Emotions in Ubiquitous Information Systems: An Empirical Investigation of Electrodermal Activity and Its Relation to Service Breakdowns, Perceived Ease of Use, and Task Performance

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The President:

Prof. Dr. Thomas Bieger

Dedicated to my family.

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Abstract

Information and communication services have become ubiquitous in our everyday life and, in turn, research on Ubiquitous Information Systems (UIS) has received increasing attention. UIS services can elicit both negative and positive emotions, which are not necessarily perceived consciously by individuals but which may still have an impact on predictors and outcomes of UIS service use. Due to the limitations of psychological self-reports in uncovering these automatic cognitive processes, the current work investigates emotional stimuli of UIS services with neurophysiological data. In particular, we choose electrodermal activity as an indicator of physiological arousal and assess its utility for the design and use of UIS services. To account for the neurophysiological nature of electrodermal activity and to investigate its value in relation to established self-report instruments, we integrate the stimulus-organism-response paradigm with a two-systems view of cognitive processing. Against the background of this theoretical framework, we hypothesize relationships between breakdown events of UIS services (the emotional stimuli), physiological arousal and perceived ease of use (manifestations of the organism's automatic and inferential cognitive processes), and task performance (the response of the organism). We also consider physiological learning processes related to generalization effects. In order to test the hypotheses, we use empirical data from two studies. Results indicate that electrodermal activity is a useful measure for the design and use of UIS services, even though generalization effects can reduce its reliability. Moreover, we demonstrate that electrodermal activity is related to perceived ease of use and task performance. We finally discuss the theoretical and practical implications of our results, examine the limitations of the current work and outline future research.

Zusammenfassung

Informations- und Kommunikationsdienste gehören mittlerweile zu unserem Alltag, weshalb ubiquitäre Informationssysteme (UIS) zunehmend wissenschaftlich untersucht werden. UIS-Dienste können sowohl negative als auch positive Emotionen hervorrufen, die nicht notwendigerweise bewusst wahrgenommen werden, aber dennoch die Nutzung dieser Dienste sowie deren Konsequenzen beeinflussen können. Aufgrund der Einschränkung von Befragungen diese automatischen, kognitiven Prozesse aufzudecken, untersuchen wir in dieser Arbeit emotionale Stimuli von UIS-Diensten mit neurophysiologischen Daten. Wir nutzen dazu Hautleitwerte als Indikator physiologischer Erregung und untersuchen ihre Brauchbarkeit für die Entwicklung und Nutzung von UIS-Diensten. Um einerseits den neurophysiologischen Charakter von Hautleitwerten zu berücksichtigen, diesen andererseits aber auch mit etablierten Befragungsinstrumenten vergleichen zu können, integrieren wir das Stimulus-Organismus-Reaktion-Paradigma mit einem Zwei-Sichten-Model kognitiver Prozesse. Auf Basis dieser theoretischen Grundlage stellen wir Zusammenhänge zwischen Defekten in UIS-Diensten (die emotionalen Stimuli), physiologischer Erregung und wahrgenommener Benutzerfreundlichkeit (die Manifestation automatischer respektive analytischer kognitiver Prozesse des Organismus) sowie Arbeitsleistung (die Reaktion des Organismus) her. Hierbei berücksichtigen wir auch physiologische Lernprozessen in Bezug auf Generalisierungseffekte. Empirische Daten aus zwei Studien werden ausgewertet um die Zusammenhänge zu testen. Die Ergebnisse zeigen auf, dass Hautleitwertmessungen im Rahmen der Entwicklung und Nutzung von UIS Diensten nützlich sind auch wenn die Reliabilität der Messungen durch Generalisierungseffekte eingeschränkt sein kann. Zudem stellen wir dar wie Hautleitwerte mit der Benutzerfreundlichkeit von UIS-Diensten und der Arbeitsleistung zusammenhängen. Wir diskutieren schließlich die theoretischen und praktischen Implikationen unserer Ergebnisse, zeigen die Grenzen dieser Arbeit auf und skizzieren zukünftige Beiträge.

Abbreviations

AISM	Abstract Information System Model
AmI	Ambient Intelligence
CI	confidence interval
Cskin	skin conductance
d	effect size
ECG	electrocardiogram
EEG	electroencephalography
f^2	effect size
Hz	hertz
I	current
IKS	Interactive Knowledge Stack for small to medium CMS/KMS providers, EU project
IS	Information Systems (field of research) or information system when used as IS service
M	mean
Mdn	median
µS	microSiemens
N	total sample size
n	subsample size
PEU	perceived ease of use
PLS	partial least squares
Q^2	predictive relevance
q^2	effect size
r	effect size
R	resistance
R^2	coefficient of determination
RQ	research question

Rskin	skin resistance
s	seconds
SC	skin conductance
SCL	skin conductance level
SCR	skin conductance response
SD	standard deviation
S-O-R	stimulus-organism-response
SiDIS	Situational Design Methodology for Information Systems
TOS	ticket order service
UIS	ubiquitous information system
VIF	variance inflation factor
V	voltage

1 Introduction

The first chapter of this dissertation provides background information on the relevancy and steadily increasing diffusion of ubiquitous information systems (UIS). We then tackle the question as to why the investigation of neuroscience measures in general and electrodermal measures in particular seem to be promising with regard to emotions and in-situ evaluations of UIS designs. Against this background, research questions are formulated and their relevancy to the design and use of UIS services within the field of Neuroscience Information Systems (NeuroIS) are outlined. There then follows a brief description of the theoretical framework and methods that are to be used to answer the research questions. We finally provide a description of the formal organization of the remaining chapters and conclude with a summary.

1.1 On the relevancy of ubiquitous information systems

One of the core research activities of the Information Systems (IS) community during the last forty decades revolves around investigations into the "effective design, delivery, use and impact of information technology in organizations and society." (Avison and Fitzgerald, 1995, p. xi) Accordingly, the core objective of IS research is to increase the efficiency of business organizations (Hevner et al., 2004). During the last two decades, however, information and communication services have become ubiquitous in our everyday lives: be it an "always-on" Internet-connected smartphone for electronic commerce activities (Frolick and Leida-Chen, 2004; Mennecke and Strader, 2002), a smart watch, glass or lens for instant notifications, mobile payments or sensor-based health applications (Cecchinato et al., 2015; Lucero et al., 2014; Rawassizadeh et al., 2014), radio-frequency enabled mobile tickets (O'Connor, 2008), health and life insurance services based on real-time data streams from wearable devices (Callaway and

Rozar, 2015; Chiauzzi et al., 2015; Schmidt, 2015) or a black box with a global positioning sensor that tracks the location of cars for insurance purposes or driver assistance (Adell et al., 2011). These kinds of services have been discussed under umbrella terms such as ambient intelligence (Keegan et al., 2008), experiential computing (Yoo, 2010), internet of things (Fleisch, 2010; Fleisch and Mattern, 2005; Floerkemeier et al., 2008), nomadic computing (Lyytinen and Yoo, 2002b), pervasive computing (Hansmann et al., 2012), smart products (Janzen and Maass, 2008; Kowatsch et al., 2008; Maass, 2007; Maass et al., 2008; Maass and Varshney, 2008; Mayer et al., 2011; Pfefferle, 2007; Thiesse and Köhler, 2008), ubiquitous computing (Cousins and Varshney, 2009; Lyytinen and Yoo, 2002a; Lyytinen et al., 2004) or ubiquitous information systems (Kowatsch and Maass, 2013; Maass and Varshney, 2012; Paefgen et al., 2012; Vodanovich et al., 2010). All of these terms can be traced back to the seminal article entitled "The computer for the 21st Century" by Mark Weiser (1991). Since this present dissertation is written predominantly for the IS community, the term ubiquitous information system (UIS) has been adopted and defined as a composite of people, processes, information and communication services embedded in hardware that is interconnected and interwoven into our lives (Vodanovich et al., 2010).

1.2 In situ responses to UIS stimuli by electrodermal activity

In addition to traditional IS built for business tasks and organizations, UIS are designed to support people in everyday situations that particularly include emotional phenomena such as sensory pleasures or esthetic enjoyment (Astor et al., 2013; Holbrook and Hirschman, 1982; Kowatsch et al., 2015a; van der Heijden, 2004). Common to both traditional IS and UIS, in particular in early stages of IS designs and implementations, are also phenomena related to IS stimuli that lead to negative emotions and feelings as a consequence of human-computer interaction. For example, negative IS stimuli such as breakdown events or unexpected interaction errors are related to a decrease in user performance and user acceptance of the IS service and have been investigated in the IS community by referring to the technostress concept (Ayyagari et al., 2011; Ragu-Nathan et al., 2008; Riedl, 2013; Riedl et al., 2012; Tams et al., 2014; Tarafdar et al., 2007). Technostress was originally defined by Craig Brod as "a modern disease of adaptation caused by an inability to cope with the new computer technologies in a healthy manner." (Brod, 1984, p. 16) In this present work, we adopt the following, more recent definition of technostress by Weil and Rosen (1997) because it not only highlights the various psychological and physiological dimensions of technostress but also locates technostress in both the organizational setting as a consequence of user interactions with traditional IS and in everyday settings at home while interacting with UIS. Here, technostress is defined as "any negative impact on attitudes, thoughts, behaviors, or body physiology that is caused either directly or indirectly by technology." (ibid., p. 5)

To systematically capture these various positive and negative IS stimuli in situ and at the time at which they are perceived and processed cognitively, neuroscience measures have recently been proposed and adopted to complement or even replace self-report instruments in disciplines like Neuroeconomics[1] (Bhatt and Camerer, 2005; Camerer et al., 2004; Clarke, 2014; DeWitt, 2014; MacKillop et al., 2014; Rustichini, 2005), Neuromarketing[2] (Deppe et al., 2005; dos Santos et

[1] "Neuroeconomics is the application of cognitive neuroscience to economic behavior using functional brain imaging tools. Neuroeconomics develops models of economic behavior that are based on measurement of brain activations that underlie human processes, behavior, and decision making in experimental games where subjects are given different tasks and payoffs (e.g., Rustichini 2005). For a detailed review of the neuroeconomics literature, please see Camerer et al. (2004)." (Dimoka et al., 2011, p. 689)

[2] "Neuromarketing is the application of cognitive neuroscience theories and functional brain imaging tools to marketing. By understanding how the human brain activates in response to marketing and advertising stimuli (Zaltman 2003), neuromarketing aims to build superior models to understand consumer behavior and market products (Lee et

al., 2015; Groeppel-Klein, 2005; Lee et al., 2007; Plassmann et al., in press; Plassmann and Weber, in press; Smidts et al., 2014; Van Praet, 2014; Zaltman, 2003) or Neuroscience Information Systems (NeuroIS)[3] (Astor et al., 2013; de Guinea et al., 2014; Dimoka, 2010; Dimoka et al., 2012; Dimoka et al., 2011; Hu et al., 2015; Riedl et al., 2010a; Tams et al., 2014; vom Brocke and Liang, 2014).

Among the various neuroscience measures derived from brain imaging tools (e.g. functional magnetic resonance imaging, positron emission topography, electroencephalography or magnetoencephalography) and psychophysiological tools (e.g. eye tracking, electrodermal measures, facial electromyography or electrocardiogram) (cf. Dimoka et al., 2012; Riedl et al., 2010a), only a small subset is appropriate to address research questions on perception and cognitive processing "in the wild" and at the exact time of external stimuli; that is, they have to be portable, noninvasive and unobtrusive (Astor et al., 2013; Dimoka, 2012). In line with these requirements, and compared to similar tools such as mobile electrocardiograms (Astor et al., 2013) or eye-tracking devices (Serfas et al., 2014), recording electrodermal activity represents the most cost-effective approach for collecting neuroscience data (Dimoka et al., 2012). And it has already been adopted for in-situ evaluations in the field of marketing research (Groeppel-Klein, 2005). Even more intriguing, electrodermal activity results from sympathetic neuronal activity and is related to emotional states (e.g. arousal, fear or enjoyment), cognitive states (e.g. attention) and behavioral reactions (e.g. stress, relaxation) (Bagozzi, 1991; Bagozzi et al., 1999; Critchley, 2002; Critchley et al., 2000; Figner and Murphy, 2011; Kroeber-Riel, 1979; Portas et al., 1998; Raskin, 1973). Due to this broad

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al. 2007). For a comprehensive review of the neuromarketing literature, please see Lee et al. (2007)." (Dimoka et al., 2011, p. 689)

[3] The concept of NeuroIS was originally proposed by Dimoka et al. (2007). It can be defined as a subfield of IS research that "relies on neuroscience and neurophysiological theories and tools to better understand the development, use, and impact of information technologies (IT)." (Riedl et al., 2010a, p. 245)

range of construct coverage, electrodermal activity “has become one of the most frequently used biosignals in psychophysiology.” (Boucsein, 2012, p. 1)

Although “electrodermal phenomena are not yet fully understood” (ibid.) the existing body of literature and theories may be used to inform the design and evaluation of UIS since a variety of research questions and constructs related to the adoption and effective use of (ubiquitous) IS are related to cognitive processing (e.g. belief and attitude formation) and behavioral phenomena (e.g. task performance) (Davis et al., 1992; Hu et al., 2015; Kamis et al., 2008; Komiak and Benbasat, 2006; van der Heijden, 2004; Venkatesh et al., 2003; Venkatesh et al., 2012). The construct perceived enjoyment, for example, is used to explain the adoption of hedonic IS (van der Heijden, 2004), and the related concept joy has been already successfully linked to electrodermal activity in the neuromarketing context more than a decade ago (Groeppel-Klein, 2005).[4] Another example is the technostress construct as introduced above. Here, the physiological dimension of technostress was measured by electrodermal activity (Riedl et al., 2013).

1.3 Research questions and contributions to NeuroIS research

The NeuroIS community, though aware of the potential of electrodermal activity (Dimoka et al., 2012; Riedl et al., 2010a), has so far neglected its use as a low-cost, noninvasive and unobtrusive in-situ evaluation measure for the design and use of UIS services – for a corresponding literature review, see Section 2.7; therefore, the following research question seems to be worth an investigation:

> *Is electrodermal activity a useful measure for the design and use of UIS services?*

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[4] In this study perceived enjoyment was termed and conceptualized as the emotion joy.

We attempt to answer this question by elaborating on the theoretical and practical contributions of using electrodermal activity as a NeuroIS measure for the effective design and use of UIS services. The overall research question is divided up into four rather concrete subquestions as described in the following paragraphs.

First, electrodermal activity can only be a useful measure for the design and use of UIS services if it is sensitive enough to show variance in response to UIS stimuli. Although it has already been shown that electrodermal activity is sensitive enough in the context of traditional IS – for example, in response to the interactivity and vividness characteristics of an e-commerce website (Sheng and Joginapelly, 2012) or in response to a computer breakdown (Riedl et al., 2013) – current research lacks evidence in the UIS context. In particular, and in contrast to traditional IS, using UIS services while individuals freely move, gesticulate and interact by, for example, speech and touch gestures leads to several potential sources of physical and physiological noise that may partially influence or even reduce the signal-to-noise ratio to a degree where variance of electrodermal activity in response to UIS stimuli cannot be observed anymore. One example refers to noise artifacts, inevitably involved during touch gestures, from movements of the hand, a location where electrodermal activity is usually measured by two electrodes (Boucsein, 2012; Kowatsch, 2012; Teubner et al., 2015). Other examples are unintended contact of the electrodermal sensors with other physical objects (Kowatsch, 2012), or physical activity during human-computer interaction, which leads to sweating and thereby, an increase in electrodermal activity that is not a consequence of an UIS stimulus (Kappeler-Setz et al., 2013). Limited evidence, however, exists in the field of marketing research where electrodermal activity measured with a mobile device showed significant variance in individuals as a consequence of characteristics of in-store environments while these individuals moved freely around and searched for products (Groeppel-Klein, 2005). Still, evidence for the sensitivity of electrodermal activity while interacting with UIS services needs to be investigated, leading us to formulate the first research question (RQ) as follows:

RQ1. *Is electrodermal activity sensitive enough to be able to significantly respond to stimuli while individuals move, gesticulate and interact with UIS services?*

Second, a major threat to the reliability of physiological measures in general is the effect of habituation (Groves and Thompson, 1970; Thompson and Spencer, 1966). Habituation is defined as "decreased response to repeated stimulation" (Groves and Thompson, 1970, p. 419) and can also lead to a sub-process termed generalization which extends the effect of habituation to similar stimuli (Grizzard et al., 2015; Rankin et al., 2009; Stein, 1966). Physiological responses such as electrodermal responses to repeated or even similar IS stimuli may decrease steadily over the course of time, i.e. electrodermal activity may loose sensitivity and thus, no longer be reliable. Habituation and generalization therefore represent major shortcomings when using electrodermal activity as a NeuroIS measure in comparison to psychological self-report instruments. For example, one would not change an answer just because one was asked the same question several times in response to the same stimulus and within a short period of time. As a consequence, habituation and generalization processes in electrodermal responses might lead to unreliable results of longitudinal studies that employ a repeated measures and within-subjects design, thus making electrodermal activity as a measure irrelevant for the design and use of UIS services. For a more general literature review on IS research employing a repeated-measures design see Kehr and Kowatsch (2015).

Generalization effects may become even more relevant in design science research that describes a theory-guided design of IS and rigorous validation of IS designs (Hevner et al., 2004; Peffers et al., 2007; Winter, 2008). It usually employs several build-and-evaluate loops and thus, requires subjects to inherently be confronted with similar stimuli during the design process.[5] For example, subjects may evaluate a narrative or mockup of a UIS service in an early stage of development whereas an interactive prototype of the same service, which represents a similar but not the same stimulus as the narrative or mockup, is used in later stages (Janzen et al., 2010a; Kowatsch and Maass, 2013).

Against this background, and especially because it has not been appropriately addressed in prior work (see Section 2.7), the important question arises as to whether electrodermal activity is an appropriate measure for study designs that use similar UIS stimuli in the form of a within-subjects factor. We therefore formulate the second research question as follows:

RQ2. *Subject to the generalization effect of physiological responses, is electrodermal activity an appropriate measure for UIS studies that employ similar UIS stimuli as a within-subjects factor?*

Third, we are interested in electrodermal phenomena that are appropriate for the design and use of UIS services and thus are related to IS constructs that either predict or represent consequences of system use. Examples of predicting constructs are situation service fit (Kowatsch, 2012; Kowatsch and Maass, 2013; Maass et al., 2012), perceived enjoyment (Kamis et al., 2008; van der Heijden, 2004), perceived ease of use, or perceived usefulness (Davis, 1989; Kowatsch and Maass, 2010). By contrast, the consequences of UIS use usually describe constructs related to a system's utility and success (DeLone and McLean, 1992; DeLone and McLean, 2003; Huanga et al., 2012; Kowatsch and Maass, 2009; Petter et al., 2013; Petter and McLean, 2009). Examples include intentions to purchase products or to prefer retail stores (Kamis et al., 2008; Kowatsch and Maass, 2010; Kowatsch et al., 2011; Sheng and Joginapelly, 2012), group performance

[5] More details on design science research and its relevance to the current work are provided in Section 2.2 of Chapter 2.

(Zigurs and Buckland, 1998), website success (Palmer, 2002; Sheng and Joginapelly, 2012), organizational performance (Avison and Fitzgerald, 1995; Hevner et al., 2004) or health outcomes (Agarwal et al., 2010; Kowatsch et al., 2014; Pletikosa Cvijikj et al., 2014). Prior research in the field of NeuroIS that investigates electrodermal activity as a consequence of breakdown events of IS services (Riedl et al., 2012) or characteristics of a website (Sheng and Joginapelly, 2012) provide limited evidence on the relationship of electrodermal activity with predictors or outcomes of service use.

In order to make sound assumptions about the relationships between electrodermal activity and the constructs outlined above, an appropriate conceptualization of the former is inevitable for the following two reasons. On the one hand, the term *electrodermal activity* has delivered only limited semantic meaning related to IS or UIS research up till now, due to its low-level character as one particular physiological measure. That is, there seems to be no intuitive relationship with, for example, established IS constructs such as perceived enjoyment or perceived ease of use, nor is there a match with existing theoretical models such as the (revised) technology acceptance model (Davis, 1989; Venkatesh and Davis, 2000) or the (revised) unified theory of acceptance and use of technology (Venkatesh et al., 2003; Venkatesh et al., 2012).

On the other hand, a common conceptualization of electrodermal activity is desirable to create a consistent terminology in IS research. This seems to be especially important due to the fact that prior research has adopted various conceptualizations of electrodermal activity. For example, it is evident from the literature review that electrodermal activity has been conceptualized in terms of a more generic construct such as physiological arousal (Chanel et al., 2009; Harley et al., 2015; Kneer et al., 2016), as well as more specific, even conflicting constructs such as fear (Chittaro and Sioni, 2015), enjoyment (Groeppel-Klein, 2005), stress (Chittaro and Sioni, 2014a; Moody and Galletta, 2015; Riedl et al., 2013), decision-making (Zhou et al., 2015) or cognitive absorption (Léger et al., 2014a). In this regard, it is open whether electrodermal activity should be conceptualized as a genuine predictor, or as a consequence of UIS use that stands on its own, or whether it is a physiological counterpart of an already existing predictor or consequence of UIS use. Thus, we formulate the third research question as follows:

RQ3. *Which viable conceptualization of electrodermal activity can be related to predictors or outcomes of UIS use?*

Finally, it remains uncertain, whether electrodermal activity among other NeuroIS measures and related predictors or outcomes of UIS service use must be seen as either complements or alternatives to psychometrics (Tams et al., 2014). On the one hand, and in line with Dimoka et al. (2011), Riedl et al. (2010a) argue that neuroscience measures

> "…allow us to improve existing theories and develop new theories with higher levels of explained variance of important dependent variables (e.g., information processing, technology acceptance, user productivity), if compared to research based on traditional data sources. Therefore, we unequivocally consider neuroscience theories and tools as complements, not substitutes to existing IS theories and tools." (ibid., p. 257)

In the context of the current work, electrodermal activity may add variance in dependent IS constructs in addition to psychological measures collected, for example, by self-report instruments. In that case, physiological measures and psychological measures tap into distinct dimensions of a focal construct. For example, Tams et al. (2014) have shown that variance explained in task performance was significantly higher if stress measured physiologically via salivary alpha-amylase was added as a predictor to the psychological self-report measure of stress.

On the other hand, NeuroIS measures such as electrodermal activity, could also be "alternatives for IS researchers who do not rely on self-reported measures, such as IS economists and design scientists." (Dimoka et al., 2011, p. 693) In that case, the same underlying dimension of a focal theoretical construct is measured both psychologically and physiologically. For example, Sheng and Joginapelly (2012) found that the degree of arousal was consistent among self-reports and electrodermal activity for subjects interacting with a website that provided features of medium and high interactivity. However, this finding was not consistent for a website that was not interactive.

Against this background that challenges the relationship between physiological and psychological measures, the last research question can be formulated as follows:

RQ4. *Are electrodermal activity and psychological self-reports complementary or alternative measures of the same underlying IS construct?*

Answers to these questions will contribute to the proposed NeuroIS research areas on the design and use of systems and business outcomes (Dimoka, 2012). Consistent with NeuroIS research that “seeks to contribute to (i) the development of new theories that make possible accurate predictions of IT-related behaviors, and (ii) the design of IT artifacts that positively affect economic and non-economic variables (e.g. productivity, satisfaction, adoption, well being)” (Riedl et al., 2010a, p. 245), this present dissertation has the following objectives: to identify new determinants (RQ1) related to predictors and outcomes of UIS use (RQ3), and to better understand their reliability (RQ2) and dimensionality (RQ4).

1.4 Theoretical framework

Due to the nature of electrodermal activity, i.e. its reactivity to external emotionally competent stimuli (e.g. Bechara and Damasio, 2005; Bechara et al., 2000; Damasio and Carvalho, 2013; Damasio, 1994), and inline with prior IS research that investigates emotional reactions in response to external stimuli and their impact on behavioral outcomes (Jiang et al., 2010; Parboteeah et al., 2009; Sheng and Joginapelly, 2012; Tams et al., 2014; Xu et al., 2014a), we develop our research framework on the basis of the Stimulus-Organism-Response (S-O-R) paradigm (Mehrabain and Russell, 1974) and a two-systems view of cognitive processing (Evans, 2003; Kahneman, 2003; Stanovich and West, 2000).

The S-O-R paradigm assumes that changes in the internal states of an individual (e.g. changes in electrodermal activity as part of the organism) triggered by stimuli from the external environment (e.g. UIS stimuli) lead to specific behavioral responses. This paradigm allows us therefore to model the basal causal pathway from UIS stimuli to behavioral outcomes of UIS service use via an individual's cognitive processes. To even better understand the characteristics and interdependencies of these processes, we integrate a two-systems view of cognitive processing into the realm of the organism of the S-O-R paradigm. This view defines automatic and inferential cognitive processes and helps us to derive assumptions about the relationship of emotional processes measured by electrodermal activity and feelings among other, more utilitarian evaluations of IS constructs relevant to this work.

The combination of the S-O-R paradigm and the two-system view of cognitive processing as our research framework allows us therefore to appropriately describe not only changes of electrodermal activity in response to a stimulus via the automatic Stimulus-Organism link (RQ1), while taking into account the effect of generalization (RQ2), but also to conceptualize electrodermal activity and to discuss its relationships with related constructs that are subject to automatic and inferential processes (RQ3 and RQ4). The proposed framework enables us also to identify and model the impact of electrodermal activity on relevant outcomes of UIS service use at the automatic Organism-Response link (RQ3), again with respect to the generalization effect (RQ2).

In summary, we derive the research model and hypotheses of the current work from our research framework that combines the S-O-R paradigm and a two-systems view of cognitive processing to tackle the four research questions.

1.5 Mixed methods in design science research

To test the research model and hypotheses, empirical data from two laboratory studies are used. These studies were conducted in 2011 and 2012 as part of the Ambient Intelligence use case of the European integrated project *Interactive Knowledge Stack for small to medium CMS/KMS providers (IKS)*. The objective of these studies was to evaluate UIS services that are integrated into an everyday environment, in particular an interactive bathroom (Janzen et al., 2011a; Janzen et al., 2010a; Janzen et al., 2010c; Kowatsch and Maass, 2013; Kowatsch et al., 2013; Maass et al., 2012). The research partners involved in the IKS use case on Ambient Intelligence applied design science research. For the specific purpose of designing and validating UIS services in the above mentioned project, a dedicated design method termed Situational Design Methodology for Information Systems (SiDIS) was developed that emphasizes holistic UIS situations with its social actors, information, services and physical objects (Janzen et al., 2011a; Janzen et al., 2010a; Maass and Janzen, 2009; Maass and Janzen, 2011; Maass and Varshney, 2012). As a consequence, data from both studies reported on in this dissertation was collected during evaluations within the SiDIS method and included repeated exposure to the same UIS services based on different instantiations, i.e. narratives, mockup and an interactive full-size bathroom in the second study.

Finally, in each of the two studies a quantitative and qualitative mixed methods approach was applied (Creswell, 2009). That is, empirical data on human-computer interactions with a UIS service were obtained (a) by observations of the experimenter based on video recordings; (b) by self-report questionnaires filled out by study participants; and (c) by neurophysiological data, in particular, electrodermal activity, collected from the study participants with the help of sensors that were connected to a mobile skin conductance recorder. Adopting this mixed methods approach, using and integrating data from different empirical data acquisition instruments, helped us also to address common method bias in the current research (Podsakoff et al., 2003).

1.6 Structure and logic of the remaining chapters

The remaining chapters of this dissertation are structured as follows. Next, related work is discussed. Then, theories from IS research, neuroscience and psychophysiology are used to develop a research model with its hypotheses, according to the four research questions. Thereafter, the study design is described in detail to test the hypotheses and to answer the research questions. Here the sampling, procedure and instruments used for the two empirical studies and the particular UIS service are presented. The results are then presented with regard to the hypotheses and research questions. We finally discuss the theoretical and practical implications of our results, examine the limitations of the current work and outline future research.

1.7 Summary

In this introductory chapter, we have proposed the use of electrodermal activity as a novel NeuroIS measure for the evaluation of emotional phenomena related to UIS services. After outlining the advantages of electrodermal activity for the design and use of UIS services we formulated the overall research question that was further broken down into four more specific research questions, as listed in Table 1. We then introduced the theoretical framework of the current work by describing the Stimulus-Organism-Response (S-O-R) paradigm and a two-systems view of cognitive processing. A brief description of the mixed method approach as part of the design science research method SiDIS followed to inform the reader about the particular context in which the empirical data was obtained in order to answer the research questions. We finally outlined the structure and logic of the remaining chapters.

Table 1. Research questions

	Research question (RQ)
Overall RQ	Is electrodermal activity a useful measure for the design and use of UIS services?
RQ1	Is electrodermal activity sensitive enough to be able to significantly respond to stimuli while individuals move, gesticulate and interact with UIS services?
RQ2	Subject to the generalization effect of physiological responses, is electrodermal activity an appropriate measure for UIS studies that employ similar UIS stimuli as a within-subjects factor?
RQ3	Which viable conceptualization of electrodermal activity can be related to predictors or outcomes of UIS use?
RQ4	Are electrodermal activity and psychological self-reports complementary or alternative measures of the same underlying IS construct?

2 Related Work

In this chapter, relevant concepts are introduced and discussed, in order to better understand the remainder of this work. Accordingly and complementarily to the beginning of the first chapter, we further discuss the distinctions between information systems (IS), ubiquitous IS (UIS) and UIS services. We then present design science research as a methodology that was employed while designing and evaluating the focal UIS service of this work. Regarding the latter, i.e. the evaluation of IS in general, and UIS services in particular, we subsequently discuss perceived characteristics of information technology and how they were measured with the help of traditional self-report instruments in IS research. In order to address the shortcomings of these self-reports, Neuro-Information-Systems research is introduced, and with it electrodermal activity is proposed as a low-cost, portable, noninvasive and unobtrusive measure relevant for the evaluation of UIS services. Next, changes in electrodermal activity as a consequence of interoceptive und exteroceptive processes in homeostatic regulation, its measurement, parameters and shortcomings are described in more detail. We finally review research that utilizes various parameters of electrodermal activity in the context of human-computer interaction as these findings are expected to help us in informing our research model and hypotheses in the next chapter. A brief summary concludes this chapter.

2.1 Ubiquitous Information Systems

In line with Vodanovich et al. (2010), in this dissertation we define IS in a very broad sense as a composite of "people, processes, information, and communication systems and technologies" (ibid., p. 713); and we use the term UIS, when technology is meant, as "hardware such as tabs, pads, boards, dust, skins, and clay that are interconnected and interwoven into the very fabric of our lives through ubiquitous networks." (ibid.) Furthermore, Vodanovich et al. propose four dimensions to better understand the distinction between traditional, organizational-based IS and UIS. These four dimensions are:

a) The *context of the IS*, i.e. traditional IS are largely found in the organizational or office context (e.g. Davis et al., 1989; Davis et al., 1992; Davis and Venkatesh, 1996; Davis and Venkatesh, 2004; Venkatesh et al., 2003), compared to UIS located in the home context (e.g. Janzen et al., 2010a; Kowatsch and Maass, 2013; Maass et al., 2012; Röcker et al., 2005);

b) The *character of the activities or tasks* supported by the IS, i.e. traditional IS usually support professional tasks (e.g. Daskalopulu et al., 2002; Dennis et al., 2001; Fuller and Dennis, 2009; Goodhue and Thompson, 1995; Sambamurthy and Chin, 1994; Zigurs and Buckland, 1998; Zigurs et al., 1999), compared to UIS most often supporting personal tasks such as purchase decisions (e.g. Kowatsch and Maass, 2010; Kowatsch et al., 2011; Lee and Benbasat, 2010; Maass and Kowatsch, 2008a; Maass and Kowatsch, 2009; van der Heijden, 2006);

c) The *subjects* interacting with the IS, i.e. traditional IS are mostly used by digital immigrants, compared to UIS that are used by digital natives in the most instances;[6]

d) The *information and communication technology* embedded in the IS, i.e. traditional IS provide information and communication services such as email on desktop computers, fax and telephone services on dedicated and often separate

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[6] In contrast to digital immigrants, digital natives are people who have grown up with UIS technologies such as smartphones, tablets or smart watches and corresponding services such as YouTube, Facebook, Twitter or Instagram (Prensky, 2001; Vodanovich et al., 2010).

and non-mobile hardware, whereas UIS allow access to the same and even more services on mobile devices, wearables or via Internet of Things services (Fleisch and Mattern, 2005; Hansmann et al., 2012; Weiser, 1991).

Although one can generally agree with these dimensions for describing various instances of IS and their individual characteristics, it must be noted that a strict distinction between IS and UIS will be obsolete in the upcoming years as UIS are increasingly also adopted in the organizational and professional contexts by digital immigrants, in particular due to an increased demand for operational agility with new digital options (Sambamurthy et al., 2003) and the implementation of UIS as a means for innovative and ubiquitous consumer and client services (Junglas and Watson, 2006; Kowatsch and Maass, 2013; Kowatsch et al., 2014; Maass and Varshney, 2012; Pletikosa Cvijikj et al., 2014; Volland et al., 2013).

Against this background of UIS and consistent with the notion of a service system in the literature (Maass and Janzen, 2011; Maass and Varshney, 2012), a UIS service supports an individual by providing information and communication capabilities to perform a particular task. With regard to this work, the above-mentioned dimensions help us to better define the scope and subject of investigation. As will be described in full detail in the methods chapter, one particular UIS service – a ticket order service – will be evaluated. This service is meant to be integrated into a private bathroom at a user's home[7] and allows users to book tickets for various public events such as music concerts, movies or theater plays. Users are allowed to interact with the ticket order service using speech commands and touch gestures, as outlined in previous works (Kowatsch, 2012; Kowatsch and Maass, 2013; Maass et al., 2012). From the average age of the subjects who par-

[7] The prototype of the interactive bathroom that was studied in the current work was not installed in a real user's home but in a building on the campus of two German universities.

ticipated in the two studies presented in this dissertation we can assume that they are rather digital natives than digital immigrants.

