phase with a website that a user frequently uses may be significantly different from when a user does not know the website and uses it for the first time. For means of simplicity, and due to a lack of research on the post- and repeated-use phases (Nissen and Gier, 2021), both the post-use and repeated-use are summarized into one phase. Both deal with intentions to re-use the website in the future and thereby, with facilitating familiarity and preferences in users (and maybe even loyalty). The following Table 2.4 summarizes the identified works and their main results in the three identified use-phases.

Study	**Pre-Use**	**Use**	**P/R-Use**	**Method**	**Findings**
Kim and Fesenmaier, 2008	x			Screenshots, Questionnaire	Inspiration and usability perceptions were most important for the formation of first impression attitude. Credibility is also a significant impact factor on first impression attitude, but not as important as inspiration and usability.
Robins and Holmes, 2008	x			Screenshots, Questionnaire	Visual aesthetics has a positive influence on perceived content credibility within the first few seconds.

Study	Pre-Use	Use	P/R-Use	Method	Findings
Tuch, Bargas-Avila, Opwis, and Wilhelm, 2009	x			Screenshots, Questionnaire, HR, EDA, facial expression, performance	Visual complexity of websites has multiple effects on experienced pleasure and arousal, facial expressions, ANS activation, task performance, and memory.
Kim and Son, 2009			x	Screenshots, Questionnaire	Perceived usefulness and satisfaction positively influence loyalty. Personalization and learning positively impact switching costs, which further positively influence loyalty, purchase intentions, and inattentiveness to alternatives. Further, loyalty positively influences use intention and word of mouth.
Bonnardel et al., 2011	x	x		Website Use, Questionnaire, Use Duration, Use Behavior	Blue and orange websites were preferred by users - independent from their profession. Green and magenta were least preferred. In a second study, users preferred the blue and orange website over the grey website. During use, users spent more time on the orange website than on the blue or grey website.
Alberts and van der Geest, 2011	x			Screenshots, Questionnaire	The color of a website impacts the user's experienced emotions and perceived trust. The blue website was rated highest in perceived trustworthiness while the black website was rated lowest in perceived trustworthiness.

Study	Pre-Use	Use	P/R-Use	Method	Findings
Tuch, Presslaber, et al., 2012	x			Screenshots, Questionnaire	Visual complexity and adherence to expectation (= prototypicality) positively impact perceived aesthetics within a few miliseconds. Visual complexity directly impacts perceived aesthetics while prototypicality requires longer stimulation time to have an effect.
Crutzen et al., 2012	x			Screenshots, Questionnaire	Visual complexity has a negative impact on use intentions which is mediated through the attitude towards the website that is formed during first impression.
Thielsch and Hirschfeld, 2012	x			Screenshots, Questionnaire	Perceived aesthetics differs not significantly between 50, 500, and 1000ms presentation time.
Roth et al., 2013	x			Screenshots, eye tracking	Website elements are spotted faster when they are placed in the area that was expected by the user than when users have to search them first. This also has a positive impact on user performance.

Study	Pre-Use	Use	P/R-Use	Method	Findings
Thielsch, Blotenberg, et al., 2014	x	x	x	Website use of (1) known and (2) unknown website, Questionnaires	Content is rated as most important factor, with its importance rising from first impression to recommendation (post-use). Aesthetics is rated as second in importance for first impressions and usability was rated second in importance for the use and post-use phases. Usability's importance was rated constant across use phases while the importance of aesthetics decreased from first impressions to recommendation.
Lowry et al., 2014	x			Screenshots, Questionnaire	Websites with different levels of credibility (and including logos at different credibility levels) have a significant effect on trust and distrust formation.
Lazard and Mackert, 2014	x			Screenshots, Questionnaire	Findings reveal that increased design complexity (variation and structure of used visual elements) was positively associated with higher levels of perceived design aesthetics, attitude toward the website, perceived message comprehensibility, perceived ease of use, perceived usefulness, perceived message quality, and perceived visual informativeness.

Study	Pre-Use	Use	P/R-Use	Method	Findings
Thielsch, Engel, et al., 2015	x	x		Screenshots, Website Use, Questionnaire, performance (task completion and time on task)	Expected usability is highly depended on perceived aesthetics and is not significantly correlated with experienced usability during use or objective usability such as task performance.
Douneva et al., 2016	x			Screenshots, Questionnaire, memory performance	Websites manipulated in color, large pictures, and equal text/image ratio are rated at first impressions. Large pictures and equal text/image ratio are rated as more aesthetic than strong color use of one color family. Memory performance is best on websites with equal text/image ratio.
Uribe et al., 2017	x			Screenshots, Questionnaire	There is a significant correlation between extracted texture, luminance, and color from image files and reported perceived aesthetics of a website.
Iten et al., 2018	x	x		Screenshots, Website Use, Questionnaire	Appeal of website design on first impression is decisive for user's willingness to use the website. Whether there is an intention to continue to use the website is, however, decided by the actual use experience.

Study	Pre-Use	Use	P/R-Use	Method	Findings
Lee and Ha, 2019		x	x	Website Use, Questionnaire	Low usability and low aesthetics have a significant impact on first impressions and first time use. However, their negative impact on user satisfaction decrease with growing familiarity with the website over repeated use.
Tella, 2019		x		Website Use, Questionnaire	The impressions build during first website use are most significantly impacted by perceived aesthetics.

Table 2.4. Utilized Constructs in Pre-Use, Use, and Post-/Repeated-Use (P/R-Use) Phase from Related Literature

On a measurement method level, this table reflects the motivation for this doctoral thesis. From the 19 reviewed papers only 2 papers employed additional psychophysiological measurements to investigate the constructs of interest, and both use peripheral nervous system activity and not neural activity (Roth et al., 2013; Tuch, Bargas-Avila, Opwis, and Wilhelm, 2009). The remaining papers used questionnaire data, and only some papers used performance data in addition.

In Figure 2.4, we see that papers with focus on the **pre-use phase** where the first impression of a website is of interest mainly investigated the perceived usability and ease of use (Kim and Fesenmaier, 2008; Lazard and Mackert, 2014; Thielsch, Blotenberg, et al., 2014; Thielsch, Engel, et al., 2015), perceived trustworthiness (Alberts and van der Geest, 2011; Kim and Fesenmaier, 2008; Lowry et al., 2014; Robins and Holmes, 2008), and attitude toward the website (Bonnardel et al., 2011; Crutzen et al., 2012; Kim and Fesenmaier, 2008; Lazard and Mackert, 2014; Tuch, Presslaber, et al., 2012). It is also noteworthy that 88% of the papers focused on the visual design of the website or the aesthetic perception, and 25% considered color as the website design element of interest (Alberts and van der Geest, 2011; Bonnardel et al., 2011; Douneva et al., 2016; Uribe et al., 2017). As stimuli, screenshots of the websites were used based on which participants had to rate their perceptions and

expectations about the website. In conclusion, the perceived aesthetics based on the visual design of the website, and the resulting perceptions of usability, trustworthiness, and attitude seem to be particularly focused on in the pre-use phase.

Given that these perceptions may change when actual use is considered, several studies have investigated actual first website use of unknown websites as stimuli. These papers are sorted to the **during-use phase**. The main identified constructs in this phase are the perceived aesthetics of the visual design (Bonnardel et al., 2011; Iten et al., 2018; Lee and Ha, 2019; Tella, 2019; Thielsch, Blotenberg, et al., 2014; Thielsch, Engel, et al., 2015), perceived usability and ease of use (Lee and Ha, 2019; Thielsch, Blotenberg, et al., 2014; Thielsch, Engel, et al., 2015), as well as the resulting use and purchase intentions (Iten et al., 2018; Thielsch, Blotenberg, et al., 2014). The percentages in Figure 2.4 for usability, usefulness, and use intentions show that these constructs seem to become more important over during-use and repeated-use phase compared to the pre-use phase, as they have been focused on more in these phases.

Finally, only few studies have considered more than just first impressions of screenshots and the first use of websites, by taking a look at the **post-use phase or at repeated-use**. These studies have also utilized perceived usability and ease of use (Lee and Ha, 2019; Thielsch, Blotenberg, et al., 2014), the perceived usefulness, content quality, and use intentions (Kim, Ferrin, et al., 2009; Thielsch, Blotenberg, et al., 2014), as well as loyalty and recommendations (Kim, Ferrin, et al., 2009; Thielsch, Blotenberg, et al., 2014) as their focal constructs. Interestingly, these studies have also included the aesthetic perception of the visual design as investigation factor, although to a lesser extent than pre-use and during-use studies.

On an abstract level, a shift can be observed in the utilized constructs of the use phases. Especially perceived trustworthiness and credibility, as well as the attitude toward, and perceived aesthetics of the website are mostly investigated for the first impression or first use of a website. Aspects of visual design, usability, ease of use, usefulness, and use intentions seem to be of importance across all use phases. However, during-use and repeated-use phases were more frequently measured with functionality and usability-related constructs such as perceived ease of use, usefulness, and purchase intentions. This is supported in studies that investigated the shift between pre-use first impressions and the impressions gained during actual use (Lee and Koubek, 2010; Thielsch, Blotenberg, et al., 2014). These studies found that perceived aesthetics is most influential for first impressions, and that during actual website use, experienced usability becomes more influential on behavioral intentions

	visual design/ aesthetics	usability/ PEOU	credibility/ trust	attitude	emotion	usefulness/ content	use/ purchase intention	recommendation/ word of mouth	loyalty
Pre-Use (16 paper)	88%	25%	25%	31%	13%	13%	19%	6%	
During-Use (6 paper)	100%	50%		17%	17%	17%	33%	17%	
Post-/Repeated-Use (3 paper)	67%	67%				67%	67%	67%	33%

Figure 2.4. Distribution of Utilized Constructs Across Use Phases

Note. Cells are marked in light grey when 25-50% of papers per use phase used the construct, they are in grey when 51-75% of papers used the construct, and in dark grey when >75% of papers used the construct.

than aesthetics (Lee and Koubek, 2010; Pohlmeyer, 2011; Thielsch, Blotenberg, et al., 2014).

It further needs to be noted that prior to use, expectations about the website's usability are triggered based on the visual design (LaValley and Umapathy, 2015; Lindgaard, Fernandes, et al., 2006; Tractinsky et al., 2006). But that does not necessarily mean that these expectations are supported during actual use, and therefore, perceived usability during use might be rated differently (Thielsch, Engel, et al., 2015). Yet, the impressions and expectations formed in the pre-use phase are suggested to impact the perceptions during actual use through a halo effect (Lindgaard, Fernandes, et al., 2006; Minge, 2008; Tractinsky et al., 2006). In line with this, the perceived aesthetics based on the visual design in the pre-use phase have often been assumed to be spontaneously processed, and to further influence behavioral intentions and the later processing of the website (Bölte et al., 2017; Lee, Choi, et al., 2012; Thielsch, Blotenberg, et al., 2014; Tuch, Roth, et al., 2012). This once again highlights the necessity to include neurophysiological measurements in this research field to make these spontaneous processes measurable and investigate in how far they interact with evaluated constructs.

Against the background of the phases from CX and UX, as well as the reviewed literature and the utilized constructs, the framework for this thesis can be derived (Figure 2.5). In this framework, the prior discussed phases of UX are mapped to the phases of CX. Within each phase, the most frequently utilized constructs in the reviewed literature are summarized. The three UX phases of the framework, as well as the identified constructs provide the structure for the included essays in this thesis.

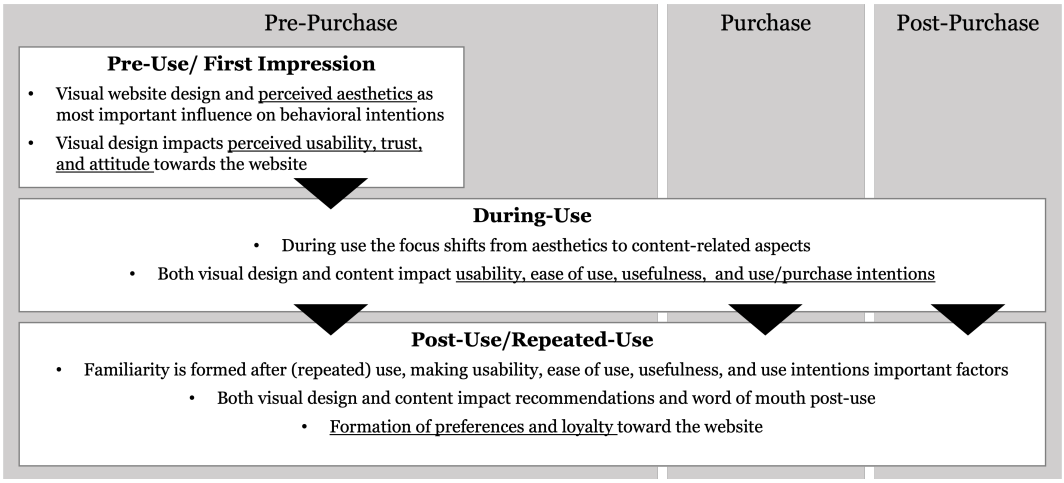


Figure 2.5. Framework of this Thesis

2.3. Framework and Integration of the Papers

Against the elaborated background, this thesis considers the UX of an ecommerce website going through the three phases: *i)* pre-use/ first impression, *ii)* during-use, and *iii)* post-use/ repeated-use. As was shown by the state of the art in the prior section, different evaluations of the website are processed, and of importance to the user. Therefore, this section summarizes the key constructs in each phase and introduces the included essays in the respective phase. A summary of all included papers in each of the phases with bibliographic information and the used stimuli and constructs is presented in Table 2.5.

2.3.1. Papers in the Pre-Use Phase

In the pre-use phase, primarily the visual design and resulting aesthetic perception, as well as the expected usability, and perceived trustworthiness of the website are of importance. Given that several papers considered the impact of color in the first impression of users, this thesis will include three papers with focus on color as website design element for the pre-use phase.

In the first paper 1, the perceived aesthetics and use intentions of a shoe selling website presented in four different colors are measured through self-reported data. This is complemented with fNIRS data of the PFC to identify which neural processes are elicited through color, and how color is processed on a neurophysiological level. The paper therefore introduces a duality of psychological and physiological color processing on websites. The results reveal that, in comparison to the blueish website, (1) grey scaled websites require higher cognitive load (physiological) but are rated as aesthetically pleasing (psychological), (2) greenish websites are rated as less

Phase I: Pre-Use / First Impressions	
Paper 1: Psychological and Physiological Effects of Color Use on eCommerce Websites: A Neural Study Using fNIRS	
Authors:	Anika Nissen
Published In:	International Conference on Information Systems (ICIS) 2020
Ranking:	VHB-Ranking = A, Impact Factor = nA
Stimuli:	Color on shoe selling website, screenshots
Used Measures:	fNIRS, visual aesthetics, purchase intention
Paper 2: Design Mode, Color, and Button Shape: A Pilot Study on the Neural Effects of Website Perception	
Authors:	Anika Nissen, René Riedl
Published In:	NeuroIS Retreat 2021
Ranking:	VHB-Ranking = nA, Impact Factor = nA
Stimuli:	Color, button shapes, and design mode on e-learning website, screenshots
Used Measures:	pleasure, arousal, trust, attitude toward the website, use intention
Paper 3: Visual Website Design from an Evolutionary Psychology Perspective: Results of an Experiment Based on Neuroimaging and Self-Report Measures	
Authors:	Anika Nissen, René Riedl, Reinhard Schütte, Peter Kenning
Published In:	Unpublished essay
Ranking:	VHB-Ranking = -, Impact Factor = -
Stimuli:	Color and button shape on e-learning website, screenshots
Used Measures:	fNIRS, pleasure, arousal, distrust, attitude toward the website
Phase II: During-Use	
Paper 4: Utilizing Mobile fNIRS to Investigate Neural Correlates of the TAM in eCommerce	
Authors:	Anika Nissen, Caspar Krampe, Peter Kenning, Reinhard Schütte
Published In:	International Conference on Information Systems (ICIS) 2019
Ranking:	VHB-Ranking = A, Impact Factor = nA
Stimuli:	Electronic devices on operating websites, website use
Used Measures:	fNIRS, perceived ease of use, perceived usefulness, purchase intention
Paper 5: Why He Buys It and She Doesn't – Exploring Self-Reported and Neural Gender Differences in the Perception of eCommerce Websites	
Authors:	Anika Nissen, Caspar Krampe
Published In:	Computers in Human Behaviour (CHB)
Ranking:	VHB-Ranking = nA, Impact Factor = 8.957
Stimuli:	Electronic devices on operating websites, screenshots and website use
Used Measures:	fNIRS, visual aesthetics, perceived ease of use, perceived usefulness, purchase intention
Phase III: Post-/Repeated-Use	
Paper 6: A Neural Investigation of E-Loyalty on eCommerce Websites	
Authors:	Anika Nissen, Nadine Gier
Published In:	International Conference on Information Systems (ICIS) 2021
Ranking:	VHB-Ranking = A, Impact Factor = nA
Stimuli:	Books on ecommerce websites, binary decisions with screen-shots
Used Measures:	fNIRS, binary decisions/ preference, familiarity

Table 2.5. Overview of the Included Papers in Relation to UX Phases

aesthetically pleasing (psychological) while they do not require more neural resources (physiological), and (3) reddish websites are rated as less aesthetically pleasing (psychological) and require higher neural processing resources (physiological). Together, the results show that the neural effort to process a color can sometimes overlap with the self-reported pleasure (as shown for reddish websites), but it does not necessarily reflect the self-reported data (as shown for the grey scaled websites). Therefore, to dive deeper into the topic of color processing on ecommerce websites, further studies have been conducted.

The second paper 2 in the pre-use phase is a pre-study to paper 3, and focuses on color, and its interactions with the design mode (light or dark design), as well as button shapes. The paper measures the self-rated pleasure and arousal, perceived trust, attitude toward the website, and use intentions through an online survey. The results indicate that design mode (light vs. dark) significantly affects users' pleasure, arousal, trust, attitude, and use intention. Furthermore, color (blue vs. red) significantly influences pleasure, arousal, and use intentions, which supports the findings from paper 1. Finally, button shape (rounded vs. sharp) does not significantly influence any of the dependent self-reported measures. A reason for this may be that design mode and color are more eye-catching and may have therefore overwritten potential effects due to button shapes. Consequently, a third study has been conducted that also employs fNIRS in addition to self-reported data.

In the follow-up study in paper 3, color and button shape are once again investigated as website design elements. This time, self-reported data of pleasure and arousal, distrust, and attitude toward the website are complemented with fNIRS data on the PFC. This is done as a means to also capture more subtle, potentially unconscious, processes and effects of button shapes on users. The results reveal significant differences in self-reported pleasure, distrust, and attitude toward colored versus uncolored websites, further supporting paper 1 and paper 2. Moreover, colored websites led to deactivation in the right dlPFC when compared to uncolored websites. When comparing blue and red websites, a significant deactivation in the left vmPFC, OFC, and the left dlPFC was identified for the blue website, which is in line with the reduced cognitive load measured in paper 1. Further, when comparing the use of sharp versus rounded button shapes, significant increases in the premotor cortex and dmPFC, as well as in the right vmPFC and OFC, were identified for rounded shapes. This activation assumes the attribution of negative valence to sharp buttons and reveals effects of this website design element that could not be detected by self-reported data alone. As this paper has not yet been published, the theoretical stance taken in the paper and the discussion and interpretation of results within the

paper are preliminary and need to be treated with caution.

Across all three included papers, it can be seen how there is a duality between self-reported constructs and the neural activation measured on the PFC. While the most significant effects can also be detected by questionnaires, more subtle effects that users may not become aware of can be measured with fNIRS. Similarly, further investigations during actual website use support this finding for overall website evaluation that is not limited to color and button shape as design elements.

2.3.2. Papers in the During-Use Phase

In the reviewed related literature, a shift of importance from visual design to more functional and usability-related factors has been identified during actual website use. Crucial constructs that are evaluated during use are therefore the perceived ease of use, usefulness, and use intentions of a website. Therefore, two studies have been conducted which focus on these constructs for operating websites that sell consumer electronics.

Paper 4 addresses the common constructs of the Technology Acceptance Model (TAM) being perceived ease of use (PEOU), perceived usefulness (PU), and purchase intention (PUI) for three operating ecommerce retailers which were prior unknown to participants (= first use). In a pre-study, the included retailers were evaluated regarding the included constructs which resulted in one retailer being rated high, one being rated medium, and one being rated low in the TAM constructs. This self-reported data was further complemented with neural measurements on the PFC during website use. Results show that for the high and medium rated websites, mostly medial PFC areas on the right hemisphere were activated, while the low rated website resulted in increased activation of the left vmPFC/OFC. The results assume increased emotional processing for participants who rated the websites higher than the average of the sample, which may be linked to higher use and purchase intentions.

To further elaborate on the findings from paper 4, we were interested in whether the observed preferences and resulting neural activation depend on demographic characteristics of participants, by taking a look at the biological gender as influencing factor. The self-reported results reveal that men and women do not significantly differ in their expressed evaluations of ecommerce websites. However, the neural results indicate that gender-related differences in the processing of ecommerce websites are influenced by unconscious effects, which might explain the inconsistent gender-specific research findings. Men tend to require greater neural activity when using ecommerce websites. Websites evaluated as useful and visually aesthetic lead

to significant neural activation in brain regions of the left hemisphere for men in comparison to women, whereas websites evaluated as less useful and appealing reveal neural activation in brain regions of the right hemisphere in male participants.

Altogether, the results of the papers included in the use phase reveal that there are processes visible in the PFC as a response to websites at different levels of ease of use and usefulness, which results in differences in purchase intentions. Furthermore, the effects observed on a neural level are influenced by demographic factors such as the biological gender of participants. These effects do not necessarily become visible in self-reported data, and therefore, they need to be further discussed. Next to biological, gender-related effects, there may also be differences in the processing of websites depending on the familiarity with and preference for a certain website. Therefore, the final paper included in the following use phase addresses this topic.

2.3.3. Paper in the Post-/Repeated-Use Phase

In the post-/ and repeated-use phase, the reviewed studies from related literature have focused on similar aspects as in the use phase, but additionally, also the formation of loyalty and therefore, preferences have been investigated.

The final paper 6 therefore sheds more light onto the formation of loyalty by looking at user preferences for familiar and repetitively used websites. The results of a binary decision scenario show that antecedents to loyalty might be associated with an activation of the bilateral dlPFC, and the right vmPFC/OFC. Furthermore, a non-hypothesized deactivation of the left superior dmPFC was identified. This activation pattern can be related to increased perceived pleasure and reward attribution of the target website, as well as higher associated familiarity and user preference. Based on this, it is discussed that antecedents to loyalty may be associated with neural lock-in effects. These lock-in effects may be elicited through continuous, positive, and pleasant UX which ultimately lead to an emotional attachment that is “neurally encoded” into the users’ brain.

Across all three use phases, the included papers show how the perception and interaction with a website leads to neural activation. The observed neural activity further helps to uncover processes which are often not identified in the self-reported constructs. In the following chapters, the included papers are presented. Thereafter, the role of the investigated brain regions across all papers for the evaluation of ecommerce websites is discussed in relation to the current identified knowledge in neuroIS research. After that, the implications of the achieved results for each UX phase are discussed.

Chapter 3

Phase I: Pre-Use/ First Impression

3.1. Paper 1: Psychological and Physiological Effects of Color Use on eCommerce Websites: A Neural Study Using fNIRS

Abstract

Colors surround us in all life situations and have the power to influence our mood and emotions, which makes color a crucial impact factor for decision making in ecommerce environments. Therefore, this research paper aims to explore the psychological and physiological effects of color use on websites with a neuroimaging method. For this, an experiment was designed in which 24 healthy participants watched an online shoe shop in 4 different colored versions during which their neural activity in the prefrontal cortex was measured. While comparing the neural activity between the different employed colors, distinct implications can be derived. That is, in comparison to the blueish website, (1) grey scaled websites require higher cognitive load but are rated as aesthetically pleasing, (2) greenish websites result in more negative valence while they require not more neural resources, and (3) reddish websites are rated low in valence and require higher neural processing resources.

3.1.1. Introduction

Blue as the sky, red as fire, green as the grass – color surrounds us in all life situations and can significantly impact our mood and emotions (Abegaz et al., 2015; Patil, 2012). Consequently, it is evident that colors impact human decision making processes in shopping environments by heavily influencing their first impressions and evaluations of products (Bäumer et al., 2019; Bonnardel et al., 2011). In line with this, a large part of product evaluations stem from the coloring of their packages (Singh, 2006). In ecommerce contexts, the coloring of websites does not only influence the way products are perceived, but also impacts more than half of the following purchase process (Chang and Lin, 2010; Westerman, Sutherland, et al., 2012). However, it stands to question how exactly and why color yields so much power over customers' decision processes. To give an example, the color blue seems to be especially relevant as it was found that blue as environmental color raises the likelihood of purchases (Becker, 2002). This is in line with research focusing on color as website design element. These studies have found that blue websites are consistently rated as more

favorable and more trustworthy (Cyr, Head, and Larios, 2010; Fortmann-Roe, 2013; Palmer and Schloss, 2010; Seckler et al., 2015). Consequently, it is not surprising that websites are often designed in decent blue hues (i.e. Facebook, Twitter, PayPal) (Herbert, 2016).

One reason for this might lie in the general popularity of blue, as it is consistently chosen as favorite color by people even across different cultures (Granger, 1952; Heller, 2000), which might be explained by typical associations of blue being space, openness, calming, or faithfulness (Heller, 2000). In the frame of ecommerce websites, however, it is questionable whether these associations provide a satisfactory explanation. Consequently, another explanation might be, that colors do not only emotionally impact customers, but also have the power to influence their cognitive capabilities (Westerman, Sutherland, et al., 2012). As a result, we are wondering, how different colors might impact cognitive and emotional processes of ecommerce customers. Especially, as customers might be unaware of these processes which makes it difficult to apply questionnaires in such an experiment, we employ a neuroimaging method to receive physiological data which might provide explanations for possible color effects. In the frame of NeuroIS research, it has been shown that psychophysiological data in general, and neural data in particular, can generate deeper insights into human perception and information processes (Dimoka, 2010; Riedl, Banker, et al., 2010). Consequently, color related cognitive and emotional processes in the human brain will be assessed in this paper by employing the neuroimaging method fNIRS. fNIRS has been proven to offer a reliable method with which cortical brain activity can be measured in natural user and shopping environments (Nissen, Krampe, et al., 2019). Therefore, it is a non-invasive, mobile method which is mostly robust to (movement) artefacts and allows to assess crucial brain regions which are typically involved in human decision making (Kopton and Kenning, 2014; Krampe, Gier, et al., 2018; Krampe, Strelow, et al., 2018). Therefore, this measurement method is chosen to detect neural differences between four differently colored ecommerce websites and the impact of their coloring on the cognitive and emotional processing of the websites in the brain. Differences in the observable neural processing can further be used to explain and draw conclusions regarding website perception and behavioral intentions. Consequently, knowing the neural effects of color can help with design choices when users should be i.e. influenced to be more relaxed or when their attention should be evoked. With this, the following research question is tackled in this paper: *How does color as corporate website design impact users' psychological aesthetic perceptions and physiological processing of the underlying website?*

To the best of our knowledge, there is no existing study focusing on neural responses to colors in the prefrontal cortex in the context of economic decision making which is why this paper provides exploratory research in this area. Through this, this paper contributes to the body of knowledge by offering additional, new insights into the neural processing of ecommerce websites which complement existing research and offers further, fruitful explanations, about why and how websites are processed. In detail, this paper shows how subtle changes in the neural processing of websites due to color changes might have a significant impact on the decision making of customers and thus, on psychological processes, which are not necessarily reflected in self-reported data. That is, users themselves might not be aware of the here identified neural changes – however, they add explanation approaches as to why and how we perceive the differently colored websites the way we do. The remainder of this paper is structured as follows. Firstly, related literature regarding the use of colors on ecommerce websites and their impact on decision making, as well as neuroscientific literature revealing brain regions involved in decision making and color processing, is presented. After that, our research method is briefly presented which consists of an online survey conducted to create appropriate stimuli and explanations regarding how fNIRS works as a measurement method. After that, the fNIRS experiment is conducted and its results are presented. This paper closes with a discussion of the neural results in which possible implications of these results are derived, and finally, with a conclusion including limitations of this work and further directions.

3.1.2. Related Literature

Color in Website Design

Colors of websites are probably one of the most significant influence factors when it comes to beauty evaluations of a website (Cyr, Head, and Larios, 2010; Pandir and Knight, 2006; Tuch, Bargas-Avila, Opwis, and Wilhelm, 2009; Zheng et al., 2009). While colors determine whether a website is evaluated as beautiful or not, the results of this evaluation are critical for assumptions that users make about the website's usability and trustworthiness (Cyr, Head, and Larios, 2010). That is, websites which are perceived as highly aesthetic are often also perceived as highly usable through the halo effect induced through beauty (Hartmann et al., 2008; Lindgaard, Dudek, et al., 2011; Reinecke and Bernstein, 2011), and consequently, users are more likely to use the website. Having so far described color as a corporate design factor and thus, as an aesthetic instrument, it can also be used for informational purposes (MacIntyre, 1991). For instance, web designers can make use of what is referred to as the Restorff effect which describes that colored objects which significantly stand out from the rest do not only draw our attention but are also remembered better (Parker et al.,

1998). Through this, designers can subconsciously influence their users' behavior and interaction with the website (which is by now researched under the term of digital nudges (Terres et al., 2019; Weinmann et al., 2016)). However, in this paper we will focus on color as the corporate design element of the website and thus, as an influence factor on (psychological) aesthetic evaluations of websites which further impact purchase decisions. In line with this, blueish colors in shopping environments have been shown to lead to increased purchases when compared to reddish environments (Becker, 2002; Bellizzi and Hite, 1992). Furthermore, these increased purchases might be reasoned with blueish ecommerce websites inducing more positive attitudes towards the products on the website (Biers and Richards, 2005). Another reason could be that blue websites seem to be rated as more trustworthy and more reliable as websites in other colors (Chang and Lin, 2010). However, colors can not only have an impact on the website perception and the way products on a website are evaluated, but also on the cognitive capability of users (Westerman, Sutherland, et al., 2012). This has been proven in other contexts, where students performed better in a test on a blue sheet when compared to a red sheet (Soldat et al., 1997). This leads to the assumption, that the impact of colors on a website might not only impact customers' cognitive and emotional processing of the website in the brain, but also their cognitive capabilities.

One way to explain this lies in the physics of color which describe that color comes in different light wavelength lengths; while reddish colors are long wavelength light, blueish and greenish colors are short wavelengths of light. Further, white is a mixture of all color, while black represents the absence of light. These light wavelengths are then received by cones in our eyes from which we have more for perceiving long wavelength light, than we have for the shorter wavelength light (Hunt, 1998; MacDonald, 1999). Consequently, the human eye is also more sensitive for reddish colors than for blueish colors, which might further require higher neural capacities to process the elicited sensations. Following this thought and the point that human processing capacity is limited (Buschman et al., 2011), especially in terms of working memory, it might be hypothesized that reddish colors or physically speaking colors with long wavelengths of light (on websites) limit the user's capacity for processing the content elements of websites because the processing of the color itself requires higher capacities than colors with short wavelengths of light (i.e. blue or green). An alternative explanation to this is given by an evolutionary approach which poses that long wavelength colors infer negative emotional states which further narrow down the focus of attention (Osaka et al., 2013). Further, this might explain why long wavelength colors tend to increase performance on detail-oriented, attention-required cognitive tasks, while short wavelength colors seem to increase creativity (Mehta

and Zhu, 2009). When transferring these findings to the ecommerce environment, the effect of short wavelength light, namely a positive emotional, relaxing effect on users, might thus, increase their emotions and satisfaction on websites designed primarily in color with short wavelengths.

In line with this, it is evident that colors in ecommerce environments yield the power to unconsciously influence customers' mood and emotions which further influence their decision making (Patil, 2012). For instance, customers' mood on websites has been shown to be most positive on blueish, and most negative on reddish websites (Abegaz et al., 2015). Apparently, websites colored in a way that induce a negative mood lead to increased memorability of the web shop, but also to decreased buying intentions (Pelet and Papadopoulou, 2012). In how far customers' emotions and decision making is influenced by the corporate color of the website, however, might also depend on the customers' cultural backgrounds. That is, different cultures assert different meanings to colors which influence our perceptions of and behavioral intentions on websites (Grossman and Wisenbilt, 1999; Silic et al., 2017). Therefore, the generalizability of color studies has to be treated with caution and might be possible only for the culture in which the study took place. Nevertheless, blue color in general, and websites designed in blue in particular, seem to be favored consistently across several studies and independent of the cultural background of the participants in the studies (Bonnardel et al., 2011; Chang and Lin, 2010; Cyr, Head, and Larios, 2010; Heller, 2000; Seckler et al., 2015).

Consequently, based on the prior described literature, the color independent popularity of blue further leads to us hypothesizing that blueish colors require less processing resources of the brain and might thus, be perceived as more pleasant. Furthermore, this also leads to the hypothesis that human color perception is twofold, meaning that it consists of *(1) a physiological component* and *(2) a psychological component*. The former is solely dictated by the physics of color and the human color vision, while the latter can be influenced by culture, personal beliefs, emotions etc. This differentiation is in accordance with stages of color processing found in the brain (Bartels and Zeki, 2000; Zeki and Marini, 1998), which once again supports the relevance and value to employ neuroimaging methods as explanatory data source.

Decision Making and Color Processing in the Prefrontal Cortex

Although there is neuroeconomic research focusing on decision making and its neural correlates in the PFC (Kopton and Kenning, 2014; Krampe, Gier, et al., 2018; Krampe, Strelow, et al., 2018), to the best of our knowledge, there is no research that investigates the impact of color on decision making on a neural level in ecommerce

contexts. Generally, the cortical parts of the PFC can be distinguished into four main regions being the dorsolateral prefrontal cortex (dlPFC), the dorsomedial prefrontal cortex (dmPFC), the ventromedial prefrontal cortex (vmPFC), and the ventrolateral prefrontal cortex (vlPFC) (Carlén, 2017). The medial parts of the PFC are typically more related to processing emotional stimuli, while the lateral parts are rather related to cognitive processing. In the following, each area and its function are briefly presented, and the main results are summarized in Table 3.1.

The **dlPFC** is directly related to cognitive processes in decision making including reward evaluation and error detection (Chen, Jimura, et al., 2015; Greening et al., 2011; Hutcherson et al., 2012). Furthermore, activity in the dlPFC is increased when making perceptional decisions for which perceived information (for instance visual information) is linked to the decision and finally, to resulting behavior (Heekeren et al., 2006). In connection with the dmPFC, the dlPFC is also increasingly active when facing a decision conflict (Mitchell et al., 2009). In economic and brand-related research, the dlPFC is also shown in what is called the "first choice brand effect" in which consumers, when confronted with their first choice brand of a product, reveal decreased neural activity in the dlPFC (Deppe et al., 2005; Krampe, Gier, et al., 2018). This connection is further supported as, in prior fNIRS studies, the dlPFC has also been found to be increased in processing positive and negative emotional stimuli (Hoshi, Huang, et al., 2011; Hu, Zhuang, et al., 2019; Wang, Li, et al., 2018). In the context of color processing, the right dlPFC seems to play a role when processing objects with abnormal color (i.e. a blue strawberry) (Zeki and Marini, 1998). Therefore, it might also show increased activity in unexpected or unaesthetic color use in websites. Furthermore, the dlPFC is bilaterally increased when comparing normal and abnormal color use on stimuli (Zeki and Marini, 1998), as well as when colors have to be categorized (Bird et al., 2014; Siok et al., 2009). However, the latter is more related to cognitive processes as is the reward evaluation and error detection named at the beginning. When drawing back to the prior section, we assumed that – in relation to physiological color perception – the reddish colored website might reveal higher neural activity due to it requiring more resources to be processed. An assumption which is based on the sensitivity of the human eye to different colors and further supported by Soldat et al., 1997, which showed decreased human performances on red sheets.

The **dmPFC** has, in connection with the dlPFC, been found to be tightly connected to behavioral performance monitoring and adjusting behavior to external stimuli (Taren et al., 2011). In line with this, the dmPFC shows increased neural activity when humans face a decision conflict (Mitchell et al., 2009). However, it

seems that this region is not only related to intentionally adjusting behavior, but also involved in processing and intentionally forming first impressions and the resulting attitudes (Gilron and Gutchess, 2012). Next to these partly conscious processes, the medial PFC in general, and the dmPFC in particular is connected to the amygdala and thus, it has been related to cognitively control emotional processing in the amygdala (Buhle et al., 2014; Delli Pizzi et al., 2017). In line with its connection to the amygdala, it is thought that the dmPFC is increased when processing and attributing negative emotional stimuli (Schienle et al., 2014). In relation to color processing, areas of the dmPFC bilaterally have been to found to be activated in color categorization processes and color discrimination (Bird et al., 2014; Siok et al., 2009).

Next to the dmPFC, the **vmPFC** is also part of the amygdala circuit and is also thought to control processes in the amygdala such as forcing cognitive control and re-appraising emotional stimuli (Buhle et al., 2014) as well as directing attention to relevant stimuli (Dolcos et al., 2011). Therefore, the vmPFC shows increases when humans evaluate their own emotional states (Terasawa et al., 2013), as this requires cognitive reflection of one's state. By means of fNIRS, researchers were also able to detect increases in this area when facing rewarding stimuli (Doi et al., 2013). In decision making contexts, the vmPFC has shown to play a role in uncertainty and anticipation processes (Motzkin et al., 2014), which underlines its role in the re-appraising of stimuli. Furthermore, this area seems to be crucial for rational decision making, as people with lesions in the vmPFC seem to make irrational decisions in economic contexts (Koenigs and Tranel, 2007; Naqvi, Shiv, et al., 2006), which might be due to its role in (cognitive) emotion regulation. An increase in this area has also been linked to increased buying intentions of consumers (Plassmann, Kenning, and Ahlert, 2007). In the context of attributing valence to visual stimuli, the vmPFC has been increased for aesthetically pleasing pictures (Brown et al., 2011; Cela-Conde, Garcia-Prieto, et al., 2013). In the context of color processing, especially the left vmPFC has shown increased neural activity when processing objects with abnormal color compared to normal colored objects (Zeki and Marini, 1998), which might stand in contrast to its role in processing beautiful images but is in line with re-appraising processes of stimuli.

Finally, the **vlPFC** is typically attributed to semantic processing (Snyder et al., 2011), yet it was found that areas related to semantic processing are also required for color perception (Siok et al., 2009). Furthermore, it also plays a role in controlling hand and eye movements in general, and when having to cancel eye movements in particular (Ellard et al., 2017; Heinen et al., 2006). These functions lay the

Brain Areas	Functions
dorsolateral prefrontal cortex (dlPFC)	· Processes in decision making, reward evaluation & error detection · Perceptional decision making (linking perception to action) · Activated for positive and negative emotions · Activated when processing unnormal color (= error detection) · Deactivated for favored brand
dorsomedial prefrontal cortex (dmPFC)	· Performance monitoring and behavior adjustment · Activated when facing a decision conflict · Involved in forming first impressions and attitudes · Activated in processing negative emotional stimuli
ventromedial prefrontal cortex (vmPFC)	· Force cognitive control on emotional processes · Evaluation of own emotional state · Activated for rewarding and pleasant stimuli · Activated in relation to increased buying intentions · Activated for favored brand
ventrolateral prefrontal cortex (vlPFC)	· Semantic processing and color perception · Plan and cancel hand and eye movements · Related to both positive and negative emotion processing · Activated for colored stimuli, but not for uncolored stimuli

Table 3.1. Summary of Brain Functions in the PFC

conclusion near that, when transferred to website use, increases in this area might point to increased hand and eye movements and thus, to an increased effort to search for and find relevant information on the website. Moreover, the vlPFC is functionally connected to the amygdala and thus, it is related to emotion regulation (Ellard et al., 2017). In relation to the valence of the stimuli, the right vlPFC was found to be primarily activated when processing negative stimuli (Wager, Davidson, et al., 2008), while the left vlPFC has been found activated for both positive and negative emotional valence (Himichi and Nomura, 2015). In addition, the right vlPFC was also observed to be increased when processing colored objects compared to black and white objects (Zeki and Marini, 1998). Consequently, it can be assumed that increased activations in this area will be observed for websites rated as unaesthetic or for websites, which have intensive color use in their overall design. Given the discussion of human color vision and the idea to split the color perception into physiological processing and psychological perception, these two aspects (color intensity and aesthetics) might be two sides of the same coin. That is, colors requiring increased neural processing power might also be perceived as less aesthetic prior to any psychological attribution to that color.

3.1.3. Research Method

The following, empirical part of this paper is conducted using two measurement methods: (1) the neuroimaging method fNIRS is used which is complemented by (2) a questionnaire which focuses on the visual appeal of the websites and the resulting purchase intentions. With focus on color as an impact factor, we designed

an ecommerce website that sells shoes and designed the corporate design of the website in different colors. In order to make reasonable decisions regarding which colors to include and which colors to select for the shoes that are represented on the websites we conducted an online survey. In this survey, we asked 247 German people with no selection criteria through an online platform (sample= 60.7% male, 38.5% female, .8% divers, average age $M = 39.94$ years ($SD = 12.511$), self-estimated online purchases per month $M = 4.139$ ($SD = 4.729$)) in which color they would design a website if they had to, and in which color they would buy sneakers. For the website, 38.1% of the participants selected blue, 25.9% chose white/grey/black, 14.6% chose green, and 11.3% chose orange; the rest of the sample chose one of the remaining color choices being 5.7% red, 2.4% violet, and 2.0% yellow. Now, for stimuli design, both the results of this survey and from prior related literature are regarded. That is, the most chosen colors are apparently blue, greyscales, green and orange. While these results perfectly support the prior presented literature, they will also serve as color variations for our stimuli. That is, the website in blueish design will act as comparison baseline since blue is consistently favored across all identified studies. As we are interested in the effects of short and long wavelength colors, as well as the absence of color, we will further include one representative color scheme for each of these states which is greyscales for the uncolored version, greenish design for the short wavelengths, and orange for the long wavelengths since these colors were rated highest in our survey. Furthermore, as the designed websites show the product page of a sneaker, we selected white and black sneakers from different brands to use for the product pages according to the most chosen color(s) white/grey/black (63.2%) for sneakers from the survey (with the remainder being 21.1% for blue, 6.5% red, 3.2% violet, 2.8% green, 2.0% orange, and 1.2% yellow). Further, except for these variations, prices, icons, and texts were exactly the same for each sneaker on each website version. Also, each website color and sneaker combinations were shown in randomized order to each participant. In order to avoid gender-based biases, sneakers for both males and females were included for all participants.

The neuroimaging method fNIRS is used as main method in this work to assess neural activity in the PFC of participants to receive deeper insights into appraisal and decision-making processes for the different colors. The method fNIRS has been applied in the field of neuroscience, as well as cognate disciplines (Kim, Seo, et al., 2017; Krampe, Gier, et al., 2018). Furthermore, in the context of human-computer interaction and interaction design, fNIRS has been shown to be a feasible method for measuring usability and user experiences of graphical user interfaces (Hill and Bohil, 2016; Pollmann, Eštočinová, et al., 2016). Consequently, fNIRS has proven to provide a reliable method when investigating cognitive and emotional processing. In

the context of color perception, it has also been applied in a study in which primary colors were distinguished solely based on the neural activity measured with fNIRS (Liu and Hong, 2017). In comparison to fMRI, fNIRS offers a lightweight and portable method which can be applied in real-life contexts, while measuring the same biological processes. Further, when compared to EEG, which offers the same mobility and even higher temporal resolution, fNIRS has a higher spatial resolution, tends to be more user-friendly and most importantly, more robust to movement artefacts of the whole body and facial expressions when participants for instance talk during measurements (Hill and Bohil, 2016; Irani et al., 2007; Kim, Seo, et al., 2017).

In earlier studies, fNIRS data was found to highly correlate with the more mature fMRI blood-oxygen level dependent (BOLD) signal (Huppert et al., 2006; Strangman et al., 2002). fNIRS operates with near-infrared light sent by sources that is absorbed, reflected or scattered by the human brain tissue, or more precisely by oxygenated and deoxygenated hemoglobin, and received by detectors (Figure 3.1). The reflected and scattered light from the sources can be visualized with a banana shape and thus, it is typically referred to as "photon banana". In addition to the detectors that detect the reflected light by the brain, short-distance channels can be employed to filter out light that was reflected on extracerebral levels (Tachtsidis and Scholkmann, 2016; Tak and Ye, 2014). As a consequence, fNIRS takes advantage of this characteristic as the amount of oxygenated and deoxygenated blood for a given brain region can be calculated with the received light by the detectors (Ferrari and Quaresima, 2012; Funane et al., 2014). This measurement therefore is an indirect parameter of neural cortical brain activity. Consequently, fNIRS yields potential for IS research, as it is a portable and lightweight technology that appears to be mostly robust to (movement) artefacts and can therefore be applied in practice-relevant scenarios (Brigadoi, Ceccherini, et al., 2014; Leff et al., 2011). However, fNIRS has some shortcomings that might be relevant for IS research. Most predominately, fNIRS still has a limited spatial resolution compared to fMRI, allowing to penetrate the human brain only on cortical structures (Ferrari and Quaresima, 2012; Scholkmann et al., 2014). This, however, is sufficient to capture neural responses related to cognitive and emotional processing and decision making on ecommerce websites.

To complement the neural data, the visual appeal of the websites was measured with self-reported scales using three items from the Visual Aesthetics of Website Inventory (VisAWI) developed by Moshagen and Thielsch, 2010. In their questionnaire, they include the aspects of colorfulness, simplicity, and diversity which are each represented by 4 – 5 items, including reversed items. Simplicity (SIM)

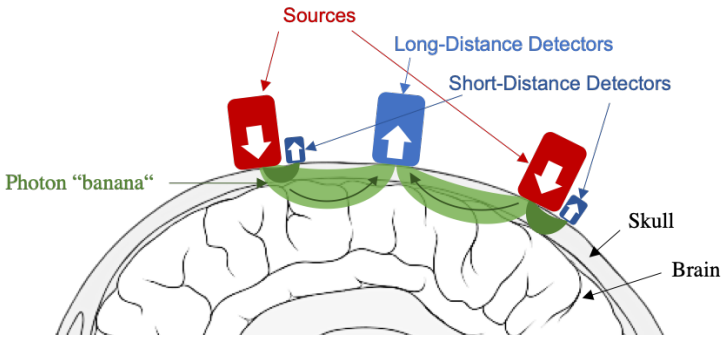


Figure 3.1. Operating Principle of fNIRS

mainly comprises whether the content is easy to grasp and whether the overall layout appears harmonic. Diversity (DIV) describes the prior described visual complexity and variety which represent the originality of a website. Further, colorfulness (COL) considers whether the color scheme seems appealing and attractive or not. In addition to this, we wanted to assess whether the change in color has a significant impact on PUI and consequently, PUI was added as construct.

3.1.4. fNIRS Experiment for Neural Color Processing

Sample and Study Design

Overall a sample of N = 24 participants was recruited from the local university with 75% being male, 25% being female. From the sample, 87.5% were right-handed, 12.5% were left-handed. All participants had normal or corrected to normal sight, one participant had a mild red-green color blindness. Average age of the participants was $M = 26.33$ ($SD = 3.985$), 54.2% are students, 41.7% are employees, and 4.2% are searching for employment. To check, whether participants are suitable as representatives for online shoppers, we asked them how often per month they made a purchase online from which resulted an average of $M = 3.51$ purchases per month ($SD = 3.45$). For the study design, the prior selected, color manipulated websites are used as stimuli in connection with the short scales of the VisAWI, as well as the questions whether participants would make a purchase on the shown website. The questions and websites are shown in randomized order as depicted in Figure 3.2.

Before the experiment started, participants were informed about their privacy and data protection rights, as well as the operating principle of fNIRS. After participants signed the informed consent, the mobile fNIRS headband was placed on the participants' head. To ensure that the headband is located according to the anatomical brain structures of the participants, the craniometric point of the nasion, where the top of the nose meets the ridge of the forehead, was used to

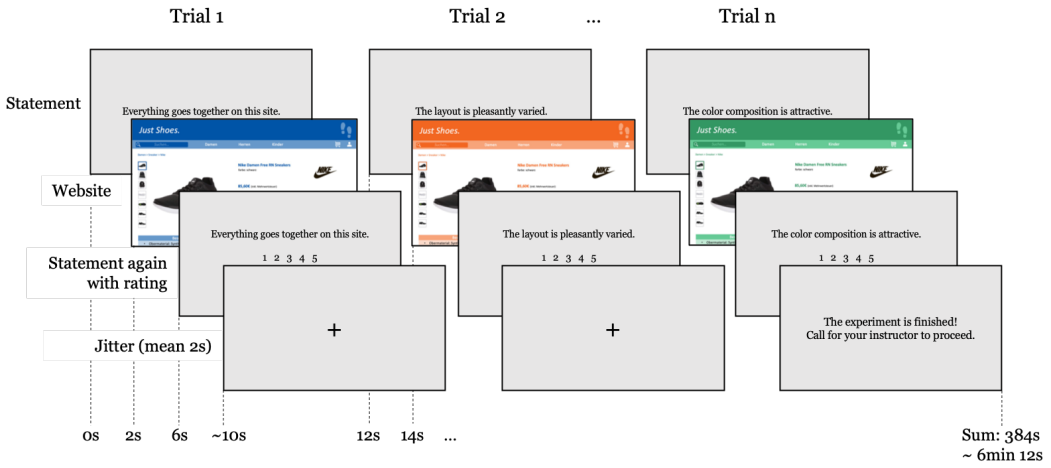


Figure 3.2. Study Design of fNIRS Experiment

assure comparability between participants. To avoid data biases due to experiment equipment interference, several variables were controlled for (Gefen, Ayaz, et al., 2014). First, the room luminance was kept constant while using artificial luminance in the experiment room. Second, although being more robust to movement artefacts than EEG, the fNIRS signal might still be influenced by abrupt (head) movements (Cui, Baker, et al., 2015). Therefore, participants were asked to avoid fast and abrupt (head) movements while wearing the fNIRS headband. Third, as dense and dark hair is likely to absorb the infrared light, it was moved aside in order to allow the light to penetrate the scalp and tissue (Zhao and Cooper, 2017). The headband was calibrated for every individual participant through which data quality was assured. Moreover, we noticed every unusual or uninstructed behavior by our participants in an experimental notebook, which was considered in the data analysis process. Having finished the calibration procedure, participants were instructed to start with the study. After finishing the study, participants were freed of the fNIRS headband and had to fill out a closing questionnaire including the demographic and shopping behavior related questions.

Data Acquisition and Processing

Data was acquired using a continuous wavelength fNIRS device developed by NIRX with a headband montage holding 8 sources, 7 long-distance detectors, and 8 short-distance detectors. The average distance of the long separation channels was set to 30mm, the average distance of the short separation channels was set to 8mm which provides an optimal distance to filter out extracerebral activity to further reduce the signal to noise ratio (Brigadoi and Cooper, 2015; Goodwin et al., 2014; Yücel, Selb, et al., 2016). The wavelengths of the infrared light are 760nm

and 850nm, the sampling frequency was 7.81Hz which was resampled to 7Hz in the pre-processing procedure. The raw fNIRS data was processed using the NIRS AnalyzIR toolbox (Santosa et al., 2018). At first, optical density was calculated, after which the data was bandpass filtered with a high cut-off frequency of 0.2 Hz and a low-cutoff frequency of 0.01 Hz which filters out artefacts due to heart rate and respiration (Pinti, Scholkmann, et al., 2019; Zhang, Zhou, et al., 2017). As the subjects sat (relatively) still in front of the laptop and did not move, no motion filters were applied to the data. Further, short separation channel regression was applied by using the Linear Minimum Mean Square Estimations (LMMSE) (Saager and Berger, 2005; Scholkmann et al., 2014), followed by calculating hemoglobin values by using the modified Beer-Lambert Law with the partial pathlength factor (PPF) set to 0.1 (Delpy et al., 1988; Kocsis et al., 2006). Hemodynamic response function (hrf) was used as baseline function for the general linear model (GLM)). For the group analysis, a mixed effects model with conditions as fixed effects and subjects as random effects was selected. Further, as already stated to in the stimuli section, the blue website will act as baseline for comparisons, the further named black website is representative for the absence of color, the green website represents short wavelength colors, and finally, orange represent long wavelength colors. The questionnaire data was analyzed using an ANOVA with Tukey-HSD post-hoc tests which allow for multiple group comparisons (Tukey, 1949). A threshold of $p < .05$ (Bonferroni corrected) was applied for the group comparisons.

Results

The self-reported questionnaire results reflect what has been found in literature before. The ANOVA results were: $F_{\text{SIM}}(3, 188) = 3.045(p < .03)$, $F_{\text{DIV}}(3, 188) = 3.916(p < .01)$, $F_{\text{COL}}(3, 188) = 3.730(p < .012)$, and $F_{\text{PUI}}(3, 188) = 3.630(p < .053)$ which show statistical significance for all constructs except for purchase intention. For the other three constructs significant differences were found only between the orange and the blue website with Bonferroni corrected p-values of $p = .018$ for simplicity, $p = .036$ for diversity, and most significantly $p = .006$ for colorfulness (detailed mean values can be seen in Table 3.2).

Although no significant outcomes in the purchase intention of users were found, the neural results show significant differences when contrasting the differently colored websites. As prior studies which focused on color design in shopping environments consistently show that blue is favored, the blue website provides the basis for the contrasts in this study. In Table 3.3, the significant channels are sorted according to their related brain regions and reported with their t-values, degrees of freedom (dfe),

	SIM		DIV		COL		PUI
Subgroups	*1*	*2*	*1*	*2*	*1*	*2*	*1*
Orange	2.98		2.73		2.58		2.63
Green	3.25		3.15		2.88		2.92
Black	3.31		2.77		2.9		3.17
Blue		3.56		3.25		3.31	3.23

Table 3.2. Mean Values from Self-Reported Ratings

Note. homogenous subgroups distinguished for $p < .05$, Bonferroni corrected

Contrast	Brain region	Channel	t-stat	dfe	p	q	power
Black - Blue	**vlPFC (left)**	21	2.907	92	.005	.058	.892
		22*	3.638	92	.001	.014	.974
	dlPFC (left)	6	2.37	92	.020	.137	.760
	dlPFC (right)	9	2.026	92	.045	.211	.640
	dmPFC (left)	12	-2.358	92	.020	.137	.756
		13	-2.209	92	.030	.178	.707
Green - Blue	**vlPFC (right)**	16*	3.367	92	.001	.017	.954
	dlPFC (left)	6	2.229	92	.028	.121	.714
		7	-2.618	92	.010	.069	.830
	dmPFC (left)	12	-2.243	92	.027	.121	.719
Orange - Blue	**vlPFC (right)**	16*	2.764	92	.007	.036	.863
	dlPFC (left)	7*	-2.748	92	.036	.036	.860
		14*	3.103	92	.031	.031	.923
	dmPFC (right)	8*	2.759	92	.036	.036	.862
	dmPFC (left)	4*	-3.532	92	.001	.017	.968
		12*	2.759	92	.036	.036	.862

Table 3.3. t-Statistic Results for HbO Contrasts for Channels with $p < .05$

*Note. * channels with $q < .05$*

p-values, q-values (= false discovery rate (FDR) corrected p-values) (Benjamini and Hochberg, 1995) and statistical power. In this table, it can be seen that not all significant channels in p-values are also significant in their q-values. Therefore, and as the q-value provides a correction for false positives, the further as significant and relevant identified brain regions are the left vlPFC which was activated on the black website. Further, the right vlPFC was identified to be significantly activated for the green website compared to the blue website. Finally, increased activity in the right vlPFC, right dmPFC, left dlPFC and left dmPFC was identified or the orange website, as well as decreased activity in the lateral left dlPFC. Also, only the q-value significant channels as named above will be included in the discussion. To get a better impression on how the activations look on the human brain, the significant channels (with $p < .05$) are mapped and the further relevant channels ($q < .05$) are marked with flags in Figure 3.3; with the red dots representing the sources, and the blue dots representing the detectors of the fNIRS.

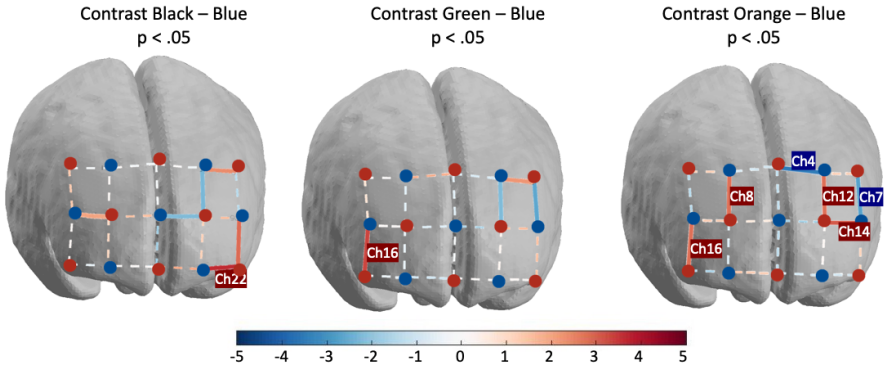


Figure 3.3. HbO t-Statistic for all Three Contrasts

Note. channels with $p < .05$ are continuous lines, channels with $q < .05$ are marked with flags

3.1.5. Discussion

Generally, and across all included conditions, brain areas of the vlPFC, dlPFC, and dmPFC seem to mainly modulate the differences in the perception and processing of ecommerce websites which are presented in different colors. The further, detailed discussion and interpretation of the neural results in this study will follow the order of the contrasts in Table 3.3.

Interpretation of Neural Results

Thus, starting with the contrast between the black and blue website, which were found to be not rated significantly different in the questionnaire employed in the experiment. On a neural level, main activation differences were found in the left vlPFC which showed increased oxygenated hemoglobin (HbO) levels for the black website. The identified increased left vlPFC has shown to be related to semantic processing and directing eye movement (Leung and Cai, 2007; Snyder et al., 2011). Further, the left vlPFC has been shown to be involved in processing (negative) distractions and when short-term memory is required (Weintraub-Brevda, 2018). All these aspects might result from the lack of differentiation between decorative website elements and content elements – as all are designed in black, white or grey. Consequently, this website version provides no 'easy detectable' contrast between website elements with different functions. As a result, areas responsible to eye movement and detecting distractions are increasingly active and may demand a higher processing load of the user. Users require more effort to search for and identify relevant information on this website – which may further result in different performances if users were to undergo a performance test on the websites. However, these differences might also be too subtle to be visible in performance tests that track cursor movements, time on task, or number of errors. Consequently, the application of additional, psychophysiological

measurements such as eye tracking seems reasonable to further validate the suggestion that the lack of contrast between decorative and content elements on the website increases the eye movement of users and thus, the effort required to identify relevant information on the website. Another possible explanation as to why the left vlPFC was found activated could be its role in processing positive and negative emotional stimuli (Himichi and Nomura, 2015). However, since the results from the self-reports revealed no significant difference in the aesthetic attribution of the black versus the blue website, we believe the activation due to a lack of contrast lies more at hand.

Next, for the green website in comparison to blue, main activation differences were identified in the right vlPFC which was activated on the green website. Generally, this area has been found to be increased for negative stimuli (Wager, Davidson, et al., 2008). Along this, no further significant changes could be observed which may result in the interpretation that, regarding the cognitive processing and performance on the green website, no severe differences do exist. However, green websites tend to be rated as unaesthetic which is perfectly reflected in the increased neural activity in the right vlPFC. This is in line with the role of the vlPFC in decision making being to receive motivational and emotional information and further to control the adapting behavior of the user (Sakagami and Pan, 2007). This could further explain the lower rated purchase intention on this website compared to the blue website, as the negative and unpleasant perception further results in decreased intentions to buy.

Overall most activations were found for the orange and blue website comparison which shows that the general processing demand, both cognitively and emotionally, is drastically increased on orange websites. In particular, the right vlPFC was activated which might point to processing a stimuli attributed as negative or unpleasant (Wager, Davidson, et al., 2008). Further, on both hemispheres the lateral dmPFC was increased which is also involved in processing abnormal coloring of objects and thus, it further supports our suggestion regarding the need for higher processing required for reddish colors. The dmPFC, however, plays a role in processing first impressions (Gilron and Gutchess, 2012) and when a stimulus, in this case the website, is attributed with negative valence (Schienle et al., 2014). In line with this, the orange website was also rated lowest in the self-reported, aesthetic scales and thus, seems to elicit a negative emotional experience. Negative emotions have further shown to restrict attentional, neural resources to one focus point (Osaka et al., 2013) which is why the here described increases can be observed. Finally, the left inferior dlPFC was also found increased in the orange-blue contrast which is involved in perceptional decision making (Heekeren et al., 2006) and which followingly supports that reddish colored websites require higher cognitive processing than blue websites.

However, next to the increased activations, we also identified decreases in the left superior dmPFC and left lateral dlPFC. Increases in the left lateral dlPFC generally point to processing aesthetic stimuli (Cela-Conde, Marty, et al., 2004) which holds true in this comparison, as the higher rated aesthetic blue website revealed higher neural activity in this area than the low and as unaesthetic rated orange website. Consequently, the dlPFC as a brain region might need further differentiation in sub-regions. In the frame of this study, and thus, in the frame of color perceptions, the inferior, more medial dlPFC might be responsible for the physiological color processing while the lateral dlPFC might be responsible for the psychological color processing. Further, decreases were also identified in the superior dmPFC which refers to the motor cortex that is involved in controlling actions and movement. Therefore, a deactivation in this region points to less motion intentions in users which might be a predictor for behavioral intentions, or ultimately for actual behavior on the website. Paired with the prior described regions, it seems that the perception and processing of orange websites requires overall a higher neural processing load than blue websites.

Implications for the Physiological and Psychological Differentiation

Consequently, this paper has shown that human color perception on ecommerce websites might in fact consist of two components being (1) physiological and (2) psychological – both of which are represented in different neural activation patterns. Furthermore, when considering the overall neural pattern three main implications of this exploratory research can be derived for each website color, however, all of these will need further validation in future studies. Firstly, the findings on the black website support and extend interaction design studies and user interface guidelines that demand for buttons and interactive website elements to be easily detectable. Given this result, the effect of the greyscale design choice is not just an aesthetic decision, but severely impacts the interface's usability and the way users process it. That is, users might require more neural effort to search for and direct their attention to relevant website elements when compared to blue websites. These differences, however, might be so subtle that performance tests or self-reports are not able to detect them. Nevertheless, they are existent and observable through neuroimaging methods and thus, should be considered when designing interfaces. Consequently, and based on our neural results the following implication can be formulated stating that physiologically, there is an absence of attention markers to the human visual system, and psychologically, an individual beauty evaluation of the website takes place:

I 1: Websites designed completely in greyscales reveal similar aesthetic appreciation as blue websites (psychological component), however, they require a higher cognitive load (physiological component).

Secondly, the findings from the green website show that although no significant self-reported differences were observed, a focus on the neural processing of the green website in comparison to the blue one reveals that there are in fact differences in the processing and attribution of emotional valence to the website. What is more, no severe differences in the cognitive processing areas were found, resulting in the evaluation of this website being primarily emotional. A reason for this might be that the wavelengths of blue and green colors lie close together in the light spectrum and thus, the physical sensation produced in the visual nerve is similar. However, this apparently does not seem to influence the psychological attributions of this color which revealed a different beauty evaluation than for the blue website both in the neural activation and in the self-reported ratings:

I 2: Websites designed predominantly in greenish colors do not require higher cognitive load from users (physiological component) compared to blue websites, however, they reveal increased negative valence attribution and hence, a more negative emotional experience (psychological component).

Third and finally, most changes in the neural activity were identified for the orange website which acted representative for reddish websites. The identified activated areas revealed that not only are reddish websites perceived as unaesthetic and unpleasant, but also as being unnormal colored. Additionally, reddish websites (or websites with long wavelengths) seem to require a higher load of sensory processing due to the human's eye being more susceptible to reddish colors than to blueish ones (Hunt, 1998; MacDonald, 1999), which is in line with our argumentation in the related literature section. Consequently, higher demand in purely processing this information is perceived as unpleasant and might even reduce users' performance (Soldat et al., 1997). From these findings, the following and final implication can be derived from our results as in this case, both as physiological, wavelength-based sensation difference is present, as well as the psychological beauty evaluation which might in this case be influenced both by psychological and physiological factors:

I 3: Websites designed predominantly in reddish colors are perceived as unpleasant and unaesthetic (psychological component), and further require increased sensorial processing compared to blue websites (physiological component).

The three derived suggestions reflect the main findings of this study. However, they require further investigation and need to be validated by upcoming, confirmatory studies. This is not only necessary for validating the interpretation used in this work, but also required to test the generalizability of these implications to websites relating to other sectors such as social media or banking. Nevertheless, our results show that both the psychological and physiological effects of color as a design factor on ecommerce websites have a significant impact on how these websites are perceived and processed. At this point, it has to be once again noted that except for color no other aspect of the websites was manipulated so that functionally and content-wise, all included websites are the same.

3.1.6. Conclusion

In our study, we have shown that color is processed both psychologically and physiologically in decision making relevant brain regions for ecommerce websites. In line with this, our results let us suggest that physiological color processing might impact the psychological color perception on websites, due to some colors requiring more neural resources than others – a process, which users might not be aware of. Therefore, the application of neuroimaging methods for this research context is inevitable. However, as every study, this research work also has its limitations.

One **limitation** of this work can be regarded to the used stimuli in our experiment. That is, we conducted a survey in which we asked participants which colors they would pick to design a website. Yet, the included colors might not reflect colors which are typically used by existing online ecommerce websites. However, as using actual ecommerce websites also has further influence factors such as brand name and associations, it is inevitable to create to the users' unknown websites if effects such as color should be observed while controlling for other influencing factors. Furthermore, no between-groups comparisons and analyses were conducted. These, however, could be regarded in future research as for instance personality traits, general favorite color, or cultural background of participants might influence their perception and processing of used colors. Further, the impact of color-based design choices on neural processing and consequently, economic decision making was for this study only investigated on a shoe selling online shop of which participants saw screenshots. In reality, however, customers do not only look at screenshots of websites, but they interact with the given website, which might further impact the processing and perception of color in the brain. Also, although the sample employed here in this study is representative in terms of handedness and red-green blindness, it is male dominant and thus, the results might be biased as neural activity can differ

between males and females. Another point concerning our sample is that while the sample size is accurate and average for neuroscientific studies, it is rather small for IS research. Finally, the context of a shoe shop and the comparably smaller sample of this study might further limit the generalizability of our results to this type of ecommerce and male dominant samples.

Future research could therefore focus more on this aspect and further relate identified neural activations to user performance and user behavior to strengthen the implications derived in this paper and to filter out possible biases due to the male dominant sample employed here. Follow-up studies could also conduct a market analysis and include representative ecommerce websites regarding the used color scheme in their study. In line with this, future work should also consider much more nuances and color hues to increase variability and further validate the results of this study. Relating to the findings on the greyscale website, it might be reasonable to use eye tracking in addition to neuroimaging methods to obtain a clearer picture of the relation between what we look at and what we process during it. Another approach could be to include measurements both of the prefrontal cortex and the visual cortex and further analyze, how activations in both areas are related to one another in the context of ecommerce websites. In relation to behavioral outcomes, future research could also focus more on actual decisions and user behavior and how the brain regions identified in this paper are involved when actual behavioral changes can be observed. Yet, it does not necessarily have to be ecommerce websites – colors work and affect our perceptions in any graphical interface and thus, a variety of application contexts could be investigated in the future. Probably, the impact and effect of color might not be the same across different use contexts but might vary between whether an ecommerce website is investigated or whether primarily functional software such as enterprise resource planning systems are observed. Furthermore, gender or personality traits of customers might also impact their color perception and processing, so that future studies could focus on differences in the neural processing of color depending on user characteristics. Finally, a further option of future research would be to investigate the cognitive load on ecommerce websites or user interfaces by utilizing EEG or fMRI. Nevertheless, this paper offers a promising start and opens up further discussions regarding human physiological processing and psychological color perception and their impact on decision making processes on ecommerce websites.

3.2. Paper 2: Design Mode, Color, and Button Shape: A Pilot Study on the Neural Effects of Website Perception

Abstract

The investigation of website aesthetics has a long history and has already been addressed in NeuroIS research. The extant literature predominantly studied website complexity, symmetry, and colors. However, other design factors have not yet been examined so far. We studied two new factors (design mode: light vs. dark, button shape: rounded vs. sharp angled) along with color (blue vs. red). Specifically, we examined the impact of these three factors on several outcomes. Results from a repeated-measures MANOVA indicate: (i) design mode (light vs. dark) significantly affects users' pleasure, arousal, trust, attitude, and use intention, (ii) color (blue vs. red) significantly influences pleasure, arousal, and use intentions, while (iii) button shape (rounded vs. sharp) does not significantly influence any of the dependent measures. Based on these results, follow up functional near-infrared spectroscopy studies are developed which aim to further complement our self-report findings.

3.2.1. Introduction

Website aesthetics is a major determinant of user perception and use intention (Cyr, Head, and Larios, 2010; Lavie and Tractinsky, 2004; Moshagen and Thielsch, 2010; Ngo, Teo, et al., 2003). Aesthetics impact perceived trustworthiness, usability, and UX (Lee and Koubek, 2010; Tuch, Bargas-Avila, and Opwis, 2010), and is therefore a critical factor in web design (e.g., ecommerce websites). Within the field of website aesthetics, several determinants of aesthetic and beautiful websites have been identified, such as symmetry, complexity, balance, colors, and shapes (Bauerly and Liu, 2006; Moshagen and Thielsch, 2010; Ngo, Teo, et al., 2003; Tuch, Bargas-Avila, and Opwis, 2010). Several aesthetic factors have also already been investigated based on neurophysiological measurement, such as symmetry (Vasseur et al., 2019) and color (Nissen, 2020a,b). However, other design factors have received much less attention or have not been studied at all, including shapes of different user interface (UI) elements, in particular the shape of buttons (Tao et al., 2018). Research indicates that different shape forms (curved, sharp) influence perceptions

of aesthetics, emotion, and purchase intentions (Bar and Neta, 2007; Westerman, Gardner, et al., 2012). The stimuli used in these studies comprise lines, abstract figures, products, and interior designs (Bar and Neta, 2006; Guthrie and Wiener, 1966; Silvia and Barona, 2009; Vartanian, Navarrete, et al., 2013). More importantly, it has been consistently found that sharp objects and designs often lead to increased activation in arousal and fear-related brain areas, particularly in the amygdala, while curved designs elicit activations in reward-related brain areas, particularly in the anterior cingulate cortex (ACC) (Bar and Neta, 2007; Vartanian, Navarrete, et al., 2013; Westerman, Gardner, et al., 2012). At this point, it needs to be noted that all neurophysiological studies on shapes were conducted with functional magnetic resonance imaging (fMRI) (Bar and Neta, 2007; Vartanian, Navarrete, et al., 2013). Although fMRI offers high spatial resolution, it is limited in its external validity due to participants' being required to stay in position. Especially for measurements which involve looking at or using a website, more natural measurements must complement fMRI research since restraining the movements of users may have an impact on the intensity of emotional experience (Kemp et al., 2015). Thus, an investigation of button shapes on websites not only offers room for upcoming studies with self-reported and behavioral measures, but also with mobile neuroimaging methods such as functional near-infrared spectroscopy (fNIRS).

In addition, a recent trend in UI design in general, and in website design in particular, is the use of dark mode. Although this design trend has been around for several years already, scientific research on the effects of different design modes (dark vs. light) is scarce (Nazeriha and Jonsson, 2020; Pedersen et al., 2020). First results indicate that while no significant impact on user performance seems to exist (Pedersen et al., 2020), trust ratings are higher for the light mode (Nazeriha and Jonsson, 2020). However, practice more often adapts this trend in major operating systems and apps (i.e. Windows 10, macOS X), as well as on websites. While the use of dark mode is often justified with saving resources of OLED displays, an investigation on how this impacts users' experiences is still lacking (Nazeriha and Jonsson, 2020).

Consequently, both button shape and design mode may have a significant impact on users' perceptions and attitude towards a website. Given that, to the best of our knowledge, only little scientific research on the effects of round versus sharp button design exists, along with the fact that only few studies on the effects of dark design mode are available, this study aims to instigate such research. Because color in web-site design may strongly affect website perception, and hence may even override the effects elicited by button shapes (Leder et al., 2011), we also consider color in

our study. Against this background, based on the context of ecommerce websites, this pilot study investigates three design factors with an online survey: sharp versus curved buttons, dark versus light design mode, and red versus blue color scheme of the website. The results of this survey will then be used to select stimuli and experimental designs for a follow-up neuroimaging study.

The remainder of this paper is structured as follows: First, we discuss related work on human evaluations of curved versus sharp designs, as well as the use of color and design mode in website design. Next, we develop our working hypotheses. Afterwards, the experimental design and method is presented, followed by the results. We close this paper with a brief discussion and an outlook on the follow-up study.

3.2.2. Related Work and Hypotheses

Human Preference for Curved Shapes

Humans tend to prefer round or curved shapes and objects over sharp, rectangular, or angular shapes and objects (Bar and Neta, 2006, 2007; Guthrie and Wiener, 1966; Silvia and Barona, 2009). This has been consistently found across several research contexts such as car design, consumer product designs, abstract shapes, or interior architectural design (Bar and Neta, 2007; Leder et al., 2011; Silvia and Barona, 2009; Vartanian, Navarrete, et al., 2013; Westerman, Gardner, et al., 2012). Since this preference can also be observed in new born babies and great apes, evolution has likely shaped this preference (Munar et al., 2015). Also, curved designs tend to be regarded as more natural and harmonious compared to sharp angled design (Gómez-Puerto et al., 2016). Following the processing fluency theory of aesthetic pleasure, curved design might be more fluently processable by humans and is therefore regarded as more beautiful (Bertamini, Palumbo, and Redies, 2019; Reber, Schwarz, and Winkielman, 2004). This finding is substantiated by an fMRI study in which participants judged curved designs as more beautiful, which was associated with activations in a neural network related to aesthetic and reward processing (Vartanian, Navarrete, et al., 2013). Next to aesthetic evaluations, curved designs also tend to be associated with quiet or calm sounds, green color, and relieved emotion while sharp designs are more attributed to loud and dynamic sound, red color, and excited emotion (Blazhenkova and Kumar, 2018). For consumer products, sharp or angular design seems to elicit negative emotions associated with threat (Aronoff, Barclay, et al., 1988; Aronoff, Woike, et al., 1992; Bar and Neta, 2006; Lundholm, 1921; Poffenberger and Barrows, 1924), while curved designs lead not only to more positive aesthetic evaluations, but also to increased purchase intentions (Westerman, Gardner, et al., 2012). Consequently, we propose that websites with round buttons will elicit a

more positive emotional experience (measured with pleasure), which further results in approach behavior (measured with use intention):

> *H* 1*: Websites with round buttons will be rated higher in pleasure and use intention, if compared to websites with sharp buttons.*

Color and Design Mode

Research on the impact of color on human perception and emotion has a long history (Munsell, 1912; Newton, 1704; von Goethe, 1810), and has also been frequently re-searched in the context of website design (Nissen, 2020b; Pelet and Papadopoulou, 2012; Silic et al., 2017). In essence, blue colors on websites have a calming, positive emotional effect, while red colors tend have a more negative emotional effect and are related to arousal (Abegaz et al., 2015; Becker, 2002; Bellizzi and Hite, 1992; Bonnardel et al., 2011; Chang and Lin, 2010; Cyr, Head, and Larios, 2010; Fortmann-Roe, 2013; Palmer and Schloss, 2010; Pelet and Papadopoulou, 2012; Seckler et al., 2015; Westerman, Sutherland, et al., 2012). Furthermore, blue websites are perceived as more trustworthy than red or yellow websites (Chang and Lin, 2010). The described effects were consistently found across a variety of studies, all of which were including different shades of blue and red, and identified the effects in behavioral and neural measurements (Nissen, 2020b). Consequently, we propose that color has a significant effect on pleasure and arousal as measures for the emotional experience, and perceived trustworthiness and attitude as indicators for behavioral intention:

> *H* 2*: Blue websites will be rated higher in pleasure, perceived trust-worthiness, and positive attitude towards the website, but lower in arousal, if compared to red websites.*

Related to colors in website design is design mode, which can either be dark or light. Design mode is an uprising UX design element, and a dark design is currently a trend in UI design as signified by its integration into major operating systems such as Windows, macOS, iOS, and Android (Riegler and Riener, 2019). Interestingly, there is a paucity of academic literature on the effects of dark mode on UX. Generally, dark mode could delay visual fatigue and increase visual comfort, especially in environments with poor lighting conditions (Erickson et al., 2020; Kim, Erickson, et al., 2019). However, although users perceive their performance to be increased on dark over light designs (Kim, Erickson, et al., 2019), studies have found that there are no significant differences in reading performance between the designs (Pastoor, 1990; Pedersen et al., 2020). With respect to perceived trustworthiness, first results suggest that websites designed in dark mode can lead to lower perceived

trustworthiness than light mode (Nazeriha and Jonsson, 2020). Consequently, we propose:

> *H 3: Websites designed in dark mode will lead to lower ratings in perceived trustworthiness, if compared to websites in light mode.*

3.2.3. Method

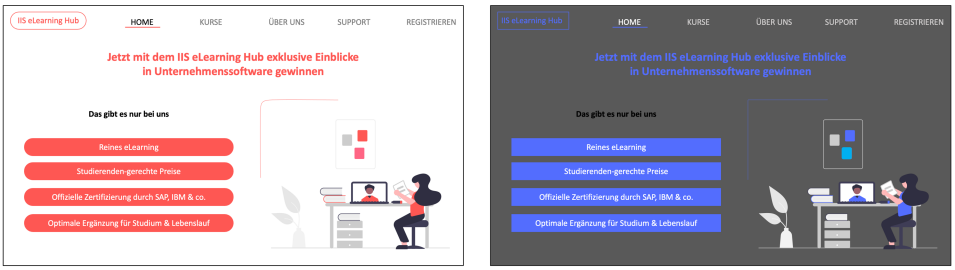
To test our three hypotheses and to identify potential stimulus material for the neuroimaging follow-up study, different versions of an ecommerce website (e-learning courses) were created and tested in this pilot study through an online survey. In this survey, participants viewed the different website designs and evaluated their perceived pleasure, arousal, trust, attitude towards the website, and use intention for each website version.