Summing up, the focal IS, and more particularly, the ticket order service investigated in the current work, can be described as an UIS service supporting digital natives performing personal tasks at home, in their bathroom. The information required to perform the tasks is shown on an interactive mirror that also allows interaction by touch gestures. The service further uses a microphone embedded in the bathroom to capture speech commands of the participants. In this regard, this instance of an UIS service perfectly fits into the UIS definition of Vodanovich et al. (2010).

2.2 Design science research

The design science research paradigm is introduced in the following to motivate and better understand the context of the research questions and, in particular, in which the UIS service as introduced above was designed and empirically evaluated. Design science research "aims at 'utility', i.e., at the construction and evaluation of generic means-ends relations." (Winter, 2008, p. 470) The underlying design process is iterative in nature consisting of several build-and-evaluate loops with the goal to "produce a viable artifact in the form of a construct, a model, a method, or an instantiation." (Hevner et al., 2004, p. 83).

Constructs are the vocabulary or symbols used in the design process. Examples include perceived ease of use (Davis, 1989), perceived relative advantage (Moore and Benbasat, 1991), perceived enjoyment (Kamis et al., 2008; van der Heijden, 2004), hedonic motivation (Venkatesh et al., 2012) or team performance (Edwards et al., 2006; Rouse et al., 1992); thus, "constructs provide the language in which problems and solutions are defined and communicated" (Hevner et al., 2004, p. 78 in reference to Schön, 1983).

By contrast, models in design science research "use constructs to represent a real world situation – the design problem and its solution space“ (ibid., in reference to Simon, 1999). Examples include the (extended) technology acceptance model (Davis, 1989; Davis et al., 1989; Venkatesh and Davis, 2000) or the (extended) unified theory of acceptance and use of technology (Venkatesh et al., 2003; Venkatesh et al., 2012), which explain predictors of behavioral intentions to use technology and actual system usage (Legris et al., 2003; Turner et al., 2010); they therefore guide "problem and solution understanding and frequently represent the connection between problem and solution components enabling exploration of the effects of design decisions and changes in the real world." (Hevner et al., 2004, p. 87f)

Next, methods describe processes that "can range from formal, mathematical algorithms that explicitly define the search process to informal, textual descriptions of 'best practice' approaches, or some combination." (ibid., p. 79f)[8] Examples of methods are the application of the normalization procedure when building relational databases (Codd, 1970; Codd, 1982), building viable artifacts in design science research in general (Peffers et al., 2007) or guidelines on how to design conceptual models of IS and UIS in particular (Janzen et al., 2010a; Maass and Janzen, 2011). Therefore, methods "provide guidance on how to solve problems, that is, how to search the solution space." (Hevner et al., 2004, p. 79).

Finally, instantiations demonstrate that "constructs, models, or methods can be implemented in a working system." Examples are in-store product recommendation agents (Janzen et al., 2010b; Kowatsch and Maass, 2010; Kowatsch et al., 2008; Kowatsch et al., 2011; Lee and Benbasat, 2010; Maass and Kowatsch, 2008a; Maass et al., 2011a; von Reischach et al., 2009), mobile health information systems (Kowatsch et al., 2014; Maass and Varshney, 2012; Pletikosa Cvijikj et al., 2014; Xu et al., 2014b), or the implemented interactive bathroom with a ticket order service (Kowatsch, 2012; Kowatsch and Maass, 2013; Maass et al., 2012),

[8] Double quotes around "best practice" in the original paper of Hevner et al. (2004) have been replaced by single quotes to preserve consistency within the current work.

which will be used as the focal instantiation of a UIS service in this dissertation. Consequently, instantiations "demonstrate feasibility, enabling concrete assessment of an artifact's suitability to its intended purpose. They also enable researchers to learn about the real world, how the artifact affects it, and how users appropriate it." (Hevner et al., 2004, p. 79).

Having introduced the basic concepts of design science research above, we are now able to add more context to the research at hand. Considering the research questions, we search for an appropriate conceptualization of electrodermal activity, i.e. a construct in design science terminology that is related to predictors or outcomes of UIS service use. This search process also requires the definition of relationships among constructs, in particular between the conceptualization of electrodermal activity as a construct, UIS service use and outcome measures of UIS service use, i.e. a model in design science terminology. This research model with its hypothesized relationships among constructs is developed in the next chapter. In order to test the model and thus, to see whether our conceptualization of electrodermal activity renders a viable construct for UIS evaluations, the interactive bathroom with one particular UIS service, which was built in the context of the design science research method SiDIS (Janzen et al., 2010a; Maass and Janzen, 2011), is utilized as an instantiation of the model.[9]

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[9] It must be noted here that the design of the interactive bathroom environment with the ticket order service, among many other services, was a joint effort of the partners of the IKS project consortium and, in particular, the ambient intelligence use case partners consisting of the German Research Center for Artificial Intelligence, the Italian National Research Council, the University of St. Gallen, Switzerland, the Software Research and Development Center, Turkey, the Hochschule Furtwangen University and the Saarland University, under the scientific direction of Prof. Dr.-Ing. Wolfgang Maaß.

2.3 Perceived characteristics of information technology

In this section, we introduce and discuss perceived characteristics of information technology for three reasons. First, outlining existing predictors of IS use will probably help us regarding the third and fourth research question, i.e. the search for a viable conceptualization of electrodermal activity and its dimensionality. Second, this approach provides background knowledge on the nature and scales of psychological self-instruments that allows us to better contrast these with the neurophysiological nature of electrodermal activity as described in later sections. Third, shortcomings of existing self-report instruments can be revealed and thus, further the search for novel alternative or complementary (neurophysiological) measures such as electrodermal activity for UIS evaluations.

In accordance with two streams of research, i.e. technology adoption research (e.g. Davis, 1989) and research on innovation diffusion theory (e.g. Rogers, 2003), perceived characteristics of information technology have been frequently studied in the IS community (Davis, 1989; Davis et al., 1992; Davis and Venkatesh, 1996; Davis and Venkatesh, 2004; DeLone and McLean, 1992; DeLone and McLean, 2003; Eastin, 2002; Gefen et al., 2003; Kamis et al., 2008; Moore and Benbasat, 1991; Tornatzky and Klein, 1982; van der Heijden, 2004; Venkatesh and Davis, 1996; Venkatesh and Davis, 2000; Venkatesh et al., 2003; Venkatesh et al., 2012; Wixom and Todd, 2005). One key concept in these research streams is adoption defined as a “decision to make full use of an innovation as the best course of action available.” (Rogers, 2003, p. 473) Consistent with this definition, UIS services in general and the ticket order service embedded in the interactive bathroom in particular are introduced in this dissertation as an innovation to the subjects of the two studies presented in the current work.

Technology adoption research, on the one hand, tries to understand individual behavior and intentions related to the use of information technology. This research therefore has its roots in social psychology, more precisely in the theory of reasoned action (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975) and the theory of planned behavior (Ajzen, 1991; Mathieson, 1991; Orbell et al., 1997). Accordingly, there exist several constructs that predict actual behavior such as beliefs and attitudes towards the behavior, subjective norm, perceived behavioral control and intentions that also mediate the relationships between the former constructs and actual behavior (Ajzen, 1991). The technology acceptance model (Davis, 1989), for example, with perceived usefulness and perceived ease of use introduces two constructs that predict actual usage of information technology via behavioral intentions and thus can be assigned to this research stream (Benbasat and Barki, 2007; Davis, 1989; Davis, 1993; Davis et al., 1989; Davis and Venkatesh, 1996; Davis and Venkatesh, 2004; Venkatesh and Davis, 2000; Venkatesh et al., 2007). For further details and a corresponding literature review on the reliability of the hypothesized relationships of the constructs of the technology acceptance model see Turner et al. (2010), King and He (2006) or Legris et al. (2003).

On the other hand, innovation diffusion theory was developed from a social science perspective and describes the "process in which an innovation is communicated through certain channels over time among the members of a social system." (Rogers, 2003, p. 474) Here, perceived characteristics of innovations such as relative advantage compared to an existing technology, complexity, trialability, observability or compatability of a new technology, for example, with existing organizational processes or demands and characteristics of private activities, have been found to positively influence the diffusion process (Moore and Benbasat, 1991; Rogers, 2003). Several articles based on this line of research have been published in IS research and marketing research alike (Choudhury and Karahanna, 2008; Dutton et al., 1987; Eastin, 2002; Fliegel and Kivlin, 1966; Mahajan et al., 1990; Moore and Benbasat, 1991; Peres et al., 2010; Rangaswamy and Gupta, 2000; Rogers, 2003; Shih and Venkatesh, 2004; Stahl and Maass, 2006; Tornatzky and Klein, 1982; Ward and Davies, 1999).

There are also attempts in the IS community to integrate both streams of research due to the fact that some constructs that predict technology adoption are related to perceived characteristics of innovations. For example, perceived usefulness (Davis et al., 1989) and perceived relative advantage (Rogers, 2003) or perceived ease of use (Davis et al., 1989) and perceived complexity (Rogers, 2003). Accordingly, new constructs have been defined, such as performance expectancy or effort expectancy, as part of the unified theory of acceptance and use of technology (UTAUT) or UTAUT2 (Venkatesh et al., 2012). Further research that has integrated technology adoption research and innovation diffusion theory is known as the DeLone and McLean model of IS success (DeLone and McLean, 1992) and its revised version (DeLone and McLean, 2003), the decomposed theory of planned behavior (Taylor and Todd, 1995) or the work of Moore and Benbasat (1991) or Maass and Kowatsch (2008a).

Although various variants of these models have been published up till now (Kamis et al., 2008; Kowatsch and Maass, 2010; Maass et al., 2012; van der Heijden, 2004), they have been criticized in the past from a methodological perspective, too. One major concern addresses the character of constructs that predict technology adoption such as perceived ease of use, perceived usefulness or perceived enjoyment. These constructs are said to be "black boxes" hiding actual cognitive processes and implications for IS designs:

> "While we do not doubt that Davis et al.'s (1989) original intention was that the influence of system and other characteristics be studied through TAM's constructs, study after study has reiterated the importance of PU, with very little research effort going into investigating what actually makes a system useful. In other words, PU and PEOU have largely been treated as black boxes that very few have tried to pry open." (Benbasat and Barki, 2007, p. 212)[10]

[10] Note: TAM stands for technology acceptance model, PU for perceived usefulness, and PEOU for perceived ease of use, respectively.

Furthermore, self-report instruments with Likert-type measurement scales (e.g. statements on perceived ease of use that have to be rated from extremely likely to extremely unlikely, cf. Davis, 1989) or semantic differentials (e.g. statements on perceived enjoyment that range from unpleasant to pleasant, cf. van der Heijden, 2004) on paper-based or online questionnaires are usually employed to capture perceived characteristics of information technology (e.g. Kamis et al., 2008; van der Heijden, 2004; Venkatesh et al., 2012). While this approach is common in the social sciences due to its ease of use, low effort and low costs, researchers need to be aware and test their data, for example, with Harman's single factor test (Podsakoff and Organ, 1986), for common method variance (CMV). CMV is generally seen as a problem in behavioral research because it is a "variance that is attributable to the measurement method rather than to the constructs the measures represent" (Podsakoff et al., 2003, p. 879). Additionally, data from self-reports may be unreliable in situations where subjects cannot or are unwilling to provide information about

> "…sensitive issues (e.g. gender, race, culture, religion), personal issues (e.g. goals or fears), deep or hidden emotions (e.g., guilt, fears, and anger), automated processes (e.g., habit and automaticity), complex cognitive processes (e.g., cognitive overload), social dynamics (social cognition), antecedents of human behaviors (e.g., beliefs, attitudes, and intentions), and moral issues (e.g., ethics and moral judgments)." (Dimoka et al., 2012, p. 680)

Finally, self-report instruments cannot capture unconscious processes at the time of IS service interaction and researchers usually have to deal with a considerable delay between the actual evaluation of an IS service and the collection of data through self-reports.

The use of a mixed method approach, i.e. combining data from electrodermal measures and data from self-report instruments would render CMV irrelevant and, as a result, implications with respect to our research questions would be more valid.

The shortcomings mentioned above bring us to the next section, which introduces a novel research stream that this dissertation aims to contribute to. It is termed Neuro-Information-Systems research. That is, neurophysiological measures such as electrodermal activity could be used to identify relevant alternative or complementary predictors of perceived characteristics of information technology in the sense of 'neuronal correlates' (Dimoka et al., 2012; Dimoka et al., 2011; Dimoka et al., 2007).

2.4 Neuro-Information-Systems research

The application of neuroscience knowledge to 'traditional' IS research was first outlined and discussed by Angelika Dimoka, Paul A. Pavlou and Fred D. Davis in 2007. In line with this work, Neuro-Information-Systems (NeuroIS) research can be defined as research that "relies on neuroscience and neurophysiological theories and tools to better understand the development, use, and impact of information technologies (IT)." (Riedl et al., 2010a, p. 245) Dimoka et al. (2011) propose the following opportunities of NeuroIS research to address not only the shortcomings of traditional IS instruments mentioned in the section above but also to inform existing IS phenomena related to the adoption and diffusion of new technologies: "(1) localizing the neural correlates of IS constructs, (2) capturing hidden mental processes, (3) complementing existing sources of IS data with brain data, (4) identifying antecedents of IS constructs, (5) testing consequences of IS constructs, (6) inferring the temporal ordering among IS constructs, and (7) challenging assumptions and enhancing IS theories." (ibid., p. 687)

First, one of the key objectives of cognitive neuroscience research is to map the location of cognitive processing to brain regions. Reusing that knowledge base can help IS researchers to better understand the neural correlates of traditional IS constructs. An example of this kind of research was originally published by

(Dimoka and Davis, 2008) who investigated the location of the constructs of the technology acceptance model, in particular, perceived ease of use, perceived usefulness and behavioral intentions to use an electronic commerce website.

Second, NeuroIS may help to identify mental processes and constructs that are hidden from consciousness and rational reasoning, or are automatic in nature and, thus cannot be explicitly captured by self-report instruments used in traditional IS research (Dimoka et al., 2011). One example of such an automatic construct is physiological technostress measured by salivary alpha-amylase that has been shown not to correlate significantly with its psychological and self-report counterpart perceived technostress (Tams et al., 2014). Another example of an automatic construct is physiological arousal that can be measured by electrodermal activity and reacts to external stimuli while the individual may not be aware of it (Boucsein, 2012). Physiological arousal measured by electrodermal activity is also one of the core constructs of the current research, as described in the next sections and chapters.

Third, data from self-reports can be complemented by existing sources of IS data that are collected with the help of neuroscience tools. In particular, in situations where questionnaires, interviews or observations cannot predict the behavior in question, objective physiological data may be an appropriate approach to tackle a corresponding research question (Dimoka et al., 2011; Mast and Zaltman, 2005). Furthermore, as outlined above, adding neuroscience data can address methodological shortcomings of self-report instruments, namely, "subjectivity bias, social desirability bias, common method bias, and demand effects. (Dimoka et al., 2011, p. 692) One research question related to this third NeuroIS opportunity remains relevant, i.e. whether neuroscience data is able to replace self-report data, rendering self-report instruments obsolete. This is a research question that will be addressed in the current work, too (cf. RQ4).

The fourth opportunity of NeuroIS research is to identify new neuroscience constructs that predict IS constructs. This can be achieved by manipulating IS designs and observing the effects not only on psychological self-reports but also on neurophysiological responses (Dimoka et al., 2011). As a result, there may be neurophysiological responses that highly correlate with self-report data or are genuine on their own. In line with this research, the present dissertation also makes use of this opportunity by observing electrodermal reactions and responses of a traditional self-report construct with respect to UIS service stimuli.

The fifth opportunity can be seen analog to the fourth research opportunity but with a focus on consequences of IS constructs. That is, neuroscience constructs may also predict outcomes of technology use. One related and relevant research question in this context is whether the neuroscience construct adds more variance in an IS outcome construct such as task performance, compared to a traditional IS construct measured by a self-report (Tams et al., 2014). Another exemplary study that investigates the outcomes of stimuli during IS use, particularly computer breakdown events, on electrodermal activity in the context of technostress research was investigated by (Riedl et al., 2013). The study revealed that electrodermal activity is a sensitive indicator of computer breakdown events as a consequence of human-computer interaction. Similar to this study, RQ3 addresses the effects of electrodermal activity on outcomes of UIS service use.

Sixth, NeuroIS research allows for a better understanding of the temporal relationships of IS constructs in order to help infer causality, i.e. the direction of these relationships (Dimoka et al., 2011; Maxwell and Cole, 2007; Maxwell et al., 2011; Mitchell and James, 2001; Zheng and Pavlou, 2010). That is due to the fact that neurophysiological data can be captured at a high temporal resolution and at the time external IS stimuli set it (e.g. the medical device NeXus-10 Mark II from Mind Media, Netherlands, collects 1024 samples per second of the electrical activity of the brain, in form of an electroencephalogram) compared to filling out a questionnaire which often requires several minutes. Accordingly, the temporal order of neurophysiological activity can be made visible, which may guide theory development of IS models on technology acceptance. This brings us to the last opportunity.

Challenging existing relationships of IS constructs and theories represents the last opportunity of NeuroIS as outlined by Dimoka et al. (2011). That is, the novel neurophysiological perspective on existing constructs and relationships as outlined in the six opportunities above adds a new dimension of granularity to existing assumptions in IS research that can lead to theoretical enhancements ranging from small iterative refinements of existing models to completely new theories on the use and impact of technology. For example, the work of Dimoka (2010) shows empirically, with the help of a functional neuroimaging study, that trust and distrust are separate IS constructs that are not correlated to each other; this NeuroIS research therefore challenges existing theories that up till then assumed a corresponding relationship between those constructs.

Overall, these seven opportunities are also consistent with the expected contribution of NeuroIS research outlined by Riedl et al. (2010a, p. 245): "NeuroIS seeks to contribute to (i) the development of new theories that make possible accurate predictions of IT-related behaviors, and (ii) the design of IT artifacts that positively affect economic and non-economic variables (e.g., productivity, satisfaction, adoption, well being)."

In order to collect and process neurophysiological data there are several methods that have been applied in or are proposed for NeuroIS research (Dimoka et al., 2012; Riedl et al., 2010a). They range from (1) brain imaging tools (Dimoka, 2010; Dimoka, 2012; Dimoka et al., 2011; Dimoka et al., 2007) such as functional magnetic resonance imaging, positron emission tomography, electroencephalography (Minas et al., 2014; Vance et al., 2014), near infrared spectroscopy and magnetoencephalography, to (2) brain morphology tools (Riedl et al., 2010a) such as mapping of brain lesions, voxel-based morphometry and diffusion tensor imaging, tools for transcranial magnetic stimulation, and (3) various psychophysiological tools such as eye tracking (Cyr et al., 2009; Djamasbi et al., 2010; Djamasbi et al., 2007), facial electromyography (Hazlett and Hazlett, 1999), heart rate (Astor et al., 2013), electrocardiogram (Sénécal et al., 2015) and electrodermal activity (Léger et al., 2014a; Riedl et al., 2013).

Considering this list of neurophysiological methods makes clear that not all of them are appropriate for evaluating UIS services in real-world environments. For example, most of the brain imaging methods, such as functional magnetic resonance imaging, positron emission tomography or magnetoencephalography, cannot be applied to a mobile or ubiquitous evaluation context, as presented later in this dissertation. Furthermore, subjects have to be seated in or lie down on the brain imaging hardware (see Dimoka et al., 2012 for corresponding illustrations A5 and A6), which not only restricts the interaction capabilities with UIS services usually embedded in physical environments and requiring interaction space, but also severely limits access to sensory cues that clearly separate UIS from traditional IS.[11] With these kinds of brain imaging methods, only simulations of UIS services and real-world environments might be adequate options for IS researchers.[12]

In contrast to the majority of brain imaging methods, psychophysiological methods are not only "highly appropriate for the investigation of a number of IS research questions, in particular in human-computer interaction and decision-making studies" (Adomavicius et al., 2009; Dimoka, 2010; Dimoka, 2012;

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[11] For example, UIS services offered by an interactive bathroom presented in prior work (Kowatsch and Maass, 2013; Maass et al., 2012) allow information objects to be taken from one physical location (e.g. the mirror in the bathroom) to another (e.g. the shower). Such interactions could not be evaluated with methods such as functional magnetic resonance imaging, positron emission tomography or magnetoencephalography.

[12] Virtual reality technology might be an option for UIS simulations. However, the underlying technology and hardware that is usually attached to the head of the subjects may probably interfere with the brain image hardware and thus, disturb the measurement or make it even impossible.

Dimoka and Davis, 2008; Dimoka et al., 2009b; Moore et al., 2005b; Randolph et al., 2006b; Riedl et al., 2010b), but also allow mobile measurement of various parameters in everyday situations (Riedl et al., 2010a). That is, these methods and tools are particularly appropriate for research in the UIS context. For example, the NeXus-10 Mark II from Mind Media, Netherlands, is a mobile device that allows measuring brainwaves (electroencephalography), muscle tension (electromyography), heart rate, relative blood flow, electrodermal activity, respiratory rate, or skin temperature.

Moreover and with respect to total costs involved in conducting NeuroIS studies, researchers interested in brain image data have to plan approximately between $100 per hour (e.g. for electroencephalography) and $500 per hour (e.g. for functional magnetic resonance imaging or positron emission tomography) (Dimoka et al., 2012). By contrast, psychophysiological tools require a budget between $25 per hour (e.g. for measuring electrodermal activity or $2,000 for the device)[13] to $100 per hour (e.g. for tracking eye movements or $10,000 for the device) (ibid.).

[13] For demonstration purposes and for NeuroIS workshops, the author has used the Arduino UNO board (https://www.arduino.cc, accessed 12 December 2015), which can be used to measure electrodermal activity. The total cost of this hardware was less than $50. See the next section for details of the technical implementation and source code of the software. A related board that has been designed specifically for biometric and medical applications is the e-Health Sensor Platform V2.0 for Arduino and Raspberry Pi. It is available for less than $400, and with the appropriate external sensors it allows monitoring pulse and oxygen in the blood, airflow, body temperature, electrocardial activity, concentration of blood glucose, electrodermal activity, blood pressure, accelerometer-related data and muscle tension (electromyography). More information is available here:
https://www.cooking-hacks.com/documentation/tutorials/ehealth-biometric-sensor-platform-arduino-raspberry-pi-medical, accessed 12 December 2015

Against this background, i.e. with respect to the appropriateness and costs of psychophysiological tools for the design and use of UIS services, we next motivate the use of electrodermal activity.

2.5 Electrodermal activity in homeostatic regulation

Electrodermal activity can generally be used to measure cognitive processes (Barry et al., 2005; Boucsein, 2012; Cohen and Waters, 1985; Critchley, 2002; Kimble et al., 1965; Warren and Harris, 1975; Waters et al., 1977), thus rendering it interesting for in situ evaluations of UIS services, particularly when compared to self-report instruments that are usually not filled out during service use but often several minutes after the interaction with it. The rationale of electrodermal activity being sensitive to cognitive processes is due to its role in the homeostatic regulation of the body that aims at keeping the body's internal environment in balance (Damasio and Carvalho, 2013; Pinel, 2014). That is, the central nervous system, which consists of the brain and spinal cord, steadily monitors (a) external stimuli via our senses, a process called exteroception, and (b) internal stimuli such as changes in our visceral system, a process called intereoception (Cameron, 2001; Damasio and Carvalho, 2013; Johnston and Olsen, 2015; Kandel et al., 2012). If a significant stimulus is detected from an exteroceptive process (e.g. a breakdown of a UIS service sensed by hearing and sight) and/or from the interoceptive process (e.g. increased heart rate or breaking out into a sweat) such that it impacts and changes a body's homeostatic state, so-called *action programs* are triggered. These action programs are "sets of innate, programmed physiological actions aimed at addressing the detected changes and thereby maintaining or restoring homeostatic balance." (Damasio and Carvalho, 2013, p. 144)

Depending on the stimulus, action programs trigger various corrective responses. For example, they may influence body functions such as perspiration (e.g. to compensate for high temperatures in the external environment), running (e.g. to escape from a dangerous situation) or cognition (e.g. to focus one's attention on how to cope with a faulty UIS service). Particularly with regard to the current work, perspiration changes the electrodermal property of the body's skin, making it more conductive, can be simply measured with the help of electrodes, as explained in the next section. Furthermore, action programs can be classified as *emotions* or *drives*. Emotions are primarily "triggered by the perception or recall of exteroceptive stimuli" and include "disgust, fear, anger, sadness, joy, shame, contempt, pride, compassion and admiration" (ibid., in reference to Ekman and Friesen, 1971; Immordino-Yang et al., 2009; Keltner and Buswell, 1996; LeDoux, 1996), whereas drives are generally triggered by "basic instinctual needs and include hunger, thirst, libido, exploration and play, care of progeny and attachment to mates" (Damasio and Carvalho, 2013, p. 144, in reference to Berridge, 2004; Maslow, 1943; Panksepp, 1998). The notion of homeostatic regulation is also consistent with the Stimulus-Organism-Response (S-O-R) paradigm that assumes that changes in internal states of an individual triggered by stimuli from the external environment lead to specific (behavioral) responses (Mehrabain and Russell, 1974). In this context, the S-O-R paradigm was recently adopted in NeuroIS research for the evaluation of an e-commerce website, with electrodermal activity being used as physiological measure of arousal, and thus as an indicator of variations of the internal state (Sheng and Joginapelly, 2012).

An exemplary overview of the mechanisms underlying homeostatic regulation in the context of the current work is depicted in Figure 1. Here, it is assumed that unexpected UIS service behavior as a consequence of an interaction error, the exteroceptive stimulus, is perceived and interpreted with the help of exteroceptive senses, in particular touch (the UIS service does not respond to a touch gesture), as well as hearing and sight (i.e. there is no confirming audible or visual acknowledgement of the UIS service as a consequence of the interaction). As a result of this exteroceptive process, action programs trigger an emotion with negative valence (e.g. anger, because the service does not work as expected) that, in turn, leads to bodily responses to cope with this challenging situation, such as facial expressions of astonishment, increased heart rate, contracted blood vessels, activated sweat glands and attention focused on the faulty UIS service with dilated pupils.[14] Then the interoceptive process of the central nervous system identifies these changes of the bodily state and triggers further action programs of the drive class to again compensate for the homeostatic imbalance.[15] Furthermore, and if the interoceptive process is perceived consciously, the individual may interpret the emotion anger as a feeling, for example, in terms of negative arousal.

[14] The bodily reactions outlined here are common effects of the activation of the sympathetic nervous system, the complementary system of the parasympathetic nervous system, both of which belong to the autonomic nervous system (Pinel, 2014).

[15] For example, the parasympathetic nervous system could be activated to compensate for the effects of the sympathetic nervous system (Pinel, 2014).

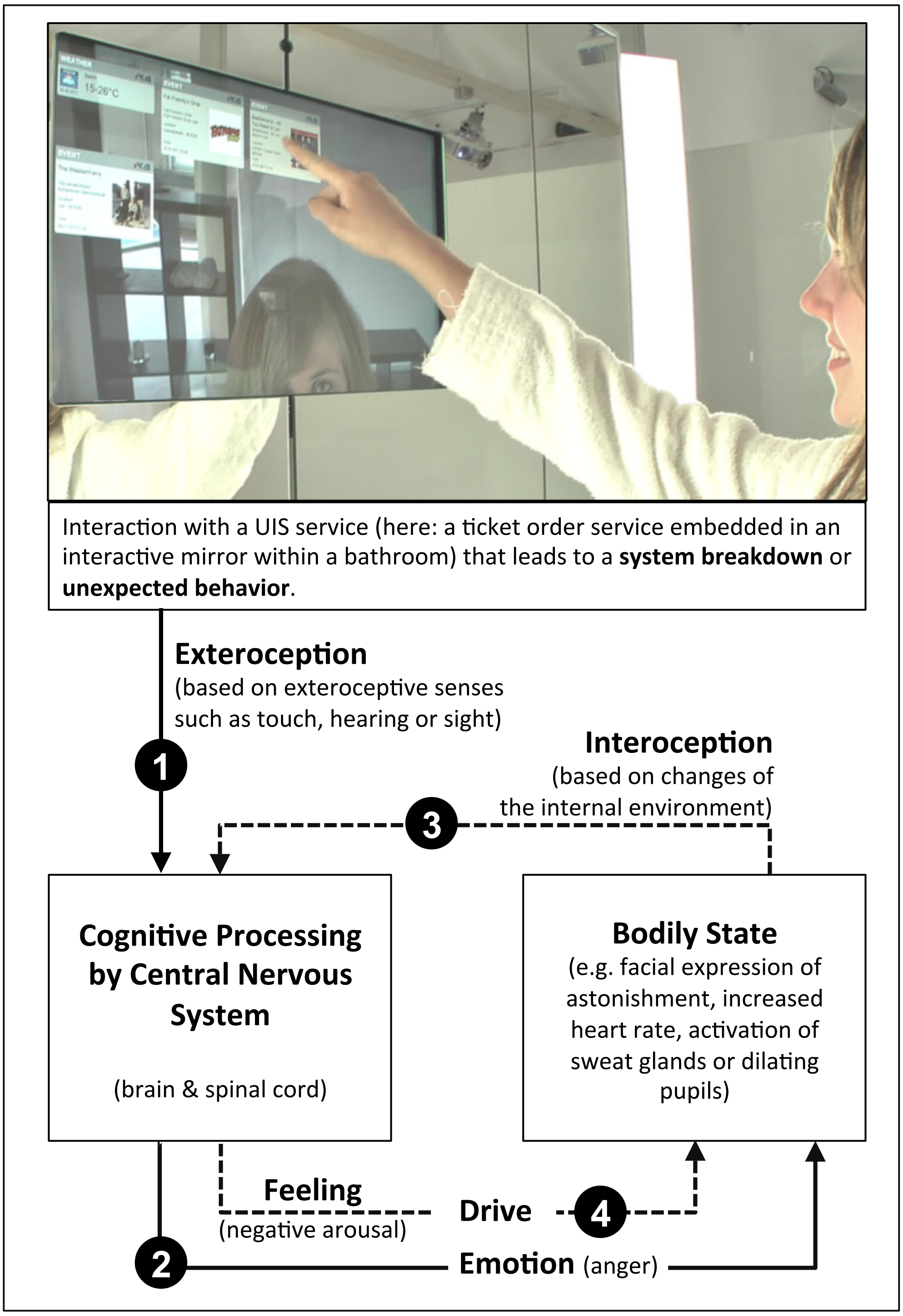

Figure 1. Exteroceptive and interoceptive (dashed) pathways in homeostatic regulation as a consequence of a breakdown event of a UIS service. Note: Numbers indicate temporal order; the figure was adapted from Damasio and Carvalho (2013, p. 144)

2.6 Measurement and parameters of electrodermal activity

As we have seen in the last section, activation of sweat glands changing a body's skin conductance is one of the potential bodily responses triggered by action programs as a consequence of exteroceptive or interoceptive processes. Skin conductance, among other related measures, are used to study electrodermal activity in psychophysiological research (Boucsein, 2012; Boucsein et al., 2012; Raskin, 1973). Originally, electrodermal activity was used to describe all electrical phenomena related to the skin (Johnson and Lubin, 1966). In 1967 methods, units and abbreviations with regard to the measurement of electrodermal activity were standardized in order to make its study more precise and comparable (Brown, 1967). We use that nomenclature for electrodermal activity in the current work, too (cf. also Table 1.1 in Boucsein, 2012, p. 2).

In psychophysiological research, electrodermal activity is usually measured non-invasively by a variation of sweat production in eccrine glands of the palms of the hand or feet exposed to direct current stimulation via two electrodes (Bagozzi, 1991; Bagozzi et al., 1999; Boucsein, 2012; Boucsein et al., 2012; Critchley, 2002; Critchley et al., 2000; Figner and Murphy, 2011; Kroeber-Riel, 1979; Portas et al., 1998). The unit of measurement adopted in this work is skin conductance, denoted as microSiemens (µS). Skin conductance is recorded at a pre-defined sampling rate such as 1 Hz (e.g. with the MentalBioScreen K3[16]) or 32 Hz (e.g. with the Mind Media NeXus-10 MKII[17]). The resolution of skin conductance values varies, too. For example, it can range from 0.001µS (NeXus-10 MKII) to 0.1µS (MentalBioScreen K3) depending on the recording device.

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16 http://www.portabioscreen.de, accessed 10 November 2015

17 http://www.mindmedia.info/CMS2014/en/products/systems/nexus-10-mkii, accessed 10 November 2015

For demonstration purposes[18], Figure 2 and Figure 3 depict the measurement of the skin conductance of the non-dominant hand of the author with two silver chloride electrodes and 5 Volt direct current stimulation using the Arduino UNO board. Here, the Arduino UNO is connected via USB to a computer that displays the measured skin conductance values. The corresponding source code is shown in Table 2. Ohm's law – i.e. the current I through a conductor in units of amperes equals the voltage V across the two end points of that conductor in units of volts divided by the conductor's resistance R in units of ohms, briefly denoted as $I = V / R$ – is applied to a serial connection of a known resistor (10.000 ohm in our example) and the unknown *skin resistor*. This allows us to derive the skin resistance, and also its inverse, the skin conductance.