Sample

The online survey was distributed through the platform clickworker to 137 participants from Germany, Austria, and Switzerland. The data of 20 participants were excluded due to missing data or because the rating of the attention check question was wrong (this question was randomly hidden between the other scales and asked participants to select '4' on the Likert scale). Consequently, a dataset of N = 117 participants remained for further analysis. The average age of the sample was $M_{\text{age}} = 40.7 years$ ($SD_{\text{age}} = 13.1 years$) with 54.7% being male and 45.3% being female. Regarding work status, 76.1% are currently employed, 12% are students, 6.8% searching for employment, 3.4% retired, .9% are in internship, and .9% are still pupils. Moreover, we asked the participants to indicate disposition to trust towards websites and their familiarity with booking e-learning courses on the web with validated scales taken from Gefen (2000) and Gefen and Straub (2004). Both ratings are based on a 5-point Likert scale resulting in $M_{\text{dispotrust}} = 3.01$ ($SD_{\text{dispotrust}} = .771$) for disposition to trust, and in $M_{\text{familiarity}} = 3.62$ ($SD_{\text{familiarity}} = .773$) for familiarity.

Stimuli and Study Design

We used a 2x2x2 factorial within-subjects study design with color (red, blue), button shape (round, sharp), and design mode (light, dark) as independent variables, and pleasure, arousal, trust, attitude, and use intention as dependent variables. The scales for pleasure were adapted from Huang, Ali, et al. (2017), arousal scales were adapted from Koo and Ju (2010), trust scales were taken and adapted from Gefen (2000) and Yoon (2002), attitude towards the website scales were taken and adapted from Porat and Tractinsky (2012), and finally, use intention scales were adapted from



a) Light design, red color and round buttons

b) Dark design, blue color and sharp buttons

Figure 3.4. Examples for Stimuli in the Pilot Study

Chen and Teng (2013). Since the study was conducted in Germany, examples of the used stimuli can be seen in Figure 3.4 (in German). The time participants took was not manipulated by the survey so that each participant could proceed at his/her own speed. All of the website versions and the scales were shown in randomized order. Each website version was shown with the scales of the dependent variables on one page of the questionnaire. When all scales were evaluated for the shown website version, participants had to click on a button to proceed with the next website. After having evaluated three different website versions, a questionnaire page with scales of the control variables disposition to trust and familiarity were shown without the websites. After that, further three website variations were presented with the scales of the dependent variables each, which was followed by a questionnaire page with demographic questions. Finally, the remaining two website versions were shown. This procedure was chosen to avoid fatigue in participants due to them having to rate the same items eight times without breaks.

Results

The data was analyzed with a repeated-measures multivariate analysis of variance (rmMANOVA) with the independent variables color, button shape, and design mode as repeated measures. Because we only included two levels per measure, sphericity is assumed. Although multivariate normality was not provided for half of the website design variations (measured with Mardia's skewness and kurtosis, threshold $p < .05$) (Mardia, 1970), rmMANOVA still seems to provide more robust results than non-parametric alternatives (Finch, 2005). Yet, the following results may be treated with care. Across all included dependent variables, significant differences could be identified for color ($F(5, 112) = 6.159, p < .001, \eta_p^2 = .216$) and design mode ($F(5, 112) = 4.161, p = .002, \eta_p^2 = .157$), but not for button shape ($F(5, 112) = 1.707, p > .05, \eta_p^2 = .031$). Furthermore, only a slightly significant interaction effect between color and design mode could be detected ($F(5, 112) = 2.405, p = .033, \eta_p^2 = .097$). No interaction effects between all three

independent variables (color x button shape x design mode), nor between color and button shape, or between design mode and button shape were found (all with $p > .05$).

Regarding button shape, no significant differences were identified in any of the dependent variables (all with $p > .05$). Thus, based on the data of this pilot study, H1 has to be rejected. However, a medium strong effect could be identified for color for which the most significant difference was found for arousal ratings ($F(1, 116) = 12.873, p < .001, \eta_p^2 = .100$), followed by slightly significant different ratings of pleasure ($F(1, 116) = 4.139, p = .044, \eta_p^2 = .034$), and use intention ($F(1, 116) = 4.264, p = .041, \eta_p^2 = .035$); all of which were rated more positive for the blue web-site versions. However, no significant differences could be identified for trust ($F(1, 116) = 2.389, p > .05, \eta_p^2 = .02$) and attitude ($F(1, 116) = 1.465, p > .05, \eta_p^2 = .012$) between the blue and red website versions. Hence, H2 is only partly supported. Finally, the strongest effect was found for design mode, thus, all included dependent variables revealed significant differences between light and dark design, with all ratings being in favor of the light design mode ($F(1, 116) = 26.03, p < .001, \eta_p^2 = .183$ for pleasure, $F(1, 116) = 13.269, p < .001, \eta_p^2 = .103$ for arousal, $F(1, 116) = 20.913, p < .001, \eta_p^2 = .153$ for trust, $F(1, 116) = 21.304, p < .001, \eta_p^2 = .155$ for attitude, and $F(1, 116) = 22.794, p < .001, \eta_p^2 = .164$ for use intention). Consequently, H3 is supported by these results.

3.2.4. Discussion & Follow-Up Neuroimaging Study

Discussion of Self-Reported Results

Given the consistency of findings in the related literature on sharp versus round object designs over several research contexts, the rejection of H1 was unexpected. Paired with the significant differences in arousal for color, and the significant differences between light and dark designed websites for all included outcome variables, we conclude that color and design mode tend to have stronger effects than button shape. In particular, this pilot study shows that an in-depth investigation of the effects of design mode on website users' perceptions is crucial.

Our investigated outcomes can have a significant effect on actual website use and thus, business success. What follows is that further investigation of design mode has high relevance for both academia and practice. Specifically, based on the findings of this pilot study, we will study potential differences in the neural processing of light and dark designed websites to gain further insights into how both design modes are perceived and processed in the brain. Also, because the extant brain

imaging literature on sharp versus round designs has revealed significant differences in neural activity related to emotion and threat processing (Bar and Neta, 2007; Vartanian and Skov, 2014), we surmise that even though no significant differences in self-reports could be observed in this pilot study, an identification of significant neurophysiological differences is likely. Furthermore, the increase in self-reported arousal for the red website is supported by neural investigations of color on websites which revealed increased activations for websites designed in reddish color (Nissen, 2020a,b). In an attempt to further validate these results, color manipulation is also planned to be included in the follow-up brain imaging study. At this point, it needs to be mentioned that the impact of color on user perceptions and processing might depend on the intensity and shade of the used colors. In our pre-study, only one level of intensity and shade was considered which was held constant across the red and the blue website version. Follow-up research on color could therefore focus on different shades and intensity levels to detect possible effects of these features on user perceptions and behavioral intentions. Finally, as already pointed out, design mode had a significant effect on users' perceptions in this pilot study. In fact, the impact of design mode might have been so overwhelming that effects due to button shape for the outcome variables were not consciously recognized by the participants.

Follow-Up Neuroimaging Study

The upcoming neuroimaging study will thus primarily focus on the effects of but-ton shape and colors by means of the mobile neuroimaging method functional near-infrared spectroscopy (fNIRS) in an attempt to overcome the limited external validity of fMRI measurements. fNIRS offers a lightweight method which is portable and thus, it can be applied to realistic use contexts (Kim, Seo, et al., 2017; Nissen, Krampe, et al., 2019). Although fNIRS has shown to be a promising method to investigate NeuroIS constructs (Gefen, Ayaz, et al., 2014; Hirshfield, Bobko, Barelka, Hirshfield, et al., 2014; Krampe, Gier, et al., 2017; Nissen, 2020b; Nissen, Krampe, et al., 2019), its application in NeuroIS research is still scarce (Riedl, Fischer, et al., 2020).

Further, the neural effects of color and shapes have been primarily measured with fMRI (Bar and Neta, 2007; Siok et al., 2009; Vartanian, Navarrete, et al., 2013; Zeki and Marini, 1998) which also assesses the hemodynamic response function (hrf) as measure to identify neural activations. While fNIRS also relies on the hrf, it is applicable in more realistic scenarios than fMRI and does not require participants to lay down. Still, since it does measure hrf, too, results from fNIRS heavily correlate with fMRI results which offers potential to compare fMRI and fNIRS results between

studies (Hoshi, Kobayashi, et al., 2001; Huppert et al., 2006; Noah et al., 2015; Sato et al., 2013). Next to fNIRS, electroencephalography (EEG) also offers a mobile method that allows for field experiments and is frequently applied in neuroIS research (Riedl, Fischer, et al., 2020; Riedl, Minas, et al., 2020). Although EEG has higher temporal resolution (Müller-Putz et al., 2015), fNIRS is more robust against task unrelated activations on cortical surfaces due to respiration or movements (Girouard et al., 2010), and also offers higher spatial resolution than EEG (Pinti, Tachtsidis, et al., 2020). While both EEG and fNIRS are limited to measuring neural activations on cortical structures, we will further focus on areas of the prefrontal cortex (PFC) as regions of interest.

Although fMRI studies on color and shapes have found activations primarily in the amygdala, they have also found significant activations in the PFC (Vartanian, Navarrete, et al., 2013; Zeki and Marini, 1998). Explanations for this can be found in several studies which investigate the links between the PFC and other brain regions. That is, across several contexts, the dorsolateral and ventrolateral PFC were found to exhibit top-down control on activations in the visual cortex due to their role in attention control (Gazzaley et al., 2007; Kornblith and Tsao, 2017; Masquelier et al., 2011). Further-more, the dorsomedial and ventromedial PFC were found to exhibit control on amygdala activations for means of emotion regulation (Buhle et al., 2014; Delli Pizzi et al., 2017; Dolcos et al., 2011; Ellard et al., 2017; Schienle et al., 2014). These findings make the PFC an interesting region to study in relation to the processing of color and button shapes, which is also well assessable by means of fNIRS. This approach is further supported by related research focusing on neural activation changes in the PFC depending on color use in the context of ecommerce websites which were assessed with fNIRS (Nissen, 2020a,b). Beyond the planned upcoming study, future research could investigate design elements such as color, button shapes, and design mode with combined EEG-fNIRS measurements to cover both the electrical potential, as well as hrf related to website design variations. Since applications of fNIRS in this research domain are still scarce, combined measurements are even rarer (Hirshfield, Chauncey, et al., 2009). Therefore, this offers a fruitful approach for other follow-up studies. As a first step, however, fNIRS offers a still novel, yet appropriate approach to validate whether prior results apply to website design, too, that go beyond the conscious recognition of design elements.

3.3. Paper 3: Visual Website Design from an Evolutionary Psychology Perspective: Results of an Experiment Based on Neuroimaging and Self-Report Measures

Abstract

Website design decisions consider visual stimuli such as colors and shapes and have a significant impact on user behavior. This article uses evolutionary psychology as a theoretical lens for studying the effects of colors and shapes on e-commerce websites. Referring to the evolutionary their meaning, we derive hypotheses that are tested in a neuroimaging experiment utilizing functional near-infrared spectroscopy (fNIRS). In a e-commerce website evaluation task, results of 38 participants reveal significant differences in self-reported pleasure, distrust, and attitude toward colored versus uncolored websites. Moreover, colored websites led to deactivation in the right dorsolateral prefrontal cortex (PFC) when compared to uncolored websites. When comparing blue and red websites, a significant deactivation in the left ventromedial PFC, orbitofrontal cortex, and the left dorsolateral PFC was identified for the blue website. Overall, these results signal a cognitive relief for the use of color on websites in general, and for the use of the color blue in particular. Further, when comparing the use of sharp versus rounded button shapes, significant increases in the premotor cortex and dorsomedial PFC, as well as in the right ventromedial PFC and orbitofrontal cortex, were identified for rounded shapes. We discuss theoretical and practical implications of our findings.

3.3.1. Introduction

In website design, the visual design and associated aesthetic perception of a website is a critical factor for positive user experience, and therefore, business success (Kwak et al., 2019; Porat and Tractinsky, 2012; Thielsch, Haines, et al., 2019). Visual website design comprises a mix of website design elements (e.g., colors, shapes, images), and the ways in which these elements are put together to create a holistic sensation (Cyr, 2014; james Garrett, 2010; Moshagen and Thielsch, 2010). Website design positively influences user experience and satisfaction, content evaluation, perceived trustworthiness, and revisit intentions (Cyr, 2008; Evanschitzky et al.,

2004; Lee and Koubek, 2010; Szymanski and Hise, 2000; Thielsch, Blotenberg, et al., 2014; Tuch, Bargas-Avila, and Opwis, 2010; Zhou and Fu, 2007). Related works have predominantly focused on behavioral intentions of users, determined either by layout aspects (e.g., symmetry, simplicity, complexity) (Altaboli and Lin, 2011; Bauerly and Liu, 2006; Deng and Poole, 2010; Moshagen and Thielsch, 2010; Ngo and Byrne, 2001; Tractinsky et al., 2006) or by selected visual design elements such as colors, shapes, and images (Abegaz et al., 2015; Bonnardel et al., 2011; Cyr, Head, and Larios, 2010; Cyr, Head, Larios, and Pan, 2009; Nissen, 2020a; Tuch, Bargas-Avila, Opwis, and Wilhelm, 2009). However, only few studies focus on elaborating explanations for a deeper understanding as to why the observed behavioral intentions occur in the first place.

With regard to the visual design elements, color has received much attention in research because the colors used in a website design can have a strong impact on users' first impressions, thereby facilitating use intentions (Bonnardel et al., 2011; Cheng et al., 2019; Lindgaard, Fernandes, et al., 2006; Nissen, 2020a; Tractinsky, 2005). Evidence indicates that cool colors (e.g., blue) have a positive impact on behavioral intentions compared to warm colors (e.g., red) (Becker, 2002; Bonnardel et al., 2011; Cheng et al., 2019; Cyr, Head, and Larios, 2010; Nissen, 2020a). Prior research also considers the effects of images on users (Cyr, Head, Larios, and Pan, 2009). In contrast, however, few scientific investigations studying the effects of shapes in user interfaces are available. For example, only a limited number of studies investigate the effects of button shapes in user interfaces (Abegaz et al., 2015; Fjeld et al., 2003; Tao et al., 2018). Altogether, despite the fact that evidence does exist regarding the effects of visual design elements in human interaction with graphical user interfaces (GUIs) – and in particular with e-commerce websites – this evidence is still limited (for details, see the review of related work in Section 2).

Analyses of the existing research findings indicate that blue color and rounded shapes seem to have positive behavioral effects, while the use of red color and sharp shapes seem to be detrimental to behavioral intentions and user performance (Abegaz et al., 2015; Bonnardel et al., 2011; Cyr, Head, and Larios, 2010; Fjeld et al., 2003; Gnambs, Appel, and Batinic, 2010; Tao et al., 2018). Moreover, analyses of the related work show that most of the available investigations have only employed self-report measures to assess the design effects on outcome variables such as perceived trustworthiness of, or attitude toward, a website (Bonnardel et al., 2011; Cheng et al., 2019; Cyr, Head, and Larios, 2010; Fortmann-Roe, 2013; Palmer, Schloss, and Sammartino, 2013). However, based on self-reports alone it is hardly possible to provide a comprehensive understanding of IS phenomena in

general (e.g., Dimoka, Pavlou, et al., 2011b), and of website design phenomena in particular (e.g., Cyr, Head, and Larios, 2010; Dimoka, Banker, et al., 2012; Riedl and Léger, 2016; vom Brocke, Riedl, et al., 2013). Therefore, in the frame of neuroIS research, the use of neurophysiological measurement has been suggested as a complement to self-reports in order to study IS phenomena. This complementary use of neurophysiological data helps to better explain why and how specific effects occur, on both perceptual and behavioral levels. As outlined in detail before, this explanatory power of the neuroscience approach is even more pronounced when it comes to universal characteristics of humans, such as those related to perception of color and shape.

It has been argued in the IS literature that evolutionary psychology constitutes a valuable theoretical lens for studying and explaining user behavior, a fact that holds particularly true for traits that are fairly consistent across different cultures, including color and shape perception (Jacobs and Nathans, 2009; Kock, 2009; Lee, 2008; Shi, 2013). In his seminal work, Kock (2009) writes: *"Evolutionary psychologists generally believe that many of our modern brain functions evolved during the period that goes from the emergence of the first hominids around 3.5 million years ago until the emergence of modern humans about 100 thousand years ago [. . .] The field of evolutionary psychology is concerned with evolved psychological traits [. . .] These are mental traits that are hypothesized to have a genetic basis, and that are assumed to have evolved among our ancestors because they enhanced those ancestors' reproductive success"* (pp. 395-397). Interestingly, only little previous website design research has used evolutionary psychology as an explanatory theoretical basis (Gnambs, Appel, and Batinic, 2010; Riaz et al., 2018), and these studies only used self-reports as empirical evidence. While this approach is not adverse per se, it is obvious that complementary neuroscientific evidence promises insight that goes beyond the knowledge that can be developed based on users' introspective accounts alone.

Brain regions of the the prefrontal cortex (PFC) integrates information from various brain areas and hence are the central decision hub in the human brain (e.g., Bechara and Damasio, 2005; Bechara, Damasio, and Damasio, 2000; Burgess et al., 2007; Damasio, 1994; Deppe et al., 2005; Koechlin et al., 1999; Krampe, Gier, et al., 2018). In related neuroIS studies, activation in the PFC has been linked to positive user experience (Ding, Cao, et al., 2020), emotion and e-loyalty (Gregor et al., 2014; Kuan et al., 2014), as well as to social interactions (Lai et al., 2016). Furthermore, activity in the PFC has also been identified for the detection of decision conflicts (cognitive dissonance) (Moravec et al., 2019), attentional and

motor planning processes (Ding, Hu, et al., 2018; Léger et al., 2014), and memory retrieval (Dong and Jeong, 2018) when interacting with IT artefacts. As a result, the present study focuses on analysis of brain data in this region as it incorporates several key processes required for website perception, evaluation, and decision making.

More precisely, we study PFC processes during human perception of websites, experimentally manipulating those websites regarding their color and shape design, and by applying functional near-infrared spectroscopy (fNIRS). fNIRS was introduced in the IS literature by Gefen, Ayaz, et al. (2014), who explicitly suggest the application of this brain imaging tool for the study of human-computer interface design questions. Specifically, Gefen, Ayaz, et al. (2014) argue that *"this could include identifying the optimal location, shape, color, picture, and other attributes [. . . and fNIRS] could also be used to gauge the ease of use of new interface designs by measuring PFC activity levels as people navigate through computer interfaces. Currently, this is done through subjective assessments. fNIR[S] creates the possibility of making these assessments objective"* (p. 65-66). The current study is a direct response to this research call. Because IS research, compared to neuroscience research in general, is not interested solely in brain data, we also measured important outcome variables that capture users' website perceptions. Specifically, based on validated self-report instruments, we assessed pleasure, distrust, and attitude toward the website. Altogether, the use of evolutionary psychology theorizing in combination with brain and self-reported data makes possible the development of novel knowledge regarding the role of color and shapes in website design.

This paper contributes to the body of IS knowledge by addressing the effects of color and button shapes as visual website design elements by using a neuroimaging experiment focused on the PFC. We also contribute to the evolutionary psychology literature in the IS domain (Kock, 2004, 2005, 2009; Kock and Chatelain-Jardón, 2011), where investigation of visual design of websites has so far been carried out only from the basis of self-reported data (Cyr, Head, and Larios, 2010; Gnambs, Appel, and Batinic, 2010; Riaz et al., 2018). Importantly, two existing neuroIS studies have already shown that evolutionary psychology theorizing, in combination with functional brain imaging, offers significant research potential (Riedl, Mohr, et al., 2014; Walden et al., 2018). Against the background of the outlined research status and the calls for user interface design research based on fNIRS, as well as the value of evolutionary psychology theorizing for IS research, the current study tackles the two following goals:

1. to explain the effects that the visual website design elements of color and shapes have on users, based on evolutionary psychology theorizing, and

2. to substantiate the theoretical explanations through neuroimaging and through self-reported data that is based on a laboratory experiment in which participants perceived and evaluated websites.

The remainder of this paper is structured as follows. First, we summarize the status of research in the area of website design that is available in IS and HCI publications. Next we provide an outline of evolutionary psychology as a theoretical lens, along with the development of our hypotheses. Afterward, we outline the methodology of our laboratory experiment and the employed neuroimaging method (fNIRS). We then present the results and a discussion in which we provide theoretical and practical implications, as well as the limitations of the present study, and finally, come to a conclusion.

3.3.2. Related Literature

Several aspects of website design have been researched in the domains of IS and HCI.[1] A structured summary of the identified related work is provided in the Appendix. These works identify various website design elements (e.g., color or animations) as relevant for the perception of a website. These elements have been found to have a significant impact from users' first impressions of a website, and these impressions were found to carry over to later interaction stages (Campbell et al., 2013; Jiang et al., 2016; Kwak et al., 2019; Lowry et al., 2014; Pengnate, Sarathy, and Lee, 2019; Ye et al., 2020). Analysis of the literature further reveals that many studies deal with layout-related design elements such as overall symmetry or complexity (Campbell et al., 2013; Chen, Lin, et al., 2011; Cyr and Head, 2013; Deng and Poole, 2010; Hasan, 2016; Jiang et al., 2016; Kwak et al., 2019; Moody and Galletta, 2015; Pengnate and Antonenko, 2013; Pengnate and Sarathy, 2017; Pengnate, Sarathy, and Lee, 2019; Seckler et al., 2015; Tuch, Bargas-Avila, and Opwis, 2010). Interestingly, images and colors have been less frequently investigated than layout-related aspects, and no single study has investigated shapes as independent variable. Specifically, only 20% of the reviewed articles investigate color as a design factor; the studied

[1]To get an overview of the recent research (since 2010) published in top journals, we conducted a literature search using "website design" as search term. We searched the eight leading IS journals defined by the AIS Basket of Eight, as well as the eight major HCI journals that were identified in a literature review by Gurcan et al. (2021) (*Computers in Human Behavior, International Journal of Human Computer Studies, Ergonomics, Journal of Neural Engineering, Interacting with Computers, Lecture Notes in Computer Science, IEEE Transactions on Neural Systems and Rehabilitation Engineering, International Journal of Human Computer Interaction*).

dependent variables are emotional valence, arousal, and attention (Ye et al., 2020), overall aesthetic perceptions (Seckler et al., 2015), consumer mood, recall of the presented information, and purchase intentions (Pelet and Papadopoulou, 2012). The studies address, as well, trust, satisfaction, and loyalty (Cyr, Head, and Larios, 2010). Overall, behavioral intentions formed through attitudes toward a website, as well as dimensions of trust, distrust, and emotional responses, were the most frequently investigated aspects in the extant literature.

Methodologically, the majority of the reviewed papers use self-reported measures (questionnaires, interviews) to collect the data for their studies. Only a limited number of papers complement self-reports with performance data such as time on task or click behavior (Moody and Galletta, 2015; Tan et al., 2015), or with eye tracking data that provide a more direct measure of attention (i.e., fixation time) and arousal (i.e., pupil dilation) (Cheung et al., 2017; Cyr, Head, and Larios, 2010; Hong et al., 2021; Ye et al., 2020). For example, studies reveal the ways in which different design features alter arousal and attention, and thereby, information processing (Cheung et al., 2017; Hong et al., 2021; Ye et al., 2020). Color has been shown to have a significant impact on users' arousal, which in turn not only impacts attention resources (Ye et al., 2020), but evaluations of visual appeal, trustworthiness, and satisfaction as well (Cyr, Head, and Larios, 2010). Moreover, the literature reports additional downstream effects, including attitude toward a website, and ultimately, users' adoption decisions (Campbell et al., 2013; Jiang et al., 2016).

What becomes evident from our review of related works is that color has a significant impact on behavioral intentions of website users, yet this effect has been investigated almost entirely with self-report measures. Although color has been investigated through the use of self-reports, and a few studies also apply eye tracking, no single study has employed neuroimaging tools to complement the perceptual and behavioral data. However, as previously noted, complementing self-reported data with neurophysiological measures can be expected to offer additional and unique insights that are not revealed through use of self-reported and behavioral data alone.

3.3.3. Evolutionary Psychology and Website Design: Theory and Hypotheses

A useful theoretical approach for studying users' reactions to colors and shapes in website design is evolutionary psychology. That is, because color and shape are basic elements that are omnipresent in everyday lives of (healthy) humans, and that were also present in nature during human evolution. Therefore, we introduce evolutionary

psychology as the underlying framework of our study. We also refer to the presented neural areas of the PFC and how they might be related to website perception.

Foundations of Evolutionary Psychology

Evolutionary psychology is an important reference discipline for the IS field (Kock, 2001, 2009; Kock and Chatelain-Jardón, 2011). Applications of this theoretical lens in IS research comprise the following major domains, among others: e-communication, post-adoption information technology use, knowledge transfer through web interfaces, e-learning, online dating (Kock, 2001, 2004, 2005, 2010), website design (Riaz et al., 2018), and the fatigue and stress that results from videoconferencing (Riedl, 2021). Moreover, two neuroIS studies use evolutionary psychology theorizing in combination with fMRI: one study investigates human interaction with and trust in avatars (Riedl, Mohr, et al., 2014), and the other study examines perception of 3-dimensional versus 2-dimensional data graphs (Walden et al., 2018).

Research on the use of color in e-learning environments also applies an evolutionary psychology perspective (Gnambs, Appel, and Batinic, 2010). By drawing on an evolutionary approach, Gnambs, Appel, and Batinic, 2010 explain how the use of color red as primary design element in web-based environments is detrimental to users' cognitive performance. This effect is explained by the function of red in human ancestral environments, wherein larger red elements often indicated a threat to a person's survival (e.g., blood). As a result of these survival-critical signals that evolved over long periods in human history, avoidance and withdrawal behavior can still be observed as a stereotypical reaction in today's modern environments. It is therefore argued that developments in digital technology are too recent to overwrite these evolved, innate responses to fundamental visual elements (e.g., color), even in virtual environments such as those found on websites (Kock, 2004). To ensure survival, both the human brain and its vision system evolved to interpret color in nature as codes that inform approach and avoidance (Humphrey, 1976).

The ability to perceive colors, as well as to recognize shapes, was not acquired just by "modern" humans, but the evolution reaches back about 440 million years ago (Vallerga, 1994). Even the human trichromacy color vision as we know it today is believed to have evolved over the past 35 million years (Bowmaker, 1998). The human need for an ability to discriminate colors and shapes had specific purpose in ancient environments, long before it had purpose in the age of websites. The alteration of a species in a way that is hereditary, and by which a species improves its survival fitness, is referred to as evolutionary adaption (EA), and the ancestral environment to which a species is adapted is referred to as the environment of evolutionary adaption

(EEA) (Cosmides et al., 1992; Darwin, 1859; van de Braak, 2013). In this context, it is logical to accept that the human vision system and the corresponding neural processing of visual information have been programmed to support survival even in ancestral environments, and thereby to increase survival fitness over time. Because different colors signified either comfort or harm in more ancient times, there is reason to assume that humans continue to have immediate neural responses to these colors, and to do so in a way which can also have behavioral consequences (Humphrey, 1976; Kock, 2004). IS research has shown that although culture modulates color preference, it only modulates it to a certain degree. In essence, the appreciation of blue websites continues to persist across different cultures (Cyr, Head, and Larios, 2010). Similarly, the meaning of red as a warning color also holds true across cultures (King, 2005). This universality and neural response to color perception supports the notion that the effects of color and shapes as design elements not only relates to the user's aesthetic and emotional evaluation of a website, but can also impact the cognitive functioning of the website user. Therefore, in the attempt to better understand the effects of website color and shape on user behavior and decision making, application of an evolutionary approach promises to yield useful insight.

Similarities Between Website Design Elements and the EEA

Human vision evolved over time, moving from only being able to discriminate between dark and light, to the ability to perceive movements, colors, and shapes (Vallerga, 1994). Researchers argue that the highly evolved trichromatic color vision of primates was influenced by the increased cognitive flexibility that is predominantly a function of phylogenetically younger areas of the brain, in particular the PFC (Jacobs and Nathans, 2009). This visual system provided significant improvements in the ability to detect edible fruits, by allowing the perception of more shades on the medium- and long-wavelength spectrum (i.e., the colors red, orange, yellow, and green) (Bowmaker, 1998; Jacobs and Nathans, 2009). This improved ability also means that both vision and brain are trained to perceive a wide range of colors in varied environments, and to have the ability to read the codes that colors signify, with regard to their meaning for individual and cultural survival (Humphrey, 1976).

Similarly, shapes or objects also convey codes, as the rounded shapes that are common in foods supplied by nature (e.g., apple or berries) tend to be associated with safety, and signal that they are touchable without harm. Sharp shapes, in contrast, signal that they might cut (e.g., sharp stones or thorns), and therefore may indicate harm if touched (Aronoff, Barclay, et al., 1988; Aronoff, Woike, et al., 1992). It is therefore reasonable to assume that if colors and shapes are used in more

artificial environments such as websites, architecture, or product design, the same responses to color and shape codes that evolved over millions of years continue to exist for humans, and contribute to decision making (Barbey and Grafman, 2011), and aesthetic appreciation (Cela-Conde, Garcia-Prieto, et al., 2013; Cela-Conde, Marty, et al., 2004) – responses that are processed primarily in the PFC.

Along with their evolutionary codes, colors and shapes as visual website design elements also convey information about the structure of the website, about which parts of the website are interactive and which are not, and they add to the overall aesthetic experience of the website. These aspects together determine, whether a website is perceived as appealing and is therefore likely to be further used. The extant website design literature utilizes different measures to capture approach or avoidance behavior toward a website (Campbell et al., 2013; Chen, Lin, et al., 2011; Deng and Poole, 2010; Lowry et al., 2014; Ye et al., 2020), thereby signifying the relevance of the most basic responses of species to environmental stimuli. However, while human interaction with a website is not usually detrimental to users' physical well-being (as its referent in the EEA would be), it can nevertheless be very harmful to the users' overall well-being – if, for example, financial data is leaked in online transactions or the user is deceived by the website provider. Consequently, benevolence evaluations are always present which are based on the visual elements that are perceived on the website.

As a result, a great deal of research has also focused on trust and distrust in websites as crucial antecedents of behavioral intentions (e.g., Dimoka, 2010; McKnight et al., 2002; Moody, Galletta, and Dunn, 2017). From an evolutionary standpoint, distrust can be conceptualized as immediate negative emotional response as it is the active expectation that the other will do harm and endanger safety (e.g., Hsiao, 2003; McKnight et al., 2002; Moody, Galletta, and Dunn, 2017; Moody, Lowry, et al., 2017). Humans have evolved through avoiding potential harm which makes distrust an evolved and crucial evaluation of a stimulus that is typically related to avoidance (Dimoka, 2010). However, we have also evolved by feeling pleasure in events and stimuli that increase our survival chances. Therefore, pleasure is often correlated with approach behavior (Mehrabian and Russell, 1974). These responses are the result of rapid, cognitive appraisals that guide decision making and behavioral intentions (Ortony et al., 1988; Scherer, 2001). In the following, we discuss the role of colors and shapes in detail based on evolutionary psychology theorizing.

Color from an Evolutionary Perspective

Physiologically, human color vision is referred to as trichromatic, because the human retina has three classes of photoreceptors for different wavelengths of light (i.e., blue, green, red) (MacDonald, 1999; Nathans, 1999). From these three primary colors, the human eye is especially sensitive to red colors and least sensitive for blues (Hunt, 1998). From an evolutionary standpoint, confrontation with larger amounts of red colors is often accompanied by negative emotional states such as distrust (Bonnardel et al., 2011; Jacobs and Hustmyer, 1974; Valdez and Mehrabian, 1994), increased cognitive load (Elliot, Maier, et al., 2007; Gnambs, Appel, and Kaspar, 2015), and avoidance behavior (Gnambs, Appel, and Kaspar, 2015; Mehta and Zhu, 2009), because in the past these colors often signaled harm through connections to fresh blood, fire, or red angry faces. This finding is further supported in studies that found red colors to be related to threat (Elliot and Aarts, 2011; Oyama, 2003). In contrast, blue colors are often associated with low arousal and positive emotional valence (i.e., pleasure). Blue colors are preferred because they are thought to signify open spaces, the daytime sky, and bodies of water (Abegaz et al., 2015; Fortmann-Roe, 2013; Suk and Irtel, 2010). This finding confirms research results in the website design literature indicating that blue websites are found to be rated as more pleasurable and more trustworthy than red websites, which typically is accompanied by a more positive attitude toward the website (Becker, 2002; Bellizzi and Hite, 1992; Bonnardel et al., 2011; Cyr, Head, and Larios, 2010; Fortmann-Roe, 2013). Considering these findings, we hypothesize that:

> *H* 1*: A blue designed website will be rated with higher pleasure, lower distrust, and more positive attitude than the same website designed in red.*

As we have outlined, both blue and red colors convey information to website users (Gegenfurtner and Kiper, 2003). Next to blue and red, achromatic colors (black, white, grey) are among the most used colors on websites (Herbert, 2016). Therefore, the question of what happens when color is absent in the sense of an achromatic website design must be explored. From an evolutionary standpoint, in the EEA visual information such as the amount of information, symmetry, contrast, or clarity have been proposed as providing a selective advantage, even if they do not serve to increase survival fitness (Reber and Schwarz, 2006). They are, thereby, associated with greater pleasure (Reber, Schwarz, and Winkielman, 2004). Since these characteristics determine the cognitive effort required to process the given visual information, researchers argue that "any variable that increases perceptual fluency [...] should increase liking for the perceived object" (Reber and Schwarz, 2006, p. 17). This hypothesis has also been supported by empirical evidence

related to visual designs (Nissen, Obermeier, et al., 2021), and to fonts (Huang, Li, et al., 2018; Motyka et al., 2016). As adding color to an interface design also adds information, an argument can be made that color in a design allows more effortless processing and therefore requires less cognitive effort. As a result, higher levels of pleasure are elicited from the increased ease of perception. Furthermore, an absence of color, and therefore of information, also means higher uncertainty for website users regarding which elements of the website can be interacted with. The importance of this condition is underscored by the identification of uncertainty as an antecedent to trust and distrust (e.g., Dimoka, 2010; Riedl, Hubert, et al., 2010). Therefore, a website without color may also increase uncertainty, as humans would naturally perceive an information deficit. This perception, in turn, has negative consequences on the overall attitude toward the website. From this standpoint, we hypothesize:

> *H 2: A colored website (red, blue) will be rated with higher pleasure, lower distrust, and more positive attitude than the same website without colors.*

Continuing with the issue of the conditions related to website users' processing effort, the lateral areas of the PFC (dorsolateral PFC (dlPFC) and ventrolateral PFC (vlPFC)) are involved in top-down and bottom-up control of the visual system, and thereby have been generally related to visual attention, attention control of visual stimulation, and cognitive effort (Gazzaley et al., 2007; Masquelier et al., 2011). In these areas, the increased neural activity has been related to higher amount of required oxygen, which is stimulated by a higher load of cognitive processing resources (Clemente et al., 2014; Li, Jiang, et al., 2014). Similarly, related neuroIS studies found the lateral PFC regions not only associated with working memory in visual processing (Clemente et al., 2014), but also related to processes of emotional valence and arousal (including threat) (Bandara et al., 2018; Warkentin et al., 2016), credibility judgments (Dimoka, 2010), and user engagement (Li, Jiang, et al., 2014; Nissen and Krampe, 2020). A recent study found that a black website results in higher lateral PFC activation than the same website in blue (Nissen, 2020a). Therefore, the argument that greater cognitive effort is the result of the lessened visual information available when color use is limited, we hypothesize:

> *H 3: A colored website (red, blue) will require less neural activation in the lateral PFC than the same website without colors.*

Activation specifically in the dlPFC has also been found in relation to trust. In a study of the perceived trustworthiness of websites, untrustworthy websites found to be related to a perception of pronounced negative emotion (i.e., distrust). Neurologically, this negative perception is correlated with increased activation of the

dlPFC, as well as of the ventromedial PFC and orbitofrontal cortex (vmPFC/OFC) (Hirshfield, Bobko, Barelka, Hirshfield, et al., 2014). While we discussed above how an absence of color will increase processing resources due to higher uncertainty and might therefore, be associated with higher distrust, the same arguments also apply for red when compared to blue websites. Furthermore, studies have shown that red colors can also have a negative impact on cognitive performance, due to the potential for increased resources required to process the color stimulation (Elliot, Maier, et al., 2007; Gnambs, Appel, and Batinic, 2010; Soldat et al., 1997). In the context of evolutionary psychology, this negative impact might be explained by the significant signal of threat (i.e., blood, fire, angry faces) conveyed by larger elements of red that increases attention load in the ultimate goal to survive (Osaka et al., 2013; van de Braak, 2013). It follows that the lateral PFC is also more likely to be activated for red websites, as compared to blue websites:

> *H* 4*: Websites designed in red color will result in greater neural activation in the lateral PFC compared to the same website designed in blue color.*

Shapes from an Evolutionary Perspective

Research indicates a human preference for rounded shapes (Bar and Neta, 2006; Gómez-Puerto et al., 2016; Guthrie and Wiener, 1966; Sander and Scherer, 2009). This preference holds true even when controlling for individual differences such as personality or artistic experience (Cotter et al., 2017; Palumbo, Rampone, et al., 2021). Interestingly, the preference for rounded shapes has also been found in great apes (Munar et al., 2015). This suggested evolutionary link acts to confirm the mechanisms of the development of shape preferences. Because rounded shapes are associated with safety, while sharp or spiky shapes naturally pose potential threat (e.g., teeth or sharp claws that cut) (Aronoff, Barclay, et al., 1988; Aronoff, Woike, et al., 1992; Bar and Neta, 2006; Munar et al., 2015), the question arises as to whether rounded shapes are actually preferred, or whether sharp shapes are just associated with more negative attitudes. In fact, one study has shown that a preference for rounded shapes does exist, while no negative attitude toward sharp shapes could be found (Bertamini, Palumbo, Gheorghes, et al., 2016). Moreover, research indicates that rounded shapes are associated with approach-related positive emotion words and with relaxed emotions, while sharp shapes are associated with avoidance-related negative emotion words, and with excited emotions (Blazhenkova and Kumar, 2018; Palumbo, Ruta, et al., 2015; Velasco et al., 2016).

Considering this evidence, we can argue that rounded shapes elicit decision processes related to higher pleasure and lower distrust more so than sharp shapes.

These responses are associated with approach or avoidance behavior (Mehrabian and Russell, 1974). In studies using a reaction task setting to measure approach and avoidance behavior toward shapes, evidence indicates that the approach reaction to rounded shapes is faster and more accurate than the reaction toward sharp shapes (Bertamini, Palumbo, and Redies, 2019; Palumbo, Ruta, et al., 2015). Considering that rounded shapes symbolize safety, we argue that rounded objects are also perceived as more approachable (Bertamini, Palumbo, and Redies, 2019). While these results were found when isolated shapes were investigated, it is not clear whether such responses can also be identified for websites where the overall visual complexity is higher. Furthermore, research findings suggest that the information provided by color is motivationally more decisive than information provided by button shapes (Bar and Neta, 2006; Leder et al., 2011; Velasco et al., 2016). A significant consequence of this finding is that the effects of shapes may not become visible in self-reported data but may only be revealed in the neural processing of the website design.

Within the decision making hub of the human brain (the PFC), activity in the vmPFC/OFC has been strongly linked to reward valuation processes and, thereby, to approach and avoidance tendencies (Brown et al., 2011; Cela-Conde, Garcia-Prieto, et al., 2013; Doi et al., 2013; Wallis, 2007). While research shows that both threats and rewards are processed in the vmPFC/OFC (Choi et al., 2013), neuroscience research has established that this area is more involved in reward processing and consequently, approach behavior than it is in threat processing and avoidance behavior (e.g., Crawford et al., 2020; Ernst et al., 2013).). These associations are supported in related neuroIS studies, where the medial parts of the PFC have also demonstrated activation with respect to both positive and negative emotions (Bandara et al., 2018), trustworthiness evaluations (Dimoka, 2010; Riedl, Mohr, et al., 2014), and working memory (De Guinea et al., 2014). Furthermore, these parts of the PFC significantly impact processes involved in preferences for websites and products (Luu and Chau, 2009; Nissen and Krampe, 2020), and have been found to be positively linked to increased purchase intentions (Grosenick et al., 2008). Results from related neuroimaging studies on the effects of shapes show that sharp shapes trigger threat processing while rounded shapes trigger reward processing (Bar and Neta, 2007; Vartanian, Navarrete, et al., 2013). These studies further conclude that rounded shapes are expected to elicit neural activation in the OFC, a highly plausible conclusion due to this area's association with pleasure (Bar and Neta, 2007). Considering that rounded objects' evolutionary codes are linked to safety and approachability, we hypothesize:

H 5: Websites designed with rounded button shapes will result in higher

neural activation in the vmPFC/OFC, compared to the same website designed with sharp button shapes.

3.3.4. Method

Non-manipulative brain research in neuroIS has been conducted based on three tools: electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and functional near-infrared spectroscopy (fNIRS) (Riedl, Fischer, et al., 2020). We compared these tools in order to make an informed selection of an appropriate neuroimaging method for the present study. While fMRI is the gold standard in neuroscience as it allows a whole-head image with high spatial resolution, it comes with the downside of high environmental noise, artificial measurements due to the fixation of participants in the scanner, and relatively low temporal resolution (Kopton and Kenning, 2014; Krampe, Gier, et al., 2017; Pinti, Tachtsidis, et al., 2020). Although fMRI is the method of choice when the study of whole brain activation is critical, this tool is not mandatory when the focus is an investigation of cortical activity such as the PFC (Gefen, Ayaz, et al., 2014). It is therefore reasonable to use a less intrusive method than fMRI that can effectively assess neural activation changes in the PFC. As a result, the preferred method is non-invasive and mobile, and allows PFC measurements to be made in a more natural environment (i.e., sitting at a desk to perform an HCI task; see Riedl, Davis, and Hevner (2014, p. 27)).

Among the mobile methods, EEG has been shown to have the highest temporal resolution, is silent, and can be applied non-invasively (Müller-Putz et al., 2015; Pinti, Tachtsidis, et al., 2020; Riedl, Minas, et al., 2020). However, EEG presents significant challenges for precisely localizing the sources of electrical activity that are measured at the surface of the head, and it is prone to artefacts caused by head movements, by facial expressions, or by hand movements if a computer mouse and/or keyboard is used (Kim, Seo, et al., 2017; Maior et al., 2015; Pinti, Tachtsidis, et al., 2020). While EEG is particularly applicable if rapid, time critical reactions to stimuli are to be assessed, it is not the best choice if general decision making processes are investigated where spatial localization is critical, and where brain processes are not as time critical (i.e., measurement of the brain signal is not required to be within a fraction of a second after stimulus perception) (Pinti, Tachtsidis, et al., 2020).

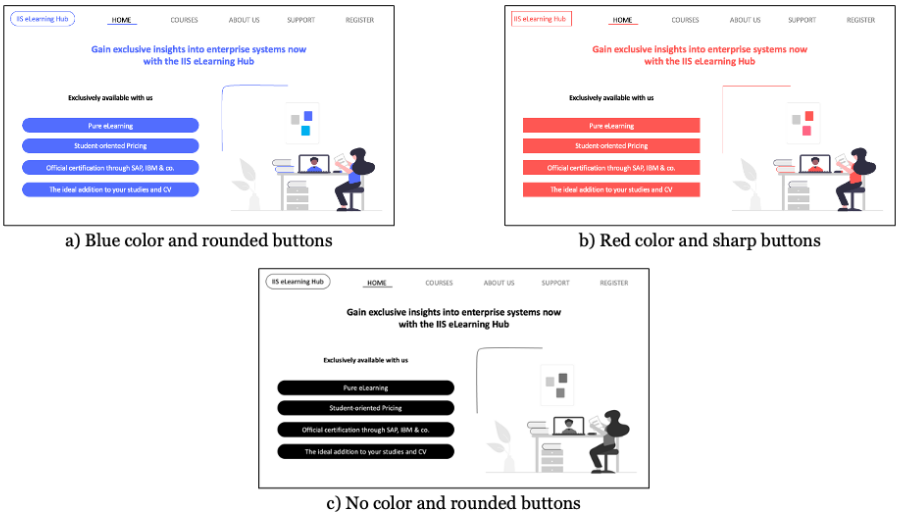
The mobile method of fNIRS constitutes a reasonable tool, because it provides significantly higher spatial resolution than EEG (although still lower than that of fMRI) while offering the same mobility and non-invasiveness as EEG (Gefen, Ayaz, et al., 2014; Hirshfield, Chauncey, et al., 2009; Irani et al., 2007; Kim, Seo, et al., 2017; Kopton and Kenning, 2014). Further, compared to fMRI and EEG, fNIRS is

robust against movement artefacts, especially those which may appear due to head movements and as a result of computer mouse and keyboard use during measurements (Cui, Baker, et al., 2015; Girouard et al., 2010; Kim, Seo, et al., 2017; Maior et al., 2015). Although fNIRS has temporal resolution limitations compared to EEG, and presents spatial resolution limitations if compared to fMRI, its advantage of achieving a "best of both" measurement, as well as its robustness against artefacts, makes it the first choice for the present study context. Several neuroIS studies have successfully utilized fNIRS in the frame of contexts such as measuring emotional experiences (Pollmann, Vukelić, et al., 2016), perceived usability (Hill and Bohil, 2016; Hirshfield, Gulotta, et al., 2011; Lukanov et al., 2016; Pike et al., 2014), mental workload (Midha et al., 2021), user trust (Hirshfield, Bobko, Barelka, Sommer, et al., 2019), the evaluation of visual website design (Nissen, 2020a; Nissen and Krampe, 2020; Peck et al., 2013), and to investigate brand effects (Krampe, Gier, et al., 2018; Krampe, Strelow, et al., 2018). Altogether, while being aware of its use for measurement on the cortical level only, we selected fNIRS as the measurement tool because it allows for testing the hypotheses that refer to neural activation in the PFC.

Sample

For neuroIS studies that employ mobile neuroimaging methods, the average sample size is 38 participants (Riedl, Fischer, et al., 2020). Further, related fNIRS studies have shown that medium-large effects at 80% power can already be detected with a sample size of 20 participants (Vassena et al., 2019). Consequently, we recruited a sample of N = 38 healthy, right-handed participants (19 male, 19 female) for our study. 57.9% of the sample is employed, and the remaining 42.1% are students. Ages ranged from 21 to 35 years ($M = 27.2$, $SD = 3.85$). To check for handedness, we used the German version of the laterality quotient (LQ) by Salmaso and Longoni (1985) (Götze, 2015). Results revealed an average LQ of $M = 84.00$ ($SD = 35.1$) which qualifies the included participants as right-handed. Further, to ensure that participants were familiar with making online purchases (see task description below), we assessed the frequency of online purchases which resulted in an average of $M = 5.87$ ($SD = 5.32$) online purchases per month. Finally, to ensure comparable head sizes and, therefore, comparable positions of the optodes on participants' foreheads, we measured head circumference, which resulted in an average head circumference of $M = 56.6cm$ ($SD = 2.27$).

In addition to the demographics, we also measured the control variables of familiarity with online shopping, and of disposition to trust, using a 5-point Likert



a) Blue color and rounded buttons

b) Red color and sharp buttons

c) No color and rounded buttons

Figure 3.5. Three Examples of the Stimuli Used

Note. The shown stimuli were originally presented in German and are translated to English for better readability in the paper

scale and translating validated scales by Gefen (2000) to German. Results revealed an average familiarity with online shopping of $M = 3.82$ ($SD = 0.80$) and an average disposition to trust of $M = 2.99$ ($SD = 0.56$). Consequently, it can be concluded that the sample participants are reasonably familiar with shopping online and are characterized by an average disposition to trust.

Stimuli

The stimuli for this study were designed and manipulated for color (blue, red, no color) and button shape (sharp, rounded). Consistent content was kept across all 6 included designs (for sample stimuli see Figure 3.5). As exemplary scenario, a website for a fictional company that provides e-learning courses in the context enterprise systems was designed. The selected blue color has the HEX-code #536dfe, the selected red color has the HEX-code #fe5853, and the no color condition (in this case black)[2], has the HEX-code #000000.[3] The background and decorative image remained consistent across all conditions, and the image was varied only with regard to the test colors of red, blue, and none.

The presentation of color is heavily dependent on the ambient light, as well as the characteristics of the display on which the stimuli are shown (LED versus OLED,

[2]Black, grey, and white are typically referred to as achromatic, and if compared to a colored stimuli, they are not defined as color (Zeki and Marini, 1998).
[3]Readers can see the colors on the website: https://www.color-hex.com/.

screen size, general brightness and saturation levels of the screen etc.) (Elliot, 2015). Consequently, our laboratory experiment was designed for all participants to view the screenshots on the same screen, with ambient light and surrounding colors held constant.

Study Design

Upon arrival, each participant was welcomed and asked to sit in front of the display. As a first step, the participant was given a questionnaire with instructions for the study and information about data privacy, in accordance with the Declaration of Helsinki. After reading through this and giving written consent to the study procedures and data use, the participant responded to the questionnaire items about demographics and was presented with the control questions. When the questionnaire was completed, the experimenter answered all remaining questions regarding the fNIRS device and further procedures of the study. The fNIRS was then placed on the participant's forehead by taking the craniometric point of the nasion as anchor to achieve comparability. The participant was then asked whether the headband sat comfortably on the head, and whether there was any pain or uncomfortable pressure. When the headband sat comfortably, the fNIRS was calibrated on the participant's head to ensure data quality and to check whether all fNIRS channels had sufficient connectivity. Finally, the experimenter left the room and the paradigm was begun. After the experimental tasks were completed, the participant's fNIRS headband was removed, the compensation of 10 Euro cash was paid, and the participant was free to leave. The study procedure was agreed upon by the local University's ethical committee.

We used a 3x2 factorial, within-subjects design with color (blue, red, no color) and button shapes (sharp, rounded) as independent variables. As more fully discussed in the related literature, both color and shapes can have a significant impact on emotional responses to the shown stimuli. For this reason we included self-reported scales of three items each for pleasure and for arousal (adapted from Huang, Ali, et al. (2017) and Koo and Ju (2010)). Additionally, we included in the study three items to allow examination of distrust toward the website (adapted from Gefen (2000)). To operationalize approach and avoidance tendency of participants, we measured the overall attitude toward the website with a 3-item self-report instrument (adapted from Porat and Tractinsky (2012)).

The described stimuli and scales were included in an event-related experimental design during which neural data on participants' foreheads were assessed by means of fNIRS. In this design, participants saw one of the website designs for 3s, after

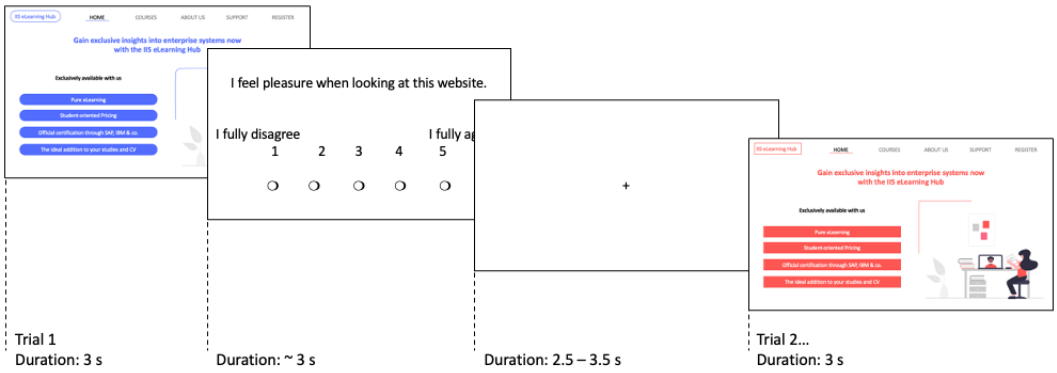


Figure 3.6. Experimental Paradigm

which one of the questions from the dependent variables appeared together with a 5-point Likert scale reaching from 1 = “I fully disagree" to 5 = “I fully agree". After the input of the rating, a cross jittered between 2.5 - 3.5s was shown as neutralizing image before the next trial began. Overall, each website design version was shown with each of the included questions resulting in 12 trials per website design, and in a total of 72 trials. The order of the trials was completely randomized (Figure 3.6).

Data Acquisition

Technically, fNIRS sends near-infrared light into the skull at two (or more) wavelengths that are reflected or absorbed by the hemoglobin in the blood (Ferrari and Quaresima, 2012; Pinti, Tachtsidis, et al., 2020). Therefore, we assessed the levels of total hemoglobin (Hb), the oxygenated as well as the deoxygenated hemoglobin (HbO and HbR, respectively), in the brain regions under the fNIRS device (Krampe, Gier, et al., 2017; Pinti, Tachtsidis, et al., 2020). Especially the HbO and HbR signals provide information identifying the brain region that is required to process the website designs, because an increase in HbO levels (and a subsequent decrease in HbR) reveals that more oxygen is required in the respective brain area that signifies a neural activation (Pinti, Tachtsidis, et al., 2020). Both the HbO and HbR signals are highly correlated to the BOLD signal produced by fMRI (Hoshi, Kobayashi, et al., 2001; Huppert et al., 2006; Noah et al., 2015; Pinti, Tachtsidis, et al., 2020; Strangman et al., 2002; Toronov et al., 2003; Wijeakumar et al., 2017), which makes the results obtained by fNIRS strongly comparable to BOLD results from related work that used fMRI as a measuring method.

The fNIRS used in this study is a mobile, continuous wave NIRSport 1 device developed by NIRX. The device comes with a sampling frequency of 7.81Hz and has two wavelengths with 760nm and 850nm. For this study, measurements were focused on the PFC, which was covered with 8 sources, 7 long-distance detectors

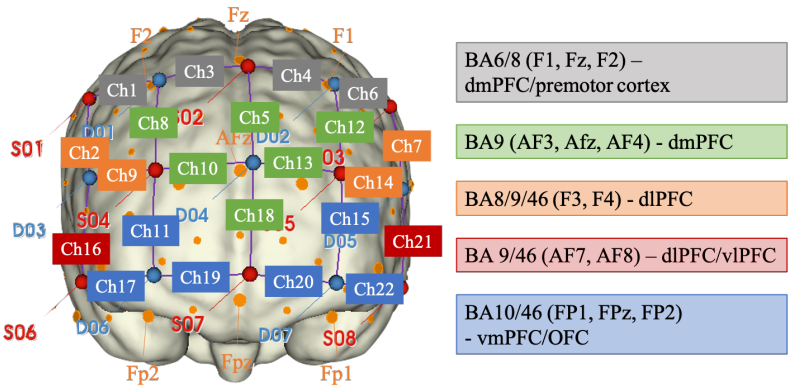


Figure 3.7. fNIRS LDDs on the PFC and Covered Subareas in Relation to Brodmann Areas (BA) and EEG 10-20 Reference Points

(LDD, average distance set to 30mm), and 8 short-distance detectors (SDD, average distance set to 8mm, one short distance detector for each source). The SDD are used to assess task-unrelated, extracerebral activation in the fNIRS signal and, thus, they provide an accurate measure to filter out noise in the data and to help to ensure that only task-dependent neural activation is considered in the data analyses (Brigadoi, Ceccherini, et al., 2014; Goodwin et al., 2014; Yücel, Selb, et al., 2016). Overall, the fNIRS montage holds 22 channels which cover most cerebral areas of the PFC. Figure 3.7 identifies the LDD channels that cover the specific brain regions (note that SDD channels are not depicted in Figure 3). The figure presents positions of the optodes are presented in relation to standardized marks of the EEG 10-20 system. Further, the channels between those marks are mapped to Brodmann Area (BA) and subsequent structural parts of the PFC based on related literature that mapped EEG 10-20 points to BA and subareas of the PFC (Herwig et al., 2003; Koessler et al., 2009) (for a detailed review of subareas that constitute the PFC and their functions see Carlén (2017) and Ridderinkhof et al. (2004)).

Data Analysis

We analyzed raw fNIRS data with the Brain AnalyzIR Matlab toolbox (Santosa et al., 2018). At first, we removed over- and non-saturated channels from further analyses. This was followed by a resampling of the sampling frequency to 4Hz, in order to address the high autocorrelation in the fNIRS signal (Huppert, 2016). After that, we calculated optical density, followed by cleansing data with the included SDD channels using Linear Minimum Mean Square Estimations to filter out artefacts due to respiration, heart rate, Mayer waves, movements, and extracerebral activity (Saager and Berger, 2005; Scholkmann et al., 2014). Finally, we calculated hemoglobin values (HbO, HbR) by using the modified Beer-Lambert Law with a partial pathlength factor

set to .10 (Delpy et al., 1988; Kocsis et al., 2006). For the hemoglobin values, changes per channel for each condition and each participant were initially calculated on a subject level. For this, we used a general linear model (GLM) with the hemodynamic response function (hrf) as baseline and the AR-IRLS as algorithm. We selected the AR-IRLS algorithm because it has been shown to provide an accurate means to further correct for motion artefacts and serially correlated errors in the hemoglobin values in fNIRS measurements (Barker et al., 2013; Huppert, 2016). After that, we applied a mixed-effects model for the group analysis by taking the conditions (color, button shape) as fixed effects, and individual differences of participants as random effects. The following section presents results from the mixed-effects model that survived the threshold of false discovery rate corrected p-values $p_{FDR} <= .01$ (Benjamini and Hochberg, 1995), while having sufficient power levels with $power > .80$.

3.3.5. Results

Self-Reported Results

Self-reported data from the questionnaire and the experimental paradigm were analyzed using repeated-measures analysis of variance (rmANOVA). Harman's one-factor test for common method bias resulted in an average extracted variance of 45.3% which is under the threshold of 50% and therefore, common method bias is not present in this study. Results from the rmANOVA reveal no significant interaction effect between colors and button shape ($F(2, 74) = 0.559, p = .574, \eta_p^2 = .015$). However, a significant main effect for color could be identified ($F(2, 74) = 27.148, p < .001, \eta_p^2 = 0.423$). Post-hoc tests revealed that both the blue and the red website versions were rated more positively than the uncolored version (blue: $t(37) = 6.395, p_{tukey} < .001$, red: $t(37) = 5.638, p_{tukey} < .001$). Measured differences were observed for pleasure (blue: $t(37) = 7.710, p_{tukey} < .001$, red: $t(37) = 5.927, p_{tukey} < .001$), for distrust (blue: $t(37) = -5.693, p_{tukey} < .001$, red: $t(37) = -4.438, p_{tukey} = .004$), and for attitude toward the website (blue: $t(37) = 7.215, p_{tukey} < .001$, red: $t(37) = 5.689, p_{tukey} < .001$), but not for arousal ($p_{tukey} > .05$). No significant differences between the blue and red websites could be identified in any of the variables ($t(37) = -0.353, p_{tukey} = .934$). Similarly, no significant main effect could be identified between rounded and sharp button shapes ($F(1, 37) = 1.210, p_{tukey} = .278, \eta_p^2 = .032$). Altogether, these results indicate that H1 must be rejected, because no significant differences in pleasure, distrust, and attitude could be identified between the blue and red websites. However, H2 is supported, due to significant differences in the considered constructs between the uncolored website and both the red and blue websites.

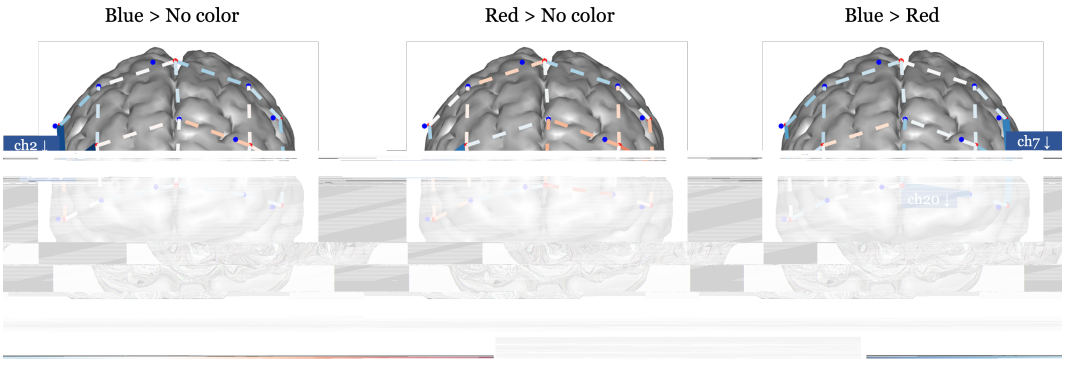


Figure 3.8. fNIRS Results for Color Contrasts from the Mixed-Effects Model

Note. Channels show the t-values of significant HbO changes (p_{FDR} <= .01, $power$ > .80).

Neural Results

Color. Starting with comparisons between the different color conditions, we calculated contrasts between all included conditions. Because no significant differences in HbR levels were identified for any of the contrasts, we present only HbO results. In the comparison of the blue versus the uncolored website design, significantly lower HbO levels were identified for the blue website version in areas of the right dlPFC (ch2: $t(222) = -4.526, p_{FDR} = .001$, ch9: $t(222) = -4.922, p_{FDR} < .001$). Similarly, this area also revealed lower HbO levels for the red website, when compared to the uncolored website (ch9: $t(222) = -3.771, p_{FDR} = .006$). These results reveal that when colored websites are compared to uncolored websites, a neural activation of the right dlPFC can be identified for the uncolored website, independent of the color that was used on the other website design. The direct comparison between the blue and red website versions resulted in lower HbO levels for the blue website version in channels related to the left dlPFC (ch7: $t(222) = -3.443, p_{FDR} = .015$), as well as in channels related to the left vmPFC/OFC (ch20: $t(222) = -4.194, p_{FDR} = .002$). The values reported here are visualized in Figure 3.8.

Button Shapes. In contrast to the effects of color, which primarily revealed activation differences in lateral areas of the PFC, the identified activation changes due to shapes lie primarily in medial areas of the PFC. When rounded versus sharp buttons are compared across all included color conditions, significantly increased HbO levels can be identified for the rounded buttons in areas of the right dmPFC/premotor cortex (ch3: $t(222) = 4.540, p_{FDR} = .001$, ch5: $t(222) = 4.057, p_{FDR} = .003$). Similar increased HbO levels are also identified for the button shape contrast on the uncolored website only (ch3: $t(222) = 6.065, p_{FDR} < .001$), where a channel related to areas of the right vmPFC/OFC also revealed significant differences (ch11:

capacity than the blue website. In line with the evolutionary associations of red, related neuroIS studies have also linked increased dlPFC activation to emotional arousal and valence (Bandara et al., 2018), threat appraisals (Warkentin et al., 2016), perception of untrustworthy internet offers (Riedl, Hubert, et al., 2010), and discredibility evaluations (Dimoka, 2010) – all of which further support the threatening color code of red and the relaxing color code of blue.

In addition to the greater activation of the left dlPFC for the red in comparison with the blue website, an activation of the left vmPFC/OFC was also identified. Based on evolutionary psychology theorizing, we argued that red colors are associated with negative emotions such as distrust. While this was not reflected on the self-reported level (in which we observed neither significantly lower perceived pleasure, nor higher perceived distrust), the activation of the left vmPFC/OFC strongly suggests that an emotional and reward-related perception of the website took place (Choi et al., 2013; Damasio, 1994; Schultz et al., 2011; Xue et al., 2009). Our result is in line with findings of related neuroIS literature, which identifies activation in the vmPFC/OFC related to low trustworthiness and credibility (Dimoka, 2010), as well as to negative emotion (Bandara et al., 2018; Hirshfield, Bobko, Barelka, Hirshfield, et al., 2014).

Altogether, our data show that the here utilized self-report measures do not appear to be capable of reflecting users' inner evaluation processes during website perception of blue versus red websites. More specifically, when users are confronted with red colors on websites, the neural activation suggests the responses of human ancestors, for whom red often signaled dangerous situations; yet, this effect does not manifest on the level of users' introspective accounts of their perceptions.

Colored Versus Uncolored Website Design When comparing colored versus uncolored website designs, we found significant differences in the self-reported data (H2). Based on evolutionary psychology, we have argued that the absence of color leads to an absence of information, complicating the use of the website. On the basis of processing fluency theory (Reber and Schwarz, 2006; Reber, Schwarz, and Winkielman, 2004), we have argued that a lack of information leads to an increased effort to process the design and, accordingly, the experienced pleasure is decreased. Given that an information deficit also comes with increased uncertainty, the absence of color in a visual design also elicits higher distrust.

The information deficit becomes particularly apparent when looking at the neural results obtained in this study. Both the blue and the red websites result in lower neural activation in the right dlPFC, as compared to the uncolored website (H4). Similar to the argumentation that red websites require more cognitive resources to be

processed than blue websites, this activation difference suggests that users' mental workload for processing both of the colored websites is lowered in comparison to the uncolored website (Clemente et al., 2014; Friehs et al., 2021; Li, Jiang, et al., 2014; Midha et al., 2021; Warkentin et al., 2016). In line with the findings of Hirshfield, Bobko, Barelka, Hirshfield, et al. (2014), dlPFC activation is also found for more negative perceptions such as distrust, which is reflected in the results of the present study. Again, this argumentation is consistent with evolutionary psychology theorizing.

Rounded Versus Sharp Shapes in Website Design Our study did not identify significant differences in the self-reported data between websites with rounded versus sharp shapes. It is possible that the overall visual design of the website, and the more prominent impact of the colors used, may have overridden the effects of the shapes, which might explain why no differences were observed in self-reported data.

However, significant differences between rounded and sharp shapes were identified in the neural data. On the basis of evolutionary psychology, we have argued that rounded shapes signify safety, and are therefore perceived as being more approachable than sharp shapes. As we found support for H5, this explanation is further substantiated (albeit only for the uncolored and the red websites, and not for the blue version or for the composite measures across all websites). The vmPFC/OFC has been consistently linked with the processing of emotional value (Choi et al., 2013; Damasio, 1994; Schultz et al., 2011; Xue et al., 2009), as well as emotion regulation (Buhle et al., 2014; Delli Pizzi et al., 2017; Koenigs and Tranel, 2007; Naqvi, Shiv, et al., 2006). The observation that this area was only activated on the website versions that required pronounced processing due to their color codes (no color, red) may point to more positive attribution of these designs when rounded shapes are used, compared to sharp shapes. A possible reason why we did not observe this effect for the blue website could be that the use of blue leads to a positive attribution and to approach tendencies, whereas the change in shapes is not strong enough to trigger additional emotional processes.

In addition to the vmPFC/OFC results, the dmPFC was activated when comparing the use of sharp versus rounded shapes across all color versions, as well as on the uncolored and the blue website versions. In related neuroIS studies, activation of the dmPFC has been related to more aesthetic websites (Nissen, 2020b), increased positive perception of visual design (Nissen, Obermeier, et al., 2021), object preference (Luu and Chau, 2009), and increased purchase intentions (Grosenick et al., 2008). In line with the explanations from evolutionary psychology proposing that rounded

shapes are perceived to result in higher pleasure and to be more approachable, these related findings support the results of the present study. Thus, the activation of the dmPFC for rounded shapes may signify an increased positive perception of the website design and, thereby, increased approach behavior. The red website version was the only case in which no significant differences in the dmPFC could be observed for the rounded shapes. Again, it is likely that color (as compared to shapes) constitutes a more dominant visual design element. In other words, the red color may have overridden a possible neural effect of shapes in the dmPFC. Nevertheless, the neural results consistently point to the effect that rounded shapes are more approachable than sharp shapes.

Implications, Limitations, and Future Research

In this study, we have shown how the use of color and shapes as visual website design elements can trigger neural responses in the users' brains. Although the conclusion is not reflected in the self-report measures used in this study, our neural results show that, on the basis of data from PFC activation patterns, rounded shapes on a website are perceived more approachable than are sharp shapes. Interestingly, our data show that users cannot provide an introspective account of these neural processes. This, of course, has significant implications for practice, not only for website design, but also for other GUIs (e.g., in enterprise systems or operating systems). In line with our results, visual design decisions such as the sharp tiles of the SAP FIORI UI, or the sharp tiles found in operating systems such as Windows, are challenged. Because we investigated the effect of shapes in the context of e-commerce websites, future research may test our hypotheses and findings in other contexts, such as visual designs of enterprise systems, operating systems, or office software. Moreover, our design results are also relevant for the business process modeling domain. In a conceptual paper, vom Brocke, Riedl, et al. (2013) argued that "All other factors being equal, modeling notations that are based on sharp-angled objects [. . .] and their corresponding artifacts (i.e., specific models developed based on such a language) are less liked (or less comprehended or accepted) than are notations and their corresponding artifacts thatr2-251(1 98.89eIR(decindings)-hat98..)-196(]ept(that)3pt(that)3pgt

Finally, we recommend replication of our study using other neurophysiological measurement tools as a basis, including both brain research (e.g., EEG, fMRI) and research related to ANS activity (e.g., electrodermal activity (EDA), heart rate variability (HRV)). As indicated in our methods section, we selected fNIRS with conscious deliberation as the most useful for our research. But we did so with the knowledge that every tool has limitations, and that different tools might provide additional important findings. As an example, if reaction time to a stimulus (e.g., a website) is critical for testing the predictions of a specific theory, EEG is the method of choice. Moreover, if researchers want to study subcortical processes, application of fMRI could be recommended. Finally, if stress reactions to stimuli that result from color and/or shape perception are the focus of a study, measurement of ANS activity based on EDA or HRV is warranted. It is clear that many avenues of future research are available to enhance the understandings that have begun with our study.

3.3.7. Conclusion

For this study, we investigated the effects of two website design elements (color, shapes) at the neural level (with a focus on identifying PFC activation through use of fNIRS), and by including self-reported constructs of pleasure, distrust, and attitude. We used evolutionary psychology as a theoretical lens for developing hypotheses on the effects of colors (red, blue, no color) and shapes (rounded, sharp). Based on a 3x2 within-subjects design, we conducted a laboratory experiment with e-commerce websites and measured participants' responses to these stimuli. Overall, our results confirm most of the predictions developed from evolutionary psychology. Specifically, we found that rounded shapes are processed with greater pleasure, and that websites with such a design are more approachable, as signified through activation in the dmPFC. Further, colored websites seem, generally, to be preferred over uncolored websites. Importantly, the red website was not rated as worse than the blue website (i.e., no significant differences could be observed regarding the self-report measures on pleasure, distrust, and attitude). Yet the neural data reveal that perception of the red website is related to higher neural activation in the left dlPFC and left vmPFC/OFC. Such brain activation signifies increased cognitive load required for processing, and is often accompanied by an increased (negative) emotional processing. These findings are consistent with predictions derived from evolutionary psychology, because throughout human development, the color red triggered negative emotion such as distrust due to the color's association with negatively connoted stimuli.

For this study we bring together two distinct avenues of research – evolutionary

psychology and neuroscience – as a means of investigating the use of neuroimaging and self-report measures in IS research, and we do so in the specific practice context of website design. Our study observes the effects of two website design elements (color, shapes) consistently confirm our hypotheses on the brain data level, but not on the self-report level. Therefore, data from our study emphasizes the importance of applying neuroscience tools in IS research (i.e., neuroIS). Nevertheless, we find that neuroscience is valuable as a complement to self-report measures, and not as a substitute (e.g., Dimoka, Pavlou, et al., 2011b; Riedl and Léger, 2016; Tams et al., 2014). With this being said, this study shows the limitations of using self-reported data only as means to evaluate visual designs on the one hand, and how evolutionary traces can still be found in the processing and perception of website designs, on the other.

Chapter 4

Phase II: During-Use

4.1. Paper 4: Utilizing Mobile fNIRS to Investigate Neural Correlates of the TAM in eCommerce

Abstract

The investigation of user behavior in IS contexts is often conducted by utilizing self-report measurements. To complement these measurements, neuroscientific methods have indicated their potential for IS research. Most pioneering research work utilized fMRI as neuroimaging method, which is associated with a decreased ecological validity. To investigate whether mobile fNIRS – an innovative, portable and lightweight neuroimaging method – can overcome the limited ecological validity of fMRI, reproducing existing neuroscientific research results, this study aims to explore whether mobile fNIRS could be used as a valid neuroimaging method for IS research, or more precisely for ecommerce research. Preliminary research findings revealed that fNIRS is capable of partly reproducing pioneering research results. Consequently, fNIRS is found to be a reliable and valid neuroimaging method to increase the ecological validity in IS research in certain situations and circumstances, providing a fruitful new avenue to investigate IS research relevant scenarios.

4.1.1. Introduction

One crucial, long-term goal of Information Systems (IS) research is to explain user behavior. To achieve this, IS research has developed several theories, models, and related constructs. In this progress, traditionally, questionnaires or other types of self-report measurements have been utilized to scientifically develop and challenge theories, models and constructs (vom Brocke, Riedl, et al., 2013). However, IS users are often only capable of providing information about the given constructs, when they are consciously aware of their perception (Riedl, Davis, Banker, et al., 2017). That said, purely applying these kinds of methods might neglect the influence of more unconscious constructs such as emotions, feelings and affect resulting in limited levels of explained variance regarding user behavior. One way to overcome this constraint might be the complementary utilization of neural, psychophysiological measurements, allowing to gain a better understanding of the user information processing and human behavior in IS (Dimoka, Banker, et al., 2012). As a consequence, a few years ago,

NeuroIS requested to add a new theoretical perspective to IS research in order to complementarily explain users' unconscious (neural) processes and the associated behavior on a neurobiological level (Dimoka, 2010; Riedl, Hubert, et al., 2010).

Following this request, in the last decade most NeuroIS researchers utilized functional magnetic resonance imaging (fMRI) (Dimoka, Banker, et al., 2012; Krampe, Gier, et al., 2018). This sophisticated neuroimaging method is characterized by a great spatial resolution that allows to explore brain structures that lie deep in the human brain (Geuter et al., 2016) and has demonstrated to be a fruitful method for IS research (e.g. Dimoka, 2010; Riedl, Banker, et al., 2010). Nevertheless, fMRI is associated with several limitations that are repeatedly reported by NeuroIS researchers (e.g. Krampe, Gier, et al., 2018). Probably one of the most important limitations, at least for IS research, is that fMRI experiments cannot be conducted in naturalistic, real-world environments, due to the fact that participants have to lie flat on their back, with their head restraint, fixated during the experimental measurement procedure (Kemp et al., 2015). One innovative method that could help to overcome this limitation is mobile functional near-infrared spectroscopy (fNIRS) (Kopton and Kenning, 2014). fNIRS has shown to be a cost efficient and effective neuroimaging method, which allows to integrate all participants (Krampe, Gier, et al., 2018). Although recent research indicated the potential of mobile fNIRS in the research fields of organizational and marketing research (Kopton and Kenning, 2014; Krampe, Gier, et al., 2018), its application to IS research is still limited (Gefen, Ayaz, et al., 2014; Krampe, Gier, et al., 2017). To address this application gap, this research work aims to explore the potential of mobile fNIRS as a valid and reliable neuroimaging method in a certain field of IS research, i.e. the acceptance and usage of shopping websites (Dimoka and Davis, 2008).

Consequently, the given manuscript is structured as follows. In the first section, we review current research findings that investigated the antecedents and consequences of users' acceptance of websites by means of the technology acceptance model (TAM) (Davis et al., 1989). Then the neuroimaging method fNIRS and the opportunities to measure IS relevant constructs such as the TAM constructs are discussed. Furthermore, the applied scientific research approach is explained, displaying the preliminary research results. Thereafter, the given research results are discussed. Finally, limitations and future research remarks as well as theoretical and practical implications and conclusions are drawn.

4.1.2. Neural Foundations

The TAM in the Frame of Neuroscience

Although the TAM has been introduced more than 30 years ago (Davis, 1985; Davis et al., 1989), constructs such as the perceived usefulness (PU), perceived ease of use (PEOU), and purchase intention (PUI) are still crucial for IS research and in particular, for ecommerce research. One of the first studies that complementarily focused on technology acceptance utilizing neuroscientific methods has been conducted by Dimoka and Davis (2008). Their work identified that apparently, constructs of the TAM might be associated with certain brain structures, in particular the amygdala, the insula, the left putamen, the anterior cingulate cortex (ACC), the dorsolateral prefrontal cortex (dlPFC), and the ventrolateral prefrontal cortex (vlPFC) (Dimoka and Davis, 2008). Some of these structures belong to the limbic system and are related to emotional processing (Purves et al., 2004), but also integrate brain regions, which are interconnected to cognitive processing such as deliberative reasoning (Cummins and Cummins, 2012). Because Dimoka and Davis (2008) utilized fMRI in their pioneering research, their work faced some shortcomings when it comes to the ecological validity as well as the involved sample size. As previously described, participants have to lie flat on their back, with their head restraint during the measurement procedure, which does not reflect an application appropriate scenario, as for example browsing a shopping website. However, since the TAM is an established and well-known model in IS research and has shown to be significantly associated with several distinct brain areas, our research aim is to reapply the research idea of Dimoka and Davis (2008) in order to demonstrate that mobile fNIRS provides a reliable and valid neuroimaging method for NeuroIS research.

Mobile fNIRS as an Opportunity for IS research?

Mobile fNIRS has been applied in the field of neuroscience, as well as cognate disciplines (Kim, Seo, et al., 2017; Krampe, Gier, et al., 2018). In earlier studies, fNIRS data was found to highly correlate with the more mature fMRI blood-oxygen level-dependent (BOLD) signal (Huppert et al., 2006; Strangman et al., 2002). In particular, fNIRS operates with near-infrared light that is absorbed, reflected or scattered by the human brain tissue, or more precisely by oxygenated and deoxygenated hemoglobin. As a consequence, fNIRS takes advantage of this characteristic as the amount of oxygenated and deoxygenated blood for a given brain region is calculated (Ferrari and Quaresima, 2012; Funane et al., 2014) – which is an indirect parameter of neural cortical brain activity. Consequently, mobile fNIRS yields potential for IS research, as it is a portable and lightweight technology that appears to be robust

to (movement) artefacts and can therefore be applied in practice-relevant scenarios (Brigadoi, Ceccherini, et al., 2014; Leff et al., 2011). However, fNIRS has also some shortcomings that might be relevant for IS research. Most predominately, fNIRS has a limited spatial resolution, allowing to penetrate the human brain tissue only up to 3 cm depth and thus, only cortical brain structures can be measured (Ferrari and Quaresima, 2012; Scholkmann et al., 2014).