Electrodermal activity can be separated into a tonic component, denoted as skin conductance level (SCL) and a phasic component, denoted as skin conductance response (SCR) (Boucsein, 2012; Dimoka et al., 2012; Figner and Murphy, 2011). Whereas SCL indicates the basic level of skin conductance, SCRs are of particular interest to this work for the following three reasons. First, SCRs can be interpreted as reactions to IS stimuli. Then, they are referred to as specific SCRs (Boucsein, 2012; Figner and Murphy, 2011).[19] Second, tonic phenomena are "of less practical significance than the specific and nonspecific [SCRs, the author], as they are less reactive to variations of experimental conditions." (Boucsein, 2012, p. 172f) And third, SCRs result from sympathetic neuronal activity triggered by exteroceptive and interoceptive processes, as outlined above, and thus are related to cognitive and emotional states (Boucsein, 2012; Damasio and Carvalho, 2013), which both play a significant role in the design and use of IS in general (e.g.

[18] It must be noted that skin conductance measurements as outlined in the current work were actually measured with the MentalBioScreen K3, a certified medical device and not with the Arduino UNO platform.

[19] One has to be aware that there are also SCRs that cannot be related to a particular (external) stimulus. Then the SCRs are nonspecific responses (NS.SCR).

Kamis et al., 2008; van der Heijden, 2004) and UIS in particular (Kowatsch and Maass, 2013; Kowatsch et al., 2014; Maass et al., 2012).

Table 2. Source code for measuring skin conductance with the Arduino UNO connections as shown in Figure 2 and Figure 3.

Source Code

```
const int sensorPin = A0;
const int Rresistor = 10000; // 10.000 Ohm Resistor
const int Vtotal = 5; // total voltage = 5 Volt
// input voltages are mapped between 0 and 5 volts into
// values between 0 and 1023.
const float resolution = 1023;
float voltValue;
int sensorValue;
float I; // current
float Rskin; // skin resistance
float Cskin; // skin conductance

void setup(){
  Serial.begin(9600);
}

void loop(){
  sensorValue = analogRead(sensorPin);
  voltValue = (sensorValue / resolution) * Vtotal;
  I = voltValue / Rresistor;
  // Vtotal = I * Rresistor + I * Rskin,
  // i.e. Rskin= (Vtotal – I * Rresistor) / I
  Rskin = (Vtotal - (I * Rresistor)) / I;
  Cskin = 1 / Rskin;
  // print skin conductance in microSiemens
  Serial.println(Cskin * 1000000.0, 2);
  delay(1000); // in milliseconds, i.e. once per second
}
```

Figure 4 shows two SCRs as a consequence of (external) stimuli and the underlying SCL. Furthermore, two SCR parameters are shown that are relevant to the current work, i.e. SCR latency and SCR amplitude. First, SCR latency represents the time from the onset of the stimulus to the onset of the SCR. These latency times usually range from 1s to 5s (Levinson and Edelberg, 1985) and are therefore relatively long, compared to other bodily responses such as changes in heart rate (Boucsein, 2012). It is important to consider latency times when recording electrodermal activity in empirical studies in order not to miss significant SCRs that start to develop up to five seconds or even longer after the stimulus onset and require, on their own, additional time to reach their maximum.

Second, the SCR amplitude defines the difference between the maximum response and the skin conductance value at the onset of the SCR. The amplitude therefore indicates the strength of the response.

It must be further noted that SCRs can also overlap as shown in Figure 4. Here, the second response starts before the first response can recover back to the underlying SCL. That is, the response onset of the second SCR is hidden or overwritten and, as a consequence, the amplitude of the second SCR cannot be derived directly. In order to address this issue, several mathematical solutions have been proposed that aim at the decomposition of the electrodermal activity signal into phasic components, i.e. separate SCRs, and the tonic component, i.e. the underlying SCL (cf. Boucsein, 2012, p. 167ff for an overview of these approaches). In this regard, the current work adopts the decomposition of electrodermal activity as proposed by Benedek and Kaernbach (2010b). Here, the authors apply nonnegative deconvolution to the original signal that results in distinct SCRs – compared to continuous SCRs as proposed in Benedek and Kaernbach (2010a) – from which the relevant parameters such as the SCR amplitude can be derived.

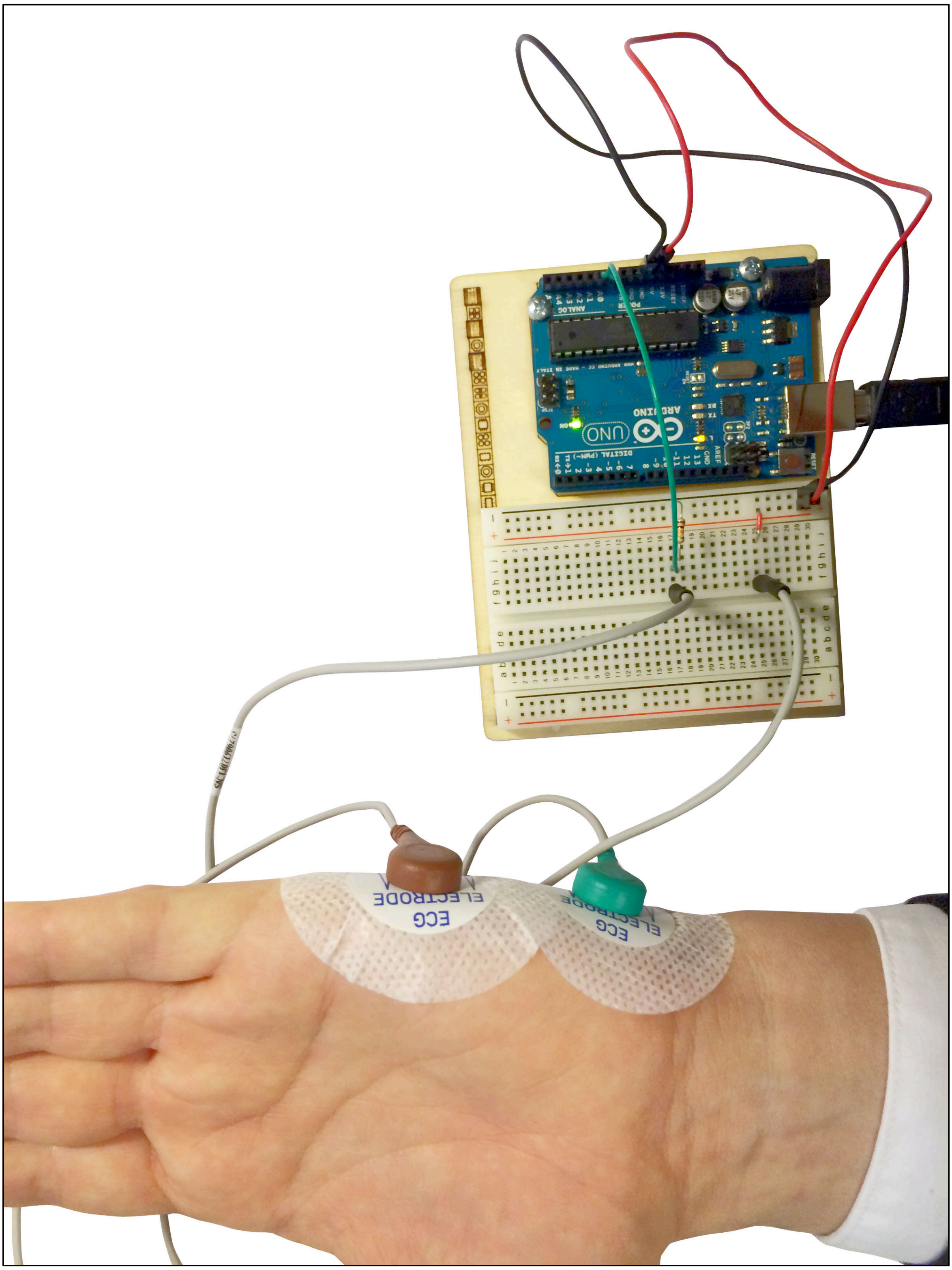

Figure 2. Measurement of the skin conductance of the non-dominant hand of the author with two silver chloride electrodes and 5 Volt direct current stimulation from the Arduino UNO board

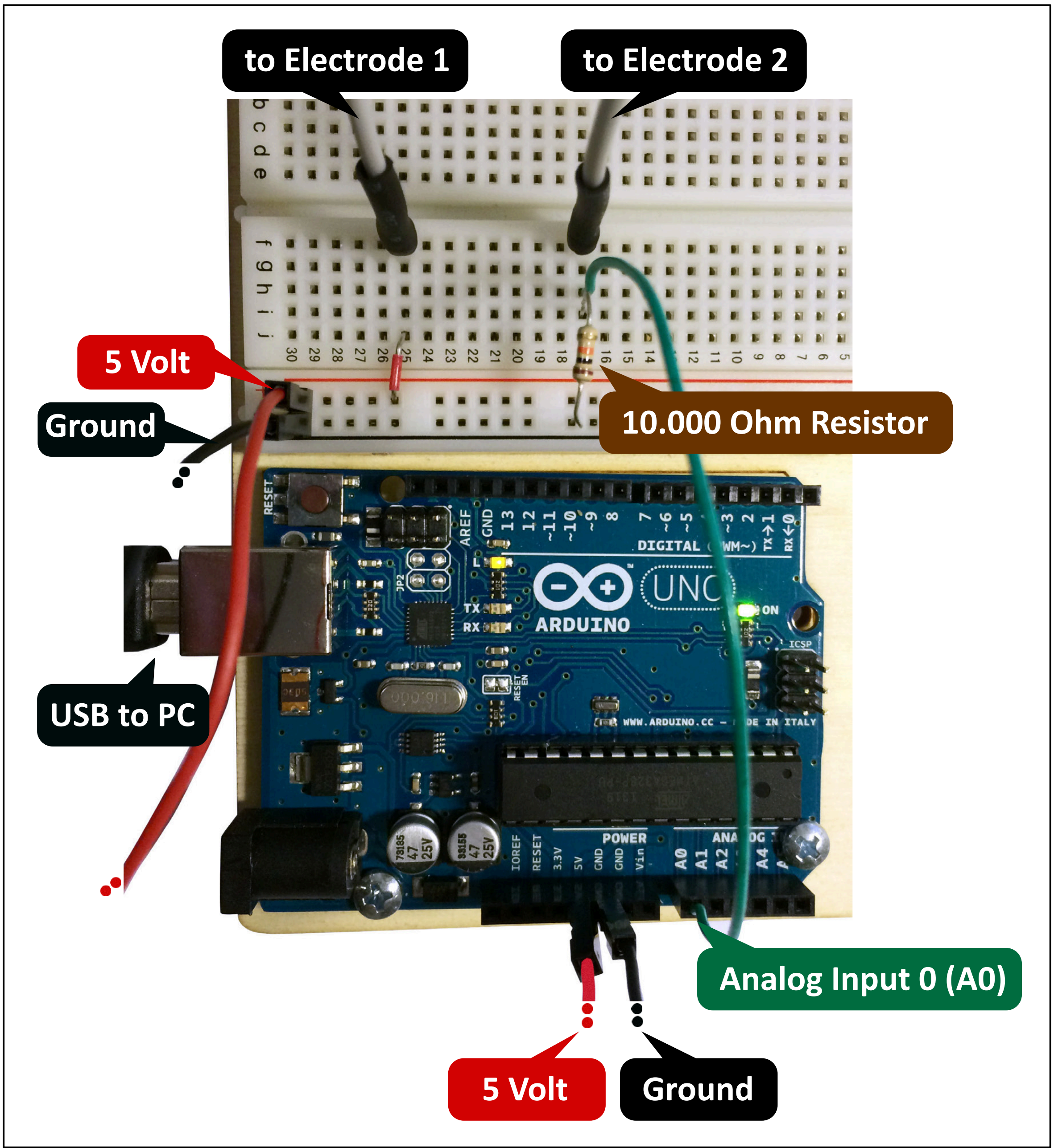

Figure 3. Connections of the Arduino UNO board for skin conductance measurement

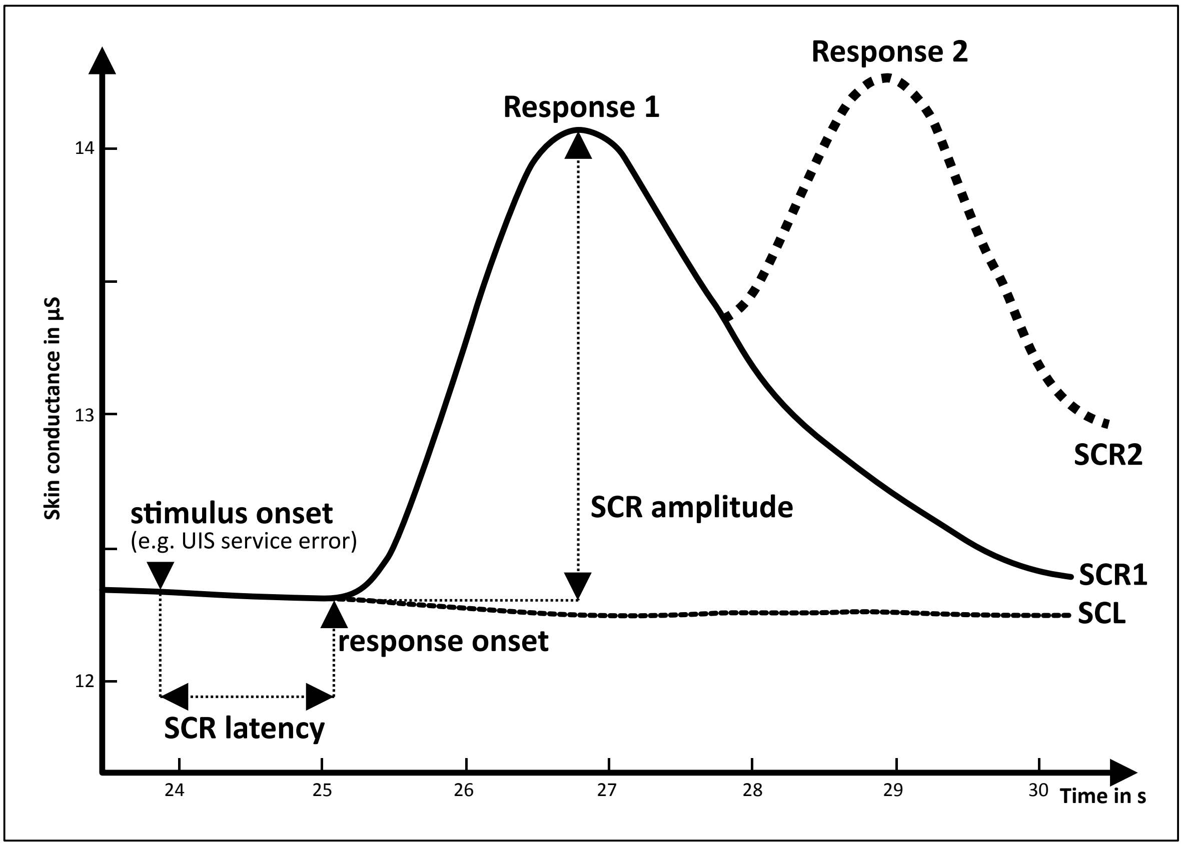

Figure 4. Two exemplary skin conductance responses (SCRs) as a consequence of (external) stimuli[20] with related SCR parameters and the underlying skin conductance level (SCL). Note: figure was adapted from Boucsein (2012, p. 154, Figure 2.15) but derived from skin conductance data of the current work

As the SCR amplitude is the most frequently parameter used to describe an electrodermal reaction (Boucsein, 2012), the total amplitude of all SCRs over a predefined period of time is of particular interest to the current work. That is, interaction with a UIS service often requires several seconds and, in turn, may elicit several SCRs. The total SCR amplitude would then be an overall indicator that represents the strength of all cumulated (external) stimuli such as several interaction errors with a UIS service.

At this point, we must mention one major shortcoming of using psychophysiological measures in general and electrodermal activity in particular, i.e. the habitu-

[20] For ease of presentation only the first stimulus is shown.

ation effect and its attendant effect, generalization. As outlined in the introductory chapter, habituation refers to a decrease in response to the same stimulus, whereas generalization extends the effect of habituation to similar stimuli (Grizzard et al., 2015; Groves and Thompson, 1970; Stein, 1966; Thompson and Spencer, 1966). In the context of electrodermal activity and its various parameters, habituation and generalization may, for example, lead to decreased SCR amplitudes in response to repeated exposures to the same or even similar UIS services. This is an important conclusion as design science research usually employs several build-and-evaluate loops in which subjects are exposed to similar services at the various stages of development. Results and implications derived from parameters of electrodermal activity that were collected during the evaluation of these services may therefore be subject to habituation or generalization biases. However, up till now, the severity of these effects has not been evaluated and corresponding evidence from prior research in the context of IS or UIS service evaluations is very limited, as we will see in the next section.

2.7 Review of related work utilizing electrodermal activity

The objective of this section is to identify and discuss publications relevant to the current work that employed parameters of electrodermal activity. In doing so, results will reveal an overview of research topics and theoretical constructs that are related to these parameters and thus may help us not only to build the research model in the next chapter but also to answer the research questions of the current work.

As a first step, search terms related to research utilizing electrodermal activity are identified from a preliminary list of NeuroIS publications. For that purpose, we reviewed titles, abstracts and keywords of the 66 selected NeuroIS publications from the website NeuroIS.org.[21] One main objective of this website is to provide information about the annual conference *Gmunden Retreat on NeuroIS* and to discuss "achievements, current research and development projects, and possible avenues for the future development of NeuroIS."[22] In combination with the list of selected NeuroIS publications (cf. Appendix A), this website seems to be a reasonable starting point for a literature review.

A rough visualization of the keywords in the form of a word cloud, depicted in Figure 5, shows that electroencephalography (EEG) is one of the more frequently used NeuroIS measures in that sample of publications. The terms electroencephalography and EEG actually appeared 30 times as keywords, whereas electrodermal activity and related terms were used less than four times. A more detailed content analysis, which included the full text of the publications, revealed that electrodermal activity was mentioned or referenced in 25 of these publications (37.9%). This set of publications includes literature reviews (e.g. Riedl, 2013), conceptual work (e.g. vom Brocke et al., 2013), related work sections of articles that then used other NeuroIS measures (e.g. Astor et al., 2013) or methodological work on how to use neuroscience tools appropriately (e.g. Dimoka et al., 2012; vom Brocke and Liang, 2014).

However, parameters of electrodermal activity were used in only six journal articles (9.1%) and two conference papers (3.0%) by means of a genuine method of data collection and analysis. Yet none of these publications addresses in-situ evaluation of UIS services, as is the subject of investigation of the current work. The resulting eight publications utilizing electrodermal activity are listed in Table 3.

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[21] http://neurois.org/index.php?option=com_content&task=view&id=50&Itemid=49, accessed 12 December 2015

[22] http://neurois.org/index.php?option=com_frontpage&Itemid=1, accessed 12 December 2015

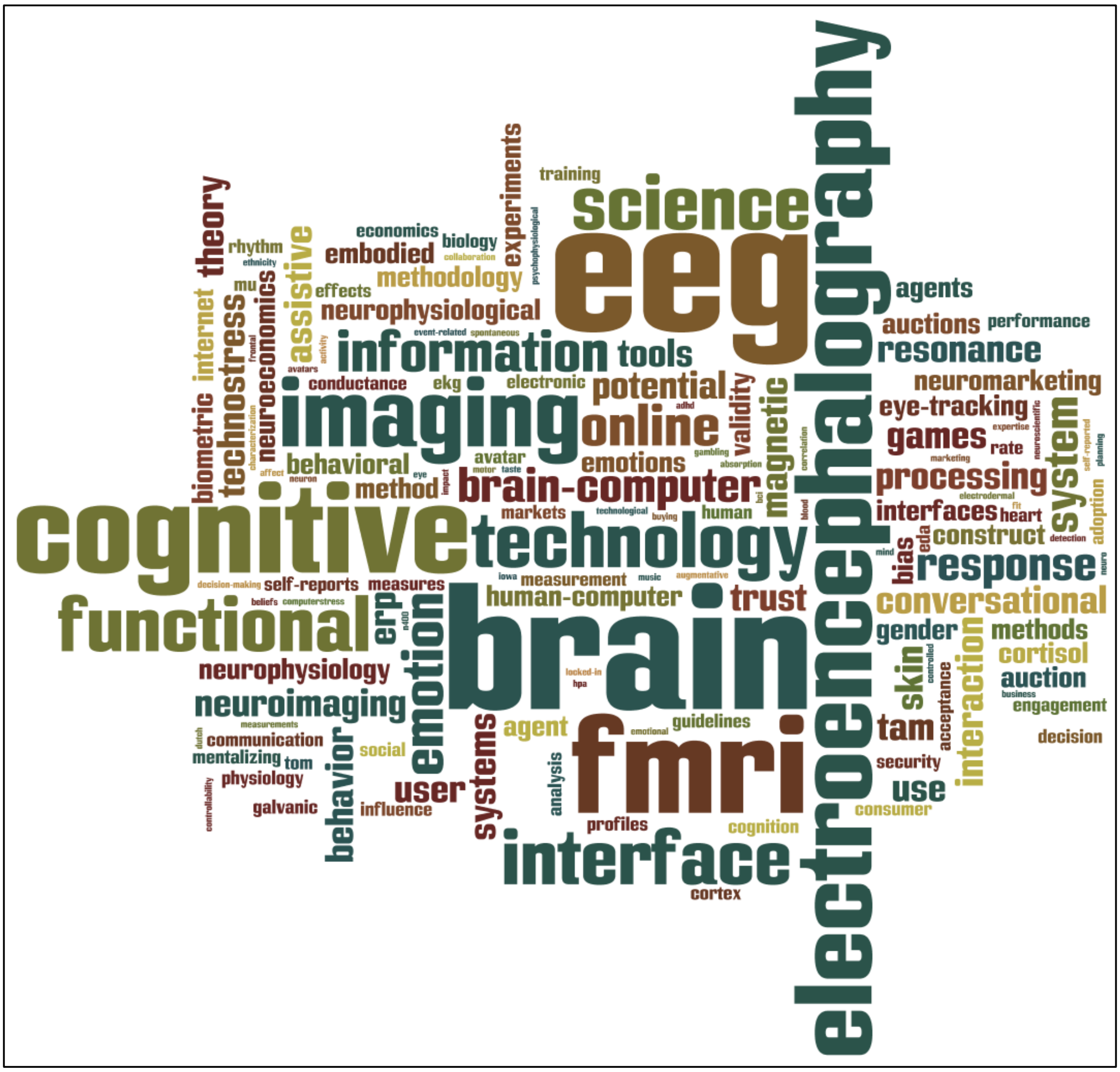

Figure 5. Word cloud based on the keywords of the NeuroIS publications from NeuroIS.org (cf. Appendix A). Note: The following terms have been dropped because of their generic character, frequent use and ease of presentation: 'NeuroIS' (36 times), 'neuroscience' (22 times), 'research' (8 times). The Wordle Java applet,[23] created by Jonathan Feinberg, was used to generate this word cloud

[23] http://www.wordle.net, accessed 5 December 2015

Table 3. NeuroIS publications from NeuroIS.org utilizing parameters of electrodermal activity. Note: * indicates articles from which keywords have been extracted by the author because the original article did not contain any keywords.

#	Authors (Year)	Title	Journal / Conference	Keywords
1	Minas et al. (2014)	Putting on the thinking cap: using NeuroIS to understand information processing biases in virtual teams	Journal of Management Information Systems	Collaboration technology, electroencephalography, information processing bias, NeuroIS, virtual teams
2	Léger et al. (2014a)	Neurophysiological correlates of cognitive absorption in an enactive training context	Computers in Human Behavior	NeuroIS, neurophysiological measures, end-user training, cognitive absorption, enactive learning
3	Léger et al. (2014b)	Emotions and ERP information sourcing: the moderating role of expertise	Industrial Management & Data Systems	Emotion, ERP, expertise, electrodermal activity (EDA), novice, physiology, enterprise resource planning (ERP) system
4	Riedl et al. (2013)*	Computer breakdown as a stress factor during task completion under time pressure: Identifying gender differences based on skin conductance	Advances in Human-Computer Interaction	ICT, technostress, gender, EDA, skin conductance
5	Adam et al. (2012)	Excitement up! Price down! Measuring emotions in Dutch auctions	International Journal of Electronic Commerce	Auction experiments, behavioral economics, bidding, consumer behavior, Dutch auction, emotions, excitement, Internet auctions, online auctions

#	Authors (Year)	Title	Journal / Conference	Keywords
6	Adam et al. (2011)	Measuring emotions in electronic markets	International Conference on Information Systems	Auctions, electronic markets, emotions, experiments, physioeconomics
7	Randolph and Jackson (2010)	Assessing fit of nontraditional assistive technologies	ACM Transactions on Accessible Computing	User interfaces, human factors, design, performance, user profiles, individual characteristics, brain-based interfaces, brain-computer interface, direct-brain interface, galvanic skin response, functional near-infrared, assistive technology
8	Randolph et al. (2005)	Controllability of galvanic skin response	International Conference on Human-Computer Interaction	Biometric interface, galvanic skin response, characterization of controllability

With the help of the keywords and full text of these publications the following preliminary list of search terms were extracted for the literature review: *electro-dermal activity, galvanic skin response* and *skin conductance*.[24] These terms were cross-validated by a full-text search in the aforementioned 25 publications that only mentioned or discussed electrodermal activity without using it as a genuine measure of an empirical study. Furthermore, the seminal book on electrodermal

[24] Abbreviations such as EDA (electrodermal activity) or GSR (galvanic skin response) are not considered, as they are defined and derived from the actual terms in brackets in the publications.

activity, i.e. Boucsein (2012) was used to assure that no relevant search term was overlooked.

As a result, the following search terms were considered in addition to the preliminary list above: *skin conductance response* and *electrodermal response*, which leads to the final list of search terms:[25]

> "electrodermal activity" *OR* "electrodermal response" *OR* "skin conductance" *OR* "galvanic skin response"

With these search terms, a systematic literature review was conducted to identify further research that uses parameters of electrodermal activity, in addition to the publications listed in Table 3. The search strategy included top IS journals, i.e. the Senior Scholar's Basket of Journals of the Association for Information Systems (AIS). Furthermore, AIS Transactions on Human-Computer Interaction, ACM Transactions on Computer-Human Interaction and the International Journal of Human-Computer Studies were considered, as the interaction with UIS services is one of the key aspects of this work. We also added the journal Computers in Human Behavior to the list of relevant journals as it appeared several times in the preliminary list of NeuroIS publications. Finally, the journal Personal and Ubiquitous Computing was included in the literature review as it publishes articles relevant to the UIS context. Coverage of the literature review ranges from January 1, 2006 to December 22, 2015.[26] Table 4 gives an overview of the outlets, databases,

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[25] Note: the search term *skin conductance response* was dropped due to the fact that we also searched for *skin conductance*. Further low-level terms related to electrodermal activity, such as the majority of abbreviations of Table 1.1 on page 2 of Boucsein (2012), were not considered due to the assumption that authors of relevant publications would have to introduce and define the high-level concept of electrodermal activity based on each of the search terms outlined above.

[26] Publications "in press" that were available as full-text (e.g. as online publications in advance) were also considered in this review.

search details, the number of hits and reviewed papers. All publications that resulted from the literature search are listed in Appendix B.

Out of 67 hits, 28 publications (42%) were found to be relevant because parameters of electrodermal activity were used as a genuine measure of an original empirical study. Consistently, editorials, methodological guidelines or publications that mentioned electrodermal activity only as a data collection tool but did not employ it, were dropped from the list of reviewed articles. With Moody and Galletta (2015) and Teubner et al. (2015) only two further articles were identified from the Senior Scholar's Basket of Journals of the AIS, in addition to those listed in Table 3. Interestingly, the majority of relevant publications were found in the International Journal of Human-Computer Studies and Computers in Human Behavior.

The consolidated list of 32 publications, i.e. relevant journal publications from NeuroIS.org as listed in Table 3 and from the literature review as listed in Table 4 and Appendix B is shown in Table 5. Here, conceptualizations, parameters and key findings of the studies related to electrodermal activity are summarized for further inspection. Subject to the generalization effect of physiological measures, Table 5 also indicates whether the authors employed a within-subjects design with repeated exposures to stimuli.

Table 4. Overview of publication outlets considered for the literature review. Note: * indicates Senior Scholar's Basket of Journals of the AIS

#	Outlet	Database	Search	Hits	Reviewed
1	European Journal of Information Systems*	Palgrave Macmillan	full text	0	0
2	Information Systems Journal*	EBSCOhost	all fields	0	0
3	Information Systems Research*	Informs	anywhere	0	0
4	Journal of AIS*	AIS eLibrary	all fields	3	1
5	Journal of Information Technology*	Palgrave Macmillan	full text	0	0
6	Journal of MIS*	EBSCOhost	all fields	8	2
7	Journal of Strategic Information Systems*	ScienceDirect	full text	0	0
8	MIS Quarterly*	AIS eLibrary	all fields	3	0
9	AIS Transactions on Human-Computer Interaction	AIS eLibrary	all fields	1	1
10	ACM Transactions on Computer-Human Interaction	ACM Digital Library	full text	8	3
11	International Journal of Human-Computer Studies	ScienceDirect	full text	10	10
12	Computers in Human Behavior	ScienceDirect	full text	10	9
13	Personal and Ubiquitous Computing	SpringerLink	full text	24	2
			Total	**67**	**28**

Table 5. Final list of relevant publications with conceptualizations, parameters and key findings related to electrodermal activity (EDA). Note: * indicates that a within-subjects design was adopted in which the same or similar stimuli were presented to the subjects of the corresponding study and thus habitation and with it generalization processes, might be involved. Abbreviations: Electroencephalography (ECG), electrocardiography (ECG), skin conductance (SC), SC response (SCR) and SC level (SCL).

#	Authors (Year)	Conceptualization of EDA and context	Parameters of EDA	Key finding(s) related to EDA
	NeuroIS.org and Senior Scholar's Basket of Journals of the AIS			
1	Teubner et al. (2015)*	***Intensity of immediate emotions*** of an individual in response to human vs. computer opponents in online auctions	Log transformed SCR amplitude	Immediate emotions were lower for auctions with computer opponents compared to human opponents
2	Moody and Galletta (2015)*	***Stress*** during an information retrieval task (EDA was one out of four formative indicators of stress; the others were heat flux, body temperature and skin temperature)	SC corrected for baseline measurement and then standardized for all subjects	Stress had a (a) negative effect on task performance and (b) no negative effect on website attitudes; (c) Information scent had a negative effect on stress and (d) time constraint had no positive effect on stress
3	Léger et al. (2014a)*	***Cognitive absorption*** during software training activity	Nonspecific SCR (NS.SCR)	The degree of NS.SCR had a negative effect on the perception of being cognitively absorbed
4	Léger et al. (2014b)*	***Emotional arousal*** of a software user in a decision-making task broken down into (a) overall arousal level (b) overall somatic response	(a) Nonspecific SCR amplitude (b) standard deviation of (a)	Higher emotional arousal during a software-based decision-making task leads to information sourcing from other humans (rather than from the software itself), particularly when novice users are involved

#	Authors (Year)	Conceptualization of EDA and context	Parameters of EDA	Key finding(s) related to EDA
5	Minas et al. (2014)*	***Arousal*** as a physiological dimension of emotional response of an individual using a chat tool	SCL	Information that supports a user's initial decision has a positive effect on arousal compared to information that challenges that initial decision
6	Riedl et al. (2013)	***Stress*** as a physiological response of an individual to a computer breakdown	Normalized SC	A computer breakdown under time pressure has a positive effect on stress of male computer users (for females this effect was not present)
7	Adam et al. (2012)	***Emotional arousal*** of a bidder in response to an auction's outcome	SCR amplitude	Loosing an auction bid leads to higher arousal than winning an auction bid
8	Randolph and Jackson (2010)*	***Emotional state / brain activity*** that can be actively controlled by an individual with a brain-based interface	SCR	The following profile may reveal the best control over emotional states / brain activity measured by SCR: "a younger adult male with blond hair who does not regularly meditate but does have extensive experience playing video games and regularly consumes alcohol" (ibid., p. 26)
	AIS Transactions on Human-Computer Interaction			
9	Sheng and Joginapelly (2012)*	***Emotional arousal*** as a response of a user to atmospheric cues of a website such as the degree of vividness or interactivity	Normalized SC	Less vivid/interactive websites lead to higher arousal (an indicator of disappointment or frustration) than medium or highly vivid/interactive websites

#	Authors (Year)	Conceptualization of EDA and context	Parameters of EDA	Key finding(s) related to EDA
	ACM Transactions on Computer-Human Interaction			
10	Zhou et al. (2015)*	***Decision-making*** process during a travel route decision-making task	Normalized SC: mean and variance of SC, frequency and total sum of SCR amplitudes, sum of estimated area of SCR	EDA parameters were sensitive to difficulty levels of decision-making and decision quality and performed better relative to pupillary parameters in this regard
11	Karran et al. (2015)*	***Physiological activation*** as a dimension of ***interest*** a user shows in response to cultural heritage material	Mean and standard deviation of SCL	SCL in combination with ECG and EEG signals can be used to infer the degree of a user's interest in cultural heritage material
12	Schnädelbach et al. (2012)	***Activation*** of participants to measure levels of ***stress***; EDA is used as an actuator of an interactive relaxation prototype	SCL	The proposed relaxation prototype leads to a decrease in SCL
	International Journal of Human-Computer Studies			
13	Felnhofer et al. (2015)	***Physiological arousal*** of an individual in response to various emotionally charged virtual park scenarios	SCL corrected for baseline measurement	Physiological arousal was not correlated with self-reported presence (in the sense of being in the virtual park); low physiological arousal was also used to indicate a state of relaxation

#	Authors (Year)	Conceptualization of EDA and context	Parameters of EDA	Key finding(s) related to EDA
14	Choi et al. (2015)*	***Physiological arousal*** as an individual's response to emotional expressions of an embodied computer agent and ***electrodermal liability*** in response to emotionally competent images	Log transformed SCR amplitude	Individuals who showed higher electrodermal liability (EL) also showed more physiological arousal and adopted a more affective processing strategy than those showing a lower EL, who adopted an inferential processing strategy
15	Kukolja et al. (2014)*	***Emotional response*** to emotionally charged images in combination with ECG, respiration and skin temperature	34 SCR parameters	SCR parameters are one of the key predictors when classifying the following emotions: sadness, disgust, fear and happiness
16	Chittaro and Sioni (2014a)*	***Stress*** of an individual during a biofeedback-controlled game in the context of a relaxation training	SCR amplitude	A single-sensor approach to stress detection based on SCR amplitude was perceived more accurate than a four-sensor approach that also included heart rate, muscle activity of corrugator supercilii and zygomaticus major
17	Zhou et al. (2011)*	***Affective arousal*** of an individual in response to emotionally competent images	Based on log transformed SC: latency, amplitude, rise time and half recovery time of SCR	SCR parameters are predictors when classifying the following emotions: excited, amused, contented, neutral, sad, fearful and disgusted

#	Authors (Year)	Conceptualization of EDA and context	Parameters of EDA	Key finding(s) related to EDA
18	Lim and Reeves (2010)*	***Physiological arousal*** of an individual in response to the agency and type of gaming activity	Frequency of SCRs and baseline-corrected SCL	An avatar as co-player led to more SCRs than an agent; competitive gaming tasks led to more SCRs and a higher SCL than cooperative tasks
19	Chanel et al. (2009)*	***Physiological arousal*** of an individual in response to self-elicited emotional episodes	Mean of SC, mean SC slope, mean and % of negative SC slope	EEG-based parameters outperformed peripheral parameters, including EDA parameters, when classifying the following emotions: excited-positive, excited-negative and calm-neutral
20	Liu et al. (2008)*	***Physiological activity***, ***affective states*** and ***task engagement*** of children with Autism Spectrum Disorder in response to computer-based tasks eliciting affective states	Mean and slope of SCL, mean / maximum / frequency of SCR amplitudes	EDA-based prediction accuracy was average compared to EMG-based or cardiovascular-based predictions regarding the following three affective states: liking, anxiety and engagement
21	Bailenson et al. (2008)*	***Physiological response***, in particular, ***emotion intensity*** and ***emotion*** of an individual in response to faces of people watching either sad or funny video clips	SCL	SCL was more relevant in detecting negative emotions (here sadness) than positive emotions (here amusement); moreover, SCL was the most important parameter in detecting sadness in male subjects; further signals used were face tracking, cardio activity and body movements

#	Authors (Year)	Conceptualization of EDA and context	Parameters of EDA	Key finding(s) related to EDA
22	Liao et al. (2006)*	***Physiologically affective states*** of ***stress*** of an individual in response to math and audio tasks, and ***fatigue*** in response to a test of variables of attention	SC	EDA in combination with other biosignals, as well as physical and behavioral parameters, are used to detect stress and fatigue in real time
	Computers in Human Behavior			
23	Kneer et al. (2016)	***Physiological arousal*** of an individual in response to variations in difficulty and violence of a first-person shooter game	Baseline corrected SC	Violent content or difficulty of game play had no effect on physiological arousal
24	Harley et al. (2015)	***Physiological arousal*** of an individual in response to computer-based learning material	Normalization of baseline corrected SC	Physiological arousal showed low agreement with self-reports compared to facial expression recognition
25	Chittaro and Sioni (2015)	***Physiological arousal*** and ***fear*** of an individual in response to variations in interactivity of a virtual environment	SCL	An interactive simulation of a terror attack led to higher physiological arousal than did a non-interactive simulation
26	Pollina and Barretta (2014)*	***Physiological arousal*** in terms of ***deceptive behavior*** of an individual in response to a security screening interview conducted by a computer agent	Maximum SCR amplitude	Physiological arousal was positively related to the number of admissions relevant in a security screening interview (e.g. usage of illegal drugs)

#	Authors (Year)	Conceptualization of EDA and context	Parameters of EDA	Key finding(s) related to EDA
27	Patel et al. (2014)	***Physiological arousal*** of an individual in response to jerky character motion in digital video clips	Baseline corrected SCL and SCR	Jerkiness had no effect on physiological arousal
28	Chittaro and Sioni (2014b)*	***Physiological arousal*** of an individual in response to a breathing (relaxation) training	Baseline corrected SCL	The various treatments of breathing training had no effect on physiological arousal
29	Kallinen and Ravaja (2007)*	***Physiological arousal*** of an individual in response to audio stimuli from either speakers or headphones	Frequency of nonspecific SCRs	Listening to audio stimuli from speakers led to higher physiological arousal than did listening from headphones for (impulsive) sensation-seeking subjects
30	Carlbring et al. (2007)*	***State of relaxation*** of an individual in response to relaxation instructions	Mean and standard deviation of SC	Relaxation instructions led to lower SC scores
	Personal and Ubiquitous Computing			
31	Kappeler-Setz et al. (2013)*	***Psychophysiological activation, emotional state*** and ***stress*** level of an individual in response to watching an action movie and relaxation exercise	SCL, amplitudes of SCRs and nonspecific SCRs	Moderate physical movement had a weak influence on electrodermal activity; 88% of SCRs co-occurred at both measurement sites, i.e. on the hand and foot
32	Repetto et al. (2013)	***Emotional state*** of an individual with anxiety disorder in response to a computer-based relaxation exercise	SCR amplitude	A biofeedback-based relaxation exercise leads to lower levels of SCR amplitudes than a relaxation exercise without biofeedback

The findings of the literature review are summarized as follows. Frist, the authors have conceptualized electrodermal activity in various ways. For example, it was used as a measure of cognitive absorption (Léger et al., 2014a), deceptive behavior (Pollina and Barretta, 2014), fatigue (Liao et al., 2006), fear (Chittaro and Sioni, 2015), stress (Chittaro and Sioni, 2014a; Liao et al., 2006; Moody and Galletta, 2015; Riedl et al., 2013; Schnädelbach et al., 2012) or a state of relaxation (Carlbring et al., 2007). However, in a major body of articles, i.e. in 14 (47%), authors conceptualized electrodermal activity in a rather generic way by using physiological arousal, physiological response or physiological activity (e.g. Bailenson et al., 2008; Chittaro and Sioni, 2014a; Chittaro and Sioni, 2014b; Harley et al., 2015; Kallinen and Ravaja, 2007; Karran et al., 2015; Kneer et al., 2016; Liu et al., 2008; Patel et al., 2014; Pollina and Barretta, 2014). In line with the last authors, we prefer a conceptualization of electrodermal activity in terms of physiological arousal, a dimension used to describe emotions and feelings (Kuppens et al., 2013; Raskin, 1973; Russell, 1980). This is due to the fact that many other conceptualizations also include a positive or negative connotation such as fear or stress and that approaches to classify these states of valence predominantly rely on a combination of several physiological, behavioral or physical signals (e.g. Bailenson et al., 2008; Chanel et al., 2009; Kukolja et al., 2014; Liao et al., 2006; Liu et al., 2008; Zhou et al., 2011) rather than on electrodermal activity alone. The work of Chittaro and Sioni (2014a) is one of the few exceptions in this regard.[27]

Second, electrodermal activity is used in various application domains. For example, in the context of electronic auctions electrodermal activity was measured in response to auction events or auction outcomes (Adam et al., 2012; Teubner et al., 2015), or in technostress research as an outcome of a computer breakdown

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[27] A detailed explanation for choosing physiological arousal as an appropriate conceptualization of electrodermal activity will be provided in Chapter 3.

situation (Riedl et al., 2013), or during information retrieval (Moody and Galletta, 2015), or decision-making tasks (Léger et al., 2014b; Minas et al., 2014; Zhou et al., 2015). Electrodermal activity was further used in a learning context during system use (Harley et al., 2015; Karran et al., 2015; Léger et al., 2014a) or in the domain of health, where it was measured in response to relaxation instructions (Carlbring et al., 2007; Chittaro and Sioni, 2014a; Chittaro and Sioni, 2014b) or used and discussed as a brain-based interface (Randolph and Jackson, 2010; Schnädelbach et al., 2012). It was also used to indicate the vividness and interactivity of websites (Sheng and Joginapelly, 2012), the emotional consequences of virtual environments (Felnhofer et al., 2015) or computer games (Chittaro and Sioni, 2015; Kneer et al., 2016; Lim and Reeves, 2010). Finally, electrodermal activity was used, to a great extent, to classify or predict emotions in order to design user interfaces that adapt to the emotional state of a computer user (Bailenson et al., 2008; Chanel et al., 2009; Kukolja et al., 2014; Liao et al., 2006; Liu et al., 2008; Zhou et al., 2011). With regard to these results, however, none of the reviewed literature applies electrodermal activity to the evaluation of UIS services. Only Randolph and Jackson (2010) and Sheng and Joginapelly (2012) use electrodermal activity in the context of IS service evaluation, and Schnädelbach et al. (2012) use it in the UIS context, however only as an actuator to change the shape of an adaptive relaxation artifact rather than a predictor of UIS service use.

Third, beside the raw skin conductance score (e.g. Liao et al., 2006), various other parameters of electrodermal activity were used separately or in combination. Adam et al. (2012), for example, only used the SCR amplitudes, whereas Kukolja et al. (2014) derived 34 parameters from electrodermal activity, including several normalizations. Nevertheless, the majority applied only a very limited set of parameters and did not consider the manifold parameters such as SCR rise time, SCR latency, SCR recovery time or the SCR frequency as outlined by Boucsein (2012). In particular, the SCL, an indicator of the general level of arousal of an individual and SCR amplitude, as a specific response to a stimulus, were employed most frequently.

With regard to the empirical findings, the studies show clearly that electrodermal activity is sensitive to various external stimuli such as relaxation instructions, emotionally charged images or stressors; and that, in combination with other biosignals, parameters of electrodermal activity can be used to predict the emotional state of an individual to some degree.

Finally, we also reviewed the 32 publications with regard to habituation and generalization effects, i.e. whether a within-subjects design was employed, and to which degree habituation and with it generalization was addressed or discussed. As we have outlined in the introductory chapter and detailed in the last section, habituation and generalization effects are major shortcomings when using electrodermal activity in within-subjects designs. In 24 publications (75%), a within-subjects design was adopted, but a discussion related to habituation or generalization processes was found in none of the publications from NeuroIS.org or the Senior Scholar's Basket of Journals of the AIS. This is surprising because the study participants described in these publications were, for example, subsequently confronted with up to 10 information retrieval tasks (Moody and Galletta, 2015), 30 auctions (Teubner et al., 2015) and even 72 computer control tasks (Randolph and Jackson, 2010). The authors of only four out of the 24 publications employing a within-subjects design (17%) discussed the habituation effect (Chittaro and Sioni, 2014a; Choi et al., 2015; Liu et al., 2008; Zhou et al., 2011).[28] Accordingly, the shortcomings related to habituation were addressed in the form of a quasi-random order of the stimuli with the objective to mitigate order effects, too. Furthermore, Patel et al. (2014) did not employ a within-subjects design but discussed it as an explanation related to parameters of electrodermal activity that led to no signifi-

[28] Chittaro and Sioni (2014a) did not use the terms habituation or generalization explicitly but they discuss *learning effects* in this context.

cant responses in their study. Generalization, i.e. the extension of the habituation effect to similar or novel stimuli, however, was neither mentioned nor discussed by the authors of the reviewed papers. This is, again, surprising as the majority of stimuli employed in these publications was not of the same sort but similar.

2.8 Summary

In this chapter, we have introduced and discussed several relevant concepts to provide contextual background knowledge for the remainder of this work. Correspondingly, we clarified the distinction between IS and UIS with the help of the four dimensions *context* (office vs. home), *activity* (professional vs. personal), *subject or user* (digital immigrant vs. digital native) and *technology* (traditional desktop-based technology vs. mobile and ubiquitous technology). We then discussed design science research and embedded its basic concepts *construct* (conceptualization of electrodermal activity)*, method* (methodology guided design and evaluation of UIS services Janzen et al., 2010a; Maass and Janzen, 2011)*, model* (conceptualization of electrodermal activity and its relationships with other constructs) and *instantiation* (one particular UIS service and its evaluation) into the current work. In the context of IS evaluations relevant for the design and use of IS services, we then discussed self-report instruments in IS research and pointed out their methodological shortcomings. To address the latter, electrodermal activity was motivated as a low-cost, portable, noninvasive and unobtrusive NeuroIS measure for the design and use of UIS services. Thereafter, we described the individual characteristics of electrodermal activity in more detail with regard to homeostatic regulation and its relationship with exteroceptive and interoceptive processes triggered by external stimuli (e.g. IS stimuli) or internal stimuli (e.g. bodily stimuli), its measurement (e.g. with the help of the Arduino Uno platform), its parameters (e.g. skin conductance level or the amplitude of a skin conductance response) and its shortcomings with respect to habituation and generalization effects.

We finally presented the results of a literature review. This review revealed that electrodermal activity is sensitive to various stimuli in various research contexts and that this measure was used and published in only four articles from the Senior Scholar's Basket of Journals of the AIS since 2006 (Léger et al., 2014c; Minas et al., 2014; Moody and Galletta, 2015; Teubner et al., 2015). Moreover, UIS services have up till now not been evaluated by means of electrodermal activity with the exception of one study (Schnädelbach et al., 2012). More surprisingly, the habituation effect was mentioned or briefly discussed in only five articles whereas the generalization effect was neither mentioned nor discussed at all.

Overall, this chapter helped us to identify relevant work to inform the design and evaluation of the research model of this dissertation, as described in the next chapter.

3 Research Model and Hypotheses

Against the background of the preceding chapters, we now develop the research model in order to answer the research questions of the current work. For that purpose, we next develop the theoretical framework as a foundation of the research model. That is, we present and discuss the Stimulus-Organism-Response (S-O-R) paradigm and a two-systems view of cognitive processing. The latter is used to unbox the organism part of the S-O-R paradigm and allows us to better distinguish automatic cognitive processes related to electrodermal activity and inferential processes related to rule-based reasoning. We then identify, define and describe the theoretical constructs and locate them in the research framework. We start with the introduction of breakdown events of a UIS service as the primary stimulus adopted in this work, because breakdown events have been shown to elicit significant responses in electrodermal activity in prior research. Afterwards we propose, with physiological arousal, a conceptualization for electrodermal activity in the form of a theoretical construct relevant to the design and use of UIS services and, consistently, hypothesize the relationship between breakdown events of a UIS service and physiological arousal, while considering generalization effects. We then present with perceived ease of use an IS construct captured by a psychological self-report instrument that is related to physiological arousal. We adopt perceived ease of use as a psychological measure to address and discuss its relationship with and dimensionality of physiological arousal. Consequently, we hypothesize the relationship between breakdown events of UIS services and perceived ease of use. We finally introduce, with task performance, the theoretical construct that presents the behavioral response in the context of our research framework. In doing so, task performance is assumed to be a relevant outcome measure related to both physiological arousal and perceived ease of use, resulting in corresponding hypotheses.

3.1 Stimulus-Organism-Response paradigm

As we have seen from our literature review, and as discussed by Damasio and Carvalho (2013) with regard to the processes involved in homeostatic regulation, physiological measures and with them electrodermal activity are sensitive to emotionally charged stimuli. Furthermore, related work in the field of NeuroIS has also modeled or discussed responses to electrodermal reactions as a consequence of cognitive processes of an individual, such as purchase intentions (Sheng and Joginapelly, 2012), well-being or health (Kowatsch et al., 2015b; Riedl, 2013; Schnädelbach et al., 2012), or performance (Kowatsch et al., 2015b; Riedl, 2013). A theoretical lens that fits these observations and which allows us to logically structure the theoretical constructs of our research model is the Stimulus-Organism-Response (S-O-R) paradigm, which was introduced by Robert Sessions Woodworth (Woodworth, 1958; Woodworth, 2009) and further developed in the field of environmental psychology by Albert Mehrabain and James A. Russell.[29] The S-O-R paradigm as conceptualized by Mehrabain and Russell (1974) states that significant environmental cues (stimulus or S) lead to emotional responses within an individual (organism or O) and that, in turn, these responses impact approach or avoidance behavior with regard to the environment (response or R). A corresponding overview of the S-O-R paradigm with its three constructs and causal links is presented in Figure 6.

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[29] Some researchers (e.g. Deng and Poole, 2010) also use the term "environmental psychology model" (M-R Model) in reference to the research and names of Mehrabain and Russell (1974). The Stimulus-Organism-Response (S-O-R) paradigm or S-O-R model, however, was used more frequently in related work cited in this dissertation (e.g. Chang et al., 2011; Jacoby, 2002; Sheng and Joginapelly, 2012; Xu et al., 2014a) and thus, we have also adopted it.

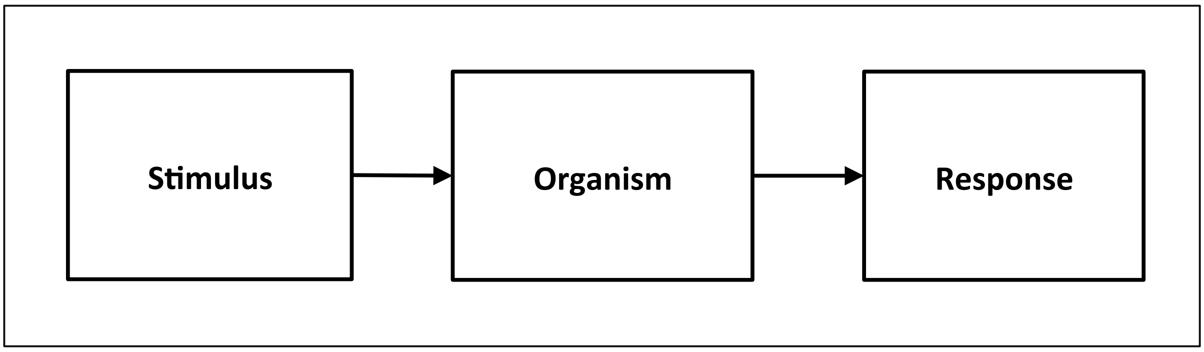

Figure 6. Stimulus-Organism-Response paradigm (adapted from Mehrabain and Russell, 1974). Note: arrows indicate causal relationships

With regard to the current work, it must be noted that the S-O link is fully compatible with the exteroceptive and interoceptive processes of homeostatic regulation. That is, these homeostatic processes are triggered by environmental stimuli which likewise lead to emotional responses and can also lead to feelings if the emotion elicited by the exteroceptive process is consciously perceived through the interoceptive pathway (Damasio and Carvalho, 2013).[30]

An example of this traditional view of the S-O-R paradigm in the field of NeuroIS and marketing research is provided in the work of Sheng and Joginapelly (2012). In their research, cues of an online store (S) are assumed to trigger responses in emotional valence and arousal (O) that, in turn, lead to approach or avoidance behavior with respect to purchase intentions (R).

Recent research has, however, adopted a broader view of the traditional S-O-R paradigm and has integrated various constructs from other theoretical models such as the Technology Acceptance Model (e.g. Kamis et al., 2008; Koufaris, 2002; Parboteeah et al., 2009) or has extended the notion of emotional responses to environmental stimuli to inferential responses (Kamis et al., 2008; Parboteeah et al.,

[30] cf. Section 2.5 of this work for more details.

2009; Xu et al., 2014a).[31] Correspondingly, there are various examples of constructs and measures related to the S-O-R paradigm, listed in Table 6.

Table 6. Examples of constructs and measures related to stimuli, organism and response concepts of the Stimulus-Organism-Response paradigm: * indicates a conceptualization of electrodermal activity

#	Author(s) (Year)	Stimulus	Organism	Response
1	Kowatsch et al. (2015b)	Limited job resources	Perceived stress, neuromotor noise, electrodermal activity, respiratory rate, heart rate variability	Avoidance behavior leading to a decrease in task performance
2	Tams et al. (2014)	Arithmetic task in the context of a memory game	Stress in the form of the salivary enzyme α-amylase	Avoidance behavior leading to a decrease in task performance
3	Xu et al. (2014a)	Trade-off transparency	Perceived enjoyment, perceived product diagnosticity	Perceived decision quality and perceived decision effort
4	Kowatsch et al. (2014) and Pletikosa Cvijikj et al. (2014)	Image stimuli provided by a relaxation service	Perceived arousal, perceived valence, perceived dominance	Avoidance behavior with regard to (a) specific (unhealthy) groceries and (b) eating too fast

[31] With inferential responses we are referring to the evaluation of constructs that rely on inferential cognitive processing (in contrast to constructs such as the emotion joy, which rely on automatic cognitive processing); for a detailed explanation, see our discussion of a two-systems view in the next section. An example of an inferential construct is product diagnosticity, defined as “the extent to which a consumer believes that a system is helpful for fully evaluating a product” (Xu et al., 2014a, p. 383). Here, an individual has to analytically reason about the helpfulness of the system in order to provide a response.

#	Author(s) (Year)	Stimulus	Organism	Response
5	Salvia et al. (2013)	Variations in difficulty in an arithmetic task	Strain, electrodermal activity, heart rate	Avoidance behavior leading to a decrease in task performance
6	Riedl (2013)	Human interaction with ICT	Activation of biological stress systems	Avoidance behavior leading to a decrease in performance productivity
7	Riedl et al. (2013)	Computer breakdown	*Physiological stress	Avoidance behavior leading to a decrease in task performance
8	Stephan (2012)	Food images	Generalization, self regulation processes, electrodermal activity	Avoidance behavior with regard to specific (unhealthy) groceries
9	Schnädelbach et al. (2012)	UIS relaxation service	*Physiological stress, self regulation processes	Approach behavior that leads to a bodily state of relaxation and long-term health
10	Sheng and Joginapelly (2012)	Vividness and interactivity of a website	*Arousal and valence	Purchase intention
11	Chang et al. (2011)	Characteristics of a retail environment	Emotional response of a consumer	Behavioral response of a consumer (e.g. buying behavior)
12	Deng and Poole (2010)	Design features of a website	Arousal and pleasantness	Approach-/avoidance-behavior toward website
13	Jiang et al. (2010)	Interactivity of a website	Cognitive involvement and affective involvement	Purchase intention
14	Parboteeah et al. (2009)	Task and mood relevant cues of an online store	Perceived usefulness and perceived enjoyment	Urge to buy impulsively

#	Author(s) (Year)	Stimulus	Organism	Response
15	Kamis et al. (2008)	Use of a decision support system and task complexity	Perceived usefulness, perceived ease of use, shopping enjoyment, and perceived control	Intention to purchase and intention to return to the online store
16	Bakker and Demerouti (2007)	Limited job resources	Job strain	Avoidance behavior leading to a decrease in organizational performance
17	Lang et al. (2007)	Job demands	Psychological and physical strain	Avoidance behavior leading to a decrease in job performance
18	Chilton et al. (2005)	Fit between the resources of an individual and job demands	Job strain	Avoidance behavior leading to a decrease in job performance
19	Koufaris (2002)	Online store features	Perceived control, shopping enjoyment, concentration, perceived usefulness, and perceived ease of use	Unplanned purchases and intention to return to the online store

Against this background of various extensions and revisions of the original conceptualization of the S-O-R paradigm by Mehrabain and Russell (1974), "it sometimes becomes difficult to determine whether certain constructs belong to the stimulus realm, the response realm, or the realm of the organism." (Jacoby, 2002, p. 52) Being aware of these ambiguities, we still adopt the basic notion and relationships of the S-O-R paradigm because of its parsimony, and because it provides a suitable theoretical rationale to locate the relevant constructs of the current work. We next describe the realm of the organism of the S-O-R paradigm in more detail and derive our research framework.

3.2 Two-systems view of cognitive processing

In particular, with regard to the fourth research question, i.e. the distinction and relationship between electrodermal activity and its (potentially) psychological counterpart and self-report measure, we further unbox the realm of the organism of the S-O-R paradigm by adopting a two-systems view of cognitive processing (Stanovich and West, 2000). This view defines two systems related to human cognition termed System 1 and System 2 (Evans, 2003; Kahneman, 2003; Masicampo and Baumeister, 2008; Stanovich and West, 2000).[32]

Stanovich and West (2000) characterize System 1 processes as "automatic, largely unconscious, and relatively undemanding of computational capacity" (ibid., p. 658). These processes infer cognitive results with the help of temporal structure and similarity in the sense of a heuristic (Sloman, 1996). For example, processing and recognition of external visual stimuli such as a house or street happens to be instantly and without any effort in healthy adolescents or adults, because they have already made this sort of cognition hundreds of times. Additionally, Kahneman (2003) adds that System 1 processes are "often emotionally charged [and that, the author] they are also governed by habit and therefore difficult to control or modify" (ibid., p. 698). These two characteristics are highly relevant to the nature of electrodermal activity with respect to emotional responses, exteroceptive processes, habituation and generalization as we have learned in Chapter 2. Prior work has discussed System 1 processes also in terms of a set of autonomous subsystems (Evans, 2003), an associative system (Sloman, 1996), heuristic processing (Evans, 1984; Evans, 1989), implicit cognition (Reber, 1993), intuitive

[32] The two-systems view of cognitive processing is also known as dual process theory.

cognition (Hammond, 1996), automatic human information processing (Schneider and Shiffrin, 1977) or automatic activation (Posner and Snyder, 1975).[33]

By contrast, System 2 processes are referred to as inferential, i.e. rule-based, analytic and rather demanding of computational effort, as outlined by Stanovich and West (2000). Related conceptualizations of System 2 processes as identified by these authors include explicit learning (Reber, 1993), rational or rule-based system (Epstein, 1994; Sloman, 1996), analytical cognition (Hammond, 1996), rational choice strategy (Klein, 1998), explicit inferences (Johnson-Laird, 1983), intellection (Pollock, 1989), controlled processing (Schneider and Shiffrin, 1977) or conscious processing system (Posner and Snyder, 1975). Following this body of research, processes related to System 2 infer cognitive results with the help of rules and abstract symbols: “Rules are abstractions that apply to any and all statements that have a certain well-specified, symbolic structure. Most important, they have both a logical structure and a set of variables.” (Sloman, 1996, p. 5) Consistently, one example in which cognitive processes of System 2 are involved would be the proof of a mathematical proposition.

In the context of the current work, the distinction between System 1 and System 2 processes is important because we can then contrast and discuss the underlying cognitive processes of electrodermal activity as an ‘automatic’ and ‘unconscious’ physiological measure of emotion and self-reports as a psychological measure that is governed not only by ‘conscious’ and ‘analytical’ processes but can be also ‘heuristic’ in situations when we process learned or hard-coded stimuli (e.g. through evolution) through the concepts of an associative system such as temporal structure and similarity. We provide a rationale for this distinction in the following two paragraphs.

[33] A detailed list of related conceptualizations of System 1 processes is provided by Stanovich and West (2000). It is also recommended to review the more recent work of Evans (2003), Evans (2006) and Masicampo and Baumeister (2008) in this regard.

The definition of System 1 processes and in particular the conceptualizations and alternative terms used by Evans (2003), Schneider and Shiffrin (1977) or Schneider and Shiffrin (1977), i.e. autonomous system and automatic activation, reassemble characteristics that are strongly related to the mechanisms underlying the exteroceptive processes in homeostatic regulation (Damasio and Carvalho, 2013) and thus changes in electrodermal activity as a consequence of emotionally-charged environmental stimuli (Boucsein, 2012). That is, electrodermal activity is triggered by the sympathetic nervous system, which is not under the conscious control of an individual. Consistently, the somatic marker hypothesis as described by Damasio (1994) states that so-called ‘marker’ signals influence cognitive processes in response to (external) stimuli,

> “…at multiple levels of operation, some of which occur overtly (consciously, 'in mind') and some of which occur covertly (non-consciously, in a non-minded manner). The marker signals arise in bioregulatory processes, including those which express themselves in emotions and feelings, but are not necessarily confined to those alone. This is the reason why the markers are termed somatic: they relate to body-state structure and regulation even when they do not arise in the body proper but rather in the brain's representation of the body.” (ibid., p. 1413)

Here, Antonio Damasio assumes conscious (‘in mind’) and unconscious cognitive processes (‘in a non-minded manner’) consistent with the two-systems view outlined above. Furthermore, both cognitive processes are assumed to depend on homeostatic processes (‘bioregulatory processes’) triggered by emotions and feelings. In line with this somatic marker hypothesis, Craig (2002), Bechara and Damasio (2005) and Craig (2009) point out that the automatic mechanisms underlying subjective feelings and emotional awareness are closely related to cognitive processes such as decision making. Moreover, Turnbull et al. (2005) and Bechara et al. (2000) have shown that emotional processes can be treated in terms of automatic processes of System 1 with the help of the Iowa Gambling Task (Bechara et al., 1994).[34]

Combining the previous assumptions of the somatic marker hypothesis, the empirical findings of prior work with recent research by Damasio and Carvalho (2013), we interpret exteroceptive processes leading to emotions as a subset of System 1 processes and interoceptive processes leading to feelings (if experienced consciously) as a subset of System 1 and System 2 processes.[35] The latter assumption with regard to feelings is made because at least basic dimensions of feelings are rapidly internalized (Bechara et al., 2000; Turnbull et al., 2005), such as the valence, i.e. whether they are positive or negative, and arousal, i.e. their intensity (Kuppens et al., 2013; Russell, 1980). Thus, System 1 processes probably govern the evaluation of these basic feelings and corresponding cognitive inferences. Processing negative feelings in response to a stranger who seems to be dangerous, or the feeling of anger in response to a UIS service that does not work as expected, would be examples in this regard. By contrast, we assume more complex feelings that are triggered, for example, by mixed emotions (e.g. Aaker et al., 2008; Hong

[34] In this complex game, subjects are asked to choose and turn cards out of four decks in the order of their choice. It depends on the card whether a subject wins or loses money. Turning cards of certain decks on a regular basis leads to a small overall gain, whereas repeatedly turning cards of other decks leads to an overall financial loss. Healthy subjects of this game quickly became aware of (they feel) the ‘winning’, ‘good’ / ‘positive’ decks, while patients with brain damage related to the emotional mechanisms were not able to anticipate the emotional consequences, i.e. reward or punishment (Bechara et al., 2000).

[35] In line with the two-systems view (Evans, 2003; Kahneman, 2003; Masicampo and Baumeister, 2008; Stanovich and West, 2000), the somatic marker hypothesis (Damasio, 1994) and other work by Damasio and Carvalho (2013), we assume processes related to emotions and feelings to constitute only a subset of all conscious or unconscious processes. For example, drives such as hunger or thirst are further action programs that also play a significant role in human cognition and behavior.

and Lee, 2010; Janssens et al., 2007; Williams and Aaker, 2002), to be processed in System 2. A corresponding example would be the evaluation of mixed feelings of a grandchild in response to the loss of her beloved grandmother who, in turn, was quite old and had a beautiful life. Here, cognitive processing potentially takes place not only in System 1 in terms of the automatic feeling of sadness and instant response but also in System 2. Regarding the latter, the grandchild might also logically reason about this situation, for example, in terms of 'all people have to die' and thus 'my grandmother, too' and 'not all grandmothers had such a beautiful life' which might lead to another feeling mitigating to some degree the feeling of sadness elicited by System 1.

As feelings, in contrast to emotions, can be expressed in words if experienced consciously, self-reports seem to be appropriate instruments for capturing the results of their underlying inferential processes of System 1 and System 2. A broad body of research has employed self-report instruments in this regard. For example, various dimensions and constructs related to feelings such as are arousal, valence or dominance were measured with self-report instruments (Bradley and Lang, 1994; Deng and Poole, 2010; Kuppens et al., 2013; Lee et al., 2012a; Russell, 1980; Sheng and Joginapelly, 2012); perceived enjoyment represents another example relevant to IS and marketing research (Koufaris, 2002; Kowatsch et al., 2014; Kroeber-Riel et al., 2009; Lee et al., 2012a; Parboteeah et al., 2009; Saadé and Kira, 2006; van der Heijden, 2004; Venkatesh, 2000; Xu et al., 2014a).

Due to the fact that feelings are only conditionally perceived if they are experienced consciously, effect sizes related to the relationship between measures of emotions such as electrodermal activity and perceptions of these emotions in terms of feelings are expected to vary to a great extent. For example, in a study relevant to the current work (Sheng and Joginapelly, 2012), electrodermal activity conceptualized in terms of emotional arousal showed no relationship with the feeling of arousal captured through the Self-Assessment Manikin (Bradley and Lang, 1994), while heart rate variability as a physiological measure of emotional valence did correspond to subjective perceptions of valence. Another relevant example is provided by Tams et al. (2014). In their study, the authors were not able to show a relationship between physiological stress measured by salivary alpha-amylase and its psychological counterpart, i.e. the feeling of stress, measured with the help of a corresponding self-report instrument.

This phenomenon of (almost) arbitrary relationships becomes even more apparent for the cognitive evaluation of theoretical constructs that are utilitarian in nature rather than hedonic, and thus emotional. In IS research, perceived usefulness represents one of these constructs (van der Heijden, 2004). It is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989, p. 320). In line with this definition, and with regard to the questionnaire items used to holistically measure perceived usefulness, cognitive processes underlying the evaluation of this belief are assumed to be rational and inferential, thus sharing System 2 properties. That is, an individual has to critically reason and reflect whether the focal system allows him or her to accomplish job tasks more quickly, to improve his or her job performance and productivity in relation to another system or approach. A relationship of unconscious and automatic evaluations related to electrodermal activity in System 1 and utilitarian constructs that are not related to feelings and also require rational inferences common to System 2 are therefore assumed to be less likely. This conclusion is quite important for the identification of an appropriate answer related to the third and fourth research questions of the present work.

Summing up this discussion, cognitive processes of System 1 such as emotional evaluations measured physiologically (e.g. by electrodermal activity) are not necessarily related to processes of System 1 or System 2 that tap into similar theoretical constructs such as feelings measured psychologically (e.g. with self-report instruments). Moreover, relationships between emotional evaluations in System 1 and evaluations in System 2 that are not primarily driven by emotions and feelings (e.g. are utilitarian in nature) are assumed to be much less likely.