Hypotheses Development

Following the overarching research goal, this research work aims to partly – based on the technical capabilities of mobile fNIRS – reproduce the pioneering research results by Dimoka and Davis (2008). In their work, they utilized fMRI to investigate PU, PEOU, and PUI in ecommerce when participants had to purchase a digital camera on a website with low ratings of PU, PEOU, and PUI, and on a website where the given constructs have been rated high. They identified several neural activity patterns for the manipulated constructs. More precisely, results indicated increased neural activity in the caudate nucleus and ACC for high PU, increased dlPFC activity for PEOU, and increased vlPFC activity for PUI on websites with both high PU and PEOU (Dimoka and Davis, 2008). However, based on its technical capabilities, it should be evident that mobile fNIRS is only able to shed light on cortical but not subcortical, deeper lying brain regions (Krampe, Gier, et al., 2018). Consequently, based on the capabilities of mobile fNIRS, we might only be capable of measuring neural activity in brain regions of the dlPFC and vlPFC elicited through different ratings of the TAM constructs (being PU, PEOU and PUI), leading to the following hypotheses:

> *H 1: By means of mobile fNIRS it is possible to indicate, that higher self-reported TAM constructs are associated with increased neural activity in the dlPFC.*
>
> *H 2: By means of mobile fNIRS it is possible to indicate, that higher self-reported TAM constructs are associated with increased neural activity in the vlPFC.*

4.1.3. Study 1: Survey to Select Shopping Websites

To keep the study comparable with the pioneering research work by Dimoka and Davis (2008), a similar target product – namely a digital camera – was chosen, acting as the stimulus, which needed to be searched for on different shopping websites. Consequently, five comparable ecommerce websites were chosen, which all sell electronic products; namely Alternate, Computeruniverse, Crowdfox, Digitalo,

and PNShop. For the questionnaire employed in this survey, each website was screenshotted and the prices of the products on each website were manipulated so that there are no biases due to different pricing strategies. Before answering the questionnaire for each website, participants were asked whether they know the website or not. In case they knew the website, questions regarding PU, PEOU, and PUI were not shown for the respective website. In addition, the order in which the websites are portrayed was fully randomized. For each website, participants were asked to rate their overall impression of the website on a Likert scale ranging from 1 to 10, with 1 standing for the lowest score and 10 for the highest. Afterwards, users were asked to answer the TAM constructs, which were a slightly adapted version of the ones used by Dimoka and Davis (2008). The items in the questionnaire were translated and retranslated by an independent person to ensure linguistic correctness. The order in which the website with the associated questions were shown was also fully randomized. A recognition question was included as a closing point for each website to ensure that participants did not know the website from prior use. This procedure was meant to avoid biases due to previous experiences or the desirability for a specific provider. Thereafter, participants were requested to provide demographical data as well as questions regarding their shopping behavior.

The sample of study 1 consists of 142 participants. Due to the marker variable, which was a comparatively long text (239 words), that required a predefined answer to test participants' attention, 17 datasets were eliminated. Additionally, 10 datasets were deleted due to the recognition questions at the end of each website. As a result, the validated and analyzed sample comprises N = 115 participants (57.4% male, 36.2% female, 6.4% divers).

Results Study 1 On average participants made an online purchase $M = 4.28$ times per month ($SD = 3.879$). A one-way analysis of variance (ANOVA) between the different websites was calculated to identify the two most contrasting websites in terms of the previous described constructs; the Tukey honest significance difference (HSD) post-hoc test was utilized allowing to run multiple comparisons between the group mean values (which in this case are the displayed websites, resulting in $k = 4$). It further identifies homogenous subgroups within the sample while applying at least a significance level of $p < .05$ and a 95% confidence interval.

The questionnaire item overall impression indicates that PNShop is rated significantly lower than all the other websites at a high significance level of $p < .001$ ($PNShop : 4.346$, $Crowdfox : 6.343$, $Alternate : 6.424$, $Digitalo : 6.46$, $Computeruniverse : 6.879$). This effect can also be observed for the TAM

constructs. PU has been rated lowest for PNShop, which significantly differs from all other websites at a significance level of $p < .001$ ($PNShop$: 2.585, $Crowdfox$: 3.36, $Alternate$: 3.226, $Digitalo$: 3.232, $Computeruniverse$: 3.724). Furthermore, PU for Computeruniverse is rated highest, which not only differs significantly from PNShop, but also from Alternate and Digitalo at a significance level of $p < .05$. Consequently, PNShop has the lowest PU and Computeruniverse the highest ratings. Similar trends are observed for PEOU ($PNShop$: 3.097, $Crowdfox$: 3.889, $Alternate$: 3.85, $Digitalo$: 3.817, $Computeruniverse$: 4.149), as well as for PUI ($PNShop$: 2.259, $Crowdfox$: 2.984, $Alternate$: 2.929, $Digitalo$: 2.893, $Computeruniverse$: 3.306). In summary, the website PNShop could be identified to have the lowest and the website Computeruniverse the highest rankings on a significance level of $p < .001$. The website Digitalo provided a third subgroup lying between PNShop and Computeruniverse, although being closer to Computeruniverse than to PNShop. As a consequence, these three websites were chosen as stimuli material for study 2.

4.1.4. Study 2: Mobile fNIRS Experiment

Experiment Design and Sample Characteristics

Building upon the research results of study 1, the three chosen websites are used as stimuli in the given neuroscientific experiment. A mobile fNIRS system integrating an 8 source/8 detector headband was utilized to measure neural activity during actual website use. Before the experiment started, participants were informed about their privacy and data protection rights, as well as the operating principle of mobile fNIRS. After participants signed the informed consent, the mobile fNIRS headband was placed on the participants' head. To ensure that the headband is located according to the anatomical brain structures of the participants, the craniometric point of the nasion, where the top of the nose meets the ridge of the forehead, was used to assure comparability between participants. To avoid data biases due to experiment equipment interference, several variables were controlled for (Gefen, Ayaz, et al., 2014). First, the room luminance was kept constant while using artificial luminance in the experiment room. Second, although being more robust to movement artefacts than EEG, the fNIRS signal might still be influenced by abrupt (head) movements. Therefore, participants were asked to avoid fast and abrupt (head) movements while wearing the fNIRS headband. Third, as dense and dark hair is likely to absorb the NIR-light, it was moved aside in order to allow the light to penetrate the scalp and tissue (Zhao and Cooper, 2017). The headband was calibrated for every individual participant through which data quality was assured. Moreover, we noticed every unusual or uninstructed behavior by our participants in an experimental notebook,

which was considered in the data analysis process. Having finished the calibration procedure, participants were instructed to start with the experiment, browsing the first website. After they completed the task for the first website, participants were instructed to close the webpage by clicking the home button and open the questionnaire for evaluating the used website, which was an app on the home screen. When they finished the questionnaire for website 1, they once again had to close the app by clicking the home button and proceeded to website 2. The order in which the websites were presented to the participants was fully randomized for each participant. The questionnaires used to investigate the constructs were the same that were previously utilized in study 1, to keep the results comparable. Also, the task for each website was the same; participants were asked to browse for a digital camera for around 2-3 minutes and finally make a decision. The camera should then be placed in the shopping cart with which their interaction with the website ended. No further specifications were made.

31 right-handed, healthy participants were measured from which 6 data sets had to be excluded due to corrupted fNIRS files. The resulting sample size of n = 25 consists of students (73%) and employees (27%); with 32% female. The average age was $M = 25.9$ years of age ($SD = 0.43$). The average number of purchases per month that are usually made by the participants was $M = 3.53$ ($SD = 1.776$). The sampling rate of the mobile fNIRS system was 7.81Hz. Before further analysis, the collected raw data were pre-processed (Pinti, Scholkmann, et al., 2019). Therefore, the raw data were bandpass filtered with a low cutoff frequency of 0.01Hz and a high cutoff frequency of 0.2Hz. Throughout this procedure, spike artifacts and irrelevant frequencies, as for example the heart rate, are removed. Afterwards, hemodynamic states have been calculated utilizing the Beer-Lambert Law (Kopton and Kenning, 2014; Scholkmann et al., 2014). Given the fact that no information about the anatomical brain structure of the participants was available, the parameters used to compute the hemodynamic states were set as follows, the distance of the first channel was set to 3 cm, the wavelengths were specified to values of 760 and 850nm and the associated differential pathlength factor (DPF) was set to 7.25 for the wavelength of 760 nm and 6.38 for the wavelength of 850nm, in accordance with commonly utilized values reported in literature (Kohl et al., 1998; Zhao, Tanikawa, et al., 2002). As baseline function for the general linear model (GLM) the hemodynamic response function (hrf) was used. As the oxygenated hemoglobin (HbO) signal has been shown to correlate with cerebral blood flow better than the deoxygenated signal (Hoshi, Kobayashi, et al., 2001), the analysis concentrates on the HbO signal.

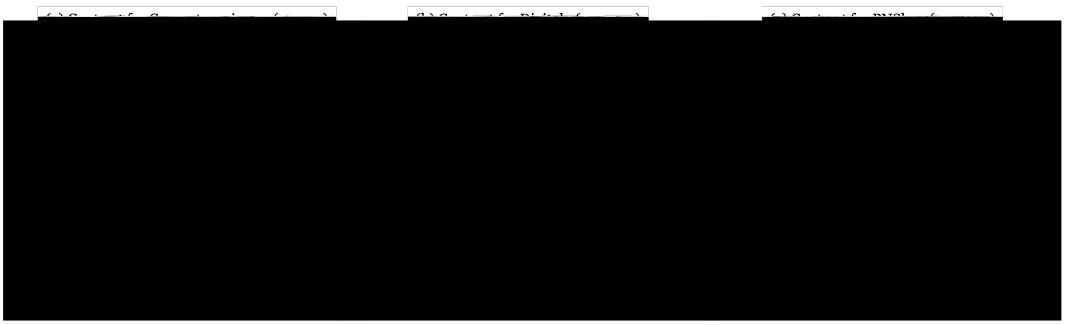


Figure 4.1. t-Statistic Contrasts for High Ratings – Low Ratings

Results Study 2

For the self-reports, an ANOVA using the Tukey-HSD post-hoc test was calculated. Results indicate that the homogenous subgroups are consistent across all constructs for PNShop compared to Computeruniverse and Digitalo at a significance level of $p < .05$. The results are for the overall impression 3.61, 7.1 and 7.26; for PU 2.68, 3.616, and 3.864, for PEOU 3.048, 4.056, and 4.168; and for PUI 1.88, 3.18 and 3.25 for PNShop, Digitalo, and Computeruniverse, respectively. Analogous to study 1, the used Likert scales ranging from 1 (very low)– 10 (very high) for overall impression, and from 1 (very low) – 5 (very high) for the remaining constructs (PU, PEOU, and PUI). Interestingly, while Digitalo and Computeruniverse were significantly differentiated from the sample of study 1, in study 2 Digitalo was rated only slightly lower than Computeruniverse. This might be due to the reduced sample size in this study, as the effect between Digitalo and Computeruniverse was not as significant in comparison to PNShop.

The groups were split according to the average ratings of the websites, assuming that users with higher ratings are generally less critical about the website's usability and design of ecommerce websites. An approach, which is supported by prior research findings, indicating that the importance of the design of websites and the correlated perception of PU and PEOU differs between individuals (Cyr and Head, 2013; Pengnate and Sarathy, 2017). In order to investigate whether there are differences in neural cortical prefrontal activity for each website, the neural activity patterns while browsing the websites of group 1 were contrasted to neural activity patterns of group 2. Figure 4.1 indicates the results for which the t-statistics have significant effects on a significance level of $p < .1$ and $p < .05$.

The contrast of the Computeruniverse website (high vs. low ratings) indicates an increased neural activity for participants that rated the website high versus those who rated it low in the right dlPFC and lateral parts of the dorsomedial prefrontal cortex

(dmPFC), as well as the right orbitofrontal cortex (OFC) on a modest significance level of $p < .1$. For the website Digitalo, an increased neural activity in lower parts of the right dlPFC, dmPFC, as well as right OFC for the group that rated the websites high versus those who rated them low was shown on a significance level of $p < .05$. Consequently, the activity pattern of the right OFC is the same for both Digitalo and Computeruniverse. The PNShop website shows at a significance level of $p < .05$ an increased neural activity for the left OFC for high versus low ratings. Following these results, H1 is supported. However, as no significant neural activity changes were found in the vlPFC, H2 needs to be rejected.

4.1.5. Discussion and Limitations

The overarching aim of this research work is to identify, whether mobile fNIRS is capable to partly reproduce the research findings by Dimoka and Davis (2008). The results indicate that mainly areas of the right dlPFC, right dmPFC, and OFC show an increased neural activity for participants that rated PU, PEOU and PUI high in their self-reports, supporting the research findings by Dimoka and Davis (2008). As increased activity in brain regions of dlPFC and dmPFC imply emotional processing (Britton et al., 2006; Etkin et al., 2011), the preliminary results indicate that browsing ecommerce websites involves emotional processing, too. This effect seems especially relevant, given that participants consciously favor the utilized website. When taking a closer look on the neural correlates of the activated brains structures, further suggestions can be drawn regarding the underlying subconscious processes in the human brain that occur while browsing ecommerce websites. In a plethora of contexts, the dlPFC plays a role in working memory processes (Barbey, Colom, et al., 2013; Dolcos et al., 2011), as well as (strategic) decision making processes (Krampe, Gier, et al., 2018). These two constructs are often found in economic decision making related to online shopping. Consequently, being more willing to make a purchase on a website seems to lead to increased cognitive load (Mangina et al., 2009), which might be elicited by increased engagement with the respective website. Next to the dlPFC, brain regions of the OFC display a significant increased neural activity for the websites Computeruniverse and Digitalo, as well as for the website PNShop, however laterally different. Independent of the lateralization, the OFC is also interconnected to various cognitive processes, e.g. to (spatial) working memory, directing attention to relevant stimuli and evaluation processes (Dolcos et al., 2011). Furthermore, the OFC was also found to be activated while appraising visual stimuli that are rated as beautiful and thus, as aesthetically pleasing (Brown et al., 2011; Cela-Conde, Garcia-Prieto, et al., 2013). Moreover, the OFC also seems to be increasingly activated in combination with the ventromedial prefrontal cortex

(vmPFC) when general pleasantness is reported by participants (Kühn and Gallinat, 2012). Furthermore, in shopping contexts, the OFC has also been shown to be activated in purchase decisions and is associated with an increased willingness to pay (Plassmann, Kenning, and Ahlert, 2007).

Although the given research results support H1, the preliminary results fail to display the increased neural activity in the vlPFC (H2). In this regard, it should be evident that the original research work by Dimoka and Davis (2008) reported an increased neural activity in the vlPFC, which, however, failed to reach the required significant threshold of $p < .05$. The vlPFC lies anatomically next to the dlPFC and is typically associated with semantic processing and the categorization of objects (Dolcos et al., 2011). Furthermore, the vlPFC is also activated when being in a state of flow (Yoshida et al., 2014). While the used stimuli in this work are probably not sufficient to elicit a state of flow, the websites employed by Dimoka and Davis (2008) might have demanded more semantic processing than ours. This potential explanation is in line with the evolution of website design shifting from text-heavy websites to clean and simple designed websites. Especially the increased use of images combined with better broadband availability, might reduce the cognitive load in semantic processing in brain regions of the vlPFC. However, until now there are no studies investigating this topic, indicating the need for further investigations to support our proposition.

With regard to the limitations of this work, at first it should be noted that the recruited sample for study 2 was locally bound by the same university. Moreover, the sample size of n=25 participants might be, especially in regard to the questionnaire-based utilized mean value distribution, a limitation. However, the current standard sample size in neuroscientific and fNIRS studies, which is known to incorporate sufficient statistical power, consists of 20 participants (Riedl, Hubert, et al., 2010; Vassena et al., 2019). In comparison to these research findings, we included a larger sample to gain more statistical power. Consequently, our preliminary results might be closer to reality, including a greater sample size and thus, more variability. Furthermore, while the natural setting of the study is its ultimate strength, it might also be a limitation. Participants stayed differently long on each website, some spoke aloud while using the websites, whereas others did not. While manipulating the prices for the products in study 1, the actual websites that were used in study 2 varied in their prices. Given the similar results in the self-reported ratings of study 1 and 2, it is shown that price did not strongly affect our data. Reasons for this might be, that participants did only put a chosen camera into a shopping cart but did not proceeded further in the purchase process. Consequently, effects that prices of products may

have on individual users cannot be accounted for in this study. In order to partly avoid biases, comparisons were made per website, and not across websites.

4.1.6. Theoretical and Practical Implications

Theoretically, our paper implies that NeuroIS research conducted with fNIRS is capable of partly reproducing research findings from conducted fMRI studies. This is especially relevant, given the fact that studies including neuroimaging tools as data input add further control variables to (TAM related) constructs, which might not be controlled for otherwise. For example, while education, age or gender are commonly used as control variables, variables such as the participants' neural activity, average ratings (as conducted here), or handedness have not been applied often. This seems especially relevant as IS research understands the "human decision maker" as a bodiless person. This implied assumption has been proven wrong given the fact that neurobiological (emotional) changes in the body reduce the number of alternatives a person might choose from in early stages (see i.e. (Damasio, 1994)). These control variables might provide further information of how the perception of websites influences participants' rating of the TAM constructs. For instance, our preliminary findings which indicate an increased activity in the OFC in the right hemisphere for the two high rated websites and an increased activity in the left hemisphere for the low rated website. This finding leads to the presumption that depending on the individual perception and evaluated beauty of a stimuli, the lateralization of the OFC might be different and thus, could act as control variable. Furthermore, neuroscientific methods such as (mobile) fNIRS can help to solve or explain variations or contradictions in previous research works.

Practically, this paper implies that mobile fNIRS in itself might offer innovative perspectives for the investigation of BCI and the design of graphical user interface (GUI) as it is an affordable user-friendly method, which is applicable in real-life contexts. Consequently, researchers and practitioners could quantify neural activity while tracking mouse movements of users, to make predictions about their GUI's efficiency, without the need to ask users directly. Moreover, fNIRS allows researchers and practitioners to include participants, which might be rejected in other neuroscientific studies (e.g. fMRI) based on physical characteristics. In conclusion, this study should encourage the application of fNIRS to gain a deeper understanding of the antecedents of subjective ratings, as well as to make accurate predictions about user evaluations and, consequently, their behavior.

4.2. Paper 5: Why He Buys It and She Doesn't – Exploring Self-Reported and Neural Gender Differences in the Perception of eCommerce Websites

Abstract

Studies of gender-related differences in the perception of ecommerce websites dependent on the websites' aesthetics, usefulness, ease of use, and purchase intentions, give contradictory results. To shed light on these conflicting findings, in addition to self-reported data from two online surveys (Study 1 & Study 2), our research uses the neuroimaging method of functional near-infrared spectroscopy to explore possible gender-related differences (Study 3). By conducting three studies, users' conscious and unconscious (neural) evaluations of ecommerce websites are explored. The self-reported results reveal that men and women do not significantly differ in their expressed evaluations of ecommerce websites. However, the neural results indicate that gender-related differences in the perception of ecommerce websites are influenced by unconscious effects, which might explain the inconsistent gender-specific research findings. Men tend to require greater neural activity when using ecommerce websites. Websites evaluated as useful and visually aesthetic lead to significant neural activation in brain regions of the left hemisphere for men in comparison to women, whereas websites evaluated as less useful and appealing reveal neural activation in brain regions of the right hemisphere in male participants. The results provide several theoretical and practical implications for the evaluation of and gender-specific decision making on ecommerce websites.

4.2.1. Introduction

Gender differences in the perception of real-world objects have been widely investigated across a variety of research fields. Studies have found that gender differences are predominately driven by biological, cognitive, behavioral, or social influencing factors (Costa et al., 2001; Gefen, Nitza, et al., 2007; Gefen and Ridings, 2005; Putrevu, 2003; Sun et al., 2010). On the perception of websites, research has shown that men and women may perceive them differently (Dimoka, 2010; Riedl, Hubert, et al., 2010). While men tend to focus more on the utility and usefulness of websites

(Pengnate and Sarathy, 2017; Ramakrishnan et al., 2014; Zhang and Prybutok, 2003), women tend to value more consistent button use and the aesthetic design of a website (Cyr and Bonanni, 2006; Mahzari and Ahmadzadeh, 2013; Ramakrishnan et al., 2014; Simon and Peppas, 2005). Other studies, however, have found no significant differences between men's and women's evaluation of websites (Afshardost et al., 2013; Al-Maghrabi and Dennis, 2009), resulting in inconsistent research findings. Consequently, it is not yet evident whether there exist gender-related differences in the perception of (ecommerce) website design.

However, for researchers and designers, it is crucial to understand whether or not these differences exist. This applies particularly to the fields of information systems (IS) research and marketing, given that several factors, such as the accessibility of information and trustworthiness of a website, have been shown to be influenced by the perception of a website's design (Cui, Wang, et al., 2012; Cyr, Head, and Larios, 2010; Pengnate and Sarathy, 2017). Different website design choices might impact the perception and, consequently, the behavior of women and men to a different extent. This makes it even more important to explore gender-related differences in website perceptions on multiple levels, involving biological and ideological factors, to better understand the theoretical and practical repercussions.

Because some website design cues are known to be unconsciously processed (Lindgaard, Fernandes, et al., 2006; Tractinsky et al., 2006), some of the gender-related differences might be accessible only by neuropsychological measurements. In related research, such neuropsychological measurements have proven to be a reliable additional data source that can provide deeper insights into existing IS-relevant constructs (Dimoka, Banker, et al., 2012; Riedl, Davis, Banker, et al., 2017). Moreover, neuropsychological measurements seem to be particularly suitable for investigating (unconscious) perception processes in IS (Dimoka, Banker, et al., 2012).

Accordingly, our work aims to shed light on (possible) gender-related differences in the perception of ecommerce websites and website design. Whereas prior studies often solely applied self-reported measurements to investigate users' perceptions, our study applies the neuroimaging method of functional near-infrared spectroscopy (fNIRS) to investigate the neural underpinnings of German users' perceptions of website design. The application of fNIRS may overcome biases associated with the conscious reflection of thoughts through self-reports, while providing additional, ecologically valid, insights into the gender-related differences of the perception of ecommerce websites (Gefen, Ayaz, et al., 2014; Kim, Seo, et al., 2017; Kopton and Kenning, 2014; Krampe, Gier, et al., 2018).

The remainder of this paper is structured as follows. First, we review the relevant literature on gender differences in ecommerce website usage and the underlying neuroscientific brain processes. Next, we describe our research approach. We then present the three conducted studies consisting of two online surveys (Study 1 and Study 2) and a neural experiment (Study 3). Finally, the results are discussed and conclusions are drawn.

4.2.2. Theoretical Background

In this paper, *gender* refers to both the biological sex as well as the ideological gender, given that both types of gender have been shown to impact consumers' evaluations of websites (Fischer and Arnold, 1994; Northey et al., 2020; Palan, 2001).

Gender Differences in Users of eCommerce Websites

Previous research has found three main areas of gender differences between users' perceptions of ecommerce websites: (i) visual design and appeal, (ii) perceived trustworthiness, and (iii) perceived usefulness (PU) and PEOU.

(i) Visual design and appeal Visual design and aesthetic elements are the first cues users perceive when visiting a website. Before any content is processed, the website's colors, shapes, fonts styles, and pictures are scanned almost immediately within the first 50 milliseconds (Lindgaard, Fernandes, et al., 2006; Tractinsky et al., 2006). These components influence the perceived visual complexity of the interface, which impacts users' behavior and their evaluations of the website. While the complexity of a website (e.g., the number of cues displayed) might objectively be the same for several websites, users' individual perceived complexity might be different, depending on the users' cognitive abilities to process information (Cui, Baker, et al., 2015; Wang, Li, et al., 2018). Nevertheless, differences in the perceived complexity of a website might also appear between gender, given that women tend to prefer media-rich websites in comparison to men (Simon and Peppas, 2005). Interestingly, the overall visual design of websites also seems to be more important for women than for men (Pengnate and Sarathy, 2017). The importance of visual appeal and its association with the overall satisfaction of a website has also been shown to be more important for women than for men across several studies (Cyr and Bonanni, 2006; Cyr and Head, 2013; Enoch and Soker, 2006; Terzis and Economides, 2011; Zhou and Xu, 2007).

More generally, it seems that men and women process website information differently. Neuroscientific results related to the construct of "beauty" demonstrate

that women process stimuli perceived as beautiful bilaterally in the parietal cortex, while men tend to process the same stimuli in the parietal cortex of only the right hemisphere of the brain (Cela-Conde, Ayala, et al., 2009; Fedrizzi, 2012). As human decision-making processes have been related to brain regions of the prefrontal cortex (PFC) (Deppe et al., 2005; Krampe, Gier, et al., 2018), possible gender differences in decision making on ecommerce websites might be associated with neural activity differences in the PFC. To the best of our knowledge, there are no existing studies that focus on gender-specific neural differences in relation to websites' visual aesthetic and usefulness perceptions. However, there are several studies investigating the neural processing of "beauty" in an economic context, revealing that aesthetically pleasant stimuli induce greater neural activity in brain regions of the frontmedial, ventromedial, and orbitofrontal cortex (Krampe, Strelow, et al., 2018; Nissen, Krampe, et al., 2019; Plassmann, Kenning, Deppe, et al., 2008). Men tend to display higher neural activity in the PFC than women, when conducting the same tasks (Cinciute et al., 2018; Kalia et al., 2018; Li, Luo, et al., 2010), and these differences in neural activity tend to be more left-lateralized (Chuang and Sun, 2014). Following this previous research, therefore, the PFC may provide possible explanations of whether (and how) there are different neural activity patterns between men and women when exposed to ecommerce websites.

(ii) Perceived trustworthiness The influence of the perceived trustworthiness of a website seems to be consistent across most studies, whereby women tend to be more skeptical about whether or not they can trust an ecommerce website (Dimoka, 2010; Riedl, Hubert, et al., 2010; Rodgers and Harris, 2003). This seems to be particularly relevant when a website is being used for the first time (Albert et al.,ly relevleviia(P)1.0(

Economides, 2011; Zhou and Xu, 2007), but that men are more focused on the content provided and navigation performance of websites. Although some studies, in contrast, find no gender-related differences, the majority of the reviewed studies do support these trends. Thus, based on previous research findings related to visual website appeal, we hypothesize the following:

> *H 1: Because women consider the aesthetics of ecommerce websites to be more important compared with men, women rate the aesthetics of less preferred websites significantly lower than men do (measured with the Visual Aesthetics of Websites Inventory (VisAWI) scales) (Study 1).*

In line with the first argument, men tend to be more focused on functional aspects such as the usefulness of an ecommerce website. Therefore, men might be influenced by the PU that has an impact on the overall satisfaction with the website. Consequently, we propose that men evaluate the PU as more important compared with women, leading to the following hypothesis:

> *H 2: Women evaluate the usefulness of a website that is perceived as less favorable better than men do (measured by the TAM constructs PU, PEOU , and PUI) (Study 2).*

It has been shown that the measurement of neural cortical activity in the PFC can help to increase the explained variance of website-related characteristics (i.e., aesthetics, PU, PEOU , PUI). However, to the best of our knowledge, no gender-related investigations of these brain regions in the context of ecommerce website evaluations have been conducted so far. As studies investigating gender differences in other contexts have found that men tend to have higher left-lateralized neural activity (Chuang and Sun, 2014), we assert that this tendency will also be accountable for the perception of the ecommerce websites looked at in our study, leading to the following hypothesis:

> *H 3: Men indicate increased left-lateralized neural activity in brain regions of the PFC in comparison to women, when using specific ecommerce websites (measured with fNIRS) (Study 3).*

The specific gender-related differences dependent on the IS-relevant constructs in our study have not yet been explored in NeuroIS research, except for pioneering studies investigating these neural gender differences in the frame of trustworthiness (Dimoka, 2010; Riedl, Hubert, et al., 2010). Consequently, to answer the third hypothesis, we followed a data-driven approach, expanding the scope of H3. The collected neural data will provide additional insights into the (neural) perception

4.2.4. Study 1: Gender Differences in Website Aesthetics

Study Design and Sample

Study Design. The standardized and validated VisAWI questionnaire was used to investigate the participants' aesthetic perceptions of websites (Moshagen and Thielsch, 2010). The VisAWI aims to identify how users subjectively perceive the aesthetics of graphical interfaces, measured along the constructs of simplicity, diversity, colorfulness, and craftsmanship (Moshagen and Thielsch, 2010, 2013). The VisAWI has been used in various studies and is known to have good validity and reliability (Altaboli and Lin, 2011; Moshagen and Thielsch, 2010; Seckler et al., 2015). Consequently, the three selected websites Computeruniverse, Digitalo, and PNShop (Figure 4.2) were shown in randomized order to the participants, who were then requested to answer the VisAWI constructs on a 5-point Likert scale (from 1 = totally disagree to 5 = totally agree). In addition, participants were requested to indicate whether they already knew of or had used the website before. The participants who indicated that they did were excluded from the data analysis. Finally, participants were asked to answer demographic questions as well as a control item to exclude inattentive participants. As control item, a text (240 words long) was displayed that stated in the last sentence which answer should be selected in the upcoming question. The online survey was distributed using an online platform with no restrictions except for age (being at least 18 years of age).

Sample. The questionnaire was distributed to 287 participants, from which 249 participants completed the self-reported survey. After data purification (eliminating the responses of participants who answered the attention control variable incorrectly (n = 17), and participants who did not select "male" or "female" as their gender (n = 12)), a final sample size of N = 219 participants was used for the data analysis (one additional data set had to be deleted due to providing an outlying value of 300 online purchases per month). The average age of participants was M = 35.8 years (standard deviation (SD) = 10.8), and the sample consisted of 59.82% male and 40.18% female participants. Most of the participants were employed (79.7%), 14.7% were students, 4.3% were currently searching for employment, and 1.3% were in an apprenticeship. As the overarching topic was online shopping, participants were also asked to indicate how many online purchases they typically made per month, which resulted in $M = 3.85$ purchases per month (SD = 3.26). Finally, so that the results could be compared across studies, a control questionnaire exploring the construct of impulsive buying (Rook and Fisher, 1995) was also included in the survey, resulting in an average of $M = 2.34$ (SD = 0.78).

Website	Simplicity		Diversity		Colorfulness		Craftsmanship	
Gender	m	f	m	f	m	f	m	f
Computeruniverse	3.59	3.70	3.40	3.42	3.56	3.50	3.54	3.64
Digitalo	3.40	3.50	3.04	3.03	3.28	3.30	3.34	3.48
PNShop	2.40	2.48	2.61	2.68	2.91	3.04	2.68	2.75

Table 4.1. Gender-specific Mean Ratings of the VisAWI Scales

Results

Reliability of Variables For the website-related items, Cronbach's Alpha (CA) was calculated to test the reliability of all included constructs. The results indicate CA_{SIM} = .864 for simplicity, CA_{DIV} = .814 for diversity, CA_{COL} = .822 for colorfulness, and CA_{CRA} = .793 for craftsmanship; all of which suggest very good reliability (Blanz, 2015) and are in line with prior identified values for the employed scales (Moshagen and Thielsch, 2013).

To explore the internal consistency, we calculated the item-rest correlations (also known as corrected item-total correlation) for each included item and each website (all items and values are provided in Appendix.3). All values for item-rest correlations were above the threshold of .3 and are therefore included in the analysis (Nunnally, 1978; Zijlmans et al., 2018).

Grouping and Control Variables In pursuit of the overarching research goal of investigating gender-specific differences in the perception and evaluation of ecommerce websites, we first tested whether there were significant differences in our sample regarding age, purchases per month, and impulsive buying. A multivariate analysis of variance (MANOVA) including the three control variables as dependent variables, and gender as independent variable, revealed no significant differences between the two gender groups ($F(3, 213) = 0.586$, $p = .625$). Furthermore, univariate tests for each dependent variable revealed no significant differences with regard to the two gender groups (age: $F(1, 215) = 0.136$, $p = .713$; impulsive buying: $F(1, 215) = 0.710$, $p = .400$; purchases per month: $F(1, 215) = 1.256$, $p = .264$).

Results of Study 1 Because all three of the websites were shown to each participant after one another in randomized order, we ran one-way repeated measures ANOVAs for each of the included constructs (simplicity, diversity, colorfulness, and craftsmanship), with gender as the between-subjects factor. As the assumption of sphericity was violated for all of the constructs, further analyses were run using Greenhouse–Geisser correction and post-hoc tests with Tukey-corrected p-values. The results show

significant differences between the three websites for simplicity ($F(1.73, 374.84) = 131.271$, $p < .001, \eta_p^2 = .377$), diversity ($F(1.9, 411.50) = 62.205$, $p < .001, \eta_p^2 = .223$), colorfulness ($F(2, 432.93) = 27.572$, $p < .001, \eta_p^2 = .113$), and craftsmanship ($F(1.9, 412.73) = 76.05$, $p < .001, \eta_p^2 = .26$).

However, no significant differences between gender could be identified for any of the measures used (simplicity: $F(1, 217) = 1.61$, $p = .206, \eta_p^2 = .007$; diversity: $F(1, 217) = 0.129$, $p = .719, \eta_p^2 = .001$; colorfulness: $F(1, 217) = 0.097$, $p = .755, \eta_p^2 < .001$; craftsmanship: $F(1, 217) = 1.51$, $p = .221, \eta_p^2 = .007$). Similarly, no interaction effect between website and gender could be identified (simplicity: $F(1.73, 374.84) = 0.012$, $p = .979, \eta_p^2 = .000$; diversity: $F(1.9, 411.50) = 0.196$, $p = .811, \eta_p^2 = .001$; colorfulness: $F(2, 432.93) = 0.861$, $p = .423, \eta_p^2 = .004$; craftsmanship: $F(1.9, 412.73) = 0.185$, $p = .821, \eta_p^2 = .001$). The mean values by website, gender, and construct are provided in Table 4.1.

Discussion of Study 1

The results reveal that the website Computeruniverse was significantly the highest evaluated in all of the measured constructs (simplicity, diversity, colorfulness, and craftsmanship). The website PNShop was the lowest evaluated in all of the constructs (all with $p < .001$), while the difference between PNShop and Digitalo was also significant, but not as great as that between PNShop and Computeruniverse (all $p < .003$ for PNShop versus Digitalo comparisons). In a comparison between Computeruniverse and Digitalo, differences could be identified only for diversity ($p < .01$) and colorfulness ($p < .05$), but not for simplicity and craftsmanship (both with $p > .05$).

Although no significant gender differences were identified ($p > .05$), female participants generally and consistently evaluated the ecommerce websites on all constructs better than men did (Table 4.1). In particular, regarding the colorfulness of websites, there seem to be gender-related differences, because colorfulness was the only construct in which no significant differences between the women's rating of PNShop and both the women's and men's rating of Digitalo could be identified ($t(434) = -2.202$, $p = .239$ and $t(582) = -1.889$, $p = .410$, respectively). These results lead to the rejection of H1, but indicate a tendency for women compared with men to evaluate websites' aesthetics as being more important. This tendency fails to reach the significant threshold of $p < .05$. Even so, the results are in line with recent studies (Afshardost et al., 2013; Forgas-Coll et al., 2013) that found no significant gender differences in the perception of website aesthetics. Based on these results,

it might be concluded that there exist no directly observable differences between gender in evaluation regarding the **visual design** of ecommerce websites.

4.2.5. Study 2: Gender Differences in Website Utility

Study Design and Sample

Study Design. In Study 2, the same experimental procedure, using the same ecommerce websites as in Study 1, was applied. However, this time, participants were requested to evaluate the websites on a 5-point Likert scale (from 1 = totally disagree to 5 = totally agree) for the TAM constructs PU, PEOU , and PUI. To avoid a familiarity bias caused by prior usage of one of the websites, participants were again asked whether they had seen or visited the ecommerce websites before. If they stated that they were familiar with the websites, these participants were excluded from the data analysis. Moreover, at the end of each websites' evaluation, participants were asked once again whether they were still convinced that they had not known the website prior to this visit. Additionally, the same control question to measure the users' attention as in Study 1 was included, consisting of an extended text paragraph after which participants had to choose the right answer. After that, participants had to give their demographics and rate the impulsive buying scale after which they were thanked and debriefed.

Sample. The initial sample consisted of 142 participants, from which 26 data sets had to be excluded because participants failed to answer the attention control question correctly (n = 11) or because they indicated no gender (n = 15). As a result, the final sample used for the data analyses included N = 116 participants, where n = 68 were men and n = 48 were women. Average age was $M = 34$ years (SD = 11.4). The majority of the sample was in employment (56.9%), 33.62% were students, 8.62% were searching for employment or retired, and 0.86% were in an apprenticeship. As in Study 1, participants were asked to indicate how many online purchases they typically made per month, which resulted in $M = 4.03$ purchases (SD = 3.30). Finally, participants were asked to answer questions about their tendency for impulsive buying, resulting in a mean value of $M = 2.15$ (SD = 0.88).

Results

Reliability of Variables. Again, CA values for the included TAM constructs were calculated to test reliability. The results indicate good reliability, with CA_{PU} = .864, CA_{PEOU} = .888, and CA_{PUI} = .908 (Blanz, 2015), which is in agreement with scale reliability found in previous studies that employed the TAM scales (Khasawneh,

Website	PU		PEOU		PUI	
	m	f	m	f	m	f
Computeruniverse	3.68	3.82	4.15	4.17	3.28	3.31
Digitalo	3.18	3.37	3.75	4.02	2.8	3
PNShop	2.56	2.56	3.04	3.11	2.15	2.37

Table 4.2. Results from the Online Survey

Note. PU = perceived usefulness, PEOU = perceived ease of use, PUI = purchase intention

2018; Xia et al., 2018). We further calculated the item-rest correlations to ensure internal consistency of the scales. All of the questionnaire items used and the values are provided in Appendix.4. Similar to Study 1, all values for item-rest correlations were above the threshold of .3 and are therefore included in the analysis (Nunnally, 1978; Zijlmans et al., 2018).

Grouping and Control Variables. Similar to Study 1, a MANOVA including the three control variables as dependent variables, and gender as independent variable, revealed no significant differences between the two gender groups ($F(3, 100) = 1.25$, $p = .295$). Further, univariate tests for each dependent variable revealed no significant differences with regard to the two gender groups (age: $F(1, 102) = 0.016$, $p = .901$; impulsive buying: $F(1, 102) = 3.803$, $p = .054$; purchases per month: $F(1, 102) = 0.220$, $p = .640$).

Results of Study 2 In accordance with Study 1, a one-way repeated measures ANOVA to compare the utility-related constructs of PU, PEOU , and PUI was conducted for each of the constructs. Thus, each construct and the websites were used as repeated measures, while gender was set as a between-subjects factor. Because the assumption of sphericity was violated for PU and PEOU , all of the following analyses were completed by using Greenhouse–Geisser correction. For the post-hoc tests, Tukey-corrected *p*-values are used.

Analogous to Study 1, Study 2 did reveal significant direct effects between the websites for all three of the constructs (PU: $F(1.8, 131.14) = 56.53$, $p < .001, \eta_p^2 = .436$; PEOU : $F(1.81, 132.44) = 66.55$, $p < .001, \eta_p^2 = .477$; PUI: $F(1.98, 142.6) = 40.46$, $p < .001, \eta_p^2 = .360$). However, once again, no significant direct effects for gender could be identified for any of the constructs (PU: $F(1, 73) = 1.01$, $p = .319, \eta_p^2 = .014$; PEOU : $F(1, 73) = 0.46$, $p = .502, \eta_p^2 = .006$; PUI: $F(1, 73) = 0.894$, $p = .347, \eta_p^2 = .012$), and no interaction effect was visible between website type and gender for any of the constructs (PU: $F(1.8, 131.14) = 2.75$, $p = .073, \eta_p^2 = .036$; PEOU : $F(1.81, 132.44) = 0.28$, $p = .737, \eta_p^2 = .004$; PUI: $F(1.98, 142.6) = 0.351$, $p = .702, \eta_p^2 = .005$).

Discussion of Study 2

The results of Study 2 do not support H2, indicating that there are no significant differences when asking participants directly about the utility of an ecommerce website as perceived by PU, PEOU , and PUI. Similar to Study 1, however, some previous research findings contradict these results, indicating that men and women do differ in their perception of websites regarding PU, PEOU , and PUI (Pengnate and Sarathy, 2017; Ramakrishnan et al., 2014). This is also valid for the results of Study 1 concerning website aesthetics. However, as already pointed out, there are also studies that support our results that there are no gender-related differences in self-reported data (Afshardost et al., 2013; Al-Maghrabi and Dennis, 2009). Consequently, there might be some influencing factors that cannot be explored with direct measurements, but that might impact users' perception of ecommerce websites on an unconscious level.