We are now able to derive the theoretical framework of the current work as depicted in Figure 7. It integrates the two-systems view of cognitive processing into the realm of the organism of the S-O-R paradigm. It further depicts the relevant generic constructs of this work. That is, the characteristics of a UIS service represent the various stimuli similar to related work in IS research (e.g. Deng and Poole, 2010; Jiang et al., 2010; Kamis et al., 2008; Koufaris, 2002; Kowatsch et al., 2014; Parboteeah et al., 2009; Pletikosa Cvijikj et al., 2014; Riedl, 2013; Riedl et al., 2013; Sheng and Joginapelly, 2012; Xu et al., 2014a). Likewise, behavioral responses related to UIS service use represent approach or avoidance behavior in the realm of the response construct in the S-O-R paradigm, as related research within the IS community indicates (Jiang et al., 2010; Kowatsch et al., 2015b; Riedl, 2013; Riedl et al., 2013; Salvia et al., 2013; Tams et al., 2014). In between and against the background of this section's discussion, we are now able to unbox the organism realm of the S-O-R paradigm by differentiating between System 1 and System 2 processing, which we label automatic and inferential cognitive processing, respectively.[36] Automatic cognitive processing refers to unconscious evaluations such as emotion formation or quick heuristic labeling of these emotions in the form of feelings, while inferential cognitive processing refers to analytical and rule-based evaluations such as beliefs that are utilitarian in nature. Examples in IS research for automatic cognitive processing are physiological and psychological evaluations related to emotions and feelings (Sheng and Joginapelly, 2012; Tams et al., 2014; Xu et al., 2014a), while inferential cognitive processing happens rather in the evaluation of beliefs such as perceived usefulness (e.g. Kamis et al., 2008; Parboteeah et al., 2009), cognitive involvement (Jiang et al., 2010) or perceived product diagnosticity (Xu et al., 2014a). The research

[36] We use the terms inferential cognitive processing and automatic cognitive processing in the remainder of this work in order to provide a more specific semantic meaning rather than just to refer to System 1 or System 2. The latter terms can also be misleading in a dissertation that investigates emotions in ubiquitous information 'system' services.

framework thus indicates the causal relationships derived from prior work as outlined above and in the last section.

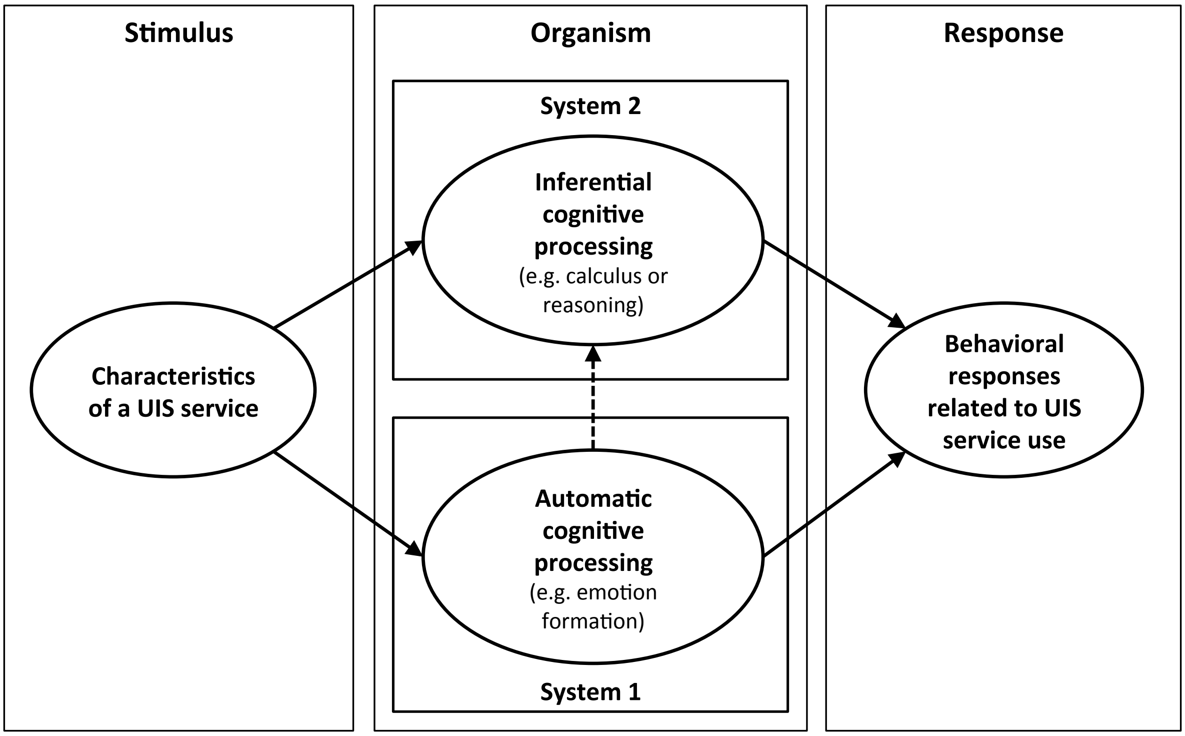

Figure 7. Research framework of the current work integrating the Stimulus-Organism-Response paradigm (Mehrabain and Russell, 1974) and a two-systems view of cognitive processing (Stanovich and West, 2000). Note: (dashed) arrows indicate (conditional) causal relationships.

In summary, the research framework allows us to appropriately describe not only changes of electrodermal activity in response to a stimulus via the automatic Stimulus-Organism link (RQ1) while considering the effect of generalization[37] (RQ2) but also to conceptualize electrodermal activity and to discuss its relationships with related constructs that are subject to automatic and inferential processes (RQ3 and RQ4). Moreover, the proposed framework allows us to identify and model the impact of electrodermal activity on relevant outcomes of UIS use at the

[37] The effects of generalization will be made explicit in the research model after it is introduced and discussed later in this chapter.

automatic Organism-Response link (RQ4), again with respect to generalization effects (RQ2). We derive the particular constructs and hypotheses for our research model along this framework in the following sections.

3.3 The stimulus: breakdown of a UIS service

In accordance with the first research question, the objective of this section is to identify and define an emotionally competent stimulus that affects electrodermal activity in a way useful for the design and use of UIS services. For that purpose, we first infer relevant requirements, then apply these requirements to the stimuli employed in the related work of our literature review. Finally, we select and define an appropriate stimulus.

The first basal requirement guiding our search for an appropriate stimulus is derived from its definition. Accordingly, an emotionally competent stimulus is defined as a "specific object or event that predictably causes an emotion" (Bechara and Damasio, 2005, p. 339). An appropriate stimulus must therefore presumably elicit physiological responses in electrodermal activity that are, in turn, measurable. An example would be an increase in the skin conductance level or skin conductance response as a consequence of emotionally competent images (Lang, 1995; Lang et al., 2008). Satisfying this first requirement would, however, also include relaxation stimuli (e.g. Carlbring et al., 2007; Schnädelbach et al., 2012) that lead to a decrease of the skin conductance level, evoking the emotional state of relaxation or satisfaction (Bradley and Lang, 1994; Russell, 1980).

The second requirement is derived from the description of the parameters of electrodermal activity in Section 2.6. Here, skin conductance responses (SCRs) are particularly relevant in the context of the current work because they can be interpreted as short-term reactions to external or internal stimuli, as opposed to long-term changes in the skin conductance level that are less sensitive in this regard (Boucsein, 2012; Damasio and Carvalho, 2013; Figner and Murphy, 2011). Examples include significant SCRs as a consequence of variations in computer agents (e.g. Teubner et al., 2015) or features of websites (e.g. Moody and Galletta, 2015). As a consequence and second requirement, appropriate stimuli must therefore elicit measurable SCRs.

In line with our research framework, the stimulus must further be a specific object or event related to or caused by characteristics common to IS and UIS services. This third requirement is consistent with our overall research question and guarantees that the stimulus is inherently related to a UIS service such that any physiological responses to it may be potentially relevant for its optimization and revision. In other words, this sort of stimulus and its physiological response potentially contribute to the design and use of UIS services. That is, these stimuli reveal automatic processes and emotional responses of an individual that may affect feelings (Sheng and Joginapelly, 2012), beliefs (Xu et al., 2014a), or outcome behaviors (Deng and Poole, 2010) related to IS or UIS services. Electrodermal activity elicited by the level of interactivity of a website would be an appropriate example (e.g. Sheng and Joginapelly, 2012), while responses to emotionally competent images (e.g. Zhou et al., 2011) or video clips (e.g. Bailenson et al., 2008) would not satisfy this third requirement.

Lastly, UIS services are unique in the sense that an individual may interact with them while he or she moves, gesticulates or speeches. Moreover, UIS services may inherently offer interaction by speech and touch gestures. All of these physical actions introduce “noise” not only to the perception of the stimulus itself but also to the measurement which, in turn, may mitigate the usefulness of electrodermal activity for the design and use of UIS services. One example represents noise artifacts from movements of the hand, a spot involved in touch gestures, where electrodermal activity is usually measured (Boucsein, 2012; Kowatsch, 2012; Teubner et al., 2015). Accidental contact of the electrodermal sensors with other physical objects such as an interactive mirror can also lead to unintended noise artifacts (Kowatsch, 2012), or sweat resulting from physical activity rather than from the focal stimulus of interest (Kappeler-Setz et al., 2013). As we have seen from our literature review in Section 2.7, no research exists that has employed electrodermal activity to measure responses to UIS services while individuals were moving, gesticulating or interacting 'in the wild'. According to the study protocols, subjects were rather asked to stay calm, and they participated in the experiments while sitting on a chair in highly standardized laboratory environments (Liao et al., 2006). We therefore further restrict relevant stimuli to those triggered by human-computer interaction as a provisional proxy. We do so because human-computer interaction, in particular mouse and keyboard interactions with traditional IS services, involves at least some sort of physical movement.

The four requirements for an appropriate stimulus are summarized in Table 7. Due to the fact that the second and fourth requirements discussed above are specializations of the corresponding first and third requirements, we name them REQ1a/b and REQ2a/b, respectively. This makes the search procedure more transparent, while allowing for the identification of stimuli that do not satisfy the specific requirements REQ1b or REQ2b at the same time. Stimuli that comply to several or all requirements are then discussed, in order to choose the stimulus that seems to be most appropriate in the context of the current work.

Table 7. Derived requirements for the identification of appropriate stimuli

#	Requirement (REQ)
REQ1a	The stimulus must cause an emotion that affects electrodermal activity
REQ1b	The stimulus must cause one or several skin conductance responses
REQ2a	The stimulus must be a specific object or event related to or caused by characteristics common to IS and UIS services
REQ2b	The stimulus must be related to human-computer interaction that involves some sort of physical movement

The results of the search for an appropriate stimulus based on the literature already reviewed in Chapter 2 and in line with the four requirements are shown in Table 8.

Here, a total score is calculated for each paper or study, according to the number of requirements met.

Table 8. Stimuli from the literature review and how they satisfy the four requirements listed in Table 7. Note: [1] indicates that raw skin conductance scores were used for the analysis, i.e. including skin conductance responses; [2] indicates that the non-dominant hand was used for the measurement

#	Authors (Year)	Stimulus	REQ1 a / b	REQ2 a / b	Total score
	NeuroIS.org and Senior Scholar's Basket of Journals of the AIS				
1	Teubner et al. (2015)	Human opponents in contrast to computer opponents in online auctions	X / X	– / –	2
2	Moody and Galletta (2015)	Variations in information scent of a website / interface design	X / –[38]	X / X	3
3	Léger et al. (2014a)	Software interaction / no specific stimulus	– / –	– / –	0
4	Léger et al. (2014b)	Variations in decision categories before IS use	X / –	– / –	1
5	Minas et al. (2014)	Challenging vs. non-challenging information before IS use	X / –	– / –	1

[38] Time constraints had no significant effect. Moreover, in this study electrodermal activity was only one of four formative measures of stress, and was even less related to the overall stress score than heat emitted by the body. It is therefore not possible to reveal the unique sensitivity of the electrodermal measure in this study. Furthermore, the path coefficient between information scent and stress was significant at the .001 level, but with a value of -0.132 it fails to show meaningful predictive power (Chin et al., 2003). Finally, with the non-significant predictor of time constraint, information scent explained the moderate amount of 22.9% variance of the stress construct.

#	Authors (Year)	Stimulus	REQ1 a / b	REQ2 a / b	Total score
6	Riedl et al. (2013)	Computer breakdown[39]	X / X[1]	X / X[2]	4
7	Adam et al. (2012)	Variations in type and outcomes of online auctions	X / X	– / –	2
8	Randolph and Jackson (2010)	Software interaction with biosignals in terms of an actuator / no specific stimulus	– / –	– / –	0
	AIS Transactions on Human-Computer Interaction				
9	Sheng and Joginapelly (2012)	Variants of a website with regard to degree of vividness and interactivity[40]	– / –	X / X	2
	ACM Transactions on Computer-Human Interaction				
10	Zhou et al. (2015)	Variants in decision factors before a computer-based route planning task is conducted	X / X	– / –	2
11	Karran et al. (2015)	Cultural heritage material	X / –	– / –	1
12	Schnädelbach et al. (2012)	Variations in opacity of a relaxation image, electrodermal activity is used as actuator	– / –	X / –	1

[39] Normalized skin conductance scores were only significant for male and not for female subjects who performed a computer task under time pressure, as opposed to subjects without any time constraints.

[40] Normalized skin conductance scores were higher for less vivid / less interactive websites, but no significant differences were found.

#	Authors (Year)	Stimulus	REQ1 a / b	REQ2 a / b	Total score
	International Journal of Human-Computer Studies				
13	Felnhofer et al. (2015)	Variations in virtual park scenarios with interaction	– / –	X / X[2]	2
14	Choi et al. (2015)	Study 1: Emotional expressions of an embodied computer agent	– / –	X / X[2]	2
		Study 2: Emotional expressions of an embodied computer agent[41]	X / –	X / X[2]	3
		Study 1/2: emotionally competent images	X / X	– / –	2
15	Kukolja et al. (2014)	Emotionally competent images	X / X	– / –	2
16	Chittaro and Sioni (2014a)	Variation in emotions of an avatar, electrodermal activity is used as actuator	– / –	X / –	1
17	Zhou et al. (2011)	Emotional images	X / X	– / –	2
18	Lim and Reeves (2010)	Interaction with human-controlled avatar in contrast to a computer agent	X / X	– / –	2
		Competitive game play versus cooperative game play	X / X	– / –	2
19	Chanel et al. (2009)	Self-elicited emotional episodes	X / –	– / –	1

[41] Highly sensitive participants in terms of electrodermal liability experienced higher arousal in response to anger expressed by the computer agent: $F(2,1128) = 5.438$ and $p = 0.004$, $\eta^2 = 0.01$. However, the effect was small and it is not made clear which extend electrodermal activity contributed to it relative to the measurement of the heart rate that was included in the statistical test.

#	Authors (Year)	Stimulus	REQ1 a / b	REQ2 a / b	Total score
20	Liu et al. (2008)	Task 1: Computer-based anagram solving	X / –	– / –	1
		Task 2: Playing the computer game pong	X / –	X / X[2]	3
21	Bailenson et al. (2008)	Faces of people watching either sad or funny video clips	X / –	– / –	1
22	Liao et al. (2006)	Study 1: Combined math and audio tasks	– / –	– / –	0
		Study 2: A test of variables of attention	X / X[1]	– / –	2
	Computers in Human Behavior				
23	Kneer et al. (2016)	Variations in difficulty and violence in a first-person shooter game	– / –	X / X[1]	2
24	Harley et al. (2015)	Computer-based learning material	– / –	– / –	0
25	Chittaro and Sioni (2015)	Variations in interactivity of a virtual environment	X / –	X / X	3
26	Pollina and Barretta (2014)	Security screening questions conducted by a computer agent	X / X	– / –	2
27	Patel et al. (2014)	Jerky character motion in digital video clips	– / –	– / –	0
28	Chittaro and Sioni (2014b)	Variations in relaxation stimuli	– / –	X / –	1
29	Kallinen and Ravaja (2007)	Audio stimuli from either speakers or headphones	– / –	X / –	1
30	Carlbring et al. (2007)	Relaxation instructions	X / –	– / –	1

#	Authors (Year)	Stimulus	REQ1 a / b	REQ2 a / b	Total score
	Personal and Ubiquitous Computing				
31	Kappeler-Setz et al. (2013)	Watching an action movie in comparison to a relaxation task	X / X	– / –	2
32	Repetto et al. (2013)	Computer-based relaxation exercise with biofeedback	– / –	X / –	1

As a result, with a computer breakdown we could identify only one stimulus that satisfied all four requirements (Riedl et al., 2013). Particularly, a computer breakdown in the form an error message increased the standardized mean values of skin conductance scores from .41 before the breakdown to .61 after the breakdown at the .05 level for 18 male subjects who were asked to conduct an online shopping task under time pressure. This increase yielded a significant and large effect of η_p^2 = 0.28 with F(1,17) = 6.583 (Bakeman, 2005; Cohen, 1988).[42] This large effect was, however, not present for female subjects and when the online shopping task was not performed under time pressure (Riedl et al., 2013). Although this seems to be a shortcoming, we still choose breakdown of an IS service, defined as malfunctioning of technology, as a useful stimulus in the context of the current work for the following four reasons.

First, a breakdown is a generic stimulus in the sense that it is not only relevant for the evaluation of IS services but also for UIS services (Vodanovich et al., 2010; Yoo, 2010). We assume that the potential for breakdown events is even higher for UIS services. For example, UIS services offer multimodal channels of human-computer interaction by physical touch gestures or speech interaction

[42] Following Bakeman (2005, p. 382, Formula 6) we calculated the effect size based on the degrees of freedom (df) and the F statistic as follows: $\eta_p^2 = df_{effect} * F / (df_{effect} * F + df_{error})$.

(Kowatsch and Maass, 2013; Maass et al., 2012), and thus, provide potentially more sources of malfunctions than traditional IS services that are controlled by mouse and keyboard interactions.

Second, a breakdown is inherently related to the characteristics of an UIS service. Consistently, the stimulus can be interpreted in terms of a system's quality that, in turn, impacts outcomes and success of the underlying UIS service. The relevance of system quality and its relation to overall IS success has already been outlined and discussed in prior research in reference to the (revised) DeLone and McLean Model of Information Systems Success (DeLone and McLean, 1992; DeLone and McLean, 2003; Petter et al., 2013; Petter and McLean, 2009). Breakdown events are therefore also relevant for the design and use of UIS services as they impact the effort related to their use. Examples of related IS constructs are effort expectancy (Venkatesh et al., 2003; Venkatesh et al., 2012) or perceived ease of use (Davis, 1989; Venkatesh, 2000; Venkatesh and Davis, 2000).

Third, several breakdown events in a row may obviously lead to an avoidance behavior with regard to the focal UIS service that, in turn, probably will lead to a reduction in task performance of an individual (Riedl, 2013; Riedl et al., 2013) and, mediated by job strain, even to a decrease in organizational outcomes (Ragu-Nathan et al., 2008). In this regard, service breakdowns are also related to constructs such as perceived usefulness or performance expectancies, i.e. relevant predictors of technology adoption and their use (Davis, 1989; Venkatesh, 2000; Venkatesh and Davis, 2000; Venkatesh et al., 2003; Venkatesh et al., 2012).

Finally, a service breakdown may also lead to technology-induced stress, referred to as technostress (Brod, 1984; Ragu-Nathan et al., 2008; Riedl, 2013; Riedl et al., 2013; Weil and Rosen, 1997).[43] In the short term, this might result in negative emotions and attitudes toward the focal UIS service. In the long term, however, due to repeated service breakdowns, technostress may negatively impact

[43] See Section 1.2 for a detailed description and formal definition of technostress.

the health and well-being of individuals who are not able to appropriately cope with these technical hassles. Technostress becomes even more relevant in this regard if breakdown events are induced by UIS services in the everyday life of people outside of office hours (Weil and Rosen, 1997).

3.4 Physiological arousal and the generalization effect

The objectives of this section are to conceptualize electrodermal activity and to describe its variation as a consequence of UIS service breakdowns. In accordance with the automatic S-O link of our research model adapted from Mehrabain and Russell (1974) and Stanovich and West (2000), the physiological model of homeostatic regulation (Damasio and Carvalho, 2013) and empirical evidence from prior work (Riedl et al., 2013), we make the basic assumption that breakdown events of UIS services elicit significant electrodermal reactions measured by short-term skin conductance responses. We further conceptualize electrodermal activity as a more generic construct in terms of physiological arousal that reflects the intensity of automatic emotional reactions instead of prior work that has adopted more specific constructs with even oppositional meanings such as stress (Riedl et al., 2013), interest (Karran et al., 2015), joy (Groeppel-Klein, 2005) or fear (Chittaro and Sioni, 2015), for the following two reasons.

The first reason why we conceptualize electrodermal activity in terms of physiological arousal is justified empirically by the results of our literature review. In the majority of the reviewed articles (27, 84%), authors have adopted terms related to the strength of emotions. Examples are intensity of immediate emotions (Teubner et al., 2015), physiological, emotional or affective arousal (Minas et al., 2014), brain activity (Randolph and Jackson, 2010), activation (Schnädelbach et al., 2012), electrodermal liability (Choi et al., 2015) or state of relaxation (Carlbring et al., 2007). The most prevalent term in this regard is physiological arousal, which was used in 11 (34%) articles (e.g. Harley et al., 2015; Kneer et al., 2016; Lim and Reeves, 2010; Minas et al., 2014). Physiological arousal seems therefore to be a common term in related work relevant to this dissertation.

Second, feelings – consciously experienced emotions – can be described within two fundamental dimensions, valence and arousal (Kuppens et al., 2013; Russell, 1980). Correspondingly, an individual would be able to describe the valence of a feeling by stating that he or she feels miserable, sad or annoyed, i.e. negative emotions are experienced; or that he or she feels pleased, satisfied or content, i.e. the emotions are perceived as rather positive.[44] Likewise, the arousal of experienced emotions can range from a feeling of sleepiness, exhaustion and boredom, i.e. states of low intensity, to feelings of high intensity in terms of anger, excitement or astonishment. As a consequence, positive feelings can be experienced not only in combination with little arousal (e.g. feeling relaxed) but also with high arousal (e.g. feeling excited), while the same holds true for negative emotions such as feeling depressed (low arousal) or frustrated (high arousal). Against this background, the use of electrodermal activity alone to derive particular emotions of the emotional space is strongly limited (Bailenson et al., 2008; Chanel et al., 2009; Kukolja et al., 2014; Liao et al., 2006; Liu et al., 2008; Sokolov and Boucsein, 2000; Zhou et al., 2011). Moreover, electrodermal activity varies in reaction to the intensity of the emotionally competent stimuli (Boucsein, 2012; Damasio and Carvalho, 2013; Damasio, 1994), and prior work indicates the reactions are stronger for negative than for positive emotions (e.g. Adam et al., 2012; Bailenson et al., 2008; Sheng and Joginapelly, 2012). The latter findings also indicate that breakdowns of IS services may lead to significant electrodermal reactions due to the fact that they are assumed to be perceived in terms of negative events as a consequence of human-computer interaction.

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[44] The phenomenon of mixed emotions describes the fact that negative and positive emotions can be experienced at the same time, as described in prior work (Aaker et al., 2008; Hong and Lee, 2010; Janssens et al., 2007; Williams and Aaker, 2002).

We therefore conclude that electrodermal activity refers to arousal rather than the valence of emotions and formulate the following relationship: breakdown events of UIS services are positively related to physiological arousal. This relationship, however, does not consider the mitigating effect of habituation and generalization for within-subjects designs that employ similar UIS stimuli repeatedly. We therefore develop a more elaborate relationship in the remainder of this section.

As already defined in the introductory chapter, habituation appears to be relevant with repeated stimuli in a way that bodily responses decrease by means of an underlying learning process (Groves and Thompson, 1970; Rankin et al., 2009; Thompson and Spencer, 1966). For example, physiological arousal in response to video game violence significantly decreased in subjects after three game playing sessions within three weeks (Ballard et al., 2006). Or, in the context of our work, an example would be the following: interacting unsuccessfully three times with a defective UIS service and thus becoming aware that it does not work as expected will probably lead to weak or even no physiological arousal the fourth and fifth times of interaction.

In order to overcome the effect of habituation, a few authors from our literature review have favored employing a counterbalanced, within-subjects design in which the order of stimuli is systematically varied or randomly assigned to each study participant (Chittaro and Sioni, 2014a; Zhou et al., 2011). While this approach indeed has its methodological advantages in within-subjects designs to address order effects (Cozby, 2009), the decrease in physiological arousal after several exposures to particular stimuli, for example 30 auctions per study participant (Teubner et al., 2015) or even 72 computer control tasks (Randolph and Jackson, 2010), will inevitably reduce sensitivity until the signal-to-noise ratio equals or is less than one. Depending on the severity of the habituation effect and individual traits (Patel et al., 2014), physiological arousal may even not be sensitive enough after a few times of stimuli exposure. For example, Patel et al. (2014) found no significant reactions in physiological arousal of their study participants in response to jerky video movements.

Even more intriguing, Grizzard et al. (2015), among other psychologists (Carnagey et al., 2007; Rankin et al., 2009; Stein, 1966), have shown that the habituation effect is present even for similar, but not the same, stimuli. This characteristic and sub-process of the habituation effect is known as generalization and is formally defined as "the extension of the habituation response to novel (i.e., new), similar stimuli" (Grizzard et al., 2015, p. 65).[45] It was, for example, shown that physiological arousal measured by electrodermal activity as a consequence of watching a video clip of real-life violence was lower for subjects who played a violent video game in advance (Carnagey et al., 2007). Accordingly, generalization effects also have to be considered in empirical IS studies that measure physiological arousal of subjects who are exposed to several similar IS stimuli such as different variants of an e-commerce website (Sheng and Joginapelly, 2012).

Against this background and with regard to the context of the current work, we have to be particularly aware of habituation and generalization effects for the design and use of UIS services, as they may elicit the same or similar stimuli. However, with a particular focus on design science research that generates various instantiations of IS services from narratives to mockups to working prototypes during several stages of the design process (e.g. Janzen et al., 2010a; Kowatsch and Maass, 2013; Maass and Janzen, 2011), we are especially interested in the generalization effect in the current work. As the presence of generalization is also a more conservative approach to testing for habituation, under the assumption that the presence of generalization also implies the presence of habituation for the same stimuli, we expect our empirical findings to be more generic and thus also relevant for related and future research.

[45] Generalization is also known as dishabituation (Rankin et al., 2009).

As a consequence, we assume the relationship of the automatic pathway of the Stimulus-Organism link of our research framework from breakdown events to physiological arousal to be mitigated by the generalization effect. We therefore formulate our first hypothesis as follows:

> ***H1:*** *The generalization effect will mitigate the positive relationship between breakdown events of a UIS service and physiological arousal for individuals who were confronted with similar services in advance.*

3.5 Perceived ease of use and physiological arousal

In this section we discuss physiological arousal with regard to existing predictors of UIS use, while formulating corresponding relationships. In doing so, we address the third and fourth research question of the current work from a theoretical point of view.

As discussed above, breakdown events of UIS services are inherently related to characteristics of these services and thus can impact perceived system quality, a multidimensional construct that is "measured in terms of ease-of-use, functionality, reliability, flexibility, data quality, portability, integration, and importance" (DeLone and McLean, 2003, p. 13); perceived system quality is highly relevant for the adoption, use and success of IS services (DeLone and McLean, 1992; DeLone and McLean, 2003; Petter et al., 2013; Petter and McLean, 2009). Out of this multi-facetted construct, ease of use – conceptualized as an individual's belief about technology – is not only a classic predictor of intentions to use systems (e.g. Benbasat and Barki, 2007; Davis, 1989; King and He, 2006; Lee et al., 2003; Legris et al., 2003; Turner et al., 2010; Venkatesh, 2000; Venkatesh and Davis, 2000; Venkatesh et al., 2007; Venkatesh et al., 2003; Venkatesh et al., 2012; Wixom and Todd, 2005) but also, and even more important, an appropriate construct that we assume to be sensitive to breakdown events of a UIS service and a complementary measure to physiological arousal, for the following reasons.

First, breakdown events of UIS services are hypothesized to be negatively related to perceived ease of use, because the latter is defined as “the degree to which a person believes that using a particular system would be free of effort.” (Davis, 1989, p. 320) Correspondingly, each breakdown event would add effort while using a UIS service, as the individual has to cope with the breakdown on his or her own or, in the worst case, even contact colleagues or service personnel. Or, from a different perspective, breakdown events lead to a loss of control, a construct that has been defined as “an individual’s perception of the availability of knowledge, resources, and opportunities required to perform the specific behavior” (Venkatesh, 2000, p. 346), and which has been shown to represent a significant determinant of perceived ease of use in a longitudinal study with three repeated measures (ibid.). We therefore formulate the second hypothesis as follows:

H2: *Breakdown events of a UIS service are negatively related to perceived ease of use with respect to that service.*

Second and consistent with H1 and H2, we assume perceived ease of use and physiological arousal to be complementary measures of a higher level construct denoted as ease of use that, similar to the technostress construct as conceptualized by Tams et al. (2014), consists of a physiological dimension (physiological arousal) and a psychological dimension (perceived ease of use). That is, we expect no significant correlation between these two constructs except that they explain more variance in a theoretically related outcome variable than either of them alone would. We discuss this assumption in the following paragraphs.

In contrast to the automatic cognitive processes that impact variations in physiological arousal, as outlined above, inferential cognitive processes are assumed to be active during belief formation with respect to perceived ease of use. That is, pursuing the theory of reasoned action (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975) and the theory of planned behavior (Ajzen, 1991), perceived ease of use is a belief formed reasonably by subjective evaluations about an object, in our case a particular UIS service. The underlying belief formation process is therefore hypothesized to be rational in nature, i.e. a person intentionally forms the belief by reflecting the stimuli from a UIS service, any consciously anticipated emotions, i.e. feelings, and the experience made with regard to how easy it was to interact with it. In particular, the original questionnaire items of the perceived ease of use scale developed by Davis (1989) support the rational belief formation process by prompting survey participants to systematically reflect and reason about the various dimensions of ease of use such as the degree of learnability, controllability or understandability of human-computer interaction. The assumption of an underlying rational cognitive process in forming the belief with respect to perceived ease of use is further supported by various studies that show a positive and significant relationship between perceived ease of use as predictor of theoretically related and 'rational' constructs such as perceived usefulness (e.g. Davis, 1989; Kamis et al., 2008; King and He, 2006; Kowatsch and Maass, 2010; Lee et al., 2003; Legris et al., 2003; Turner et al., 2010; van der Heijden, 2004; Venkatesh, 2000; Venkatesh and Davis, 2000; Venkatesh et al., 2003; Venkatesh et al., 2012; Wixom and Todd, 2005).

Against this background, physiological arousal can only be captured by perceived ease of use if it is processed consciously as a feeling. However, as for other physiological measures (Tams et al., 2014), there seems to be no causal relationship between automatic processes and rational processes since there is no guarantee that physiological responses are consciously perceived as feelings and thus, object to inferential processes. Accordingly perceived enjoyment (as a feeling and not physiological arousal as an emotion) has been conceptualized and empirically shown to be related to perceived ease of use (van der Heijden, 2004; Venkatesh, 2000).

Moreover, as we have learned from prior work, and formulated in our first hypothesis, habituation and generalization effects lead to decreased physiological responses. Thus, these effects challenge a potential relationship between automatic and inferential processes even more if breakdown events happen on a regular basis.

Automatic processes also react to other sources of stimuli that may happen at the same time as breakdown events do. For example, homeostatic regulation increases perspiration due to an increase in temperature or physical activity that, in turn, impacts variations in electrodermal activity not related to breakdown events at all.

Finally, our assumption of complementary measures has found empirical support in prior work. For example, Sheng and Joginapelly (2012), Pollina and Barretta (2014) and Tams et al. (2014) found only low correlations between self-report instruments and related physiological measures, with respect to electrodermal activity or the level of cortisol.

In summary, we expect a negative relationship between breakdown events and perceived ease of use as formulated above in H1 but no, or at least only a weak, relationship between physiological arousal and perceived ease of use.[46] Regarding the latter relationship, we assume perceived ease of use and physiological arousal to be complementary measures that both explain significantly more variance in a theoretically related outcome measure than one of these measures alone (Tams et al., 2014). With task performance, we will now introduce and discuss such an outcome measure.

3.6 The behavioral response: task performance

The objectives of this section are to identify relevant outcome measures of UIS service use related to physiological arousal (RQ3) and to promote our discussion

[46] Although we do not formulate a hypothesis on a weak and probably non-significant relationship between physiological arousal and perceived ease of use, we will indeed test our assumption with the empirical data of the current work.

about our complementary view of physiological arousal and perceived ease of use as described in the last section (RQ4).

As we have seen in Section 3.1, prior work has defined various responses as a consequence of cognitive processing within the realm of the organism. Examples include perceived decision quality and decision effort (Xu et al., 2014a), purchase intentions (Sheng and Joginapelly, 2012) or impulsive buying (Parboteeah et al., 2009), approach or avoidance behavior toward a website (Deng and Poole, 2010) or intentions to return to an online store (Koufaris, 2002). Task performance, defined as the degree of efficiency with respect to computer-based tasks (Tams et al., 2014), is another example that not only was investigated in prior work (e.g. Bakker and Demerouti, 2007; Chilton et al., 2005; Kowatsch et al., 2015b; Lang et al., 2007; Riedl, 2013; Riedl et al., 2013; Salvia et al., 2013; Tams et al., 2014) but also represents an outcome measure that is particularly relevant to the last two research questions (RQ3 and RQ4), for the following reasons.

First, several breakdown events in a row obviously lead to cognitive processes while coping with the focal IS or UIS service that, in turn, negatively influences an individual's task performance (Riedl, 2013; Riedl et al., 2013). That is, an individual is cognitively absorbed and spends time overcoming breakdown events, a process that reduces resources for performing the actual target behavior. We therefore assume physiological arousal that indicates automatic cognitive processes in response to breakdown events to be negatively related to task performance. This assumption is empirically supported by prior work that found relationships between task performance and electrodermal activity as a consequence of arithmetic tasks (Salvia et al., 2013) or a cognitive challenging manipulation of a website's degree of information scent (Moody and Galletta, 2015). Also, related automatic responses, for example, indicated by a physiological stress measure, were negatively related to task performance (Tams et al., 2014).

Subject to generalization effects of physiological responses and consistent with our first hypothesis, we also assume that an individual who repeatedly faces similar UIS services shows decreased responses to breakdown events. The latter, in turn, reflects a decrease in sensitivity and predicting power of physiological arousal and thus mitigates the negative relationship between physiological arousal and task performance. We thus formulate the third hypothesis as follows:

> ***H3:*** *The generalization effect will mitigate the negative relationship between physiological arousal and task performance for individuals who were confronted with similar UIS services in advance.*

Second, perceived ease of use is defined with respect to the degree an individual believes that using a system is free of effort (Davis, 1989). As for physiological arousal, computer breakdowns increase that effort because an individual has to manage the breakdown situation in addition to the actual computer-based task. As a consequence, and due to inferential cognitive processes, he or she would probably report a lower degree of perceived ease of use and with it a decrease in performance. Consistently, a broad body of work has found a positive relationship between perceived ease of use and perceived usefulness (for a meta analysis see King and He, 2006; Legris et al., 2003; Turner et al., 2010) because performance is one of the key dimensions of the latter construct (Davis, 1989).[47] With respect to our definition of task performance above – it is not defined as a belief about task performance but as an objective measure – it should, however, be pointed out that

> "…perceived usefulness and ease of use are people's subjective appraisal of performance and effort, respectively, and do not necessarily reflect objective reality. […] Thus, even if an application

[47] For example, task performance was operationalized in the original scale of perceived usefulness as follows: "Using CHART-MASTER would improve my job performance." (Davis, 1989, p. 340)

> would objectively improve performance, if users don't perceive it as useful, they're unlikely to use it“ (ibid., p. 335).

Against this limitation we still assume that, in line with our research framework – other characteristics of a UIS service being equal – breakdown events are such strong stimuli that they will not only clearly impact perceptions of ease of use but also reveal a positive relationship between perceived ease of use as an outcome of inferential cognitive processes and actual task performance. Related work provides also evidence in this regard. Tams et al. (2014), for example, have shown that subjective perceptions of stress were significantly related to an objective measure of task performance. We therefore formulate our last hypothesis as follows:

H4: *An individual's perceived ease of use of a UIS service has a positive relationship with task performance.*

By combining the third and fourth hypotheses, we can show that physiological arousal and perceived ease of use are complementary measures of a higher-order construct ease of use if both measures explain more variance in task performance than one alone (Tams et al., 2014).

3.7 Summary

In this chapter, we have integrated a two-systems view of cognitive processing into the realm of the organism of the Stimulus-Organism-Response (S-O-R) paradigm to derive the research framework of the current work. That is, we have adopted the basic notion and relationships of the S-O-R paradigm because of its parsimony and because it provides a suitable theoretical rationale to define and locate the relevant constructs and causal relationships of the current work. Further, we have integrated a two-systems view of cognitive processing for the purpose of better distinguishing automatic and inferential cognitive processes. This allows us to discuss assumptions about the relationship between emotional processes measured by electrodermal activity and feelings among other, more utilitarian evaluations of constructs that, in turn, help us in the conceptualization of electrodermal activity and hypotheses development. Subsequently, specific theoretical constructs and hypothesized relationships were identified, introduced and defined against the background of the research framework and related work. Accordingly, Figure 8 depicts the research model as an overview of the hypothesized relationships between the relevant theoretical constructs of this work. It states that the degree of breakdown events of a UIS service, i.e. the stimulus in our research framework, has a positive relationship with physiological arousal and a negative relationship with perceived ease of use. In this regard and following a two-systems view of cognitive processing, two cognitive processes are triggered within the organism part of the S-O-R paradigm. First, the automatic cognitive process of System 1 leads to an increase in physiological arousal as a consequence of breakdown events, while the inferential cognitive process of belief formation of System 2 leads to a decrease in perceptions related to ease of use. Moreover, task performance is conceptualized as the behavioral outcome of the cognitive processes in our research framework. It is negatively influenced by perceived ease of use and positively by physiological arousal, respectively. Subject to the generalization effect of physiological responses we assume that the hypothesized pathway from breakdown events of a UIS service to task performance through physiological arousal is mitigated if the same subjects are confronted with similar UIS services in advance. In line with prior work (Grizzard et al., 2015), we argue therefore only for the generalization effect in the automatic pathway and explicitly no impact of it on the inferential pathway via perceived ease of use. That is, we assume that subjects' inferential evaluations in response to breakdown events are not affected by similar UIS services that they were exposed to in advance.

In summary and for ease of reference, the specific formulation of the four hypotheses is provided in Table 9.

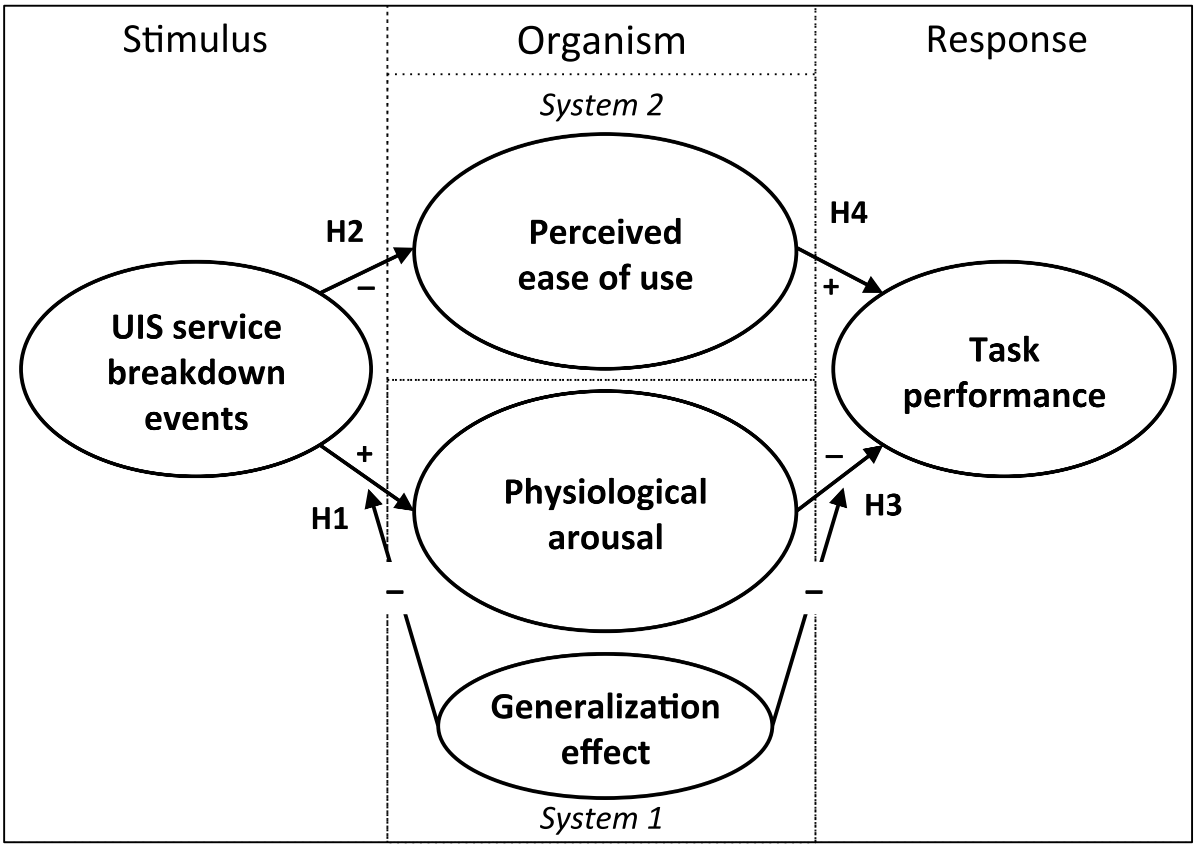

Figure 8. Research model. Note: arrows indicate the hypothesized relationships and whether they are positive (+) or negative (–)

Table 9. Hypotheses

#	Hypothesis
H1	The generalization effect will mitigate the positive relationship between breakdown events of a UIS service and physiological arousal for individuals who were confronted with similar services in advance.
H2	Breakdown events of a UIS service are negatively related to perceived ease of use with respect to that service.
H3	The generalization effect will mitigate the negative relationship between physiological arousal and task performance for individuals who were confronted with similar UIS services in advance.
H4	An individual's perceived ease of use of a UIS service has a positive relationship with task performance.

4 Method

In order to test the four hypotheses of our research model and also to answer the research questions of the current work, we use empirical data from two studies in which UIS services have been evaluated iteratively by applying a mixed methods approach. The objective of this chapter is therefore to provide details about these studies such that the reader is able not only to transparently understand the operationalization of the five constructs of our research model in combination with the design and procedure of both studies but also that other researchers will be able to replicate and refine the study design in future research.

Correspondingly, we next introduce the broader context in which the studies were conducted. Thereafter we proceed with a description of the focal UIS service of the current work, a ticket order service, and three instantiations along the design process that range from a narrative over a miniature mock-up to a full-size interactive bathroom. We then explain the sampling of subjects and the procedure of the studies. Finally, we introduce the measurement instruments used in the studies and describe how they relate to the constructs of our research model before we conclude this chapter with a brief summary.

4.1 IKS, SiDIS and the evaluation of UIS services

The empirical data of this work are taken from two studies that were conducted in the context of the Ambient Intelligence (AmI) use case of the European integrated project *Interactive Knowledge Stack for small to medium CMS/KMS providers (IKS)*.[48] The primary objective of these studies was not to evaluate the research

[48] http://www.iks-project.eu (accessed 12 December 2015), partly funded under FP7-ICT, subprogram ICT-2007.4.4 - Intelligent content and semantics, project reference 231527.

model of the current work but to evaluate six UIS services embedded in a bathroom with regard to various predictors of UIS service use, such as perceived usefulness, perceived enjoyment or perceived ease of use (Janzen et al., 2011a; Janzen et al., 2010a; Janzen et al., 2010c; Kowatsch and Maass, 2013; Kowatsch et al., 2013; Maass et al., 2012). In fact, empirical data of these studies have already been published, but with a different focus, in order to propose a new construct denoted as situation-service fit (Kowatsch and Maass, 2013; Maass et al., 2012), or to preliminarily investigate the role of electrodermal activity as a predictor of behavioral intentions to use a UIS service (Kowatsch, 2012).[49] Nevertheless, the design of the studies and their mixed methods approach of data collection seem appropriate to test not only the hypotheses but also to answer the research questions of the current work. A detailed rationale for using empirical data of these studies will be provided throughout this chapter.

Since the research partners of the AmI use case adopted a design science research methodology, the studies were conducted as part of the build-and-evaluate loop, one of the central activities in design science research (Gregor and Hevner, 2013; Hevner et al., 2004; Kuechler and Vaishnavi, 2008; Peffers et al., 2007; Van Aken, 2004).[50] In particular, the Situational Design Methodology for Information Systems (SiDIS)[51], i.e. a dedicated design science method for UIS services, was developed and adopted in the IKS project (Janzen et al., 2011a; Janzen et al.,

[49] Against the background of the last two chapters, the author of the present work has further developed and revised the original conceptualization of electrodermal activity and its relationships with predictors of UIS use, as described in his Master's thesis (Kowatsch, 2012).

[50] For further details on design science, see Section 2.2.

[51] Formerly known as Methodology for Content-Centered Design of Ambient Environments (CoDesA); see also for corresponding slides and material on SiDIS: http://iss.uni-saarland.de/en/projects/ki12-designing-ami/ (accessed 12 December 2015)

2011b; Janzen et al., 2010a; Maass and Janzen, 2011; Maass and Varshney, 2009). SiDIS emphasizes the design of UIS services based on a holistic view of UIS situations and thus, takes a social system, an information sphere, a service system and a physical object system into consideration (Maass and Varshney, 2012). In reference to Maass and Varshney (2012), the social system defines the interaction of role-playing actors, for example, between the provider of a particular UIS service and a consumer standing in front of an interactive mirror in his or her bathroom. Services, by contrast, are realized by physical objects. For example, they are embedded in a bathroom and use information objects from the information sphere (e.g. from the Internet) among other services to support the interaction between the actors.[52] With respect to these four design entities of UIS, SiDIS guides the design science researcher along four phases, denoted as identification of problems and needs, design of the solution, development of the solution and, finally, solution evaluation (Janzen et al., 2011b; Janzen et al., 2010a; Maass and Janzen, 2011). Accordingly, SiDIS helps to transform preliminary and high-level instantiations of UIS services, i.e. solution designs, into specific instantiations and final solutions. SiDIS also defines several build-and-evaluate loops with respect to the various instantiations of UIS services. That is, the main goal of SiDIS is the development of empirically justified artifacts (Hevner et al., 2004; Peffers et al., 2007). Examples of high-level artifacts include narratives and conceptual models of UIS services, while mock-ups and interactive prototypes are rather low-level and specific artifacts. As these artifacts represent different forms of instantiations of the same underlying UIS services, they are, in turn, perceived as similar or related to each other such that they potentially trigger habituation or generalization

[52] Social system, information sphere, service system and physical object system "characterize key conceptual entities of UIS" (Maass and Varshney, 2012, p. 599). In the context of SiDIS, the Abstract Information System Model (AISM) is proposed as a design model by Maass and Varshney (2012) and defines the interdependencies of the aforementioned key entities of UIS.

effects if subjects face them several times. Table 10 provides an overview of SiDIS as it was applied in the AmI use case of the IKS project.

The two studies relevant to the current work were conducted to empirically evaluate the artifacts of the second and fourth design phase of SiDIS, i.e. solution design and solution evaluation. The evaluated design artifacts in the second phase were narratives and a miniature mockup related to particular UIS services, while a full-size interactive bathroom realized the same UIS services as a consequence of design activities of the fourth phase of SiDIS. Further details about these narratives, mockups and implemented UIS services are provided in the following section.

Table 10. Overview of SiDIS as applied in the AmI use case of the IKS project.

#	SiDIS Phase	Artifact	Evaluation	Related work
1	Identification of problems and needs	Problem descriptions	Workshops	(Janzen et al., 2010a; Janzen et al., 2010c)
2	Design of the solution	Narratives and mock-ups of UIS services	Laboratory studies	(Janzen et al., 2011a; Janzen et al., 2010a; Kowatsch and Maass, 2013)
3	Development of the solution	Conceptual models of UIS services	Laboratory studies	(Janzen et al., 2011a; Janzen et al., 2011b; Janzen et al., 2010a; Maass and Janzen, 2011; Maass et al., 2011b)
4	Evaluation of the solution	Prototypes of UIS services	Laboratory studies	(Janzen et al., 2011a; Janzen et al., 2010a; Kowatsch, 2012; Kowatsch and Maass, 2013; Kowatsch et al., 2013; Maass et al., 2012)

4.2 Identifying the ticket order service as the focal UIS service

Overall, six UIS services have been designed and implemented in the AmI use case of the IKS project (Janzen et al., 2011a; Kowatsch, 2012; Maass et al., 2012). However, only three of them have also been evaluated in a within-subjects design where study participants were confronted with three different instantiations of these services in a row, which, in turn, is relevant for the investigation of generalization effects in this work. As a consequence, we further review only the three remaining UIS services with regard to the research questions and research model of the current work. These UIS services are a weather information service, an event recommendation service and a ticket order service, as defined in Table 11. Details of their actual usage in combination with their spatial placement in the interactive bathroom are outlined in Table 12, with reference to Figure 9, Figure 10 and Figure 11.

Table 11. Definition of three UIS services of the AmI use case of the IKS project

#	UIS service	Definition
1	Weather information service	A UIS service that is embedded in a private bathroom and provides weather information such as temperature and forecast parameters for the local region.
2	Event recommendation service	A UIS service that is embedded in a private bathroom and recommends events such as nearby concerts or theater plays.
3	Ticket order service	A UIS service that is embedded in a private bathroom and enables persons to order tickets for events such as nearby concerts or theater plays.

Table 12. Details of use of the three UIS services

#	UIS service	Details of usage
1	Weather information service	a) A person enters the area in front of the interactive mirror, i.e. a touch-sensitive display embedded in the center of a mirror. The display also shows the mirror image of the person via an embedded camera. b) A distance sensor recognizes the person and informs the weather information service about that event. c) Weather information is shown on the interactive mirror.
2	Event recommendation service	a) A person enters the area in front of the interactive mirror. b) A distance sensor recognizes the person and informs the event recommendation service about that event. c) Three event recommendations are shown on the interactive mirror (in addition to the weather information from above).
3	Ticket order service	a) Event recommendations are shown on the interactive mirror. b) The person touches one event he or she wants to order tickets for c) The ticket order service asks via the bathroom-embedded speakers whether the person wants to order tickets for the suggested event. d) The person answers the question by the speech commands “yes” or “no”. For this purpose, a microphone is used.

Watching the video clips of subjects actually interacting with the three services revealed that the ticket order service seems to be the most appropriate focal UIS service in the current work for the following three reasons.

First, the ticket order service requires more interaction, i.e. by touch gestures and speech commands, than the other two UIS services. Per se this represents a higher chance for breakdown events than does just entering the bathroom and being recognized by a distance sensor that, in turn, triggers the weather information service and event recommendations. Results from reviewing the video clips support this assumption, as there were remarkably more technical issues related to the touch and speech interaction of the ticket order service than issues related to the distance sensor. In fact, we observed a total of 149 breakdown events related to the ticket order service: touch gestures or speech commands, for example, were not recognized in the first trial, while there were only 10 issues related to the distance sensor such that subjects had to reposition themselves to be recognized by the remaining two services.[53]

Second, weather information and event recommendations are presented at the same time, i.e. after the distance sensor recognizes a person in front of the interactive mirror. Thus, electrodermal activity will always reflect the same degree of physiological arousal for both services at the same time, rendering it useless as a dedicated measure for either of these services.

Figure 9. Overview of the interactive bathroom

[53] Cf. Chapter 5 for further details.

Figure 10. Three UIS services embedded in the mirror of the bathroom

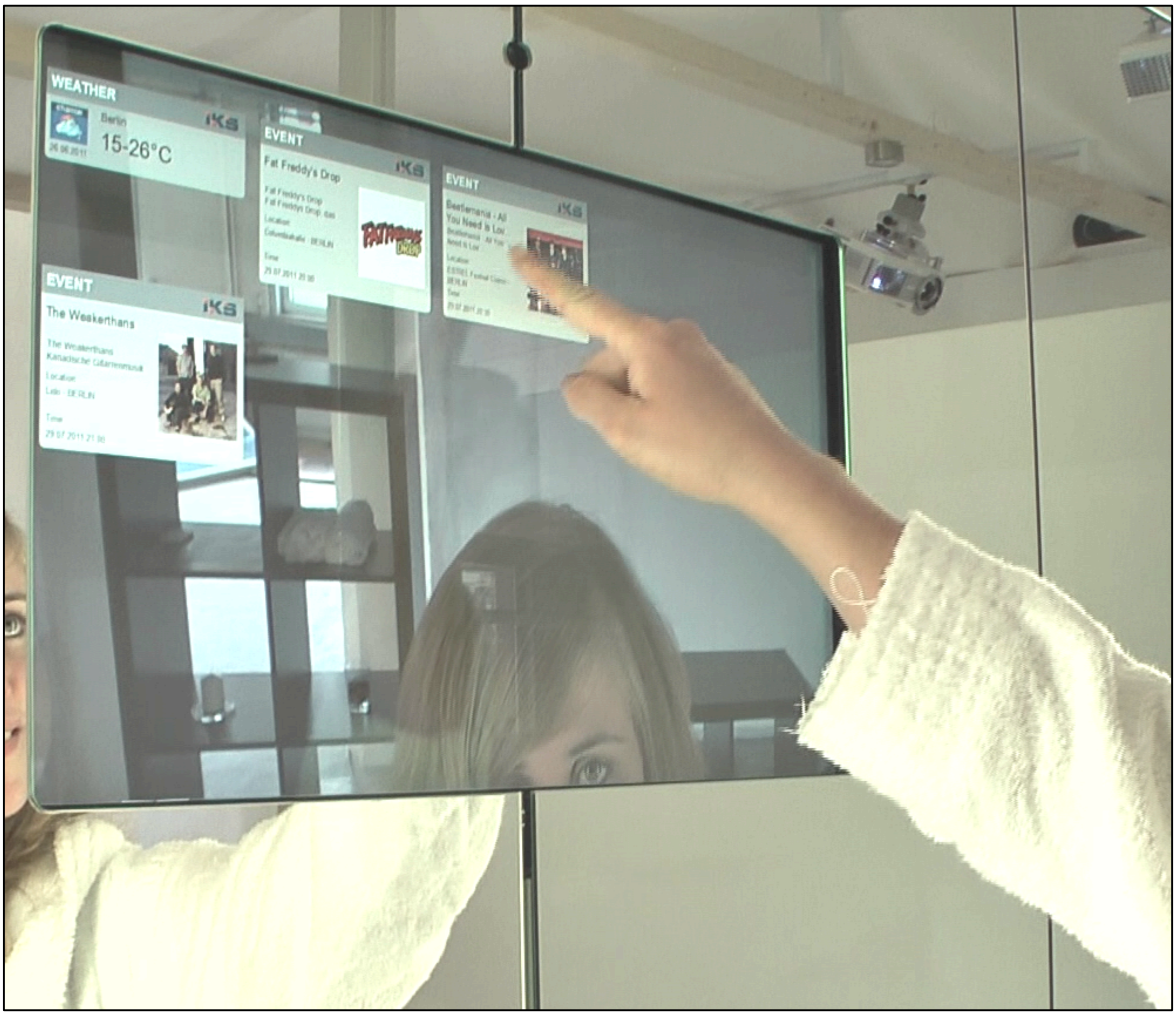

Figure 11. Ordering a ticket by a touch gesture as supported by the ticket order service embedded in the interactive mirror.

Finally, the ticket order service also requires physical movements of the arm and hand while the other services do not. This, in turn, is an important characteristic and requirement with regard to our research, which questions the usefulness of electrodermal activity as a physiological measure with respect to potential noise artifacts from movements and contact with other physical objects such as the interactive mirror in the AmI use case (RQ1).

In summary, with the ticket order service we have identified a UIS service that generally fits into the subject of investigation of the current work. We further outline its relevancy in the following section with respect to the second research question related to the generalization effect.

4.3 Making the case for three similar ticket order services

As we saw in the last section, the ticket order service generally seems to be an appropriate UIS service for the investigation of our research questions and for testing our hypotheses. We now discuss its relevancy with regard to the generalization effect. Up till now, we have just introduced one particular instantiation of the UIS service in the form of a full-size interactive prototype, showing how potential users interact with it and discussing the considerable amount of technical issues involved in its multimodal interaction by speech commands and touch gestures.

However, with respect to the generalization effect and in line with design science research in general and SiDIS in particular, UIS services are developed iteratively. Subjects thus potentially face several forms of instantiations of a focal UIS service either in parallel, i.e. with the objective of identifying the better of two or several alternatives (Hevner et al., 2004), or sequentially, in terms of revised instantiations, enhancements and further developments along the time dimension of the design process (Davis and Venkatesh, 2004). In this work, we have adopted the latter perspective because a subset of the study participants of the AmI use case evaluated three different instantiations of the three UIS services introduced above. In addition to the interactive bathroom, as introduced in the last section, subjects evaluated the services in advance with respect to a narrative and a miniature mockup, i.e. design artifacts from a rather early phase of SiDIS (in fact, its second phase).

First, the narrative that holistically describes the first three UIS services in the form of an everyday situation was formulated as follows:

> "It's Thursday morning. I get site-specific weather information when I am brushing my teeth in the bathroom. Based on weather

> information and my calendar, free-time event suggestions are given (e.g., Today, 8 p.m. – Sneak preview at CinemaOne). Do you want to order tickets?" (Janzen et al., 2010a, p. 216)

The ticket order service is mentioned implicitly in the last sentence of that narrative. In order to explicitly pinpoint study participants to the three focal services of this narrative and to assure that they evaluate the particular services separately, they were explicitly shown a definition of them according to Table 11 after they had read the narrative and before they rated corresponding questionnaire items.

Second, study participants were also confronted with a three-dimensional miniature mockup of the final interactive bathroom, to make the description of the location and spatial placement of the UIS services given by the narrative more transparent. The corresponding mockup is shown in Figure 12. In addition, subjects were shown a slide show that provided more explicit information about the three services while they were guided through the everyday situation of the narrative by the supervisor of the study, with the help of a doll that represented the person interacting with the services. The two screenshots of the slideshow that were related to the ticket order service are shown in Figure 13 and Figure 14. Before subjects evaluated the services with regard to various constructs, they were again shown the definition of the corresponding services according to Table 11, after they were guided through the narrative with the help of the mockup to assure that they evaluated the same UIS services as they did in the narrative-only condition.

The three-step evaluation of (1) reading the narrative or watching the slides and doll play in combination with the miniature mockup, (2) reading the UIS service definitions, and (3) filling out the questionnaire items was also kept consistent among the study participants for the third, interactive bathroom condition. Only the first step was "enriched" in the latter condition by reading out the narrative to the study participants such that they are consistently primed with regard to all three instantiations of the ticket order service.

Against the background of the three instantiations of the UIS services and their three-step evaluation we assume that they are perceived as similar, and thus probably trigger the generalization effect, as discussed in the following.

To recapitulate, the generalization effect in the context of the current work refers to a decrease in physiological responses due to repeated confrontations with similar UIS services. Here, we argue that the three instantiations of the UIS services outlined above are similar in the sense that only their form of implementation differs, but that their underlying definition is held constant among all three instantiations. That is, from the narrative to the miniature mockup play, to the interactive bathroom, the subject of investigation, for example, the ticket order service is kept the same. However, as the form of implementation differs, and the services become more and more transparent and explicit from the narrative to the interactive bathroom, the UIS services are experienced differently and thus perceived as similar. Prior work supports this line of argumentation, as the generalization effect was present when violence in video games led to reduced responses as a consequence of watching a video clip about a violent real life scene (Carnagey et al., 2007) or when subjects were exposed to similar video games (Grizzard et al., 2015). Furthermore, breakdown events of the ticket order service were only experienced in the full-size bathroom as a consequence of touch gestures and speech commands. That is, an additional class of stimuli was introduced with breakdown events of the implemented ticket order service, because they were neither present in the narrative nor in the mockup-based instantiation. Breakdown events may therefore further lead to a perception of a similar rather than the same UIS service.

To conclude this section, we have introduced three instantiations of UIS services and have made the case, in particular for the ticket order service, for perceiving them as rather similar than ‘same’. We therefore find these instantiations of UIS services appropriate to be adopted in the current work and expect findings in line with the first and third hypotheses, with respect to the generalization effect, as long as the same subjects have been confronted with these instantiations consecutively.

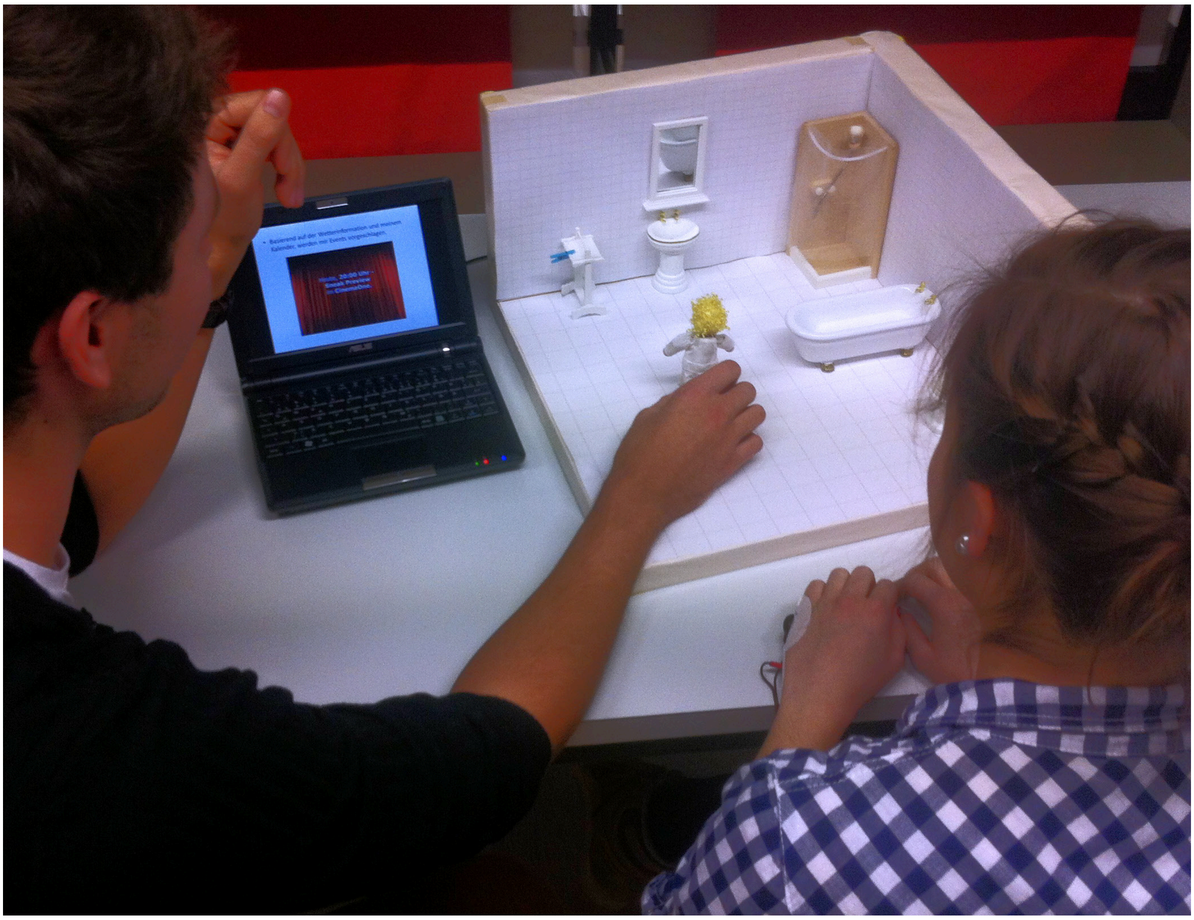

Figure 12. Mockup-based evaluation of UIS services with instructor (left) and study participant. Note: the instructor plays out the everyday situation given by the narrative while using a three-dimensional miniature mockup with a doll and a slide show.

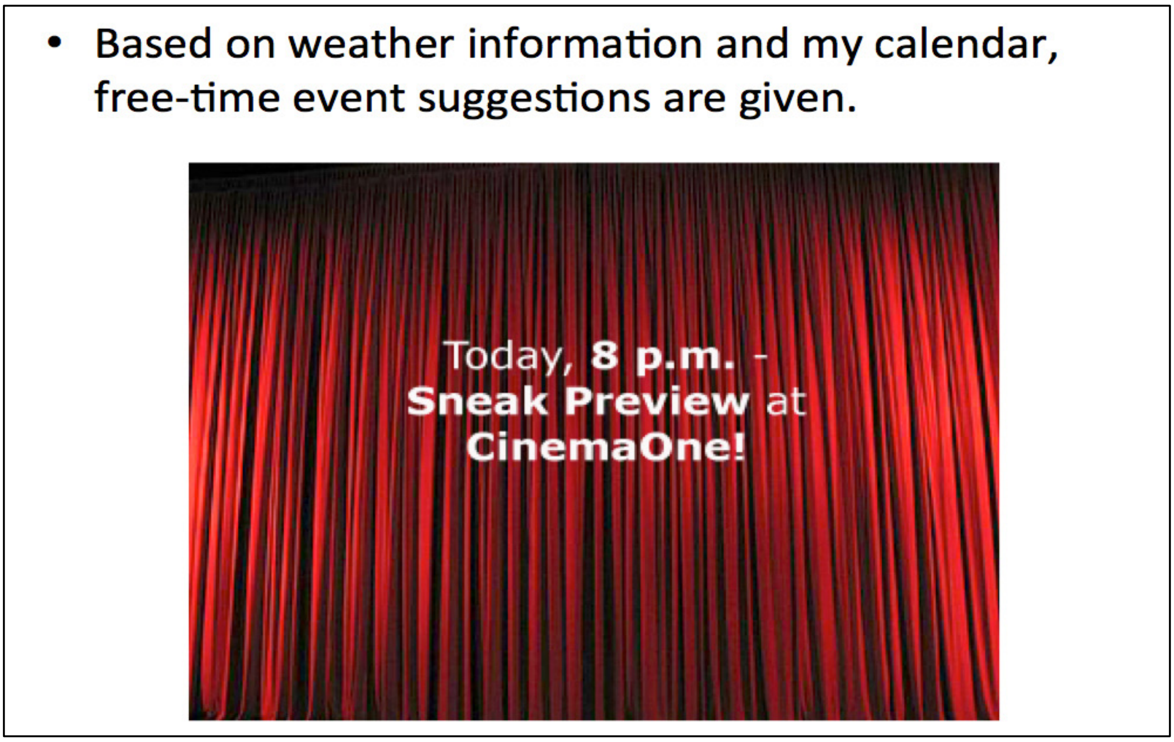

Figure 13. First slide related to the ticket order service, shown to the study participants by the instructor in the mockup-based evaluation.