To investigate whether unconscious perception processes impact users' evaluations of ecommerce websites, neuroimaging methods have been shown to be a reliable approach to exploring cognitive processes, by adding neural data to existing research findings to increase the explained variance (Venkatraman et al., 2015). The use of fNIRS might, therefore, be of particular advantage for shedding light on differences in perception between women and men, allowing us to investigate the unconscious neural processes in an ecologically valid environment such as in front of a computer.

Thus, with the following Study 3, we aim to explore the neural activity differences between male and female participants when confronted with the three different ecommerce websites.

4.2.6. Study 3: Neural Gender Differences – The fNIRS Experiment

Study Design and Sample

Measurement Method. Given the innovativeness of fNIRS, its functionality will be explained first. The neuroimaging method of fNIRS measures the amount of oxygenated (HbO), deoxygenated (HbR), and total hemoglobin in the blood by sending near-infrared light into the skull and measuring the absorption and reflection rates (Ferrari and Quaresima, 2012). The distance between senders and detectors of the fNIRS headband is typically between 15–30 mm and the light reaches 20–30 mm deep into the brain tissue (Ferrari and Quaresima, 2012; Funane et al., 2014) – making it particularly suitable to measure cortical, near-surface brain regions such

as brain regions of the PFC. In comparison to other neuroimaging methods, fNIRS is a lightweight and mobile technology similar to electroencephalography (EEG). However, in comparison to EEG, fNIRS seems to be more robust against movement artifacts and is known for its enhanced user friendliness (Irani et al., 2007; Kim, Koo, et al., 2016). Compared to functional magnet resonance imaging (fMRI), fNIRS has a similar temporal, but weaker spatial, resolution. Its advantage, however, lies in its increased external ecological validity, making it possible to apply fNIRS in realistic, real-life scenarios (Hocke et al., 2018; Krampe, Strelow, et al., 2018).

Concerning its reliability, fNIRS data has been found to correlate significantly with the more sophisticated blood-oxygenation level-dependent (BOLD) signal (Noah et al., 2015; Wijeakumar et al., 2017). In the literature, however, there is no agreement on whether HbO (Hoshi, Kobayashi, et al., 2001; Strangman et al., 2002) or HbR (Huppert et al., 2006; Toronov et al., 2003) correlate more strongly with the BOLD signal from fMRI. Consequently, recent literature has suggested reporting both signals to avoid false positives (measured effects that are not elicited through experimental stimuli) (Hocke et al., 2018; Pinti, Scholkmann, et al., 2019; Tachtsidis and Scholkmann, 2016).

In our research, before the fNIRS headband was applied to participants, they were informed about the measurement procedure in both oral and written form and were required to sign an informed consent agreement in accordance with the Declaration of Helsinki. The fNIRS device applied in our research was an 8-sensor/7-detector continuous-wave fNIRS headband integrating 22 channels. The sampling rate was 7.81 Hz, and the average distance of the optodes was set to 30 mm. The wavelengths of the near-infrared light were 760 nm and 850 nm, with the associated differential pathlength factor (dpf) set to 7.25 for the 760 nm and to 8.38 for the 850 nm, which is in accordance with commonly used values (Essenpreis et al., 1993; Kohl et al., 1998; Zhao, Tanikawa, et al., 2002). The sensor and detector locations of the headband and the corresponding channels are shown in Figure 4.3, in relation to EEG 10-20 landmarks for orientation. To avoid data biases due to equipment interference, several variables were controlled for (Gefen, Ayaz, et al., 2014). First, the room lumination was kept constant while using artificial illumination in the experiment room. Second, although being more robust to movement artifacts than EEG, the fNIRS signal might still be influenced by abrupt (head) movements. Therefore, participants were requested to avoid fast and abrupt (head) movements while wearing the fNIRS headband. Third, as the near-infrared light is likely to be absorbed by thick and dark hair, participants' hair was moved aside to allow the light to penetrate the scalp and tissue, receiving a better signal strength. The headband

was calibrated for each user individually, through which data quality was assured.

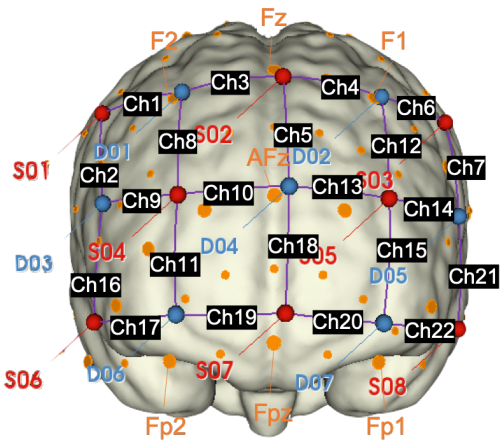


Figure 4.3. Sensor, Detector, and Channel Locations on the PFC

Data pre-processing and analysis was conducted using the software nirsLAB from NIRx. The raw fNIRS data collected was pre-processed, applying a band-pass filter with a low cutoff frequency of 0.01 Hz and a high cutoff frequency of 0.2 Hz, which allowed us to filter out noises such as heart rate and respiration (Pinti, Scholkmann, et al., 2019; Trambaiolli et al., 2018; Wang, Li, et al., 2018; Zhang, Zhou, et al., 2017). Afterwards, the hemodynamic states of HbO and HbR were computed using the modified Beer–Lambert law (Delpy et al., 1988; Kocsis et al., 2006; Kopton and Kenning, 2014; Scholkmann et al., 2014). Finally, the task-relevant changes in hemoglobin were calculated using a general linear model (GLM) with the canonical hemodynamic response function (hrf) as a baseline.

Study Design. The stimuli used were identical to the material used in Study 1 and Study 2. Participants were requested to use the three websites on an iPad Pro 12". They were asked to search for a digital camera on each of the websites. After they decided on one digital camera in their favor, the participants were asked to place it in the shopping basket. With this, the task was completed, and users were asked to fill out a questionnaire for the website used. In this study, we included the prior questions used for website aesthetics from Study 1, although this time we used the short version of the VisAWI (Moshagen and Thielsch, 2013). In addition, we included the same questions for PU, PEOU , and PUI from Study 2 in the questionnaire. Each item was evaluated on a 5-point Likert scale (1 “totally disagree” to 5 “totally agree”).

After providing these ratings, users were requested to proceed to the next website. After all three websites were used and evaluated, participants were asked to complete a final questionnaire with demographic questions.

Sample. A total sample of $N = 20$ participants (40% being female) was recruited from the local university. For further analyses, the sample was divided into two groups according to the indicated gender (n = 12 men, n = 8 women). Average age was $M = 26.1$ years (SD = 4.3). Half of the sample was in employment (50%), 40% were students, and 10% were in an apprenticeship. Analogous to Study 1 and Study 2, we also asked for self-reported online purchases per month and impulsive buying behavior. Average online purchases per month were $M = 3.11$ (SD = 1.79), and the impulsive buying ratings averaged $M = 2.09$ (SD = 0.780).

Our sample size can be regarded as an adequate number for a neuroscientific study in general, and for NeuroIS research in particular (Riedl, Banker, et al., 2010), given that the average sample size in previous neuroimaging IS-related studies is about 18 participants (Riedl, Banker, et al., 2010). Furthermore, previous studies focusing on the statistical power of brain imaging tools have indicated that a sample size of around 20 participants is sufficient for most neural effects, given that the results are grounded on (neuro-)biological determinants (Friston, 2004). For studies conducted with fNIRS, in the context of cognitive performance or affective processing, previous research has found an average sample size of 20 participants to be sufficient for reliable results (Causse et al., 2017; Ferreri et al., 2014; Nakahachi et al., 2008; Vassena et al., 2019).

Results

Grouping and Control Variables. To ensure comparability between the male and female groups with regard to the control variables of age, purchases per month, and impulsive buying, we conducted a MANOVA analogous to Study 1 and Study 2. The MANOVA included all three control variables as dependent variables, with gender as an independent variable, and revealed no significant differences between the two gender groups ($F(3, 16) = 3.05$, $p = .059$). Further, univariate tests for each dependent variable revealed no significant differences for age and purchases per month with regard to the two gender groups (age: $F(1, 18) = 0.191$, $p = .668$; purchases per month: $F(1, 18) = 0.282$, $p = .602$), but they did reveal a significant difference in the impulsive buying tendency between men and women ($F(1, 18) = 9.632$, $p = .006$).

Self-Reported Results. Similar to Study 1 and Study 2, one-way repeated measures ANOVAs were calculated for each construct (PU, PEOU , PUI, and aesthetics (AEST)), with the websites as repeated measures and gender as the between-subjects factor. Because the assumption of sphericity was violated for PEOU and PUI, all of the following analyses are controlled by using the Greenhouse–Geisser correction. Post-hoc tests were calculated with Tukey-corrected p-values.

	PU		PEOU		PUI		AEST	
Website	m	f	m	f	m	f	m	f
Computeruniverse	4.17	3.80	4.38	4.05	3.35	3.09	3.85	3.38
Digitalo	3.90	3.48	3.97	3.93	3.08	3.25	3.90	3.56
PNShop	2.65	2.85	2.85	3.25	1.58	2.16	1.90	1.97

Table 4.3. Questionnaire Results with Group Comparisons per Website

Note. PU = perceived usefulness, PEOU = perceived ease of use, PUI = purchase intention, AEST = perceived aesthetics

In agreement with the results from Study 1 and Study 2, we identified a direct effect of website type for all of the constructs (PU: $F(1.94, 34.90) = 10.660$, $p < .001, \eta_p^2 = .372$; PEOU : $F(1.52, 27.28) = 16.57$, $p < .001, \eta_p^2 = .479$; PUI: $F(1.51, 27.14) = 19.91$, $p < .001, \eta_p^2 = .525$; AEST: $F(1.91, 34.45) = 26.056$, $p < .001, \eta_p^2 = .591$). However, again, there was no direct effect of gender on any of the constructs (PU: $F(1, 18) = 0.589$, $p = .453, \eta_p^2 = .032$; PEOU : $F(1, 18) = 0.001$, $p = .972, \eta_p^2 < .001$; PUI: $F(1, 18) = 0.332$, $p = .571, \eta_p^2 = .018$; AEST: $F(1, 18) = 0.847$, $p = .370, \eta_p^2 = .045$), and no interaction effect between website type and gender could be identified (PU: $F(1.94, 34.90) = 0.766$, $p = .469, \eta_p^2 = .041$; PEOU : $F(1.52, 27.28) = 1.51$, $p = .237, \eta_p^2 = .078$; PUI: $F(1.51, 27.14) = 1.47$, $p = .245, \eta_p^2 = .076$; AEST: $F(1.91, 34.45) = 0.527$, $p = .587, \eta_p^2 = .028$). Consequently, these results support the findings from Study 1 and Study 2 and reveal that, even after actual use, no self-reported gender-related differences can be identified. The mean values of all constructs by website and gender are provided in Table 4.3.

Neural Results. Alongside the self-reported questionnaires to evaluate each website, we also measured the neural activity in the PFC. Hence, both signals, HbO and HbR levels, were calculated, acting as a proxy for neural activity of the PFC. To investigate brain activity patterns, the average HbO levels from the female group was compared to the average HbO levels of the male group. In general, the neural activity levels measured with fNIRS can be interpreted as follows: An increase in HbO levels indicates neural activation in the associated brain region, while an increase in HbR has the opposite effect and thus indicates neural deactivation in the respective brain region (Zimeo Morais et al., 2017). In the following, for the associated areas in the PFC with their related channels of our fNIRS montage (ch), we report their two-tailed *t*-values, *p*-values, Cohen's *d*, and the effect size *r*.

Figure 4.4 shows the results of the comparisons per website on different significance levels. For the participants' best-evaluated website (in all of the constructs used), Computeruniverse, we identified significantly increased neural

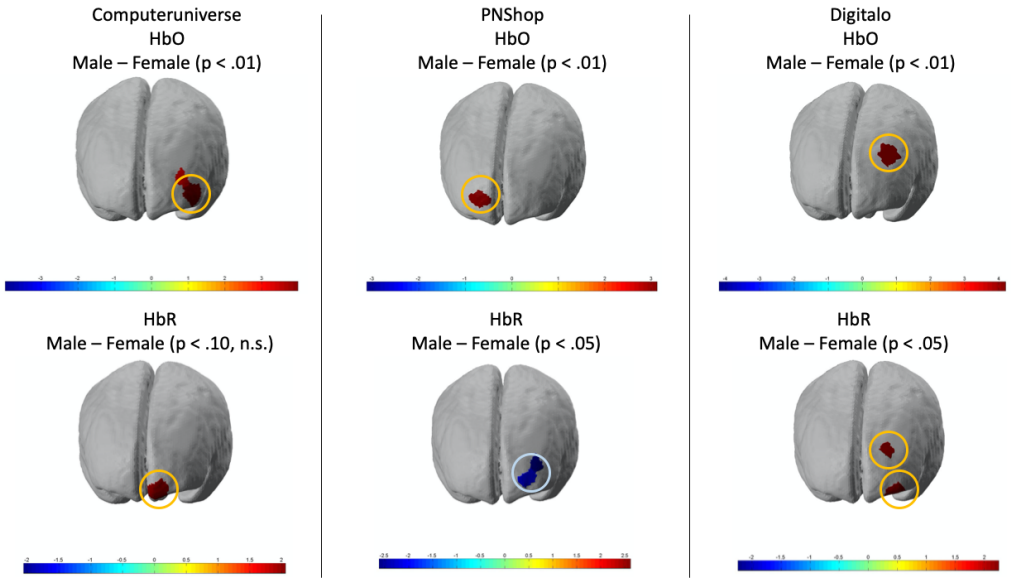


Figure 4.4. Comparison of HbO and HbR Levels Between Men and Women

Note. The figure shows t-values of significant fNIRS channels. For HbO, higher t-values indicate neural activation, while for HbR, higher t-values indicate neural deactivation

activity through increases in HbO for male participants in both the left vlPFC (ch14: $t = 3.120, p = .006, d = 1.513, r = .603$) and left inferior dlPFC (ch21: $t = 3.985, p = .001, d = 1.933, r = .695$). Further, for PNShop (the website evaluated lowest by the included constructs), the right inferior dorsomedial prefrontal cortex (dmPFC) (ch11: $t = 3.126, p = .006, d = 1.516, r = .604$) indicated increased neural activity for male in comparison to female participants. Finally, the moderately evaluated website Digitalo showed increased neural activity in the left superior dlPFC (ch6: $t = 4.2, p = .001, d = 2.037, r = .714$ and ch14: $t = 2.904, p = .01, d = 1.409, r = .576$) for male in comparison to female participants.

In addition to the HbO-based neural activity differences between men and women, the HbR signal provides additional insights into the neural processing of the three sampled websites. In particular, for the website evaluated to be the most useful, Computeruniverse, we observed an increased amount of HbR in the left ventromedial prefrontal cortex (vmPFC) (ch20: $t = 1.971, p = .065, d = .956, r = .431$) for male participants, indicating neural deactivation. Furthermore, the website evaluated as being the least useful, PNShop, revealed decreased HbR concentrations in the left inferior dmPFC (ch15: $t = -2.029, p = .058, d = -0.984, r = .442$) and inferior dlPFC (ch14: $t = -2.432, p = .026, d = -1.18, r = .508$), indicating increased neural activity in this brain region for male participants. Finally, the website evaluated to be moderately useful, Digitalo, revealed a significant increase in HbR for male participants in the left OFC (ch22: $t = 2.049, p = .056, d = 0.994, r = .445$)

and left dmPFC (ch12: $t = 2.137, p = .047, d = 1.037, r = .46$). The results are interpreted and discussed in the following section.

4.2.7. Discussion

Self-reported Results

The results of the self-reported measures investigating consumers' perceptions of the design and usability of ecommerce websites revealed no significant differences between men and women across all three studies. Consequently, we can reject the hypothesis that women focus more on visual design in comparison to men (H1). These results support previous research that found no significant gender-related differences in evaluations of ecommerce websites (Afshardost et al., 2013; Al-Maghrabi and Dennis, 2009). Consistent with claims that these differences occur mainly in cultures where equality is strongly entrenched, these findings provide an explanation. In this context, the self-reported results may show that in countries where men and women have equal rights (such as with our German sample), no gender-specific differences appear in the self-reported evaluation of ecommerce websites (Cyr and Head, 2013).

Although no significant differences have been observed, consistent tendencies have been detected as men in comparison to women tend to evaluate the utility criteria PU, PEOU , and PUI of ecommerce websites as less favorable. The indicated tendencies support the second hypothesis; however, the results fail to reach the significant threshold, leading to our rejection of H2.

Based on these research findings, we ask the critical and provocative question: Does the idea of measuring conscious, reflective gender differences still hold true for ecommerce environments? We assert that because users are becoming more experienced, and more website design elements are increasingly becoming the new standard, the reflective, deliberate differences are no longer identifiable or expressible for users.

Consequently, in line with previous research, our results show an indistinct picture of gender differences in the perception of ecommerce websites, leading to the assumption that there may also be other (unconscious) cognitive processes that affect the perceptions of male and female users.

Neural Results

To explore these unconscious neural perception processes for men and women, we applied the innovative neuroimaging method of fNIRS. The results support

H3, indicating that for websites evaluated as being useful and moderately useful (Computeruniverse and Digitalo), there was increased neural activity in the left hemisphere of the brain for male users. The least preferred website (PNShop), however, indicated increased neural activity patterns in the right hemisphere of the brain for men, for which H3 needs to be rejected. This may be because PNShop was evaluated consistently poorer by men in the self-reports on all constructs, which means that men experienced this ecommerce website more negatively than women did. In the next sections, we attempt to explain the implications of these results for both website design and gender-related differences in ecommerce website information processing.

(Highly) Usable and Aesthetic Websites Our results show increased neural activity in the left vlPFC for the website that was rated highest (Computeruniverse) on all the self-reported constructs by male participants. In general, the vlPFC has been linked to semantic processing (Snyder et al., 2011), movement control (Heinen et al., 2006; Leung and Cai, 2007), and processing of emotional stimuli, due to its connectivity to the amygdala (Wager, Davidson, et al., 2008). The right vlPFC has been linked to the processing of negative emotional stimuli (Wager, Davidson, et al., 2008). In accordance with the HSH (Killgore and Yurgelun-Todd, 2007), increased neural activity in the left hemisphere of the brain in male users might therefore indicate that men, in comparison to women, perceive the ecommerce website (unconsciously) as more pleasing. This assumption is supported by our questionnaire-based behavioral (intention) results indicating that, compared to women, men evaluate the preferred websites as being better. Hence, we propose that (unconscious) perceptional and evaluation differences exist between men and women that do not become explicitly visible in conscious reflective and self-reported measurements. In addition, increased neural activity in the left vlPFC indicates that men require more neural activity to process text elements on websites. As this neural activity pattern could not be identified for the other two, less preferred, websites, we can conclude that the brain region of the vlPFC is also involved in processing pleasant stimuli in web-based environments.

We also identified decreased neural activity in the left vmPFC for the most preferred website (Computeruniverse). The vmPFC has been associated with rational and reasonable economic decision making (Koenigs and Grafman, 2009; Naqvi, Rudrauf, et al., 2007). This might be due to its close connectivity to the amygdala (Delli Pizzi et al., 2017) and, thus, its role in emotion regulation (Buhle et al., 2014). The decrease in neural activity in this brain region could indicate that men experience more intense emotional processing that elicits less self-control in online purchase

decisions such as buying a digital camera on an ecommerce website. This again underlines the importance of website design and the "power of beauty" of ecommerce websites (Lindgaard, Fernandes, et al., 2006; Tractinsky et al., 2006).

Neural activation in the left dlPFC was found for the most preferred as well as moderately preferred websites (Computeruniverse and Digitalo) for male users. The dlPFC has been frequently found to be activated in purchase decision-making processes (Chen, Jimura, et al., 2015; Greening et al., 2011; Hutcherson et al., 2012; Krampe, Gier, et al., 2018; Mitchell et al., 2009). In this context, the dlPFC seems to play an essential role in processing sensory information while making decisions and/or planning further actions (Heekeren et al., 2006). Consequently, based on the fact that men show higher neural activity in the dlPFC when making an ecommerce-related decision, men seem to require more neural activity to process information in comparison to women, supporting previous research (Cinciute et al., 2018; Kalia et al., 2018; Li, Luo, et al., 2010). This suggests that men are more attracted by a website's design. This is in contrast to the assumption that men are predominantly driven by utility aspects of the TAM concepts (PU and PEOU), as some previous research has indicated that PU is more important to men than to women (Hwang, 2010; Sun et al., 2010; Terzis and Economides, 2011; Venkatesh et al., 2003; Zhang and Prybutok, 2003).

Additionally, neural deactivation for men was shown in the left dlPFC and left OFC. The OFC has been found to show increased neural activity when exposed to pleasant and beautiful stimuli (Brown et al., 2011; Cela-Conde, Garcia-Prieto, et al., 2013) and has also been shown to be activated with increased intention to buy (Krampe, Gier, et al., 2018; Plassmann, Kenning, Deppe, et al., 2008). This supports the hypothesis that men seem to show more extreme reactions to well and/or badly designed ecommerce websites – both in a positive and in a negative way. Due to the deactivation of this brain region for men, and the subsequent neural activity increase for women, we make the assertion that women are probably more emotionally driven when it comes to online purchases. This is in accordance with related literature indicating that women showed increased neural activation in emotion processing related brain areas (Dimoka, 2010; Riedl, Hubert, et al., 2010). Further, the significant differences we observed in the impulsive buying control variable, which was evaluated more highly by women than by men, provide additional indicators for why this effect was observed.

(Less) Usable and Unaesthetic Websites The inferior dmPFC, which was found to show increased neural activity for men on the least preferred website (PNShop)

has been linked to decision-making processes (Chen, Jimura, et al., 2015; Greening et al., 2011; Hutcherson et al., 2012; Mitchell et al., 2009) and has been found to be active in the (re-)appraisal of emotional stimuli (Buhle et al., 2014; Terasawa et al., 2013). Going back to the HSH, increased neural activity for men in the dmPFC was found only in the right hemisphere, which implies that men require more neural activity to process aversive stimuli (in this case, an unaesthetic website). This is also supported by the self-reported results indicating that, compared to women, men consistently rated PNShop as less preferable on all of the TAM constructs.

We also identified neural activation for the least preferred website (PNShop) in the left inferior dmPFC and dlPFC for men. Both of these brain regions play a crucial role in decision-making processes such as performance monitoring, adjusting behavior, and when facing a decision conflict (Mitchell et al., 2009; Taren et al., 2011). Furthermore, increases in this brain region have been associated with perceiving positive and pleasant stimuli (Hoshi, Huang, et al., 2011; Wang, Li, et al., 2018) – consequently, an increase for men might point to more negative attributions of the ecommerce website in women. Although no significant differences in the aesthetics ratings could be identified on PNShop between men and women in Study 1 and the self-reports of Study 3, this neural activation pattern seems to support the indication that visuals matter more to women than to men.

4.2.8. Conclusions, Implications, and Limitations

The self-reported measurements regarding the aesthetics and usability of ecommerce websites show no significant differences between men and women. However, the neuropsychological research findings indicate that the evaluation of aesthetically pleasing, useful, and easy-to-use ecommerce websites results in increased neural activity in the left hemisphere of the brain of male users, whereas websites perceived and evaluated as being less aesthetically and not as useful or easy to use result in increased neural activity in the right hemisphere, supporting the HSH. The neuropsychological results show that men require consistently more neural activity to process ecommerce websites for both emotional appraisals and the associated decision-making processes. This supports recent gender-related research findings that men require generally more neural activity levels than women when performing the same task (Li, Luo, et al., 2010; Sugiura et al., 2018). This may support prior findings that women tend to prefer complex websites, whereas men tend to favor clean and simple website designs (Simon and Peppas, 2005). This is made more evident with the increased neural activity observed in the right dmPFC for men confronted with the least preferred ecommerce website, which is also the website with the most

complex content elements and cues. The neural activity differences between men and women might, therefore, provide interesting implications that explain differences in their purchasing behavior.

From a practical point of view, website designers are – based on our findings – advised to consider the gender of their target group when designing a website, and offer different levels of complexity and media richness. The current research work provides a first step towards the definition of different user groups based on their neural, gender-related information processing capabilities. This might explain the inconsistent findings of prior research with regard to the perception of ecommerce websites. Moreover, the use of neuropsychological measurements might even allow to abstract away from gender in the future and solely focus on the provided neural processes of the user to identify different use groups.

Our results should, however, be seen in the light of its limitations. First, our work uses only three different ecommerce websites, focusing on electronic devices. The results might therefore not be transferable to other website designs or product categories. Thus, future research could investigate other website formats as well, such as social networks or purely informational websites, other product categories, or individual user characteristics such as age, culture, or experience levels. Second, only German participants were included in this study. This might be a limitation, given that cultural effects have been shown to have an impact on website informational processing (Cui, Wang, et al., 2012). Consequently, future research should explore cultural differences to determine whether the results hold true in different cultural environments.

Nevertheless, we have shown that men react more to pleasant and unpleasant stimuli, which may result in men buying products more frequently than women because men's neural reward system seems to be triggered more by website design than women's.

Chapter 5

Phase III: Post-/ Repeated-Use

5.1. Paper 6: A Neural Investigation of eLoyalty on eCommerce Websites

Abstract

eLoyalty provides a major competitive advantage for online businesses, however it is difficult to define. To understand the underlying mechanisms of eloyalty, a neuroimaging study was conducted, identifying possible "neural" activations that point to antecedents of the users' eloyalty. Our results show that antecedents to eloyalty might be associated with an activation of the bilateral dorsolateral prefrontal cortex (PFC), and the right orbitofrontal/ventromedial cortex. Furthermore, a non-hypothesized deactivation of the left superior dorsomedial PFC was identified. This activation pattern can be related to increased pleasantness and reward attribution of the target website, as well as higher associated familiarity and user preference. Based on this it is discussed that antecedents to eloyalty may be associated with neural lock-in effects. These lock-in effects may be elicited through continuous, positive, and pleasant user experiences which ultimately lead to an emotional attachment that is "neurally encoded" into the user's brain.

5.1.1. Introduction

To achieve eloyalty and to establish lock-in effects is a major concern of online businesses where competitors and possible alternatives are just one click away (Chen and Hitt, 2002; Ghazali et al., 2016). Given the increasing numbers in online purchases over the last years (Bhatti et al., 2020), the focus may be shifted once more to the investigation of online businesses and how they increase and establish high switching costs that lock-in users and ensure their eloyalty. While online businesses may heavily rely on network effects which bind users to their business (Farrell and Klemperer, 2007; Haucap and Heimeshoff, 2014), the associated perceived switching costs and thus, lock-in effects on end-users are often barely graspable (Tucker 2019). That is, although the main interface between online business and customer is represented through the ecommerce website, several additional factors apart from the website's quality may impact whether users will favor a website, repeatedly use it, and finally, become loyal. The product assortment, product quality, speed of product delivery, and service quality are just few of the attributes that may lead to eloyalty to the online business (Chen and Hitt, 2002; Ray et al., 2012). In

addition, website-related antecedents of eloyalty can be found in latent constructs like perceived usefulness, ease of use, website aesthetics, perceived trustworthiness, or internal states and needs of the user (Bilgihan, 2016; Kassim and nor Asiah Abdullah, 2010; Kumar et al., 2016; Legris et al., 2003; Lu et al., 2019; Pengnate and Sarathy, 2017; Srinivasan et al., 2002; Tuch, Roth, et al., 2012; Wood and Van Heerden, 2007). In summary, there is a plethora of attributes relating to the website itself, the products offered, and the services related to the products and customer care, which together make eloyalty a complex concept that is barely graspable in its entirety through distinct latent (behavioral) variables.

However, what is measurable on a behavioral level is the decision behavior of users when they are confronted with their favorite website and a possible alternative, whereby the preference for a website is a first indicator and antecedent to eloyalty. Rooted in the definition of loyalty, loyal users will choose the preferred website over the possible alternative (Burford et al., 1971; Paswan et al., 2007; Plassmann, Kenning, and Ahlert, 2007) due to different "stages" they have run through during prior use experiences with the website. In consumer related literature, four loyalty stages are proposed to be run through being cognitive, emotional, conative, and action loyalty (Oliver, 1999). Now, while the choice for the website (meaning action loyalty) can be measured through observation or questionnaires, the underlying processes leading to this decision are difficult to assess through behavioral measures. That is, users might not be able to verbalize which aspects of the online business and its website are the reasons for why they are preferred. As a result, an investigation that abstracts away from behavioral measures and distinct constructs might be reasonable. One possibility to assess the underlying processes happening when a user prefers one website over another is by looking at neural activations in the users' brains (Deppe et al., 2005; Gier et al., 2020; Krampe, Gier, et al., 2018; McClure et al., 2004; Plassmann and Weber, 2015). Therefore, a neuroimaging study of users' brain activity is reasonable to identify possible "neural" activation patterns that relate to the user's most preferred website. These might be associated with neural processes that could indicate antecedents to loyalty (Oliver, 1999).

To the best of our knowledge, only two studies have investigated neural correlates of cognitive eloyalty by means of familiarity (Sénécal et al., 2015), and emotional eloyalty (Gregor et al., 2014) with neurophysiological measurements in the frame of IS research. While both studies emphasized a different stage of eloyalty, they have opposing results, both of which are argued to be related to eloyalty. Therefore, this research aims to extend and validate these prior results without emphasizing a distinct stage of eloyalty. In order to approximate eloyalty, possible antecedents are

operationalized in line with related marketing literature by using user's first-choice preferences of familiar ecommerce websites. As a result, the following research question is answered: *"what are the neural correlates of users' first-choice websites as eloyalty antecedent in the moment of choice?"*. Consequently, to address this research question, related literature of eloyalty and its operationalization is considered along a typical user journey. Through this, constructs are identified which are frequently used as antecedents for eloyalty and thus, pose possible psychological processes which might pave the way to eloyalty. It has to be noted that these constructs are by no means intended to capture eloyalty as a holistic concept, but rather serve as a starting point to identify possible neural candidates that might participate in the network to generate eloyalty in the long run. Therefore, related neuroIS literature on loyalty and website usage is reviewed that can be used to derive hypotheses and further interpret the neural results of our experiment. After that, the method is described which follows an event-related experimental design and employs the neuroimaging method of functional near-infrared spectroscopy (fNIRS) to assess neural activity on a prefrontal, cortical level and to extend first findings generated by related literature (Gregor et al., 2014; Sénécal et al., 2015). fNIRS has already been successfully used in IS and ecommerce research and is especially suitable to access brain areas of interest, which makes it an appropriate method to assess possible neural effects of user preferences that may lead to eloyalty (Gier et al., 2020; Krampe, Gier, et al., 2018). Finally, results are presented, and their implications are discussed.

5.1.2. Theoretical Framework

In IS literature the concept of eloyalty is often approximated through constructs of service/website quality, user satisfaction, perceived risk and trust, (re-)purchase intention, and familiarity, and therefore, operationalized through its antecedents (Carter et al., 2014; Chiu et al., 2014; Gefen, 2002; Gregor et al., 2014; Kaya et al., 2019; Kim, Ferrin, et al., 2009; Otim and Grover, 2006; Sénécal et al., 2015). Further studies who focus more on website quality have also considered eloyalty as a result of high usability and website aesthetics (Cyr, 2008, 2014; Flavián et al., 2006). While these approaches have shown that the named constructs significantly impact the formation of users' eloyalty, they may only address some of the underlying processes that constitute eloyalty as overall concept. To dissolve this issue and define loyalty as concept, related literature in the adjacent discipline of marketing is consulted. In marketing literature, loyalty is defined as a biased behavioral response that is expressed over time by a decision maker (i.e., website user), with respect to one or more alternatives, and it is a function of several psychological processes (Jacoby and Kyner, 1972). Another definition, also from marketing, defines loyalty as a "deeply

held commitment to rebuy or repatronize a preferred product/service consistently in the future" (Oliver, 1999). Consequently, eloyalty is an intended behavior in the time of choice when users deliberately decide to use one website over possible alternatives. Unsurprisingly, several works in marketing literature have operationalized loyalty in terms of the "first-choice" product or brand of consumers when they are already familiar with this product/brand (Burford et al., 1971; Ostrowski et al., 1993; Paswan et al., 2007; Plassmann, Kenning, and Ahlert, 2007). When transferring this thought to websites, the questions rises: what drives users to prefer one website as their first choice over others and maintain this preference? It is assumed that eloyalty may be established through four different stages of psychological processes (Gregor et al., 2014; Jacoby and Kyner, 1972; Plassmann, Kenning, and Ahlert, 2007), which can be defined as (1) cognitive loyalty in which primarily functional aspects are evaluated, (2) affective loyalty in which an emotional, liking attachment to the brand is established, (3) conative loyalty, which is determined by the prior two phases and describes the behavioral intention to make a purchase and re-use the website, and finally, (4) action loyalty which describes the actual user behavior (Oliver, 1999). However, it is challenging to distinguish these stages from one another in terms of ecommerce website related constructs, because website aesthetics, for instance, may impact both cognitive and affective eloyalty simultaneously. Instead, they may be treated as a user journey to eloyalty.

A Potential eCommerce User Journey to eLoyalty

Typically, a user's journey with an ecommerce website starts with visiting the website for the first time and finally results in repetitive use in case of positive experiences (Karapanos et al., 2009). During these phases, a familiarization process between user and website evolves whereby different website design aspects might become more (or less) important to the user over time. For instance, functionality, visual design, and aesthetics of a website are particularly relevant for the first impression and might therefore deposit mostly on cognitive and affective eloyalty processes (Lee and Koubek, 2010; Minge, 2008; Oliver, 1999). Therefore, through designing an aesthetic and attractive website, antecedent processes to eloyalty can already be triggered during the first use of a website (Afsar et al., 2013; Kassim and nor Asiah Abdullah, 2010). Further, the longer and more often a user uses a website, the more important becomes its usability and usefulness (Lee and Koubek, 2010; Minge, 2008). Over time, the repetitive use of a website generates familiarity and trust with it and possibly, increases users' behavioral intentions through which the conative loyalty stage is addressed (Casaló et al., 2008; Oliver, 1999).

Therefore, website familiarity of the user leads to the assumption that, if familiar with an ecommerce website and its service quality, and not having made negative experience with this website, familiarity provides an additional, significant influence factor on trust, re-purchase intentions, and finally, on eloyalty (Gefen, 2000; Ha, 2004; Kaya et al., 2019; Li, Browne, et al., 2006). This, however, implies that familiarity can also backfire when negative experiences are made with an ecommerce website that negatively impact the perceived trustworthiness of the online business. As a result, although positive familiarity can be an antecedent to eloyalty formation, it cannot be used as equivalent and only antecedent. Hence, it may be considered with other constructs of aesthetics and usefulness, but also with perceived trustworthiness and user preference. Perceived trustworthiness has shown to have a major impact on user's eloyalty formation to websites by reducing probable risks and uncertainty which come with trying out new websites over familiar ones (Gommans et al., 2001; Kim and Kim, 2005; Li, Browne, et al., 2006). Consequently, trust or trustworthiness has also been frequently identified as eloyalty antecedent (Bilgihan, 2016; Gefen, 2000; Reichheld and Schefter, 2000; Wood and Van Heerden, 2007). Finally, both antecedents and consequences of loyal users are typically found in increased intentions to use and purchase, increased willingness to pay, and increased word-of-mouth promotion of the ecommerce website and its associated online business (Srinivasan et al., 2002). These constructs can be related to the conative and action loyalty stage and might ultimately reflect user preference for one website over others in a decision scenario. That is, users will choose the website for which they have higher use intentions over other alternatives. In the following, the identified antecedents along the user journey are used to identify related neurophysiological literature to derive hypotheses for the fNIRS experiment.

Hypotheses Derivation: Potential Neural Correlates of eLoyalty Antecedents

While reviewing related IS literature, two studies which investigated eloyalty and cognitive lock-in effects with EEG could be identified. One study investigated both the cognitive and emotional component of eloyalty for travel services websites and identified neural activations primarily in the left prefrontal cortex (PFC) for the preferred website (with website preference measured by usefulness, ease of use, perceived risk, and website design) (Gregor et al., 2014). The other study investigated the cognitive component of eloyalty by assessing cognitive load of users during familiarization processes while making purchases on a website (Sénécal et al., 2015). They identified through repetitive use (and thus, increasing familiarity) of the same website, that cognitive load in the PFC declined (meaning neural deactivation). This

potentially leads to what they call cognitive lock-in effects due to familiarity (Sénécal et al., 2015). Unfortunately, in these two studies, the localization of the activation and deactivation over repetitive use within the PFC is not further specified. It might be, that the increased PFC activation for preferred websites of the first study is identified in medial areas while the deactivation of the second study in more lateral PFC areas. This potential localization would be in congruence with research on (physical) brand loyalty, where studies identified that when choosing a preferred brand product, participants had a significant increase in the medial parts of the PFC and a decrease in the lateral parts of the PFC, which has been referred to as the first-choice brand effect (Deppe et al., 2005; Krampe, Gier, et al., 2018; Plassmann, Kenning, and Ahlert, 2007). Because users are often also loyal to their first-choice brand, this effect has also been used as indicator for brand loyalty (Plassmann, Kenning, and Ahlert, 2007).

However, in these studies the neural activation was identified for confrontations with first-choice, material brand products. The role of the lateral PFC in general, and the dorsolateral PFC (dlPFC) in particular, might be different for ecommerce websites. While brand-related research argues that identified deactivation in the dlPFC might indicate a cortical relief effect (Deppe et al., 2005; Krampe, Gier, et al., 2018; Plassmann, Kenning, and Ahlert, 2007), this might not be the case in online contexts, where the visual stimulation complexity is increased. Especially, users' initial experiences with brands of material products in local stores might differ on a neurophysiological level from the experience with nonmaterial, ecommerce websites. Potentially, the initial perception of a website might always be cognitively engaging, as the users have to orient themselves and process the complexity. This hypothesis is supported by research focused on the processing of websites. For instance, the left dlPFC has been found activated when confronted with pleasing visual websites which are rated as beautiful and aesthetic (Chen, You, et al., 2018; Nissen, 2020a). Furthermore, when considered in relation to websites in general, and ecommerce websites in particular, activation of the left dlPFC has also been related to increased eloyalty (Gregor et al., 2014). Consequently, although the described cortical relief effect in the dlPFC and its explanation is sound and reasonable for brand-effects, neuroIS studies in the context of ecommerce suggest that for websites, such an effect might not be observable during the initial perception. Nevertheless, it is probable that significant activation differences in the dlPFC might emerge between users who are loyal to a website and users who are not. That is, because the dlPFC is thought to be generally involved in cognitive processes (Heekeren et al., 2006; Taren et al., 2011; Teffer and Semendeferi, 2012), and might therefore reflect processes which address cognitive loyalty.

Staying with cognitive loyalty, increasing familiarity with a website seems to have distinct neural effects on users. However, as the effects are not as well researched in ecommerce context as aesthetics and purchase intentions, results are still inconclusive. The concept of familiarity has been associated with a cognitive relief for brands in the PFC and with decreased neural activations for repetitive website use, thereby making it an indicator that primarily addresses cognitive loyalty processes (Sénécal et al., 2015). However, these findings were not supported by a study investigating the neural effects of familiar websites which associated neural activity increase in the right lateral PFC to more familiar websites (Neupane et al., 2017). Although results are inconclusive, the study by Neupane et al. (2017) employed fNIRS as measurement method and did not focus on the familiarization process itself but rather on websites which were familiar to the participants prior to the study. In addition to this, fNIRS measures a different physiological signal from the brain, and has a higher spatial resolution than EEG (Irani et al., 2007; Pinti, Tachtsidis, et al., 2020). Because both their study design, as well as their measurement method is more similar to the present work, the results by Neupane et al. (2017) are primary used to derive the first hypothesis. As stated before, familiarity on its own is not necessarily an indicator for eloyalty. It can thus, only be used as an eloyalty indicator when users are positively familiar with a website, and when they prefer this website as their first choice over others. As a result, the activation of the dlPFC can be treated as an indicator for eloyalty when it is found only in those users who rate the target website as their first choice, but not in users who are familiar with the website, but do not rate it as their first choice over provided alternatives. Consequently, we aim to challenge the following hypothesis:

> *H* 1*: When the familiar website is present, users who rate this website as their first choice will have higher neural activation in areas related to the dlPFC compared to users that do not rate this website as their first choice.*

As stated by the first-choice brand effect, activation differences might also be observed in the medial parts of the PFC. Literature investigating neural correlates of aesthetics and attractiveness has also identified activations in the left medial PFC, as well as in the right orbitofrontal cortex/ventromedial prefrontal cortex (OFC/vmPFC) for attractive versus unattractive product packaging (Liu, Sourina, et al., 2010; Stoll et al., 2008). The OFC/vmPFC is a brain region, which is a part of the reward evaluation system and thus, it has been linked to processing rewarding, pleasant, and positive emotional stimuli (Brown et al., 2011; Cela-Conde, Garcia-Prieto, et al., 2013; Doi et al., 2013; Kühn and Gallinat, 2012), and might therefore point to affective loyalty. Due to the relation of the right OFC/vmPFC to processing attractive visual design, it

is no surprise that this brain region has also been found in relation to higher purchase intentions (Liu, Sourina, et al., 2010; Plassmann, Kenning, and Ahlert, 2007; Stoll et al., 2008), and when being confronted with trustworthy ecommerce websites (Dimoka, 2010). Furthermore, the studies investigating the first-choice brand for physical products have also found that the vmPFC is activated when consumers were confronted with their favored brand (Deppe et al., 2005; Plassmann, Kenning, and Ahlert, 2007). Consequently, it may be assumed that if users are confronted with their preferred ecommerce website, this confrontation may lead to a pleasant and rewarding experience and thus, it can be assumed that the OFC/vmPFC will be activated. When drawing back to the loyalty stages, given the increased medial activation due to aesthetics, trustworthiness, and purchase intentions, these constructs might be related to the affective and conative loyalty stages. That is, only those users who can choose their preferred website over others might reveal a significant neural activation in areas of the OFC/vmPFC in the moment of choice. Through these brain regions being involved in emotional processing, they may heavily imply eloyalty when found activated in users who decide for their first-choice website. That is, emotional processes are thought to drive the commitment to stick to one's preference over an alternative and are thus, pointing to loyalty (Plassmann, Kenning, and Ahlert, 2007). As a result, we propose that when users prefer a familiar website over others, and they reveal an activation in the OFC/vmPFC, they are likely emotionally attached to this website, and therefore, loyal:

> *H 2: When the familiar website is present, users who rate this website as their first choice will have a higher neural activation in areas relating to the OFC/vmPFC compared to users that do not rate this website as their first choice.*

5.1.3. Method

To test the impact of different constructs in ecommerce, a fictional website is often created for the experiment and through the manipulation of different website characteristics, the impact of the constructs is measured. However, for eloyalty such a stimuli creation would not be possible, as eloyalty emerges over time and is a longitudinal process. Hence, in this research work, a "top-down" approach is applied which means that existing and operating websites are utilized to generate, stimulate, and enable the measure of potential antecedents to eloyalty. In this regard, familiarity with the target website poses a relevant construct that is essential to test our hypotheses. Hence, as a target, Amazon is selected as leading example for a large and successful online business because it is ranked as the top-one ecommerce website worldwide (Bhatti et al., 2020). Even for users who are not loyal to Amazon

it is probable that most are familiar with Amazon and its use. It is further likely that some users prefer the Amazon website as their first-choice website over other alternatives. Therefore, to ensure that all participants are familiar with using the target website, but only some of them are loyal and therefore prefer it over offered alternatives, Amazon provides a suitable case.

Sample

In total N = 33 participants were recruited and measured in this study, however, two data sets had to be excluded due to incorrect data sampling. Regarding the existing familiarity with online shopping within the sample, two participants indicated that they had never ordered the target product category from an online retailer. However, they were familiar with Amazon for other products, and were therefore left in the sample. However, one participant indicated to never have ordered something from Amazon which is why s/he was removed from the sample. As a result, a final sample of n = 30 (14 females, 16 males; age: $M = 30.8$, $SD = 11.5$, $Min = 22$, $Max = 64$) was considered for further analyses. Although this sample size may be regarded as too small for behavioral studies, related work has shown that sample sizes $n > 20$ are appropriate for neural studies in general, and fNIRS studies in particular (Causse et al., 2017; Ferreri et al., 2014; Nakahachi et al., 2008; Vassena et al., 2019). From the resulting sample, 16 participants claimed that they occasionally order something on Amazon, while the remaining 14 participants claim to frequently shop online on Amazon. Subdivided into Amazon-ranking-groups, n = 11 (3 females, 8 males; age: $M = 29.64$, $SD = 11.707$, $Min = 22$, $Max = 64$) participants ranked Amazon as their first preference (= AG); while n = 19 (11 females, 8 males; age: $M = 31.4$, $SD = 11.7$, $Min = 22$, $Max = 58$) positioned Amazon elsewhere (= non-AG). The subgroups were not significantly different on age ($U(N_{AG} = 11$, $N_{nonAG} = 19) = 98$, p = .794), and gender ($\chi^2(1, N = 30) = 2.54$, $p = .111$), as well as shopping frequency on Amazon ($\chi^2(1, N = 30) = 1.94$, $p = .163$). As assumed above, these self-reported results support that all participants were familiar with the Amazon website, however, not all of them also preferred to use it in our study. As a consequence, participants who rated Amazon as their first choice are further treated as loyal users.

Stimuli

With its launching in 1995, Amazon is still one of the most popular and bestselling, as well as the overall leading ecommerce website worldwide (Bhatti et al., 2020; Statista and EHI Retail Institute, 2019). In a recent press release, Amazon reports an over one-third revenue increase worldwide for the second quarter in 2020 (Amazon, 2020).

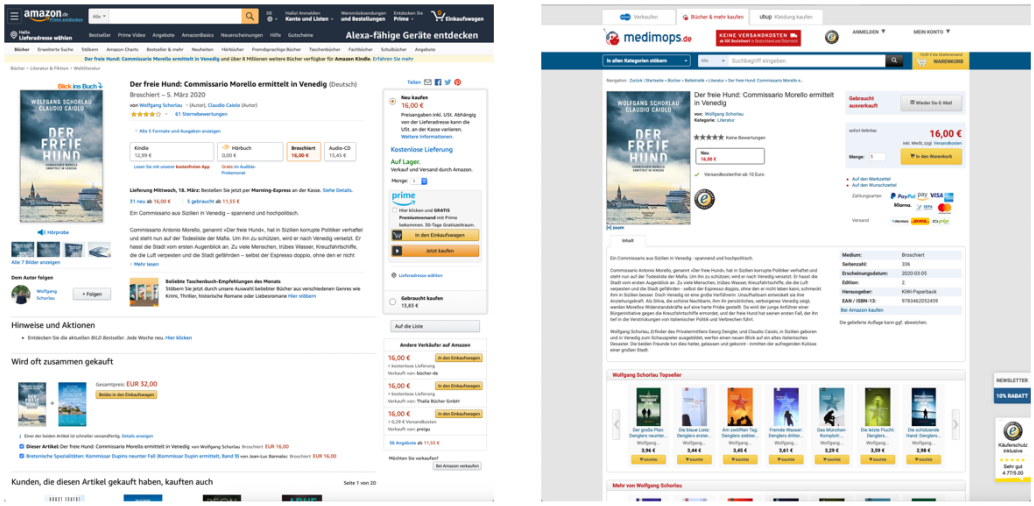


Figure 5.1. Exemplary Binary Decision of the Experimental Task

Consequently, Amazon as popular ecommerce company was chosen as target website in this study. In order to select the other stimuli, comparable websites had to be identified especially as Amazon is a generalist website whose beginnings were based on selling books online. Therefore, other online bookshops were selected in this study, which preferably sell not only books, but also more generalist products (e. g. Weltbild or Thalia). Three data sources were consulted which rank online bookshops according to their revenues (Bonner and Jacobs, 2019; Buchreport, 2019; EHI Handelsdaten, 2019). Since this study was executed in Germany, the ten highest online shops that operate in Germany were selected next to Amazon (namely: arvelle.de, buecher.de, buch24.de, osiander.de, rupprecht.de, hugendubel.de, medimops.de, weltbild.de, mayersche.de, thalia.de). In order to keep the website in their content largely comparable, the bestseller, gender-neutral book of the month was chosen (book title: "Der freie Hund: Commissario Morello ermittelt in Venedig"; authors: Wolfgang Schorlau and Claudio Caiolo) and presented on each included website. Thus, the content (selected book and price) was consistent across all included websites. Further, to keep websites as comparable as possible, the screen size was kept the same for each screenshot.

Study Design

After welcoming participants, they received information on the study, the experimental procedure, and the fNIRS device in written and verbal form. They were informed that they have to make binary decisions between ecommerce websites, choosing mentally where they would like to purchase while wearing the fNIRS headband on their forehead. As remaining questions were answered, informed consent was

given in accordance with the Declaration of Helsinki. Before the experimental task was presented to the participants on a computer screen, the fNIRS device was attached to the participant's forehead and calibrated individually in order to ensure data quality. As experimental design, a validated, robust task was chosen which has proven to accurately detect choice preferences through decisions for the first-choice brand (Deppe et al., 2005; Krampe, Gier, et al., 2018; Plassmann, Kenning, and Ahlert, 2007). During the task, stimuli (ecommerce websites) pairings were vertically displayed for 3 seconds (s) (Figure 5.1), followed by a fixation cross randomly jittered for 4-6 s. The displayed pairings were selected according to two types of binary decisions (trials): (1) the target type, in which the Amazon website was present (= AW, Amazon website), and (2) the diverse type, in which Amazon was not present (= DW, diverse websites). These two types of binary decisions were displayed in 10 blocks including 10 decisions each; 5 of which had 8 AW decisions and 2 DW decisions, and the other 5 having 2 AW decisions and 8 DW decisions to avoid habitualization and learning effects. The binary decisions within the blocks and the order of the blocks were fully randomized, as well as whether Amazon and the other stimuli were shown on the left or the right side of the screen. After the experimental task with a total of 100 decisions, participants were handed a questionnaire in which they had to prioritize the shown websites and provide demographics. Having finished the questionnaire, participants received a financial compensation of €10 and were free to leave.

Measuring Method

fNIRS was used to assess neural activity in the prefrontal cortex (PFC) of participants to gain insights into the neural processing of ecommerce websites and decision-making process of users choosing for one website over another. Generally, fNIRS utilizes the same neurophysiological phenomenon as functional magnetic resonance imaging (fMRI) to quantify brain activity and thus, the fNIRS signal correlates with the more established blood-oxygen level-dependent (BOLD) signal (Huppert et al., 2006; Strangman et al., 2002). Technically, fNIRS operates with near-infrared light which is sent into the human brain by sources and that is further absorbed, reflected, or scattered by the human brain tissue, or more precisely by oxygenated and deoxygenated hemoglobin, and received by detectors (Ferrari and Quaresima, 2012). As a consequence, fNIRS takes advantage of this characteristic as the amount of oxygenated and deoxygenated blood for a given brain region can be calculated with the received light by the detectors (Ferrari and Quaresima, 2012; Funane et al., 2014). This measurement therefore is an indirect parameter of neural, cortical brain activity. Moreover, fNIRS provides a portable and lightweight technology which appears to

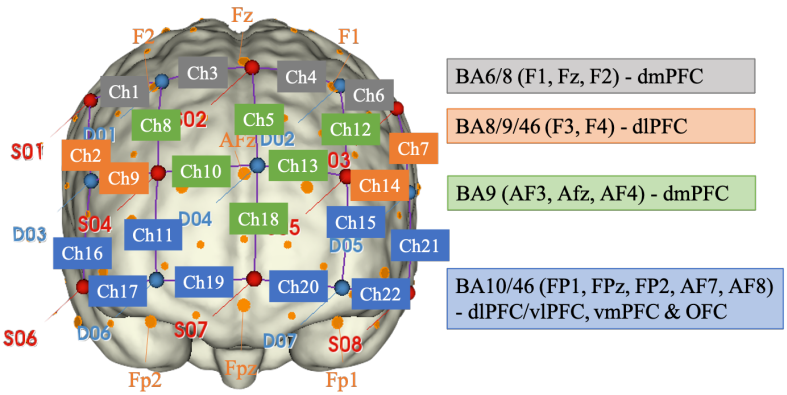


Figure 5.2. Montage Design of Used fNIRS Headband

Note. *BA = Brodmann Area, abbreviations used in brackets (i.e. F1, Fz. . .) = reference points of the EEG 10-20 system, dmPFC = dorsomedial prefrontal cortex, dlPFC = dorsolateral prefrontal cortex, vlPFC = ventrolateral prefrontal cortex, vmPFC = ventromedial prefrontal cortex, OFC = orbitofrontal cortex*

be more robust to movement artefacts than, i.e. EEG, and can therefore also be used in real-life scenarios (Brigadoi, Ceccherini, et al., 2014; Leff et al., 2011). Although fNIRS is spatially limited to cortical brain areas, related literature in which offline brand effects were repetitively measured and validated show that it is an appropriate method to investigate user's decision making between ecommerce websites (Krampe, Gier, et al., 2018). fNIRS has further proven to be a reliable method not only in related studies to offline brand effects, but also in IS research in relation to measuring neural processing and decision making on ecommerce websites (Gefen, Ayaz, et al., 2014; Gier et al., 2020; Nissen, 2020a; Nissen, Krampe, et al., 2019).

Data Pre-Processing and Analysis

Data was acquired using a continuous wavelength fNIRS device developed by NIRX with a headband montage holding 8 sources, 7 long-distance detectors, and 8 short-distance detectors (Figure 5.2). The average distance of the long separation channels was set to 30 mm, the average distance of the short separation channels was set to 8 mm which provides an optimal distance to filter out extracerebral activity to further reduce the signal to noise ratio (Brigadoi and Cooper, 2015; Goodwin et al., 2014; Yücel, Selb, et al., 2016). The wavelengths of the infrared light are 760 nm and 850 nm. The sampling frequency was 7.81 Hz which was resampled to 4 Hz in the pre-processing procedure (Huppert, 2016). The raw fNIRS data was processed using the NIRS Brain AnalyzIR toolbox (Santosa et al., 2018). At first, optical density was calculated, after which short separation channel regression was applied by using the Linear Minimum Mean Square Estimations (LMMSE) to filter out artefacts due to movements, Mayer waves, and extracerebral blood flow (Saager and Berger, 2005;

Scholkmann et al., 2014). This is followed by calculating hemoglobin values using the modified Beer-Lambert Law with a partial pathlength factor of .1 (Delpy et al., 1988; Kocsis et al., 2006).

On a subject-level, a general linear model (GLM) with the canonical hemodynamic response function (hrf) as baseline function was used. Further, the GLM uses the AR-IRLS algorithm which further filters out remaining motion artefacts in the fNIRS signal (Barker et al., 2013). Potential individual differences in the hemodynamic response are considered by treating participants as random effects in the group-level analysis. Therefore, for the group analysis, a linear mixed-effects model was calculated, taking the binary decisions (AW and DW) as fixed effects, and subjects as random effects. As a threshold for identifying significant fNIRS channel, $t - values > 2$ and $p - values < .05$ are applied to the oxygenated hemoglobin (HbO) as indicator for neural activation changes. Contrasts in the group analysis are drawn both on a user-group level, as well as on a website-dependent level (Deppe et al., 2005; Krampe, Gier, et al., 2018). Consequently, two contrasts were analyzed: firstly, for all decisions in which participants had to decide between Amazon and another website, we look at differences between participants who rated Amazon as their first-choice website (AG) and those participants who rated another website as their first choice (non-AG) (between-subjects). Secondly, as an additional analysis, only the AG participants were analyzed by investigating whether there are significant differences between the trial AW and DW binary decisions (within-subjects).

5.1.4. Results

Results for the described contrasts show a significant ($p < .05$) increase of neural activity in the right dlPFC (channel 9) and right vmPFC/OFC (channel 11) for those participants who rated Amazon as their first-choice website compared to those who did not rate it as their favorite website for purchasing books online (contrast between AG vs. non-AG; Figure 5.3, left image). Consequently, this result supports H1, indicating that activation of the dlPFC can be identified for users who are positively familiar with a website and additionally prefer this website as their first choice over others. For users who are also familiar with the website, but do not rate it as their first choice over provided alternatives, the dlPFC was not activated. Our second hypothesis H2 is also supported which stated that the OFC/vmPFC will be activated when the familiar website is present as choice option to users who rate this website as their first choice compared to users where the website is not their first-choice. As an additional analysis, the participant group that favored Amazon was analyzed in more detail. A significant neural decrease in the left superior dmPFC accompanied

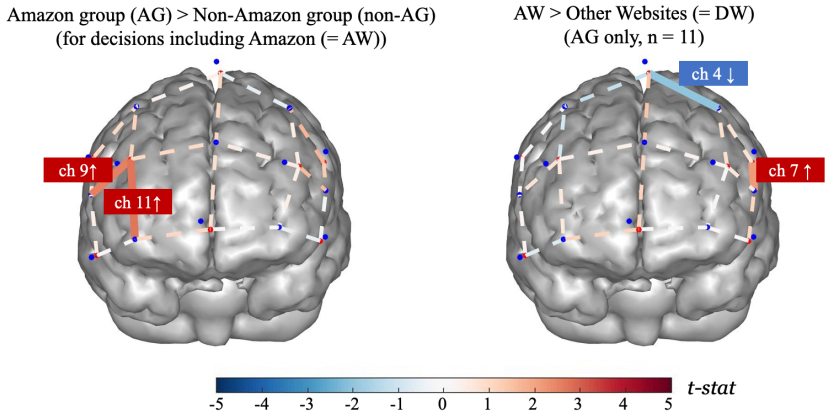


Figure 5.3. fNIRS HbO Results for Contrasts from Linear Mixed Effects Model

Note. Significant channels are flagged

Channel	Related PFC region	Contrast	t-stat	df	p
11	right vmPFC/OFC	AW (AG >non-AG)	2.704	56	.009
9	right dlPFC/dmPFC	AW (AG >non-AG)	2.52	56	.015
7	left dlPFC	AG (AW >DW)	2.178	56	.034
4	left dmPFC	AG (AW >DW)	-2.027	56	.047

Table 5.1. fNIRS HbO Results from Linear Mixed Effects Model

Note. Threshold for significant channels was $t > 2$ *and* $p < .05$

by a significant neural increase in the left dlPFC could be identified when contrasting AW with DW decisions within this group (Figure 5.3, right image). While the deactivation in the left dmPFC has not been hypothesized, the increased activation in the left dlPFC further supports H1. The corresponding t-values and p-values of the significant channels are provided in Table 1.

5.1.5. Discussion

Interpretation of the Neural Results

As hypothesized, significant neural activation changes could be observed in the in the bilateral dlPFC (H1), as well as in the right OFC/vmPFC (H2). Starting with the latter, this observed activity pattern suggests that Amazon is associated with an activation of brain areas that are frequently related to a pleasantness and rewarding attribution across several contexts (in accordance with H2) (Doi et al., 2013; Liu, Sourina, et al., 2010; Stoll et al., 2008). As a result, a confrontation with the Amazon website seems to elicit neural processes in the brain of users who rank Amazon as

first-choice, pointing to a pleasant and rewarding association with Amazon. Further, activation in this brain area have been related to a higher willingness to make a purchase (Plassmann, Kenning, and Ahlert, 2007) which supports that a confrontation with Amazon might be pleasing for loyal users. How this pleasantness attribution is elicited, however, still stands to question. One explanation could be that when seeing the Amazon website, prior experiences with this website are automatically triggered in users which attribute this website as the preferrable choice. This explanation would be in accordance with neurophysiological emotion theory, proposing that emotions from prior experiences are encoded in our bodies and therewith dictate our decisions (Damasio, 1994).

In addition to this, significant neural activity in the dlPFC supports hypothesis H1. In accordance to related literature, which was used to derive these hypotheses, neural activation of the left and right dlPFC suggests that Amazon might be perceived as easier to use, and as more visually pleasing for users who favor Amazon as their first choice (Cela-Conde, Marty, et al., 2004; Dimoka and Davis, 2008; Dimoka, Pavlou, et al., 2011a; Wang, Lu, et al., 2018). Furthermore, a related neuroIS study has identified that the right dlPFC was activated when users were familiar with a website (Neupane et al., 2017). In our work, however, all participants were familiar with Amazon, and the dlPFC was only activated in those participants that preferred Amazon over the other alternatives. Consequently, this challenges the findings by Neupane et al. (2017) and further adds to the inconsistent findings with regard to familiarity and its (neural) role for eloyalty (Gregor et al., 2014; Neupane et al., 2017; Sénécal et al., 2015). As a result, this neural activation might only be observable when a familiar website, that simultaneously is also the most preferred website, is present, and thus, it may be treated as indicator for eloyalty.

Apart from the hypothesized effects, a significant deactivation in the left superior dmPFC within the AG group for the Amazon website compared to other websites is found. Generally, the dmPFC has been associated with several processes such as the processing of negative emotional stimuli, the formation and processing of first impressions, emotion regulation, and decision making under uncertainty (Dolcos et al., 2011; Ellard et al., 2017; Gilron and Gutchess, 2012; Krain et al., 2006; Schienle et al., 2014; Volz et al., 2005). Following these findings and considering the deactivated dmPFC in combination with the activated left dlPFC, this finding could indicate that Amazon might elicit a more positive emotional attribution in users who favor a website as first-choice compared to other websites. This possible interpretation is in accordance to the former formulated pleasant and rewarding attribution to the website as assumed based on the other neural activation changes.

Consequently, the deactivation in this brain area may also contribute to user's affective loyalty to Amazon. Furthermore, another interpretation on the dmPFC could be given by the experimental task in which stimuli were only shown for 3 s. As stated above, the dmPFC has also been linked to the formation and processing of first impressions (Gilron and Gutchess, 2012), which may lead to the conclusion that a deactivation in this area relates to a decreased effort to form the impression about the stimulus. A decreased effort in forming first impressions may in this study be further attributed to user's familiarity from prior experiences (which brings low uncertainty), paired with their preferences for the presented website. Thus, it may be concluded that if users are familiar with a website due to prior experiences with it, and if they prefer this website, they require lower effort to process the first sight of this website in their dmPFC. This interpretation would be in accordance to related work which identified a lower cognitive load for familiar websites where the specific location of the activation is unknown (Sénécal et al., 2015).

Implications

The derivation of potential implications is based on the experimental study design in which participants were shown two website screenshots at the same time for 3 s only. As a result, there may have been hardly the time to fully consider both presented websites in terms of their "detailed" website design and layout. The prior discussed effects therefore occurred within the first 3 s a user is confronted (repetitively) with the (first-choice) website. Still, the appearance of the Amazon website has elicited increased positive emotional processing in the brain of those users who ranked Amazon as their first-choice website. In this moment, potential neural "lock-in effects" were elicited in only those users who prefer this website over the alternatives. Potentially this happens by (unconsciously) recalling their prior, positive experiences with this website. This recall could further impact their (in this case positive) attitude towards the website which determines their decision in favor of the website and thus, they are loyal due to being "neurally locked-in". This finding may further challenge literature focusing solely on the usability of websites, because although usability can be regarded as an important influence factor for user experiences, the emotional attachment of users to a website over time may override these effects. This is supported by related literature claiming that emotional eloyalty is the most durable one (Murray, 2002; Sadighi et al., 2015; Shih, 2012). Therefore, it may be assumed that in the moment where website vendors achieved high familiarity with their users, they have to rely on emotional, neural lock-in effects to ensure user preference for their website. Furthermore, a short confrontation with the website itself seems to suffice to elicit these emotional processes in those users which prefer

it over others, and are therefore likely loyal. Consequently, the following implication can be derived:

> *I 1: Ecommerce websites might generate an emotional, neural lock-in effect which are triggered on first impressions when users prefer the respective website over others.*

The potential emotionalization of the website might affect the processing of choice options, unconsciously narrowing down the decision sets from which users make their website choice if alternatives are offered. Reasons for this can be found when comparing our results to findings from consumer neuroscience and emotion research (Bechara and Damasio, 2005; Bechara, Damasio, Tranel, et al., 2005; Damasio, 1994; Deppe et al., 2005; Gier et al., 2020). That is, brain regions of the OFC/vmPFC are often associated with processes that regulate emotion and modulate emotional value attachment through exhibiting control on amygdala activation (Bechara and Damasio, 2005; Damasio, 1994). While this area is also activated when confronted with one's first-choice product brand (Deppe et al., 2005), it can be assumed that preferred brands have also elicited emotional attachment or at least some sort of emotional value to the user. Furthermore, in this study also the dlPFC has been found activated, which can be associated with processes where humans make reasonable decisions that are hypothesized to be guided by emotion (Bechara, Damasio, Tranel, et al., 2005; Maia and McClelland, 2004). Studies state that the dlPFC is also regularly involved in emotion regulation in addition to the OFC/vmPFC (Golkar et al., 2012; Herrington et al., 2005; Kroes et al., 2019). In emotion research, it has been hypothesized that emotions unconsciously shape our decision making by reducing the possible alternatives which are deemed worth to consider (Damasio, 1994; James, 1884). Following the here identified neural results, it may be assumed, that the Amazon-preferring users in our study seem to operate in some sort of emotion regulation and emotional attachment process. In line with the assumptions from Damasio (1994), and the general mechanisms of psychological lock-in effects (Ray et al., 2012; Shih, 2012), this emotional attribution potentially impacts their decision making by unconsciously reducing the number of considered alternatives in a decision scenario. As a result, the following implication of our study can be formulated:

> *I 2: The neural lock-in effect may unconsciously narrow down and frame the loyal users' decision set and thus, the consideration of possible alternatives to the preferred website.*

The neural results and their interpretation in this study show that keeping a

continuously positive emotional experience for users can have the power to elicit neurophysiological effects in the user's brain which might further determine their eloyalty. This study calls these neurophysiological findings "neural lock-in effects" because they refer to an activation pattern in the user's PFC only in cases where the preferred, first-choice website was present and thus, they are hypothesized to frame the users' decision set regarding the (reduced) consideration of possible alternatives. At this point, it has to be noted that the proposed implications provide first assumptions which we derived based on our neural results. For further validation, however, they would need to be proven and assessed individually in follow-up studies and should thus, be treated with caution. Nevertheless, finding a distinct neural correlate for eloyalty across different websites can have tremendous impact for practice as this provides a measure for loyalty which is less prone to bias (i.e., social desirability). Furthermore, when knowing which brain regions are involved when a user decides for or chooses a website, the degree of cognitive and emotional involvement with the website and its vendor can be better assessed. From this, the online business can then adapt the ecommerce website accordingly, depending on whether cognitive or emotional stimulation needs improvement to elicit eloyalty.

Limitations and Future Research

Although this study reveals some significant findings, it does not come without limitations. Firstly, one limitation can be found in the used stimuli for the neuroimaging study. That is, Amazon is considered as target website, and only books as were included as product. It has to be considered, that a great part of Amazon's market power also stems from its variety in offered product assortment. Consequently, the generalizability of the here identified neural effects is limited. However, this also leaves room for follow-up studies which could either still target Amazon, but vary the products shown to participants and thus, aim to eliminate the product choice as possible bias. On the other hand, the here revealed neural effects might not be unique to Amazon as vendor but might also be transferrable to other online businesses such as Google or Netflix. Consequently, future research could therefore investigate neural correlates for, i.e. Google or Netflix, to see whether the results of this study are generalizable. Another limitation of this study can be identified in that the neural lock-in effects are only investigated during binary decisions and only by the use of screenshots. While during website choice behavior, the first impression is built within the first few seconds, this scenario seems plausible. However, it might be interesting to investigate, whether the identified neural effects still hold true over a longer stimulation period. Furthermore, to validate the eloyalty construct, a longitudinal study with several measurements over time might be a valuable follow-up

experiment, where the familiarity and loyalty are experimentally manipulated and controlled to enable a better generalization of the results. On the other hand, the study could be replicated using the website logo as proxy for the brand in order to specify the effect and narrow down the complexity of the stimuli. Further, the group size and gender distribution between the AG and non-AG group was different. Several studies have pointed out that men and women have a different neural activation (Nissen and Krampe, 2020; Riedl, Hubert, et al., 2010), especially when it comes to trustworthiness evaluations. Since perceived trustworthiness was identified as antecedent to eloyalty, this limitation might have biased the analyzed data, although gender distribution was not significantly different between the groups. As a result, further validation of our results while controlling for gender-related effects and using balanced group sizes might be reasonable.

5.1.6. Conclusion

At the beginning of the manuscript, there was the question "what are the neural correlates of users' first-choice websites as eloyalty antecedent in the moment of choice?". To address this question, antecedents of eloyalty were identified and operationalized primarily through constructs of website attractiveness, user preference, perceived trustworthiness, familiarity, use and purchase intentions. Since most of these constructs were already investigated with a neuroimaging method in ecommerce environments, hypotheses were derived matching the neural results from prior studies. All proposed hypotheses were supported by the results of the neural study in which it has been shown that user first-choice decisions in favor of the target website activated the left and right dlPFC and the right OFC/vmPFC. Furthermore, a non-hypothesized deactivation of the left superior dmPFC was identified. This activation pattern has been related to increased pleasantness and rewarding attribution to the target website, as well as higher associated ease of use and familiarity to this website. Based on this, it was discussed that eloyalty may be associated with neural lock-in effects. These lock-in effects may be elicited through continuous, positive, and pleasant user experiences which ultimately leads to an emotional attachment that is "neurally encoded" into the user's brain. Based on these emotional experiences, neural lock-in effects may unconsciously reduce users' freedom of choice. The emotional attachment to the first-choice website may "dictate" them to use it through which possible alternatives might not be seriously considered. Consequently, this neurophysiological approach offers a fruitful, user-focused perspective on the neural mechanisms that underlie eloyalty of ecommerce websites and their associated online businesses.

Chapter 6

Discussion

6.1. Interpretation of Neural Results Across Included Papers

In this section, the first research goal of this thesis, namely to *"identify potential neural correlates as antecedent processes to UX constructs on ecommerce websites"* is addressed. To do so, the neural results of the included papers are now discussed from an overarching perspective. In section 2.1.2 of this thesis, we have briefly presented the state of the art of neuroIS research on the role of the PFC in IS contexts. Both in Figure 2.3 and in the table in Appendix.1, we have summarized the identified neural results to which this thesis offers further contribution. Because several of the identified literature utilized EEG as measurement method and did not distinguish between different subareas of the PFC, we will further place the results of the studies conducted in the frame of this thesis only in relation to related literature that also mapped their results to subareas of the PFC. A holistic overview is provided in Figure 6.1 that comprises the identified results from related literature (section 2.1.2), the results from the group analyses of the included papers, and additional correlation analyses that were conducted for the discussion of this thesis with data from the papers 1, 3, and 4/5[1]. Figure 6.1 therefore visually reflects the knowledge contribution of this thesis to the field of neuroIS research. The additionally calculated correlation analyses and the resulting significant correlations can be seen in Table 6.1 at the end of this section.

6.1.1. The Role of the dmPFC in eCommerce Website Processing

Related neuroIS research has so far identified the role of the dmPFC in the context of habituation to security warnings due to repeated use (Anderson et al., 2016; Vance et al., 2018). The authors mainly refer the observed dmPFC activation to the default mode network (e.g., mind wandering) due to the number of repetitions in their experimental design. However, the dmPFC does not only play a role in habituation processes. In the frame of the included papers, we have identified that an activation of the dmPFC and premotor cortex may also be related to the processing of approach/avoidance intentions towards websites based on their visual design. However, when the results are considered across all papers, the conclusions regarding

[1]Readers might wonder why not all results are included in the correlation analysis which is why we wish to briefly explain this here. Paper 2 is excluded here because only self-reported data was collected. Paper 4/5 essentially share the same data basis and are therefore, considered as one for the correlation analysis. Finally, Paper 6 only included binary decisions for the neural data and did not include any self-reported constructs directly related to the neural measurements. This results in correlation analyses being impossible to conduct for Paper 6.

Dorsomedial PFC to premotor cortex areas (dmPFC/premotor cortex) – BA 6/8/9:

Findings/ related constructs in related neuroIS literature:

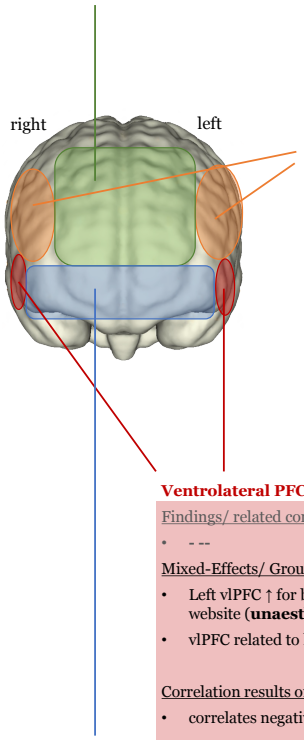
- *dmPFC ↓ related to repeated use/ habituation*

Mixed-Effects/ Group analysis results from papers (added contribution through papers):

- Pre-motor cortex ↓ for orange compared to blue website (**unaesthetic vs. aesthetic**), but also for first-choice/ **preferred website**
- dmPFC ↑ for orange compared to blue website (**unaesthetic vs. aesthetic**)
- Pre-motor cortex/ dmPFC ↑ for rounded compared to sharp buttons shapes on websites
- Right dmPFC ↑ for low perceived usefulness in men only compared to women, and for high **perceived usefulness**, **perceived ease of use**, and **purchase intention** when compared to low values of these constructs

Correlation results of data from papers (added contribution in this discussion section):

- correlates positively with **colorfulness**, **purchase intention**, and **arousal**
- correlates negatively with **diversity** on the right hemisphere, and positively with diversity on the left hemisphere
- the superior parts correlate positively with **arousal and distrust**
- the inferior part correlates negatively with **pleasure and attitude**, but positively with **perceived ease of use**



Dorsolateral PFC areas (dlPFC) – BA 8/9/46:

Findings/ related constructs in related neuroIS literature:

- *dlPFC ↑ related to emotional valence and arousal, threat appraisals, working memory and visual information processing, (dis-)credibility evaluations in the context of trust , left dlPFC ↑ related to user engagement*
- *dlPFC ↓ related to higher self-control, left dlPFC ↓ related to repeated use/ habituation*

Mixed-Effects/ Group analysis results from papers (added contribution through papers):

- Left dlPFC ↑ related to orange/red compared to blue website (**unaesthetic vs. aesthetic**), higher perceived usefulness (in men only compared to women)
- Right dlPFC ↑ related to high **perceived usefulness, perceived ease of use, and purchase intention** when compared to low values of these constructs; related to „first-choice"/ **prefered website** ; and related to uncolored compared to colored websites (**low pleasure and attitude** toward the website, **high distrust**)

Correlation results of data from papers (added contribution in this discussion section):

- correlates positively with **perceived ease of use** and **perceived usefulness**, but negatively with **diversity**
- The left dlPFC correlates negatively with **purchase intentions**, but the right dlPFC correlates positively (and stronger) with **purchase intention**

Ventrolateral PFC areas (vlPFC) – BA 9/46:

Findings/ related constructs in related neuroIS literature:

- - --

Mixed-Effects/ Group analysis results from papers (added contribution through papers):

- Left vlPFC ↑ for black compared to blue website (uncolored vs. colored), right vlPFC ↑ for green & orange compared to blue website (**unaesthetic vs. aesthetic**)
- vlPFC related to higher perceived usefulness (in men only compared to women)

Correlation results of data from papers (added contribution in this discussion section):

- correlates negatively with **purchase intentions** on the left hemisphere

Ventromedial PFC to orbitofrontal cortex areas (vmPFC, OFC) – BA 10/46:

Findings/ related constructs in related neuroIS literature:

- *vmPFC ↑ related to repeated use/ habituation, vmPFC ↓ related to higher self-control*
- *OFC ↓ related to high trustworthiness and credibility*

Mixed-Effects/ Group analysis results from papers (added contribution through papers):

- left vmPFC ↑ related to high **perceived usefulness, perceived ease of use, and purchase intention**, but also for red compared to blue websites
- right vmPFC ↑ related to low perceived usefulness (in men only), and to high **perceived usefulness, perceived ease of use, and purchase intention** when compared to low values of these constructs, as well as to „first-choice" website/ **prefered website**, and for rounded compared to sharp button shapes on websites

Correlation results of data from papers (added contribution in this discussion section):

- Correlates mixed with diversity
- Correlates positively with **perceived ease of use**, but negatively with **colorfulness**, **arousal**, **and purchase intentions**

Figure 6.1. Summary of Results Across Included Papers and Contribution Compared to State of the Art in NeuroIS

whether the dmPFC and premotor cortex is related to approach or to avoidance behavior, are mixed. On the one hand, a deactivation in the premotor cortex could be identified for unaesthetic websites which was accompanied by an increase of the dmPFC (Paper 1). Further, a deactivation in the premotor cortex without activation changes in dmPFC was identified for when users could choose their preferred website over another website (Paper 6). A case in which both premotor and dmPFC are activated was found for the comparison of websites designed with rounded compared to sharp button shapes (Paper 3). Similarly, activation in the right dmPFC was also identified for user groups who rated the perceived usefulness, ease of use, and purchase intentions higher than average (Paper 4). However, for websites rated low in usefulness, there also seems to be a gender-based difference in the activation of this brain region (Paper 5).

When drawing back to the UX framework of this thesis, the results may suggest differences in the role of the dmPFC depending on the UX phase that is considered. For *first impressions* prior to use, a deactivation in the premotor cortex and an activation in the dmPFC seem to symbolize avoidance intentions. This is also supported in the correlation analysis where we identified a positive correlation of the premotor cortex and superior dmPFC parts with the constructs of arousal and distrust, as well as a negative correlation with pleasure and attitude toward the website. Furthermore, when both the premotor cortex and the dmPFC are activated, the meaning of the identified pattern may shift from avoidance to approach intentions, as was identified for rounded buttons in the included Paper 3. This is supported by the correlation analysis in which we could identify a positive correlation between dmPFC activation and purchase intentions.

During use and after *repeated-use*, the premotor cortex and dmPFC may play a different role. The activation of the right dmPFC identified for higher perceived usefulness, ease of use, and purchase intentions rather points to an increased approach intention toward the website (Paper 4). Similarly, when users were confronted with their familiar and first-choice website, we identified a deactivation in the premotor cortex, which is in contrast to the association of this brain area to unaesthetic websites. In other contexts, the dmPFC and premotor region had been generally related to the formation of first impressions and memory of them (Gilron and Gutchess, 2012). As a result, the observed differences between pre-use and during-use/repeated-use phase may point to a difference between an impression formed based on the expectation of something compared to the actual use experience of something.