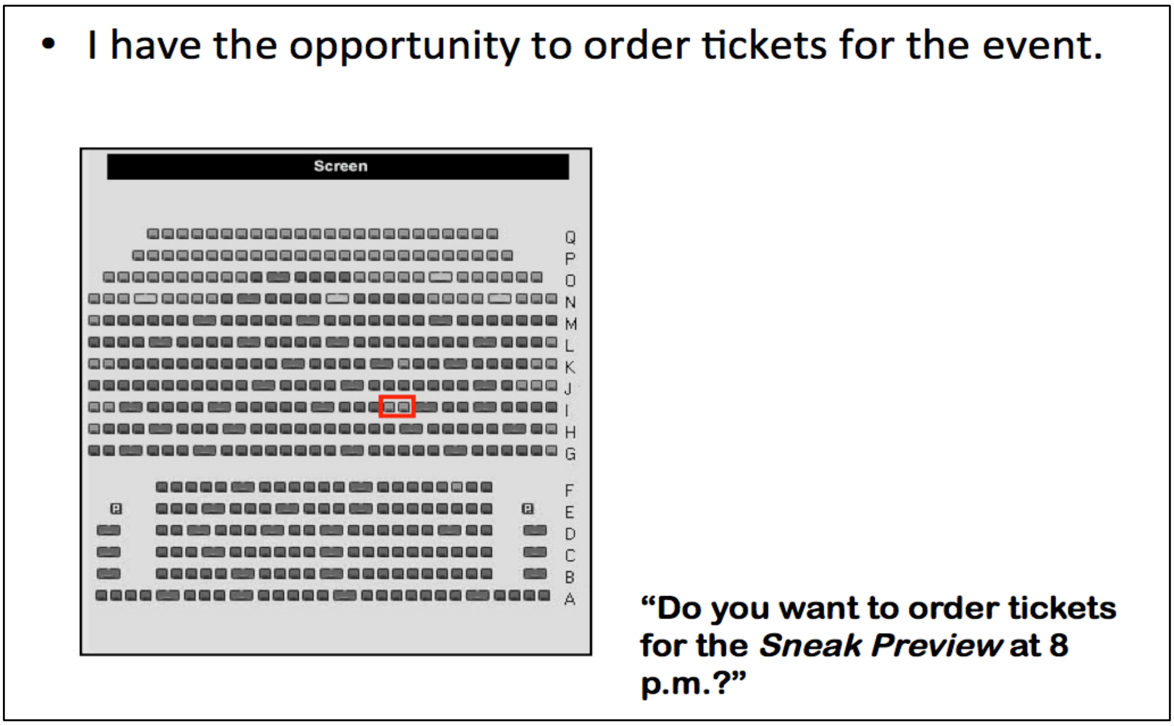

Figure 14. Second slide related to the ticket order service, shown to the study participants by the instructor in the mockup-based evaluation.

4.4 Procedure of the single- and repeated-exposure studies

Empirical data from two studies of the AmI use case of the IKS project are used in the current work. The first study was a single-exposure study in which participants were exposed to the implemented UIS services in the full-size interactive bathroom. This study is referred to as Study 1 in the remainder of this work. By contrast, the second study, called Study 2, was a repeated-exposure study that employed a within-subjects design in which study participants were consecutively exposed to the three instantiations of the ticket order service as described above. Details about the study protocol of each of these studies are provided in the following paragraphs.

The subjects of Study 1 were sampled in June 2011. For that purpose, students from technical departments of one university in the south of Germany were invited by email, and promotion carts were distributed in the cafeteria and other social meeting places (see Appendix C). The invitation included a request to participate, with a compensation of five euros, and a link to a website that provided more details about the study, including objectives and requirements for participation. Only students were allowed to participate. Interested students were also asked to book a particular time slot of 30 minutes for the study via an online ticketing system.[54]

The sampling of subjects of Study 2 was similar to that of Study 1, but was conducted in November 2012 at another university in southwestern Germany. In contrast to Study 1, participants were also recruited from non-technical departments of that university. Moreover, due to the repeated-exposure character of Study 2, a total duration of approximately 50 minutes per subject was calculated, and so hourly time slots were offered to each potential participant and the monetary reimbursement was slightly increased to seven euros.

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[54] The author implemented the online ticketing system adopted in Study 1, while in Study 2 the Doodle.ch service was used for that purpose.

The study protocol of Study 1 contained several steps, described as follows (see Appendix D for detailed instructions given to the supervisor of Study 1). In the first step, subjects were welcomed and the objectives of the study were outlined with the help of a standardized handout (see Appendix E).

Second, subjects were introduced to handling and functionality of the Mental-BioScreen (MBS) K3, a mobile device that measures skin conductance by applying a direct current and an exosomatic method of recording (Boucsein, 2012; Boucsein et al., 2012). Moreover, subjects were told that electrodermal activity measured by the MBS K3 is a novel tool for the evaluation of UIS services and thus, in addition to existing instruments such as interviews or questionnaires, might add relevant results. If subjects agreed with the measurement of their electrodermal activity, the supervisor asked them to clean their hands with water and a towel such that two adhesive electrodes (Ag/AgCl Solid-Gel) could be connected to the edge of each hand. Figure 2 and Figure 15 depict the exact positions of the electrodes as recommended by the provider of the recording device. Electrodermal activity was measured on both hands to assure at least one backup data set, in case electrodes were accidentally detached, for example during a touching gesture, hand movements or unintended contact with the bathroom furniture. Consistently, a pretest had shown that subjects were interacting with both hands at the same time such that the application of the electrodes to the non-dominant hand only – as usually recommended (Boucsein, 2012; Boucsein et al., 2012) – would have increased the risk of loosing a complete data set. The mobile skin conductance recorder was finally attached to the trousers of the subject, as shown in Figure 16. The supervisor of the study finally recorded of a subject’s electrodermal activity with the help of a test feature of the MBS K3 and, if successful, asked the participant to start the recording by pushing a corresponding button.

Third, study participants received hands-on instructions on how to use the UIS services in the interactive bathroom, while the supervisor went through the narrative as described in the last section. For standardization purposes, the supervisor pointed out that the particular information given by the UIS services, such as recommended movies or theater plays were personalized for a fictitious person called *Anna* who lives in Berlin, Germany. Moreover, the supervisor told subjects that the UIS services were not market-ready services but research prototypes that might not always work correctly and thus lead to breakdown events. However, subjects were also informed about the fact that with their feedback they could help enhance the UIS services.

Fourth, the supervisor started to record on video the interactions of study participants with the UIS services for later analyses. The video camera also recorded the current time stamp, including hours, minutes and seconds, such that the interactions with the UIS services could be synchronized later on with electrodermal activity data on the MBS K3, which also recorded time stamp information.[55] Thereafter, subjects played through the narrative, i.e. they moved into the interactive bathroom and interacted with the UIS services with the help of the instructions by the supervisor. Guidance was given to the subjects in this first run so they became used to both the narrative and the UIS services. Correspondingly, Figure 17 depicts the detailed timeline and pathway of the subjects as they were moving and interacting in the bathroom. Having successfully ordered tickets in the last step, subjects were told to step out of the bathroom and wait until the supervisor set the UIS services back to their initial state, a procedure that took about two minutes.[56] Then, in a second run, subjects played through the same narrative. This time, however, they received no guidance from the supervisor.

[55] To address any time drifts among the clocks of the video camera and the MBS K3, time was synchronized each morning of the actual study.

[56] The services were implemented in such a way that after successfully ordering a ticket no more weather information and event recommendations were displayed on the interactive mirror and thus it was not possible to further interact with the services until a technical reset was carried out.

Fifth, the supervisor asked subjects to evaluate the UIS services with the help of a standardized questionnaire printed on paper. This questionnaire contained various constructs related to the adoption of UIS services, such as perceived usefulness, perceived enjoyment, situation service fit or, relevant to the current work, perceived ease of use (c.f. Janzen et al., 2011a; Kowatsch and Maass, 2013; Kowatsch et al., 2013; Maass et al., 2012).

Sixth, the supervisor of the study stopped the video recording and the recording of the subjects' electrodermal activity. Thereafter, the supervisor thanked the subjects for their participation and handed out the monetary compensation in return for their signature, which was collected to confirm this transaction. If there was additional time, the supervisor also asked subjects for any further feedback that they considered relevant for enhancing the UIS services.

In a last step and after subjects had left the location of the study, the current date and time were noted on the questionnaire by the supervisor for synchronization purposes so that self-report data of the questionnaires, electrodermal activity of the MBS K3 and the recorded video streams could be analyzed consistently.

The study protocol of Study 2 was similar to that of Study 1 (see Appendix D for further details). In particular, the following changes were made in between the second and third steps of Study 1. Subjects were given three minutes time to relax before they were shown the narrative and, thereafter, evaluated the UIS services with an online questionnaire with the same constructs as in Study 1. Only perceived ease of use was dropped, because from just reading the narrative subjects did not use these services and thus were also not able to appropriately evaluate the degree of effort related to their use. Dropping perceived ease of use at that time of the study also seems advantageous against the background of the third and fourth research questions of the current work. That is, explicitly not referring to perceived ease of use is assumed to have no or at most just a small effect on later evaluations of that same construct. This, in turn, may result in more valid answers with respect to perceived ease of use, as prior experiences and inferential processes were not triggered explicitly by the online questionnaire. In this respect, Venkatesh (2000) refers to the concept of *anchors*, which are general beliefs about the use of IS services and *adjustments*, which are beliefs formed through direct interaction and experience with these services. Both, anchors and adjustments, are conceptualized as predictors of perceived ease of use. Accordingly, if subjects formulated their effort expectancies in response to the narrative, responses to perceived ease of use as a consequence of actually using the UIS services in the interactive bathroom would be potentially biased and thus comparison and aggregation of the results of both studies as required by the moderating hypotheses H1 and H3 would be methodologically questionable.

After the evaluation of the narrative, subjects were given another minute to relax before they were guided through the same situation by the supervisor with the help of the mockup, doll and supporting slides, as described in the last section. For the same reasons as for the narrative outlined above, subjects were not asked to evaluate perceived ease of use. Afterwards, another two minutes were given to the participants of the study to relax and mentally detach themselves from the evaluation of the mockup. In fact, the relaxation steps of Study 2 were also advantageous with respect to the second research question of the current work because there are natural upper limits of skin conductivity (Boucsein, 2012). The relaxation phases allowed subjects to calm down and, in turn, led to the capability of showing significant physiological responses to new stimuli, such as those induced by the implemented UIS services in general and the breakdown events of the ticket order service in particular. By contrast, subjects of Study 1 were not asked to relax before they interacted with the UIS services and so their potential for showing significant responses is assumed to be lower. As a consequence, if we saw reduced physiological responses of the participants of Study 2, we would probably identify major effects of generalization due to our rather conservative design, which even allowed subjects of the second study to relax in between the similar stimuli.

The exposure to the narrative and mockup, in combination with the relaxation phases and online questionnaires, resulted in an additional duration of approximately 20 minutes and, overall, a study session that lasted circa 50 minutes, compared to 30 minutes per session in Study 1. An overview of the protocols of Study 1 and Study 2 is provided in Table 13.

Table 13. Overview of the study protocols

	Single-exposure Study 1 (2011)		Repeated-exposure Study 2 (2012)	
#	**Activity**	**Duration**	**Activity**	**Duration**
1	The subject is welcomed and introduced to the objectives of the study via a hand-out.	1 min.	The subject is welcomed.	1 min.
2	The supervisor of the study explains the functionality of the MBS K3, connects electrodes to the subject's hands and starts the recording of electrodermal activity.	4 min.	See Study 1; additionally, the objectives of the study are presented via a standardized text on a computer screen.	4 min.
3	N/A		The subject watches a relaxation video (3 min.), reads through the **narrative** (0.5 min.) and evaluates the UIS services with the help of an online questionnaire (5 min.).	8.5 min.
4	N/A		The subject watches another relaxation video (1 min.). The supervisor plays through the situation given by the narrative with the help of the **mockup, doll and slides** (3 min.). Then the subject evaluates the UIS services with the help of an	9 min.

#	Single-exposure Study 1 (2011) Activity	Duration	Repeated-exposure Study 2 (2012) Activity	Duration
			online questionnaire (5 min.).	
5	N/A		The subject watches another relaxation video (2 min.).	2 min.
6	The supervisor explains the functionality of the UIS services of the **interactive bathroom** while referring to the narrative.	5 min.	See Study 1.	5 min.
7	The supervisor starts the video camera and the subject actually uses the UIS services in reference to the narrative twice. The supervisor guides the subject the first time only.	5 min.	See Study 1.	5 min.
8	The subject evaluates the UIS services with the help of a paper-based questionnaire.	13 min.	The subject evaluates the UIS services with the help of an online questionnaire.	13 min.
9	The supervisor stops the video recording and the recording of electrodermal activity. The subject is given a monetary compensation of five euros.	2 min.	See Study 1; however, monetary compensation was seven euros.	2 min.
	Total estimated duration	**30 min.**		**49.5 min.**

Figure 15. Adhesive electrodes

Figure 16. Recording electrodermal activity with the MentalBioScreen K3

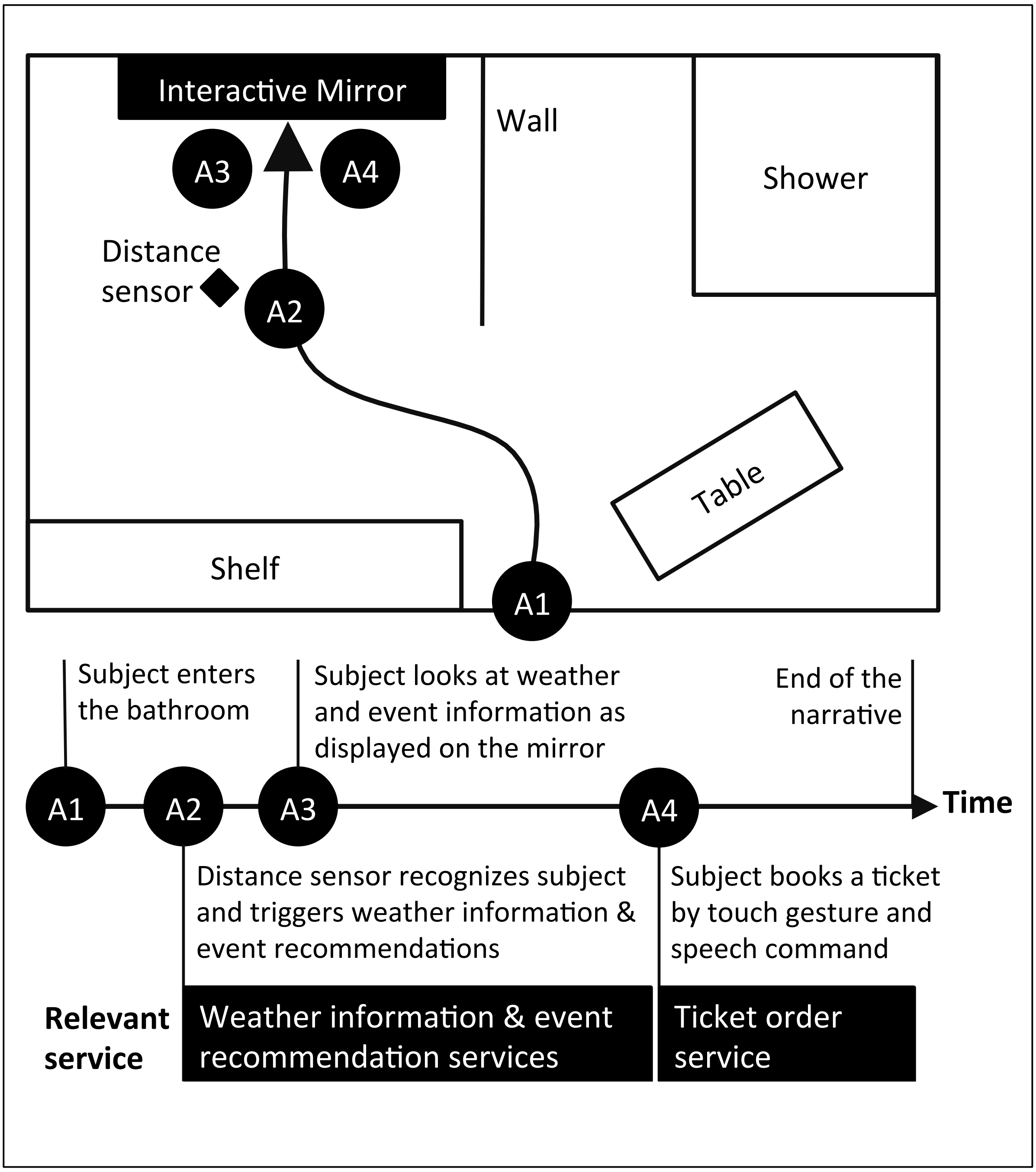

Figure 17. Detailed timeline of activities (A) related to the three UIS services. Note: the figure is adapted from Kowatsch (2012)

4.5 Observational, physiological and psychological measures

The objective of this section is to describe the operationalization of the theoretical constructs of the research model, further control variables and the methods used to collect the empirical data. Regarding the last, a mixed methods approach was adopted. That is, observations from video recordings were used to count and code breakdown events of the ticket order service and to measure task performance. Moreover, electrodermal activity was measured physiologically with a mobile skin conductance recorder, while perceived ease of use, and further control variables were measured with the help of standardized questionnaires. Details of the observational, physiological and psychological measures adopted in the current work are provided in the following paragraphs.[57]

First, we used the video recordings of the interactions with the UIS services to observe the breakdown events of the ticket order service. That is, all events related to technical issues of the ticket order service were observed and counted while the subject interacted with the mirror and played through the narrative, as described in the last section. In particular and in line with possible interactions with the ticket order service (see Table 12, Table 13 and Figure 17), these events were either related to touch gestures that were not recognized or speech commands that were not correctly understood by the service. With respect to the validity of the number of breakdown events, observations from video recordings were chosen instead of the objective system log, as breakdown events were not recorded in the system log if the UIS service did not recognize and process a corresponding manual input command from a subject.[58] The final number of breakdown events was then calcu-

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[57] In fact, the questionnaires of both studies included several items from various constructs. An overview is provided in Appendix F.

[58] The system log recorded all events relevant to the various UIS services such as 'user recognized', 'user changed position', 'user stands in front of the mirror' and manual user actions (e.g. 'touch gesture at position X', speech command 'Yes', etc.).

lated by summing up the frequency of issues related to touch gestures and speech commands of the first and second round of interaction.

Second and in line with Section 3.4, physiological arousal was conceptualized as significant electrodermal reactions measured by short-term skin conductance responses that reflect the intensity of automatic emotional reactions. Accordingly, we adopted the SCR amplitude, which is also the most frequently used parameter to describe these electrodermal reactions (Boucsein, 2012). In fact, we calculated the sum of all SCR amplitudes that had been recorded during the interactions with the ticket order service during both runs (see Table 12, Table 13 and Figure 17).[59] In this way, the total SCR amplitude reflected the degree of physiological arousal while the subjects were using the ticket order service. Moreover, SCRs being measured non-invasively with the MBS K3 usually have latencies between one and three seconds while the rise time between response onset and response peak equals half a second on average (Boucsein, 2012; Edelberg, 1972). In order to capture any last SCRs resulting from subject's interaction with the ticket order service, we included additional eight seconds after the end of the interaction for the calculation of the total SCR amplitude. Finally, in order to address the measurement issue of overlapping SCRs as described in Section 2.6 we applied nonnegative deconvolution as proposed by Benedek and Kaernbach (2010b) and adopted in related work (e.g. Chittaro and Sioni, 2015) that, in turn, resulted in distinct SCRs from which SCR amplitudes can be derived.[60]

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[59] Electrodermal activity was measured with the MBS K3 in skin conductance with a recommended sampling rate of 1 Hz and a resolution of 0.1 μS (Boucsein, 2012). We further chose the signal of the hand that was less involved in interactions.

[60] See Appendix G for further details on the extraction of the corresponding SCR amplitudes from raw data. It must be noted that electrodermal activity and derived parameters like SCR amplitude scores are not transformed into standardized values such as z-scores (e.g. Ben-Shakhar et al., 1975), because it was shown that corresponding procedures lead to a positive method bias (Boucsein, 2012; Levey, 1980; Stemmler, 1987).

Third, perceived ease of use was measured with standardized questionnaire items derived from prior work (Davis, 1989; Kamis et al., 2008; van der Heijden, 2004; Wixom and Todd, 2005). Consistent with existing research (Kamis et al., 2008; Wixom and Todd, 2005), a subset of the six original items from the perceived ease of use scale (Davis, 1989) was chosen and adapted with respect to the subject of investigation of both studies, i.e. UIS services. This resulted in four items for Study 1. The questionnaire of Study 2, however, was markedly longer than the self-reports in Study 1 because of the repeated evaluations of the UIS services with respect to their three instantiations in form of a narrative, a mockup and the full-size interactive bathroom. Thus, it was decided to reduce the perceived ease of use scale from Study 1 by one more item. In order to perform consistent analyses in the current work based on the same underlying questionnaire items, we thus reused three items related to perceived ease of use that were employed in both studies. In line with prior research (e.g. Kamis et al., 2008), seven-point Likert scales were used, ranging from strongly disagree (1) to strongly agree (7), with neither (4) being the neutral anchor. The questionnaire items adopted in the current work are shown in Table 14.

Fourth, task performance was measured objectively by taking the time in seconds required to successfully order a ticket by speech commands and touch gestures. For that purpose, again, video recordings were used and the corresponding time for both rounds was summed up. In order to assure consistent semantics between the construct and its measure, we multiplied the time in seconds by minus one such that higher values indicate shorter durations and thus, higher task performance.

Furthermore, control variables were also collected by self-reports. In particular, it was shown that a decrease in perceived alertness was related to a substantial

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Thus, a rather conservative approach is used in the current work to derive the degree of physiological arousal.

reduction in SCRs (e.g. Michael et al., 2012). We therefore used the Karolinska Sleepiness Scale (Akerstedt, 1996; Guilleminault and Brooks, 2006; Shahid et al., 2012) to test for any significant differences in perceived alertness of participants of Study 1 vs. Study 2, as these differences may have a significant impact on SCR amplitudes and may render any analyses related to habituation effects meaningless. Moreover, it has been shown that electrodermal activity in young and male subjects varies to a greater extent than in older and female subjects (Boucsein, 2012; Boucsein et al., 2012; Randolph and Jackson, 2010; Riedl et al., 2013). We therefore adopted gender and age to control for any significant differences in the population of Study 1 and Study 2. As the subjects of Study 2 were also recruited from non-technical faculties, they were also asked to rate their general technology affinity, to test whether the Study 2 population was also technologically savvy and thus behaved similar as the sample of Study 1 to IS service stimuli such as breakdown events. Corresponding questionnaire items were adapted from prior work (Kowatsch and Maass, 2012a; Kowatsch and Maass, 2012b; Parasuraman, 2000). Subjects of the second study were finally asked to rate the understandability of the instructions and items of the questionnaire and to indicate whether the study session was too long, which would probably render the empirical results of the last evaluation with respect to the interactive bathroom – in addition to the narrative and mockup – invalid. The appropriateness of the length of a study session and the understandability of instructions and items of the questionnaire were ensured as a consequence of a pretest in Study 1. Table 14 summarizes all self-report measures relevant to the current work.

Table 14. Self-report instrument. Note: * ticket order service; + Study 2 only

#	Construct and scale item wording	Scale
	Perceived ease of use (PEU) (Davis, 1989; Kamis et al., 2008; Wixom and Todd, 2005)	Seven-point Likert scale ranging from strongly disagree (0) to strongly agree (7)
PEU1	Using the * service was easy for me.	
PEU2	My interaction with the * service was clear and understandable.	
PEU3	Learning to use the * service was easy for me.	
	Demographics and control variables	10-point Likert scale ranging from extremely sleepy (1) to extremely alert (10)
ALE	**Alertness** based on the Karolinska Sleepiness Scale (Akerstedt, 1996; Guilleminault and Brooks, 2006; Shahid et al., 2012): Please indicate the degree of your mental alertness while you were in the bathroom.	
GEN	**Gender**: Are you female or male?	female, male
AGE	**Age**: How old are you?	< 20, 20-24, 25-29, 30-34, > 34
	Technology affinity (TA) (Kowatsch and Maass, 2012a; Kowatsch and Maass, 2012b; Parasuraman, 2000)	Seven-point Likert scale ranging from strongly disagree (0) to strongly agree (7)
TA1+	It is easy for me to use new technologies.	
TA2+	I am open towards new technologies.	
UND+	**Understandability** of the instructions: I found that the instructions of the study were easy to understand.	
LEN+	**Length of the study:** The study was too long.	

4.6 Summary

This chapter provided details about the procedure and measures of two empirical studies that were used to test our four hypotheses developed in the previous chapter. We first outlined the broader context of the studies that were conducted in the AmI case of the IKS project as part of the design science method SiDIS. We then proceeded by justifying the ticket order service as the focal UIS service of the current work and presented three similar instantiations relevant for the investigation of the generalization effect: (1) a simple textual narrative, (2) a three-dimensional mockup including a doll and supporting slides, and (3) a full-size interactive bathroom that allowed subjects to interact with the ticket order service. Thereafter, we provided details about the sampling of subjects and the procedure of each study's session from the perspective of a participant. An overview of the latter is shown in Table 15. We finally introduced the empirical measures adopted in both studies with respect to the constructs of our research model. Here, we adopted a mixed methods approach (Creswell, 2009). That is, empirical data on human-computer interactions with a UIS service was obtained (1) by observations from the author with the help of video recordings, (2) by standardized questionnaires and self-reports, and (3) by physiological measures, in particular, electrodermal activity. This mixed methods approach helped us also to address common method bias in the current research (Podsakoff et al., 2003). An overview of the key constructs, data collection methods and operationalizations of the current work is listed in Table 16.

Table 15. UIS services evaluated in single vs. repeated exposure studies

Exposure #	Study 1 (2011) Single-exposure to UIS services	Study 2 (2012) Repeated-exposure to UIS services
1	Implemented, full-size interactive bathroom	Narrative
2	–	Mockup with doll and slides
3	–	Implemented, full-size interactive bathroom

Table 16. Overview of the key constructs, data collection methods and operationalizations of the current work.

#	Construct	Data collection method	Operationalization
1	Breakdown events of the ticket order service	Observation from video recording while subject interacts with the ticket order service	Frequency of breakdown events of the ticket order service
2	Physiological arousal	Physiological recording of electrodermal reactions with MBS K3 while subject interacts with the ticket order service	Total SCR amplitude in µS, i.e. the sum of all SCR amplitudes during interaction with the ticket order service
3	Perceived ease of use	Standardized questionnaire with regard to the ticket order service	Aggregate of three seven-point Likert scale items with regard to the of the ticket order service
4	Task performance	Timer of video recording while subject interacts with the ticket order service	$-1\times$ time in seconds required to successfully order a ticket with the ticket order service

5 Results

This chapter presents the results related to the two studies with respect to the data selection procedure, the internal and external validity of the instruments and empirical data and finally, the hypotheses tests and the assessment of the complementary character of physiological arousal and perceived ease of use.

We first start with results of a pretest, discuss the data quality in relation to environmental conditions and present reasons why a limited amount of subjects was excluded from further analyses. Thereafter, we present and briefly discuss the demographics of the subjects and the descriptive statistics related to the core constructs and control variables of the current work. We then evaluate the internal validity of the instruments and empirical data with respect to common method variance and homogeneity considerations, which are relevant for the interpretation of the results and moderation analyses with respect to the first and third hypotheses. An assessment of the external validity of our empirical data regarding gender and age effects concludes the preliminary data analyses. Further, we introduce the partial least squares structural equation modeling (PLS-SEM) technique, which is employed in this work to test the hypotheses. Accordingly, considerations about the sample size and data distributions are briefly discussed and quality criteria of the measurement model are presented first before the results of the structural model are reported in accordance with the four hypotheses. In a last step, we empirically assess whether physiological arousal and perceived ease of use are rather complementary than alternative measures of a higher-order construct called ease of use. We conclude this chapter with a summary.

5.1 Pretest, data quality, problematic cases and outliers

This section provides details about the quality of the empirical data related to all the descriptive statistics and statistical tests of the next sections. For that purpose, we provide not only results of a pretest conducted in advance of Study 1 but also details about the data collection process and decisions made with respect to problematic cases and outliers of both studies.

First, a pretest was conducted on June 22, 2011, in advance of Study 1. The objective of this pretest was to test and revise the study protocol, the study instructions and the wording of the questionnaire items in German. For that purpose, three subjects were invited, each for one hour, and the supervisor of the study guided them through the session, along the study protocol. Any problems in the procedure were anticipated and revised, for example, the correct positioning of the video camera or the synchronization of clocks of the electrodermal activity recorder and the video camera. Additionally, interviews were conducted with each of the pretest subjects, which also resulted in minor revisions of the wording of the questionnaire items. As another outcome of the pretest, it was determined that the study session was feasible and that the instructions of the study and questionnaire items were comprehensible.

Second, Study 1 was conducted within one week, from June 27 to July 1, 2011 and Study 2 was conducted from November 27 to December 6, 2012. These short periods of time within each study were advantageous, as they mitigated any effects from environmental conditions that might influence the physiological responses, for example variations of the outside temperature. Regarding the measurement of electrodermal activity, the ambient temperature in the interactive bathroom was therefore kept close to 23°C in both studies, as recommended by Boucsein (2012), to assure the validity of the empirical data. Likewise, the bathroom was not connected to water pipes and thus air humidity in the room was neither influenced by accidental nor intentional usage of the lavatory or the shower, which, in turn, would have biased electrodermal measurements such as SCR amplitudes, as reported in prior work (Waters et al., 1979).

Overall, 55 subjects participated in Study 1. Twenty-seven of these subjects were assigned to the experimental condition and narrative that contained the weather information service, the event recommendation service and the UIS service relevant to this work, i.e. the ticket order service. Of the remaining subjects, one was dropped because her video recording was to be used for demonstration purposes, and thus the study session differed slightly. Another subject had to be excluded from further analyses because the timestamp information was not embedded in the video recording and electrodermal reactions could not be assigned to the appropriate time window when the subject interacted with the ticket order service. In the end we excluded one last subject because the z-score of the task performance variable, one of the key concepts of the research model, yielded 3.27 and thus was quite close to the recommended outlier threshold of 3.29 (Field et al., 2012). In summary, three out of 27 (11%) subjects of Study 1 were dropped from further analyses, but notably none of them was removed because of technical issues related to the mobile measurement of electrodermal activity, rendering it a robust method of data collection.

By contrast, 30 subjects participated in Study 2. All of them were assigned to the narrative and UIS services relevant to the current work. Moreover, two subjects had to be dropped because electrodermal reactions were not recorded correctly due to a technical problem with the MKS K3 recording device, which was also in response to substantial hand movements during the interaction with the ticket order service. Therefore, a total of 28 (93%) subjects of Study 2 were retained for further analyses.

5.2 Demographics and descriptive statistics

This section presents and briefly describes the demographics of the subjects and descriptive statistics of the empirical data from the two studies.

The total sample size and demographics of the study participants are listed in Table 17. Accordingly, slightly more subjects participated in Study 2 but the distribution of males and females was rather balanced in both samples. Also regarding the age of the subjects, both study groups were relatively homogenous, although we noticed three participants below the age of 20 in Study 2. Here, it must be noted again that only enrolled students were allowed to participate and thus, these three subjects were quite close to 20 years old, limiting the lower age range and resulting in a rather homogenous study sample with respect to age groups. Further analyses and statistical tests with regard to the comparability of the two study samples with respect to demographics are described in the next section.

Table 17. Demographics of the study participants

Variable	Study 1 (2011) Single-exposure to UIS services	Study 2 (2012) Repeated-exposure to UIS services	Total
N	24	28	52
Gender			
Female	15 (62.5%)	17 (60.7%)	32 (61.5%)
Male	9 (37.5%)	11 (39.3%)	20 (38.5%)
Age			
< 20	–	3 (10.7%)	3 (5.8%)
20 – 24	17 (70.8%)	13 (46.4%)	30 (57.7%)
25 – 29	4 (16.7%)	9 (32.1%)	13 (25.0%)
30 – 34	3 (12.5%)	3 (10.7%)	6 (11.5%)

The descriptive statistics of the key constructs and control variables of both studies are provided in Table 18. The frequencies of breakdown events of the ticket order service are relatively equally distributed, as are the standard deviations in both studies. By contrast, total SCR amplitudes differ moderately in their mean values and standard deviations, but not in their medians. With respect to the three questionnaire items of perceived ease of use, it can be observed that Study 2 subjects rated the ticket order service slightly better than subjects from Study 1. Overall, however, subjects of both studies rated this UIS service quite positively with respect to the degree of effort related to its use, as the mean values for PEU1

(*M*=5.37), PEU2 (*M*=5.15), and PEU3 (*M*=6.12) all lie above the neutral Likert-scale scale anchor of four. Consistent with the descriptive statistics related to perceived ease of use, it took noticeably less time for the subjects of Study 2 (circa 75s), to order a ticket on average than for those from Study 1 (circa 85s).

Moreover, subjects of both studies were alert with mean values of 6.5 for Study 1 and 7.5 for Study 2, so that both lie markedly above the neutral scale anchor of five. However, it seems that the subjects of Study 2 are slightly more alert than those from Study 1.

Furthermore, Study 2 subjects also showed high ratings regarding their perceived technology affinity, making them presumably comparable to the subjects of Study 1 that were recruited from technical departments only.

Finally, it can be preliminarily concluded that, based solely on the descriptive statistics, subjects of Study 2 understood the instructions and did not find the length of a study session too long. Or, in other words, the findings indicate that the empirical data seems to be valid and that the observations with respect to the understandability of the study instructions and perceived length are relevant for Study 1, too, because here the instructions were a subset and the length of the sessions was per se shorter.