In any case, the dmPFC seems to be involved in the formation of impressions or

the retrieval of prior experiences with ecommerce websites. In the face of the obtained mixed results in the included studies, the dmPFC may not be directly related to one valence dimension (positive, negative) but rather seems to be involved in stimulating events compared to neutral events, which is also supported in its correlation with emotional arousal (Bandara et al., 2018; Xue et al., 2009). Nevertheless, the findings of this thesis suggest that future research is needed to collect more information on the precise role of the premotor cortex and dmPFC for user evaluations of ecommerce websites.

6.1.2. The Role of the dlPFC in eCommerce Website Processing

Compared to the dmPFC, the dlPFC has been more often emphasized in related neuroIS research. Although the dlPFC is often ascribed to cognitive and rational processes such as self-control (Hu, West, et al., 2015) or working memory (Clemente et al., 2014), neuroIS studies have also identified its role in the processing of emotional valence (both positive and negative) and arousal (Bandara et al., 2018; Li, Jiang, et al., 2014; Warkentin et al., 2016). This is supported in a study which found increased dlPFC activity associated with the cognitive effort required for (dis-)credibility judgments of ecommerce websites (Dimoka, 2010). The latter results are also supported in our work where we identified that websites without color require higher cognitive load in the right dlPFC while being rated lower in pleasure and higher in distrust (thus, requiring discredibility judgments). Similarly, the left dlPFC has also been found activated for when orange or red websites are compared to blue websites. The supporting self-reported results show that the websites requiring higher cognitive load are also associated with lower aesthetic evaluations (Paper 1). This is further supported, as our correlation analysis reveals that the left dlPFC correlates negatively with purchase intentions. These findings are in line with assumptions of the processing fluency theory that proposes that stimuli perceivable with reduced cognitive load also result in higher aesthetic perceptions (Landwehr and Eckmann, 2020; Reber and Schwarz, 2006; Reber, Schwarz, and Winkielman, 2004).

However, similar to our results for the dmPFC, we also have mixed results for the dlPFC's role in the processing and evaluation of ecommerce websites and the resulting UX. That is, especially the right dlPFC was also activated in relation to high perceived usefulness, ease of use, and purchase intentions in the during-use phase (Paper 4). This positive association is supported in the repeated-use phase paper in which the right dlPFC was found activated for the preferred website, but only in users who selected this website as their first-choice (Paper 6). The calculated correlation

analysis underlines this association as we identified positive correlations between dlPFC and perceived usefulness and ease of use, as well as a positive correlation between the right dlPFC and purchase intentions.

The results show that there might be a valence-related difference in dlPFC activity depending on whether visual information is processed on first impressions and evaluated, and whether an experience is made or reflected upon. As a rule of thumb, our results suggest that high dlPFC activation in the pre-use phase is rather a negative sign with regard to UX, while its activation during-use or in the post-use phase seems to reflect a higher level of (positive) engagement with the website. However, further research is required to strengthen and validate this suggestion.

6.1.3. The Role of the vlPFC in eCommerce Website Processing

None of the identified neuroIS studies have emphasized on or found activation of the vlPFC related to their investigated IS constructs. For the case of impression formation on ecommerce websites, however, we identified the involvement of the vlPFC in some processes along the UX phases. In the included studies, we have identified an activation of the left vlPFC on a website associated with lower pleasure, higher distrust, and more negative attitude (black versus blue website, Paper 3), and an activation of the right vlPFC for websites rated as unaesthetic and with lower purchase intention (green/orange versus blue website, Paper 1). This is also supported in the correlation analysis across papers in which a negative correlation between vlPFC activation and purchase intentions was identified.

In contrast to the neural areas of the dlPFC and dmPFC whose roles for UX do not seem to be straightforward, the composite results for the vlPFC point to a negative UX attribution in cases of vlPFC activation. As a result, vlPFC activation as reaction to ecommerce website perception in the pre-use phase seems to point to a negative attribution of the website which may be due to increased cognitive load, or reduced aesthetic evaluation, and may result in lower pleasure, and decreased purchase intentions.

6.1.4. The Role of the vmPFC in eCommerce Website Processing

The mPFC in general, and the vmPFC/OFC in particular has been linked to the processing of emotional value, such as threats and rewards (Buhle et al., 2014; Delli Pizzi et al., 2017; Naqvi, Shiv, et al., 2006), and is therefore linked to both

positive and negative emotion in neuroIS works (Bandara et al., 2018). However, its association with positive experiences seems to be stronger across neuroIS studies as it is positively associated with perceived trustworthiness (Riedl, Mohr, et al., 2014), object preference in decision making (Luu and Chau, 2009), and increased purchase intentions (Grosenick et al., 2008). Habituation due to repeated use also seems to be activating the neural structure of the vmPFC (Anderson et al., 2016; Vance et al., 2018). In the included studies, we identified that men seem to generally have higher vmPFC activation on ecommerce websites than women (Paper 5). Overall, users who rate a website high in perceived usefulness, ease of use, and purchase intention generally exhibit increased vmPFC activation (Paper 4). This is supported in our correlation analysis where we identified a positive correlation between vmPFC activation and self-reported perceived ease of use. For the right vmPFC, this effect is also detected in the repeated-use phase where an activation is found for users who are confronted with their preferred ecommerce website (Paper 6). Finally, the right vmPFC was also found activated when rounded buttons were used in the website design, which was associated with increased approach intentions (Paper 3). Overall, vmPFC activation therefore seems to be mainly triggered by positive emotional experiences and approach intentions.

However, we also identified contradicting results as the OFC (an area which lies closely to the vmPFC and by means of fNIRS cannot be distinguished from vmPFC) was found *deactivated* for websites that were rated high in trustworthiness and credibility (Dimoka, 2010). This contradiction is also reflected in the correlation results, where we identified a *negative* correlation with (pleasant) colorfulness, arousal, and purchase intentions. These findings, however, partly support the results from Dimoka (2010) as websites with high credibility and trustworthiness may also come with high purchase intentions, and may also be perceived as more pleasurable in the sense of their colorfulness.

As a result, and as we have stated in the beginning of this section, activation in the vmPFC might act similar to the dmPFC. That means, the vmPFC/OFC is triggered by website elements or holistic designs which trigger reward or threat processes that yield emotional value. Whether reward or threat perceptions have activated the vmPFC needs to be interpreted from the context of the study, by using for instance self-reported data, or by analyzing users' click behavior (or other complementary measures). Nevertheless, the role of the vmPFC in value evaluation (Schultz et al., 2011), and interpretation of its meaning for the self (Ashar et al., 2017; Sander, Grandjean, et al., 2018) holds true for the perception and use of ecommerce websites, too.

Brain Area	Ch-hb	DIV	COL	PUI	AR	PL	ATT	DIS	PU	PEOU
right dmPFC/ premo-tor	1-hbo		0.218*							
right dmPFC/ premo-tor	1-hbo			0.225*						
right dlPFC	2-hbr									-0.22*
right dmPFC/ premo-tor	3-hbr	0.248*								
right dmPFC/ premo-tor	3-hbr				-0.181**					
left dmPFC/ premo-tor	4-hbo	0.226*								
left dmPFC/ premo-tor	4-hbr				-0.153*					
dmPFC	5-hbo				0.144*					
left dlPFC	7-hbr									-0.212*
right dmPFC	8-hbr				-0.13*			-0.24***		
right dlPFC	9-hbo			0.271**					0.229*	
right dlPFC	9-hbr									-0.272**
right vmPFC/ OFC	11-hbo	0.223*								
right vmPFC/ OFC	11-hbr				0.137*					
left dmPFC	12-hbr				-0.198**			-0.131*		
left dmPFC	13-hbr				-0.186**					
left dlPFC	14-hbo			-0.236*						
left dlPFC	14-hbr	0.303**								

Brain Area	Ch-hb	DIV	COL	PUI	AR	PL	ATT	DIS	PU	PEOU
left vmPFC/ OFC	15-hbr									-0.282**
right vmPFC/ OFC	17-hbo	-0.263**		-0.326***						
right vmPFC/ OFC	17-hbr				0.172**					
dmPFC/ vmPFC	18-hbr					0.151*	0.132*			
dmPFC/ vmPFC	18-hbr									-0.255*
left vlPFC/ dlPFC	21-hbo			-0.262**						
left vmPFC/ OFC	22-hbo		-0.205*							
left vmPFC/ OFC	22-hbr									-0.233*

Table 6.1. Correlation Matrix Across Included Papers

Note. Ch-hb = Channel number - hemoglobin type, DIV = Diversity, COL = Colorfulness, PUI = Purchase Intention, AR = Arousal, PL = Pleasure, ATT = Attitude, DIS = Distrust, PU = Perceived Usefulness, PEOU = Perceived Ease of Use

6.2. Implications of Results Along the User Journey

In this section, we answer the second research goal of this thesis which was to *"evaluate the potential of adding fNIRS measurements to inform UX along different use phases on ecommerce websites"*. For this, the results of each paper and their contribution are discussed in the following, from which implications for UX and neuroIS research and practice are derived.

6.2.1. Pre-Use/ First Impression

The first included manuscript in this thesis explicitly introduces a duality of processing the visual and information content of an ecommerce website. By putting the used

color of the website in the center of research, it was proposed that neural data *mainly* captures spontaneous, physiological reactions of users to website perception, while the self-reported data *mainly* captures the deliberately reflected upon, psychological processing of website perception. Note that the emphasis is to be put on "mainly" here, as we are not able to clearly differentiate both processes other than that one requires verbalization and the other does not. Nevertheless, results of this conceptualization show that what is processed on a neural level, and what is provided in a questionnaire, are two different facets. This is also supported by related neuroIS works which state that neurophysiological and self-reported data capture a similar, but not the same part of a construct (Barrett, 2016; Tams et al., 2014). A closer look at the results of Paper 1 can be used to further demonstrate the discrepancy between neural and self-reported data:

In the frame of Paper 1, we identified that a black website does require higher cognitive load to be processed on a neural level when compared to the same website in blue, although it was not rated as less aesthetically pleasing, nor was the use intention significantly lower. A similar, but contrary effect was identified on the green compared to the blue website. In this comparison, no significant differences in the neural data were observed regarding the cognitive load, however, the green website was rated as significantly less aesthetically pleasing. With these results, Paper 1 shows how the addition of fNIRS measurements allows to identify more spontaneous and not necessarily conscious effects during first impressions of websites prior to use. Since one goal of neuroIS research is to reduce cognitive load of users during IT use, and to further facilitate online transactions on websites (Dimoka, Banker, et al., 2012), this manuscript directly contributes to this goal. It is noteworthy, that these insights could only be generated by the employment of a neuroimaging method in addition to self-reported data.

In the face of the proposed duality of visual information processing of websites, and the finding that neural and self-reported data not necessarily lead to the same result, further studies have been conducted in Paper 2 and 3 to confirm and extend these results. In Paper 2, only deliberate, self-reported data were assessed for the website design elements color, design mode, and button shape. Results show that the manipulated color and design mode resulted in significant differences in self-reported evaluation, but the button shapes did not. To validate the color-related processing of websites, and to identify whether this duality is transferable to other, more subtle design elements, Paper 3 has been conducted.

In Paper 3, spontaneous, neural responses to the website design elements color

and button shape could be identified. Regarding user reactions to color use, a similar pattern emerged as in Paper 1, revealing that black websites require higher cognitive load than blue websites. However, this time, the difference between the blue and black website was also reflected in the self-reported data of participants. For the button shapes, no significant differences could be identified in the questionnaire data. The neural results, on the other hand, show significant differences that may point to increased use intentions of websites with rounded buttons. Yet, similar to the presented duality in Paper 1, this effect was only identified in the neural data, and not in the self-reported data.

Altogether, the three included papers show the significant effect that visual website design elements (i.e., colors, button shape) can have on first impressions of ecommerce websites. These effects might often be spontaneous and probably also unconscious, and are therefore, often not reflected in questionnaire data. Given that we identified significant effects on a neural level only, the added contribution of neuroimaging in general, and fNIRS measurement in particular, to UX research on ecommerce websites prior to website use is emphasized. Given that the effect was not only visible for obvious design elements such as color, but also for more subtle design changes such as button shapes, the notion of spontaneous processes that add to the overall UX is supported.

From these findings follow several implications for future research and practice that investigate first impressions of websites in the pre-use phase of the user journey. Firstly, the included papers reveal that with a sample size from 18 - 38 participants, reliable and even subtle effects can be detected as reactions to changes in the visual website design, that could not be uncovered by questionnaire data. As a result, neuroIS experiments with the mobile neuroimaging method fNIRS could be applied in practice in early stages of website development, and could be used to further inform the design of later stages. As practiced in the papers, conducting a neuroIS experiment in the pre-use phase does not require the website to be implemented yet, but can rely on screenshots or prototypes of different designs. In connection with the small required sample size, such experiments are quickly set up and conducted, and therefore, they offer a fruitful addition to the development process of ecommerce websites, for instance.

On a theoretical level, the here identified and observed neural responses to the shown website designs might be more universal in nature and may be transferable to the evaluation of other IT-artefacts such as enterprise systems or maybe even modeling languages. Ideas for this have been elaborated in more detail in the included

Paper 3, though they need validation in future studies and should therefore be treated with caution. Furthermore, we have selected fNIRS as measurement method in the included papers. Although more and more neuroIS works employ fNIRS by now, it is still underrepresented compared to fMRI and EEG. With the three papers discussed so far, we could already show that fNIRS offers a valid, mobile, and non-invasive method to investigate the formation of first impressions of users prior to website use. However, fNIRS can also be applied to the evaluation of user impressions of other GUIs as it generally allows to assess and localize spontaneous, neural responses in users' brains. Its major advantage is, that it allows for natural measurements at the same time and therefore, future neuroIS works may consider the use of fNIRS over fMRI to increase the ecological validity of their studies.

6.2.2. During-Use Phase

The topic of ecological validity and reliability of fNIRS as measurement method was further investigated in Paper 4. As the former section has shown that fNIRS offers a fruitful measurement method in the pre-use phase, Paper 4 and 5 show that it can also be used to assess neural activity during use. More precisely, the results of Paper 4 uncover that users who rate a website higher than average in usability-related constructs have a significantly increased activity in areas of the vmPFC/OFC compared to users that rate the website lower than average in the same constructs. The activated area has been related in neuroeconomic research to rewards and increased willingness to purchase (Plassmann, Kenning, and Ahlert, 2007); an association that is reflected in the findings of Paper 4.

Next to using self-reported results as discriminating factor to build the two user groups in Paper 4, we were also interested in whether there are significant differences depending on demographic characteristics. In Paper 5, the self-reported and neural data of men and women were therefore investigated during website use. Results show, similar to the papers in the pre-use phase, that significant differences could be identified in the neural data but not in the questionnaire results. Over all included websites, men required higher neural processing than women, which may be a result of men reacting stronger to visual complexity than women. Once again, the identified processes which may lead to different UX of men and women on the same website could only be identified in the neural data. With regard to the research question, we could therefore show that spontaneous processes during website use can be measured with the neuroimaging method of fNIRS. Furthermore, we also demonstrated that differences in user groups may also manifest in spontaneous

processes, or at least on a neurobiological level, that cannot be assessed without the addition of neurophysiological measurements.

The composite results of Paper 4 and 5 have several implications for future research and practice. Firstly, they show that fNIRS is a valid measurement method that can also be applied during actual website use and not only in the pre-use phase. In Paper 4, it was explicitly shown how fNIRS is able to replicate study results of an fMRI experiment on cortical levels, which underlines the prior statement. This also supports the suggestion made for future neuroIS studies, which might consider using fNIRS over fMRI if possible to further increase ecological validity while maintaining reliability and the ability to localize neural activation (albeit only on cortical levels).

Another major contribution of the two papers for both research and practice is the emphasis on different user groups utilized in the samples. While the papers included in the pre-use phase made within-subjects measurements, Paper 4 and 5 split the sample into two groups based on different characteristics. Paper 4 used the self-reported data to split the sample into two groups, while Paper 5 focused on the biological gender as discriminating factor. Especially in Paper 5, however, it was shown that not all discriminating factors of user groups may be visible in their self-reported data. Taking more demographic information into account, even though it is not differently rated in the questionnaire, may help to better inform visual website design and facilitate positive UX. Based on our findings, and as already suggested in the discussion of Paper 5, future research may even consider using the neural signal as discriminating factor to build user groups. This way, it may be possible to reach an individualization of website design and therefore, facilitate individual UX with the website.

In practice, the addition of fNIRS measurements may therefore not only help with measuring user reactions to website designs and behavior, but also in forming personas during the development process of the website. The included papers have shown that fNIRS is able to show even subtle differences between defined user groups and may therefore help to better understand the personas and target user groups of different website features.

6.2.3. Post-/ Repeated-Use Phase

In line with the thought of discriminating different user groups of a website, the final Paper 6 in the repeated-use phase aimed at identifying a significant neural pattern that discriminates loyal users from non-loyal users. In a binary decision task, participants had to choose one website over an alternative. In cases where users could chose their

preferred website, a specific neural activation could be identified in the PFC. The results show a similar pattern to Paper 4 in which users who preferred the website over others revealed a significant increase in the right vmPFC/OFC. This effect seems to hold true in the post- and repeated-use phase.

As analysis method, this paper used both a within-subjects, as well as a between-subjects analysis to identify the results. Through this, it was shown that fNIRS is capable of distinguishing the preferred website over others (within-subjects), while also being able to distinguish potentially loyal users from others (between-subjects). This therefore supports the statements made in the prior section with regard to the research question of this thesis. Furthermore, it also shows that measurements cannot only be made for testing new designs and features, but may also help to identify users who prefer the website more than others, which may not be revealed in self-reported data due to social desirability bias. Given that the loyalty topic in the frame of ecommerce websites is still scarce, the included paper offers rich contribution to the field, while also leaving room for future research in this domain. Nevertheless, Paper 6 shows that ecommerce websites which are preferred over others may have similar effects as brands and therefore, it calls for companies to establish brand effects through their ecommerce website.

6.3. Critical Appraisal and Future Research

In this thesis, we have used three UX phases derived from the definition of UX, as a frame to identify the potential of neuroIS studies for UX research on ecommerce websites. However, it needs to be critically appraised that the used phases are selected on an abstract level and that UX frameworks also propose more detailed phases of UX (for e.g., Pohlmeyer, 2011). However, in these frameworks, the here selected idea of having a phase prior to use, during use, and after repeated use, is still reflected, and commonly used when it comes to UX measurement (Vermeeren et al., 2010). Nevertheless, a selection of different phases would also change the perspective of the results which we have found to be phase-sensitive (see, e.g., the discussion about the role of the dmPFC or the vmPFC in the first section of the discussion). Given that we have also identified results which are robust across use phases, this limitation may only bias our results to some degree. Nevertheless, future research may consider looking at our results from a different perspective to identify new insights.

Furthermore, within each of the included papers, the used websites often had different foci in their products. For instance, in Paper 1 we looked at a website that sells shoes, while in Paper 2 and 3, a website which sells elearning courses has been

considered. Although these different foci have been selected consciously in order to have higher diversity in the results and thus, increase generalizability regarding which products are considered in the studies, it also is a limitation of this thesis. This limitation primarily concerns the part of the discussion in which we compared the results in each phase. Given that neural data is also sensitive to the context and the recruited sample of the study, this may result in a bias in the results of this thesis. Nevertheless, we have identified some effects which seem to be consistent across the included papers, and thus, this bias may only account for some of the findings. An approach to address this in future research could be to select one website and user group, and accompany them through all of the use phases. In this line, neuroIS experiments may also be complemented with large-scale automated A/B tests to see in how far the neural findings connect with behavioral data.

In this thesis, we have argued for fNIRS as favorable method to explore potential UX neural correlates. However, each neuroimaging method has its potentials and limitations which also impact the results of the studies (as was discussed in section 2.1.3). Therefore, future research may consider the application of EEG in similar works to assess spontaneous responses of users within milliseconds. Furthermore, first approaches in HCI research have also discussed an integration of fNIRS-EEG methods to assess both signals simultaneously (for e.g., Hirshfield, Chauncey, et al., 2009; Omurtag et al., 2017). Such method designs would allow to benefit from the increased temporal resolution of EEG while also maintaining the spatial localization of fNIRS. Furthermore, both EEG and fNIRS only reach to cortical levels of users. However, some of the processes that we identified in the PFC may also be connected to amygdala or striatum activity. Both of these brain regions lie deeper in the brain and can be reached by fMRI, for instance. Therefore, future research may also consider the additional conduct of fMRI studies to identify possible, deeper lying networks in the brain. Additionally, independent of the neuroimaging method, the following limitation needs to be noted.

In the past years, psychology, neuroscience, and social sciences have eventually come to a replication crisis in which the results of a majority of papers cannot be replicated by follow-up research (Baker, 2016; Duvendack et al., 2017; Gertler et al., 2018; Hensel, 2021). This crisis may also hit IS and neuroIS research (Conrad and Bailey, 2020), leading to several claims to increasingly include replication studies in publications (Brendel, Diederich, et al., 2021; Brendel, Niederman, et al., 2021). The challenge, especially for neuroIS, is that the results of neural data not only depend on the sample and stimuli, but also on the data analysis and pre-processing steps that are undertaken to analyze the data (as was pointed to in section 2.1.4). As

a result, researchers are trying to set standards and guidelines on how to publish reproducible EEG (Rodrigues et al., 2021), and fNIRS (Yücel, Lühmann, et al., 2021) research. While the applied data pre-processing and analysis procedures are presented in this thesis with these guidelines in mind, replication studies need to be conducted to validate the results obtained in the papers of this thesis. In this vein, the prior outlined potential neural correlates to UX constructs are first and foremost potential and require further validation.

Finally, we have shown how neuroIS studies with fNIRS can shine more light onto spontaneous processes of users as reactions to different website design elements, which can help to better understand UX on the respective websites. All papers included in the current thesis have considered desktop versions of the website. However, the market for mobile commerce increases, where the website or corresponding app of the vendor are used on a smartphone. Therefore, and to validate whether our findings hold true also for mobile commerce websites or apps, future research may consider investigating mobile websites with fNIRS.

Chapter 7

Conclusion

In the beginning of this thesis, we have shown that the identification and satisfaction of user needs in B2C ecommerce is crucial to elicit positive experiences and establish loyalty toward the business. One major interface to the consumer is the website of the business, which can impact the user and customer experience throughout the whole journey. Current approaches that aim to measure UX and related constructs have significant shortcomings and are often not able to uncover spontaneous processes in website users. Related neuroIS research proposes that a great part of human behavior is formed by these spontaneous processes and that the utilization of additional, neurophysiological measurements can help to uncover theses processes and better understand user behavior. Therefore, to elaborate the potential and contribution of fNIRS experiments for UX research on ecommerce websites, this cumulative thesis presents 6 essays along different UX phases being pre-use, during-use, and post-/repeated-use of the ecommerce website.

For each use phase, it was identified that different attributes of a website seem to be of importance for users: while aesthetics is a significant influence on first impression formation prior to use, attributes of usability and usefulness become more important during actual use. However, most of these constructs have been assessed through self-reported data only by related literature. As a means to additionally assess the spontaneous processes underlying UX, the neuroimaging method fNIRS is utilized in the included essays. Across all papers, several responses to website design factors across UX phases could be identified only on the spontaneous, neural level. The complementing self-reported data could only reveal these effects to a certain degree, and sometimes, no significant effects were detected in the self-reported data at all.

The details of the identified neural effects and their implications for UX have been elaborated in the discussion of this thesis. On the one hand, the role of the investigated brain areas in website evaluation has been discussed to advance the current knowledge about the role of PFC regions in the neuroIS field. On the other hand, the findings of each paper and their implications for UX research and practice for each use phase have been addressed. Consequently, this thesis shows the contribution of neuroIS by means of fNIRS experiments to UX research on ecommerce websites to better understand users, and thus, to improve their experiences along the user journey.

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Appendix

Appendix

A.1. Methodological Approach: PFC Activity and Its Associations in NeuroIS Research

Findings related to PFC activation in the frame of IS research (sorted after year of publication)

Note. EEG = Electroencephalography, fNIRS = functional near-infrared spectroscopy, fMRI = functional magnetic resonance imaging, PFC = prefrontal cortex, mPFC = medial PFC, dmPFC = dorsomedial PFC, vmPFC = ventromedial PFC, OFC = orbitofrontal cortex, dlPFC = dorsolateral PFC, vlPFC = ventrolateral PFC

Study	**Neuroimaging Method**	**Main Constructs**	**PFC Areas**	**Main PFC-related Results**
Nissen and Krampe (2021)	fNIRS	website aesthetics, perceived usefulness, perceived ease of use, use intention	dlPFC, dmPFC, vmPFC	Generally, men have higher neural activation on the left PFC than women. For useful websites, left dlPFC, vlPFC, and vmPFC are activated more for men. For low-rated websites the right dmPFC/vmPFC was activated in men. Authors draw a related to left/right hemisphere meaning positive/negative emotion.
Ding, Cao, et al. (2020)	EEG	user experience with smartphones	not specified	More positive user experience evokes higher activation in frontal alpha and delta bands, and weaker activation in the left central beta band and frontal theta band.
Moravec et al. (2019)	EEG	fake news, deliberate/conscious cognitive activity (memory, arousal, consciousness)	not specified	News that supports participants' beliefs but is flagged as false will trigger higher neural activity in the PFC.

Study	Neuroimaging Method	Main Constructs	PFC Areas	Main PFC-related Results
Bandara et al. (2018)	fNIRS	emotional valence and arousal	mPFC, dlPFC	mPFC is related to positive and negative emotion, premotor cortex and dlPFC are related to emotional arousal, and dlPFC is related to both emotional valence and arousal.
Ding, Hu, et al. (2018)	EEG (and ECG)	gaming, cognitive skills/ expertise	not specified	Frontal midline theta band as an indicator for top-down selective attention has been found to be lower in novices, and can be used to distinguish between professionals and novices during game play (together with HRV).
Dong and Jeong (2018)	fNIRS	episodic memory retrieval	not specified	Right PFC is required for episodic memory retrieval (decrease in HbR).
Vance et al. (2018)	fMRI	security warnings, attentions, habituation	dlPFC, dmPFC, vlPFC	Left dlPFC/dmPFC shows a signification habituation effect across days and security warning type, generally. Neural activation in the dlPFC/dmPFC and vmPFC shows significant effects for repeated measures.
Anderson et al. (2016)	fMRI	security warnings, attention, habitualization to warning due to repetition	mPFC	Bilateral mPFC is activated for static rather than polymorphic stimuli. mPFC is related to the default mode network, significant interaction effect between security warning type, repetition number, and default mode network activation. mPFC activation is higher for later repetitions.
Lai et al. (2016)	EEG	social exclusion	not specified	Left PFC activation is observed in exclusion scenarios.

Study	Neuroimaging Method	Main Constructs	PFC Areas	Main PFC-related Results
Warkentin et al. (2016)	fMRI	emotion: threat and coping appraisal of security situations	dlPFC	Increased dlPFC activity relates to threat appraisal of information security situations. Generally, the superior frontal gyrus shows activation in response to security threats, which is assumed to be related to higher uncertainty about how to respond to these threats.
Boyer et al. (2015)	fNIRS	attention, mental workload	not specified	No further localization within the PFC measured – only in the vmPFC/OFC (Fp1 & Fp2) No changes related to workload are identified, but in relation to temporal changes for event onsets, activation decreases during long duration tasks.
Hu, West, et al. (2015)	EEG	self-control, information security, decision making	vmPFC, dlPFC	Decision making involves both PFC hemispheres, and participants with higher self-control require lower neural activation in the dlPFC and vmPFC.
Clemente et al. (2014)	fMRI	perceived presence in virtual reality	dlPFC	When self-reported perceived presence is increased, neural activation in the dlPFC is decreased; the authors relate dlPFC to working memory and processing of visual information in VR.
De Guinea et al. (2014)	EEG	perceived usefulness, perceived ease of use, memory load, distraction, engagement, frustration	mPFC	mPFC theta waves are an indicator for memory load. Beta bands on PFC are positively related to distraction. Alpha and theta bands are negatively related to distraction.
Gregor et al. (2014)	EEG	emotion, eloyalty	not specified	Left PFC is related to positive emotion, and right PFC is related to negative emotion.

Study	Neuroimaging Method	Main Constructs	PFC Areas	Main PFC-related Results
Kuan et al. (2014)	EEG	emotion	not specified	Left PFC is related to positive emotion, right PFC is related to negative emotion, presence of "buy" information is linked to right PFC activation, but when combined with "like" information, left PFC is activated.
Léger et al. (2014)	EEG (and eye tracking)	decision making, top down attention, notification pop-ups	not specified	Frontal cortex is associated with top-down attention and active decision making/ motor planning process as a response to email notification pop-ups.
Li, Jiang, et al. (2014)	EEG	user engagement	left dlPFC	Left dlPFC activation signifies user engagement mediated through game complexity (increases dlPFC activation) and user familiarity (decreases dlPFC activation) with the game.
Riedl, Mohr, et al. (2014)	fMRI	trust, social interaction with humans vs. avatars	dmPFC, vmPFC	dmPFC and vmPFC are activated more during interaction with humans than with avatars when assessing their trustworthiness.
Dimoka (2010)	fMRI	trust, distrust	OFC, dlPFC	OFC decreases for trustworthy and credible online sellers. dlPFC is related to the cognitive effort of credibility and discredibility evaluations of online sellers.
Luu and Chau (2009)	fNIRS	decision making, product preference	mPFC	mPFC activation is related to preference selection during decision making.
Grosenick et al. (2008)	fMRI	purchase intention	mPFC	mPFC has strongest (positive) impact on buying decisions and is activated when the price is presented.

A.2. Paper 3: Overview of the Website Design Literature in IS and HCI Journals

The following table provides an overview of the website design literature in IS and HCI journals (sorted after year of publication, DV = Dependent Variable, IV = Independent Variable)

Authors	IV	DV	Method	Main Results
Cyr, Head, and Larios (2010)	color in website design	color appeal, trust, user satisfaction, loyalty	eye-tracking, self-reports	Color significantly impacts trust and satisfaction. Color preferences were different between cultures: German users preferred blue and grey over yellow. Overall, blue was rated highest in all constructs.
Deng and Poole (2010)	visual complexity	emotion (pleasure & arousal), approach/avoidance behavior	self-reports	High complexity leads to lower pleasure and higher arousal levels. Pleasure positively influences approach behavior, and arousal has a negative impact on approach behavior.
Tuch, Bargas-Avila, and Opwis (2010)	website symmetry and gender	perceived symmetry, intuitive beauty, aesthetics (classic & expressive)	self-reports	Symmetrical websites positively influence aesthetics' ratings of men, but not of women.
Chen, Lin, et al. (2011)	websites manipulated in familiarity, site breadth, media richness	disorientation, user engagements, intention to use	self-reports	Websites with high familiarity, breadth, and media richness positively influence user engagement and intention to use, and negatively impact perceived disorientation.

Authors	IV	DV	Method	Main Results
Pelet and Papadopoulou (2012)	color in website design	consumer mood, memorization, purchase intention	self-reports	Lower contrast between background color and foreground color enhances memorization. When contrast is highest and brightness increases, a positive effect on purchase intention is observed. No positive effect of color on mood was identified. However, in cases where mood is negative, memorization is increased and purchase intention is decreased.
Campbell et al. (2013)	competent behavior, visual appeal, relationship compatibility, relationship receptiveness	attraction/ attitude toward the website, intention to use	self-reports	Visual appeal has a significant positive impact on the perceived relationship to a website, which further positively influences the attitude toward the website, as well as use intentions.
Cyr and Head (2013)	website design varying in information content, navigation, and visual design; gender	trust, user satisfaction	self-reports	Countries with higher masculinity reveal more gender differences in trust and satisfaction evaluations. Men always rated trust and satisfaction higher than did women.
Pengnate and Antonenko (2013)	website visual appeal, usability, relevance of information	metacognitive awareness, learning performance, trust, website browsing strategies	self-reports, screen capture	Perceived trustworthiness is positively influenced by affective (visual aesthetics) and usability design levels, rather than the relevance of information.
Lowry et al. (2014)	design of website logos that communicate traits of credibility and trustworthiness during first impressions	credibility judgments, distrust, trust	self-reports	Logos associated with positive credibility judgments also result in greater trust ratings. When website design fits the logo design, trust ratings are higher. The impact on distrust was only partly supported, and the relationship between distrust and trust was not supported.

Authors	IV	DV	Method	Main Results
Moody and Galletta (2015)	information cues (visual, audio, semantic) to support task goal	user satisfaction, stress	self-reports, performance metrics	Providing information cues that fit the user's goal reduces stress and increases user satisfaction during website use. Therefore, to reduce stress during interactions, website design should focus on potential user goals.
Seckler et al. (2015)	website design (symmetry and complexity) and color (hue, saturation, brightness)	aesthetic perceptions (i.e. simplicity, diversity, colorfulness, craftsmanship)	self-reports	Symmetry has a positive impact on simplicity, diversity, and craftsmanship. Visual complexity has a negative impact on all included aesthetic facets. Hue (color) has a significant impact on colorfulness, craftsmanship, and simplicity. Saturation (color) only influence colorfulness positively. Brightness influences colorfulness and simplicity.
Tan et al. (2015)	animated elements as distractions from purchase process	annoyance, purchases, attention	self-reports, performance metrics	Animated pop-ups increase annoyance, but also increase purchase decisions in complex decision scenarios.
Hasan (2016)	visual, navigational, and informational website design characteristics	perceived irritation	self-reports	Visual, navigational, and informational website design features have a significant positive impact on perceived irritation.

Authors	IV	DV	Method	Main Results
Jiang et al. (2016)	website aesthetics (i.e., unity, complexity, intensity, novelty, interactivity)	attitude towards the website, perception of corporate image, aesthetics, perceived utility	card sorting, self-reports	Aesthetics elements (i.e., unity, complexity, intensity, novelty, interactivity) positively impact users' perceived website aesthetics. Aesthetics further positively influence perceived website utility and attitude toward the website. Finally, attitude positively impacts the perceived corporate image of the website provider. Generally, aesthetics are more important for users during first impressions than are utility ratings.
Cheung et al. (2017)	animation in website design, shopping task type (browsing vs. search task)	attention	eye tracking	When a product item is animated, attention to all items on the webpage increases. However, attention to the animated element is higher, and attention to the rest of the webpage is reduced. This effect is stronger in the browsing task than in the search task.
Pengnate and Sarathy (2017)	website design varying in visual appeal and ease of use	perceived visual appeal, perceived ease of use, perceived usefulness, trust, intention to use	self-reports	Perceived ease of use does not have a significant effect on use intentions. Perceived usefulness, visual appearance, and trust do have a positive significant effect on use intention.
Kwak et al. (2019)	halo effect on charity websites	information content quality, navigation, website speed, aesthetics, security	self-reports	Manipulated content quality (i.e., missing information) and system quality (i.e., visual aesthetics, website speed, and navigation) result in different halo effects that are elicited during first impressions. Visual aesthetics have the strongest positive impact on perceived website quality and perceived reputation.

Authors	IV	DV	Method	Main Results
Pengnate, Sarathy, and Lee (2019)	website complexity	aesthetic perception, user engagement, intention to use	self-reports	Website order positively influences visual appeal, engagement, and use intention. First impressions also persist during longer website perception in terms of the ratings of visual appeal, engagement, and use intention.
Ye et al. (2020)	visual aesthetics (classic/expressive); color as influencer on arousal	temporal processing of website design: arousal, valence, attention, approach/avoidance	self-reports, eye tracking	Arousal has an impact on attention that is allocated during first impressions, and that has a carryover effect on later website evaluations. Arousal has a mediating role between the visual aesthetics' effects and attention (i.e., high arousal reduces attentional resources). Websites rated as more aesthetic are related to more positive valence ratings and lower arousal, and subsequently lead to higher approach tendency.
Hong et al. (2021)	animation of website elements (motion, lagging, looming)	attention, memorization	eye tracking	Motion and looming animation has a positive impact on attention. Combining animation styles does not improve attention to the items. Generally, attention does have a positive impact on information memorization. These findings were primarily found in a browsing task, and not in a search task.

A.3. Paper 5: Questionnaire Items and Internal Consistency of Study 1

Constructs and Items of Study 1 with item-rest correlations and CA if item is dropped *Scales taken from Moshagen and Thielsch (2010), reverse items (R) were recoded prior to analysis)*

Websites:	Computeruniverse		Digitalo		PNShop	
Items	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped
Simplicity						
The layout appears too dense. (R)	.567	.844	.572	.831	.604	.818
The layout is easy to grasp.	.667	.817	.641	.810	.656	.803
The layout appears well structured.	.705	.808	.694	.797	.687	.795
The site appears patchy. (R)	.684	.812	.670	.802	.584	.824
Everything goes together on this site.	.682	.813	.662	.805	.700	.793
Diversity						
The design is uninteresting. (R)	.537	.775	.580	.746	.588	.739
The layout is inventive.	.580	.761	.562	.752	.567	.746
The design appears uninspired. (R)	.651	.737	.620	.732	.556	.750
The layout appears dynamic.	.562	.766	.476	.777	.550	.751
The layout is pleasantly varied.	.578	.761	.602	.739	.558	.749
Colorfulness						
The color composition is attractive.	.652	.766	.490	.810	.569	.577
The colors do not match. (R)	.624	.777	.633	.816	.316	.726
The choice of colors is botched. (R)	.614	.782	.743	.767	.555	.585
The colors are appealing.	.668	.756	.675	.799	.498	.624

Websites:	Computeruniverse		Digitalo		PNShop	
Items	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped
Craftsmanship						
The layout appears professionally designed.	.641	.755	.545	.712	.558	.685
The layout is not up-to-date. (R)	.557	.799	.544	.714	.466	.738
The site is designed with care.	.674	.741	.548	.710	.617	.655
The design of the site lacks a concept. (R)	.648	.750	.603	.679	.552	.687

A.4. Paper 5: Questionnaire Items and Internal Consistency of Study 2

Constructs and Items of Study 2 with item-rest correlations and CA if item is dropped *(Note. Scales taken from Dimoka and Davis (2008))*

Websites:	Computeruniverse		Digitalo		PNShop	
Items	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped
Perceived Usefulness (PU)						
Website X was useful in purchasing this digital camera.	.569	.846	.470	.888	.573	.909
Website X was useful for getting valuable information about this digital camera.	.769	.798	.780	.816	.802	.861
Using Website X enabled me to find information about this digital camera quickly.	.715	.809	.842	.804	.793	.863
Website X improved my performance in searching this digital camera.	.583	.844	.569	.870	.732	.876
Using Website X enhanced my effectiveness in learning about this digital camera.	.710	.809	.820	.805	.828	.854
Perceived Ease of Use (PEOU)						
Learning to use Website X would be easy for me.	.746	.851	.763	.901	.740	.872
My interaction with Website X would be clear and understandable.	.768	.845	.818	.889	.789	.860
Getting information about this digital camera from Website X would be easy.	.609	.888	.711	.917	.644	.896

Websites:	Computeruniverse		Digitalo		PNShop	
Items	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped	item-rest correlation	CA if item dropped
It was easy to become skillful at using the Website X.	.751	.850	.885	.878	.811	.856
Overall, I found Website X to be easy to use.	.746	.852	.778	.897	.736	.873
Purchase Intention (PUI)						
Given the chance, I intend to purchase this digital camera from Website X	.806	.824	.829	.897	.809	.863
Given the opportunity, I plan to purchase this digital camera from Website X	.713	.863	.782	.913	.780	.871
If I wanted this digital camera, I would purchase it from Website X	.714	.860	.837	.894	.781	.873
Given the need, I would buy this digital camera from Website X	.752	.847	.840	.893	.755	.880