To summarize this section, preliminary findings from the descriptive statistics indicate not only internal consistency of the empirical data, for example among perceived ease of use and task performance, but also validity with respect to the measurements and comparability of subjects' characteristics in both studies.

Table 18. Mean, median and standard deviations of the constructs and questionnaire items. Note: TOS = Ticket order service; * sum of both rounds of interaction with the TOS (see Section 4.4 for further details)

Construct / Measure	**Study 1 (2011)** Single-exposure to UIS services (N=24)			**Study 2 (2012)** Repeated-exposure to UIS services (N=28)			**Total** (N=52)		
	M	*Mdn*	*SD*	*M*	*Mdn*	*SD*	*M*	*Mdn*	*SD*
Breakdown events related to the TOS*	3.00	2.00	2.57	2.75	2.00	2.52	2.87	2.00	2.52
Total SCR amplitude in µS during TOS use*	16.42	13.68	8.57	18.27	12.01	14.86	17.42	13.05	12.29
Perceived ease of use (PEU) of TOS									
PEU1	5.00	5.50	1.72	5.68	6.00	1.49	5.37	6.00	1.62
PEU2	4.92	5.00	1.59	5.36	6.00	1.62	5.15	5.00	1.60
PEU3	4.92	5.00	1.59	6.32	7.00	1.25	6.12	6.00	1.15
Task performance, i.e. time in s to order a ticket with the TOS*	84.67	80.00	16.97	73.50	68.00	19.98	78.65	75.50	19.31
Alertness of subjects	6.46	6.50	1.64	7.39	7.50	1.55	6.96	7.00	1.64
Technology affinity (TA) of subjects									
TA1		–		5.93	6.00	1.27		–	
TA2		–		5.96	6.00	1.14		–	
Understandability of the study's instructions		–		5.89	6.00	1.10		–	
Perceived length of the study session		–		1.86	2.00	0.93		–	

5.3 Internal validity of instruments and empirical data

This section has the objective to test the validity of the empirical data with regard to both common method bias and the characteristics of the samples of the two studies. That is, we are interested whether the method is valid and whether the populations of the two studies are comparable or not and thus, may potentially confound the results with respect to the generalization effect. For that purpose, we assessed common method bias and tested for differences in gender, age and alertness among the two study populations. We continued by evaluating whether technology affinity of the participants of Study 2 can be assumed as high because they were not recruited from technical departments like those of Study 1. Moreover, we tested whether Study 2 sessions were not perceived as too long and whether the instructions of Study 2 were understandable.

We first assessed common method variance with respect to the overall validity of the self-report instrument. For that purpose, we applied Harman's one-factor test (Podsakoff and Organ, 1986) to the empirical self-report data from Study 1 and Study 2. All self-report variables related to the narrative introduced in the last chapter were used in the factor analysis with principal components extraction. As a result, several factors yielded eigenvalues above one and none of these factors explained more than 50% variance in each of both studies. Thus, common method bias was not significant with regard to our self-report instruments.[61]

Second, we tested for any significant gender differences in the two study populations. In line with the gender distributions listed in Table 17 and the bar charts shown in Figure 18, it seems that there are no distinct differences. This assumption was confirmed by a Pearson's chi-squared test with Yates' continuity correction ($\chi^2(1)=0.00$, $p=1.00$, $d=0$)[62] indicating that gender is independent from

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[61] Factor analysis was performed with IBM SPSS Statistics Version 21 for OS X.

[62] R: `chisq.test(table(studies$Study, studies$Gender));`
Note: For these and the subsequent tests, we used R version 3.2.2 on the x86_64-

the studies conducted in 2011 or 2012. As a consequence, the gender distribution in both studies, in particular regarding male subjects who show higher physiological responses than female subjects in general (Boucsein, 2012; Boucsein et al., 2012; Randolph and Jackson, 2010; Riedl et al., 2013), may not mitigate the generalization effect in our study populations.

Third, we investigated the independence of age group and the two study populations as listed in Table 17 and depicted in Figure 19. Because the frequencies of some age groups are below five, we used the Fisher's exact test for count data (Field et al., 2012).[63] Results indicate that the age groups are not dependent on the studies carried out in 2011 or 2012 (OR=1.08, p=1.00, 95% CI [0.31, 3.85], d=0.04) and thus younger subjects that may show higher physiological reactions than older subjects (Boucsein, 2012; Boucsein et al., 2012; Randolph and Jackson, 2010) are not disproportionately distributed in either of the two sample populations.

Fourth, it was evaluated whether subjects rated their perceived alertness differently in the two studies. As listed in Table 18 and depicted in Figure 20 subjects of Study 2 seem to be more alert than those of Study 1. Shapiro-Wilk normality tests indicate that perceived alertness is normally distributed for both sub-

apple-darwin13.4.0 (64-bit) platform. It must be further noted – and this is relevant for all subsequent tests that are performed to show no significant differences in our sample populations – that the beta error is relevant, and not the alpha error, if a decision is made in favor of the null hypothesis. Accordingly, the higher the alpha error probability lies above the .05 level, the lower is the beta error, and thus also the probability that we wrongly accept the null hypothesis. Effect sizes also reported and transformed to Cohen's *d* sample effect size according to http://www.psychometrica.de/effect_size.html (accessed 15 December 2015) for comparability reasons.

[63] R: `fisher.test(table(studies$Study, studies$Age))`

jects of Study 1 (*W*=0.94, *p*=0.15) and Study 2 (*W*=0.93, *p*>0.05).[64] We therefore used Welch's two-sample t-test[65], which indicates that Study 2 subjects were significantly more alert than Study 1 subjects (*t* (47.8)=-2.10, *p*=0.02, *d*=0.61, 95% CI [-inf, -0.19]). Moreover, according to Cohen (1988), the mean difference of alertness between the two sample distributions represents an intermediate effect.[66] This result challenges the identification of the generalization effect by a simple comparison of the SCR amplitudes, because Study 2 participants might show higher physiological responses due to the fact that they were more alert than those subjects in Study 1 (e.g. Michael et al., 2012). In fact, this assumption seems to be supported by a comparison of the mean values of the total SCR amplitudes, which yield 16.42µS for Study 1 and 18.27µS in Study 2 (see Table 18), while breakdown events were even less present in Study 2 (*M*=2.75) than in Study 1 (*M*=3.00). However, the medians of the total SCR amplitude show an opposite trend with 13.68 µS in Study 1 versus 12.03 µS in Study 2. Shapiro-Wilk normality tests indicate that the total SCR amplitudes are normally distributed for the participants of Study 1 (*W*=0.94, *p*=0.16) but not for Study 2 subjects (*W*=0.82, *p*<0.001).[67] We therefore conducted a Wilcoxon rank sum test with continuity correction for the total SCR amplitudes, which reveals no significant differences between the two sample populations (*W*=360, *p*=0.67, *d*=-0.12, 95% CI [-4.18, 5.92]).[68] We also compared the total SCR amplitude divided by the breakdown

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[64] R: `shapiro.test(study2011$Alertness);` `shapiro.test(study2012$Alertness)`

[65] R: `t.test(study2012$Alertness, study2011$Alertness, alternative="greater")`

[66] R: `tes(-2.1013,n.1=24, n.2=28);` # compute.es package Version 0.2-4.

[67] R: `shapiro.test(study2011$totalSCRamp);` `shapiro.test(study2012$totalSCRamp)`

[68] R: `wilcox.test(study2011$totalSCRamp, study2012$totalSCRamp, conf.int=T, alternative="two.sided", exact=F);`

events, as these events were on average slightly less present in Study 2 (M=2.75) than in Study 1 (*M*=3.00). Here, both Shapiro-Wilk normality tests showed that the SCR amplitudes per breakdown event were not normally distributed for the participants of Study 1 (W=0.81, p<0.001) and Study 2 (W=0.78, p<0.001).[69] Correspondingly, we performed a Wilcoxon rank sum test with continuity correction that indicated, again, no significant difference between the SCR amplitudes per breakdown event of both study samples (W=318, p= 0.75, d=-0.09, 95% CI [-1.88, 1.22]).[70] In summary, these findings show that subjects of Study 2 perceived themselves significantly more alert than subjects from Study 1. However, this difference was not present in the physiological measures, i.e. either in the total SCR amplitudes or in the SCR amplitudes per breakdown event. This might be a preliminary indication of the generalization effect, which will be further investigated in this chapter.

Fifth, to further assure the validity of the empirical data of this work, we investigated whether the subjects of Study 2 were also technical-savvy and thus, were probably similar with respect to their behavior and reactions to breakdown events than those subjects recruited from the technical departments of Study 1. Due to the fact that subjects of Study 1 were not asked to report their technology affinity, we

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The effect size was calculated by the R function 'rFromWilkox' (Field et al., 2012) and is then transformed to Cohen's *d* according to http://www.psychometrica.de/effect_size.html (accessed 15 December 2015) for comparability reasons.

[69] R: `shapiro.test(study2011$SCRampPerBreakdown);`
`shapiro.test(study2011$SCRampPerBreakdown)`
Note: Due to the fact that also no breakdown events were present for some subjects in both studies and division by zero is not allowed, we added the integer one to each breakdown event before further analyses were conducted.

[70] R: `wilcox.test(study2011$SCRampPerBreakdown, study2012$SCRampPerBreakdown, conf.int=T, alternative="two.sided", exact=F);`

assessed whether the subjects from Study 2 rated this control variable above the neutral scale value. Cronbach's alpha resulted in a viable internal consistency value of .86 for the two-item scale which lies above the recommended threshold of .70 (Nunnally, 1967). Moreover, confirmatory factor analysis with principal components extraction and varimax rotation for the three perceived ease of use and two technology affinity items resulted in factor loadings that show convergent validity of the technology affinity items, thus supporting internal consistency reported above, and discriminant validity with regard to the items of the perceived ease of use scale.[71] We therefore aggregated both technology affinity items for further analysis.[72] A Shapiro-Wilk normality test revealed that the distribution of the aggregated technology affinity variable differs significantly from a normal distribution (W=0.85, p<.001).[73] Correspondingly, we conducted a Wilcoxon signed rank test with continuity correction that, in turn, indicates that the true location of the rank (Mdn_{pseudo}=6.25) was significantly higher with a large effect than the neutral scale rank of technology affinity (V=372.5, p<.001, d=-3.36, 95% CI [5.75, inf]).[74] It can be therefore concluded that the subjects of Study 2 were rather technical-savvy and therefore probably similar to the population of Study 1.

We finally investigated whether the subjects of both samples understood the instructions of the study and whether they perceived the study session as not too long, which, in turn, might potentially bias both their physiological responses and psychological self-reports. We assumed the self-reports from Study 2 subjects to

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[71] See Appendix H for the rotated factor matrix and details of the statistical software used for this factor analysis.

[72] R: `cronbach(data.frame(study2012$TA1, study2012$TA2));`
psy package Version 1.1
`study2012$TA = (study2012$TA1 + study2012$TA2) / 2`

[73] `shapiro.test(study2012$TA)`

[74] R: `wilcox.test(study2012$TA, conf.int=T, mu=4, alterna-tive="greater", exact=F);`

be a good approximation for the self-reports of Study 1, because the latter study was shorter and the questionnaires and instructions were a subset of Study 2. With respect to the descriptives listed in Table 18, understandability of the study's instructions and perceived length of the study show a positive trend. That is, understandability was rated 5.89 on average (*SD*=1.10), which lies markedly above the neutral scale value of four, and the length of a study session was not perceived as too long with a mean rating of 1.86 (*SD*=0.93) which lies clearly below the neutral scale value. Statistical tests were conducted to test whether these observations are confirmed. For that purpose, Wilkoxon signed rank tests suitable for non-parametric data were performed because Shapiro-Wilk normality tests indicated distributions that significantly differ from normal distributions for understandability (W=0.85, p=0.001) and the perceived length of the study (W=0.80, p<0.001).[75] Results of the Wilkoxon signed rank tests confirm our observation, as they show that the true location of the rank (Mdn_{pseudo}=6.00) is significantly higher than the neutral scale rank for understandability (V=347, p<0.001, d=-3.37, 95% CI [6.00, inf]) and significantly lower (Mdn_{pseudo}=2.00) than four for the perceived length of the study (V=0, p<0.001, d=-4.08, 95% CI [-inf, 2.00]).[76] As a consequence, the internal validity of the empirical data seemed not to be affected by the instructions or the perceived length of Study 2. Moreover, due to the fact that Study 1 was just a subset of Study 2 with respect to the instructions, we assume this conclusion to hold for Study 1 as well.

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[75] R: `shapiro.test(study2012$UND); shapiro.test(study2012$LEN)`

[76] R: `wilcox.test(study2012$UND, conf.int=T, mu=4, alternative="greater", exact=F); wilcox.test(study2012$LEN, conf.int=T, mu=4, alternative="less", exact=F)`

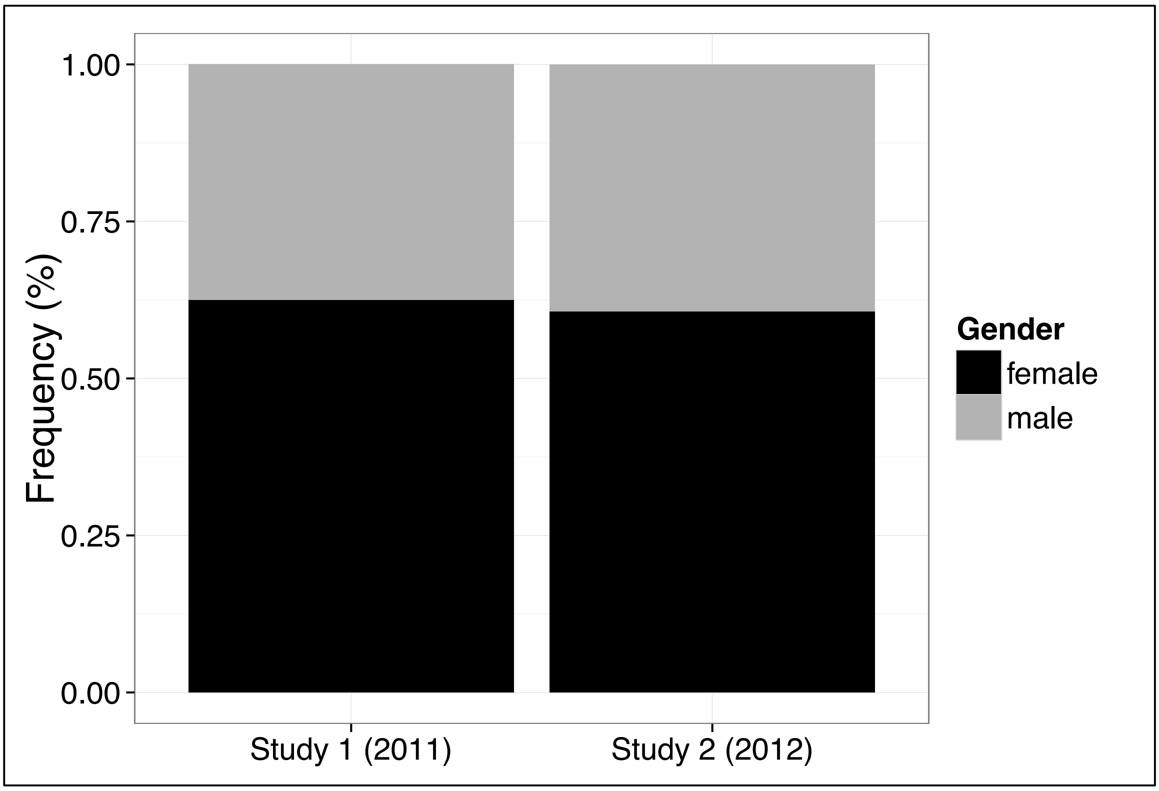

Figure 18. Gender distribution among subjects of Study 1 (*N*=24) and Study 2 (*N*=28)

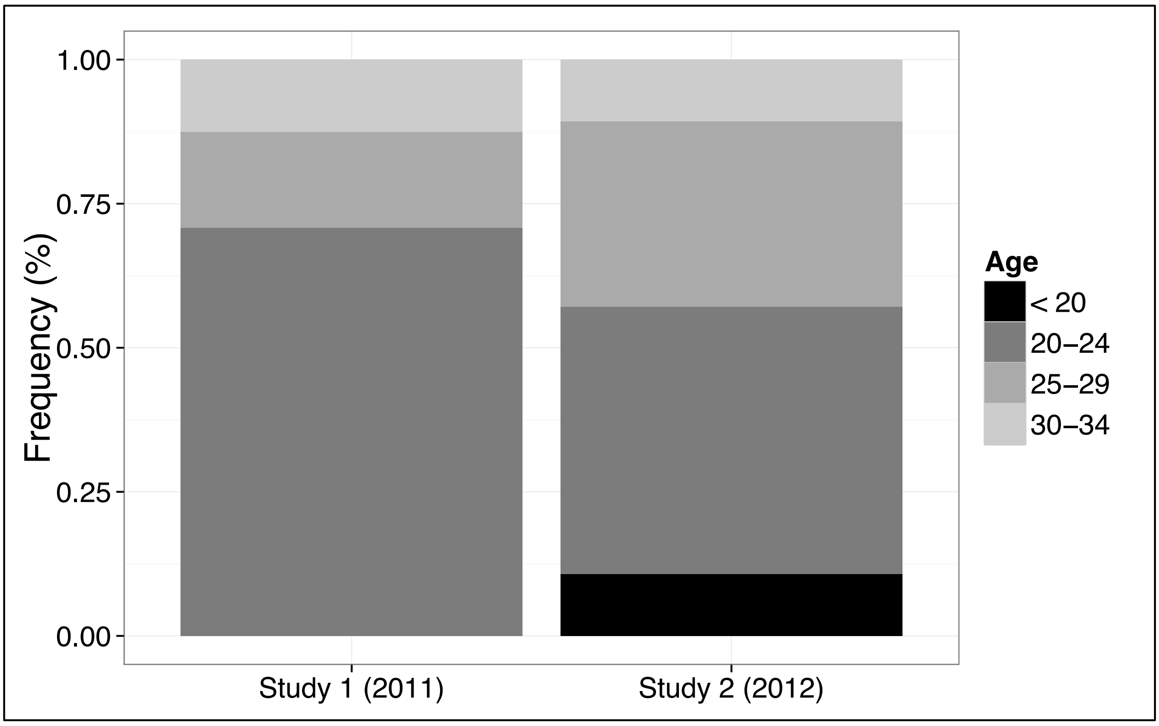

Figure 19. Age distribution among subjects of Study 1 (*N*=24) and Study 2 (*N*=28)

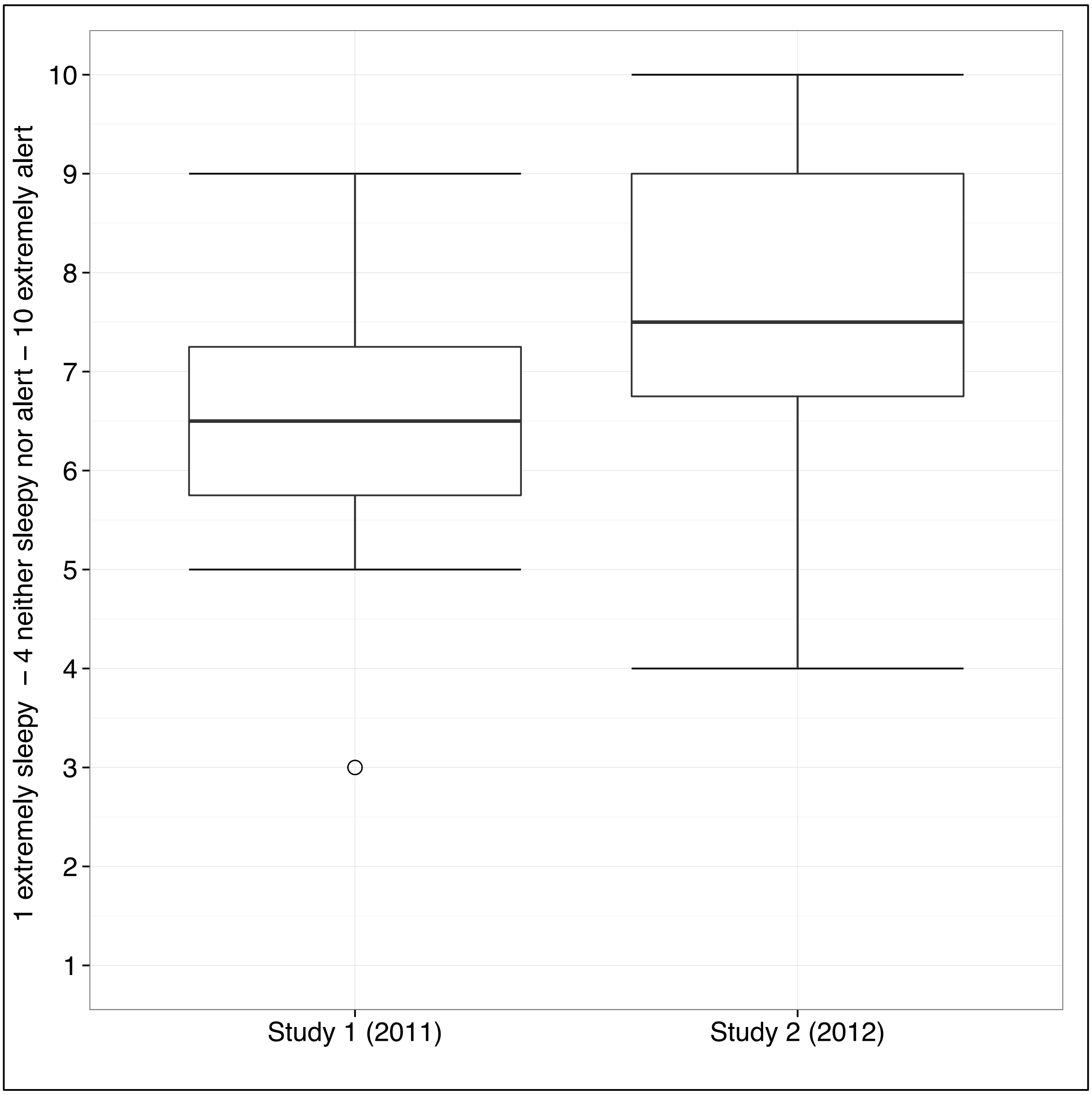

Figure 20. Boxplots for perceived alertness of the subjects from Study 1 (*N*=24) and Study 2 (*N*=28).[77]

[77] Note: The value three (the circle depicted in the boxplot of Study 1) was self-reported by two subjects; however, they were not dropped from further analyses, because they showed no outliers according to Field et al. (2012) in the four core constructs of the current work, i.e. breakdown events, total SCR amplitude, perceived ease of use or task performance.

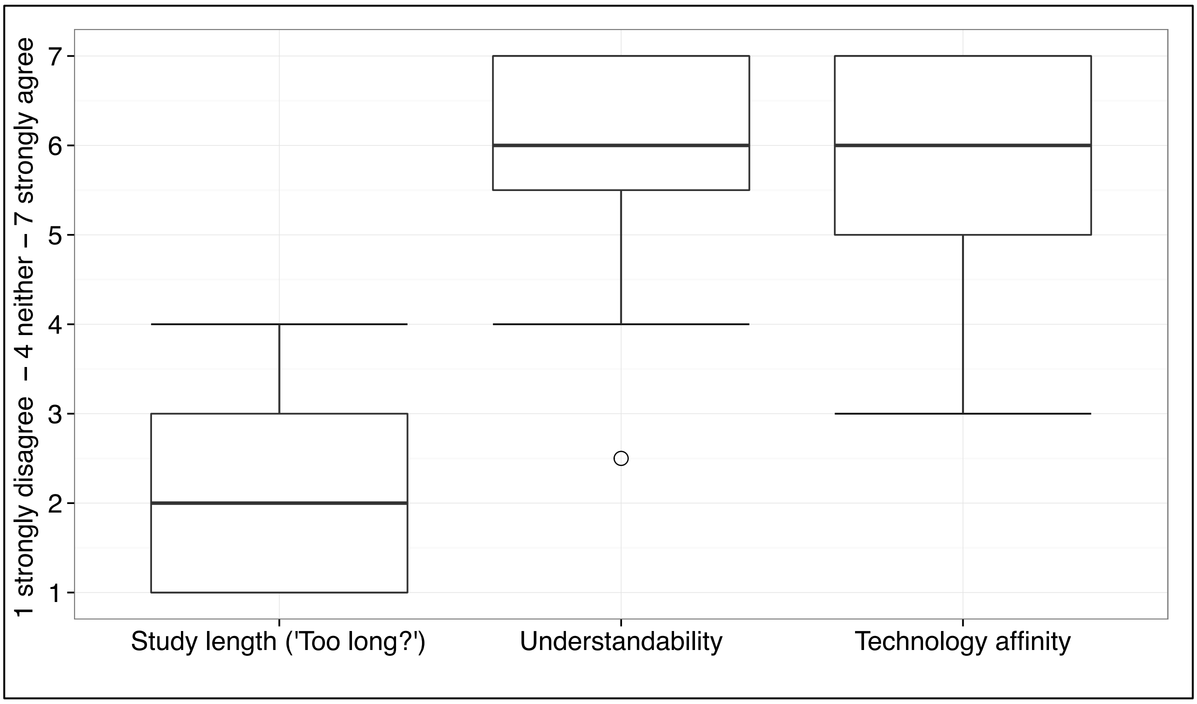

Figure 21. Boxplots for perceived length and understandability of the study and technology affinity of the participants from Study 2 (*N*=28).[78]

5.4 External validity with respect to gender and age differences

This section provides an assessment of the external validity of our empirical data. That is, we tested whether some basic relationships between our variables, in particular with regard to physiological arousal as a novel construct in the UIS context, were in line with prior work before any further analyses were conducted. In addition to the last section, we also assessed whether the methods used for data collection and processing in this work were valid. Specifically, we evaluated whether we can replicate two basic findings from prior work with respect to elec-

[78] The value three (the circle depicted for understandability) was self-reported by one subject; however, the subject was not dropped from further analyses, because it showed no outliers according to Field et al. (2012) in the four core constructs of the current work, i.e. breakdown events, total SCR amplitude, perceived ease of use or task performance.

trodermal reactions. The first finding indicates that male subjects show stronger electrodermal reactions than female subjects, while the reactions in younger subjects are stronger than in older ones.

First, prior work has shown that males show more variations in electrodermal activity than females (Boucsein, 2012; Boucsein et al., 2012; Randolph and Jackson, 2010; Riedl et al., 2013). The reasons likely lie in the fact that males produce more sweat than females, although the latter have a higher density of sweat glands (Boucsein, 2012). And with respect to the present work, Riedl et al. (2013) found that electrodermal reactions in response to a computer breakdown were stronger for male than female subjects, while performing a task under time pressure. Although our studies were not intended to replicate the study design of Riedl et al. and thus did not explicitly manipulate time pressure, we still used our empirical data to identify a similar trend of gender differences in general (Boucsein, 2012; Boucsein et al., 2012; Randolph and Jackson, 2010), and in particular with regard to Riedl et al., because the time for ordering a ticket service was per se strictly limited both in Study 1 and Study 2. Since we assume that the generalization effect mitigates electrodermal reactions in Study 2, in contrast to Study 1, we tested for gender differences for each of the two studies separately and made the total SCR amplitudes comparable by taking the number of breakdown events into account.[79] Figure 22 depicts the corresponding boxplots for the SCR amplitudes per breakdown event, by study and gender. The descriptive statistics are listed in Table 19. A first visual inspection of the boxplots reveals that the SCR scores vary to a higher extent for male subjects and that the medians of male subjects for Study 1 (*Mdn*=5.18) and Study 2 (*Mdn*=5.40) clearly lie above the medians of the female subjects for Study 1 (*Mdn*=4.03) and Study 2 (*Mdn*=3.74). We next tested for significant differences in Study 1 by applying a Welch two sample t-test, be-

[79] In fact, we calculated standardized scores by dividing the total SCR amplitude by the number of breakdown events after one event was added to the latter variable for each participant to prevent division by zero.

cause Shapiro-Wilk normality tests[80] for male (*W*=0.93, *p*=0.23) and female subjects (*W*=0.86, *p*=0.09) of Study 1 indicated normally distributed data. The t-test revealed a marginally significant difference with a large effect size (*t* (9.2)=1.81, *p*=0.051, *d*=1.20, 95% CI [-0.03, inf]) and thus supports our visual inspection for Study 1.[81] Due to the fact that the SCR amplitudes per breakdown event of Study 2 were neither distributed normally for female (*W*=0.72, *p*<0.001) nor male participants (*W*=0.84, *p*=0.03), we applied a Wilcoxon rank sum test.[82] The test indicates that gender has no significant impact on the standardized SCR amplitudes in Study 2 (*W*=107, *p*=0.27, *d*=-0.42, 95% CI [-1.23, inf]). The latter result is even more intriguing with respect to the generalization effect and the significantly higher perceptions of alertness in Study 2 (for details see the last section). That is, higher perceptions of alertness would explain why the mean values of the standardized SCR amplitudes are higher for male and female subjects in Study 2 than in Study 1 and the generalization effect might explain that there are only significant differences in Study 1 between SCR amplitudes of male and female subjects, but not in Study 2. Further analyses and hypotheses tests according to the generalization effect are presented and discussed in the remainder of this dissertation. To summarize, we could observe significant effects of gender on electrodermal reactions in Study 1 and a trend in Study 2 that have already been shown in prior work.

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[80] R: `shapiro.test(study2011$SCRampPerBreakdown[study2011$Gender == "female"]); shapiro.test(study2011$SCRampPerBreakdown[study2011$Gender == "male"])`

[81] R: `t.test(study2011$SCRperBreakdown[study2011$Gender=="male"], study2011$SCRperBreakdown[study2011$Gender=="female"], alternative = "greater")`

[82] R: `wilcox.test(study2012$SCRperBreakdown[study2012$Gender == "male"], study2012$SCRperBreakdown[study2012$Gender=="female"], conf.int=T, alternative = "greater")`

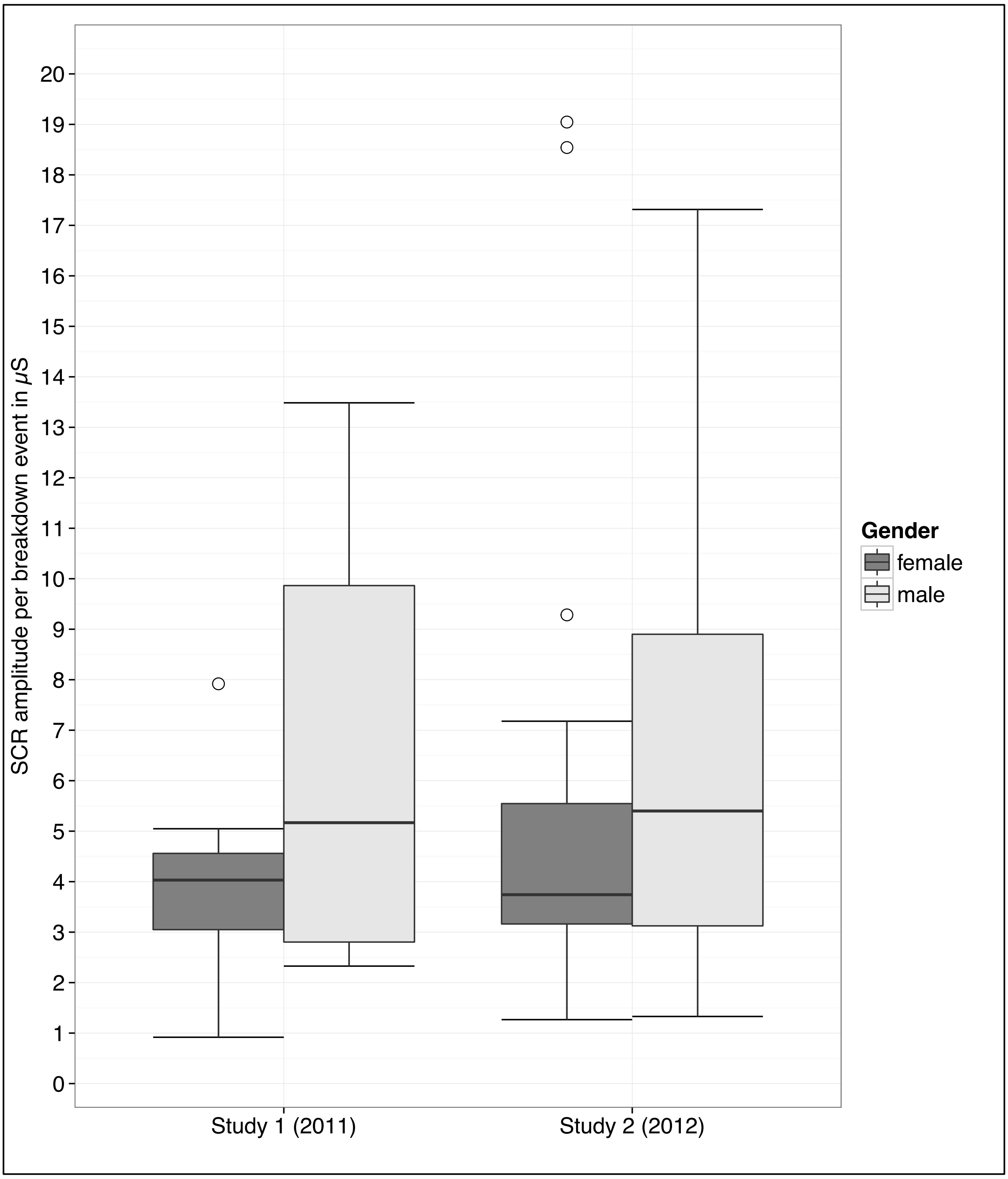

Figure 22. Boxplot for SCR amplitudes per breakdown event by study and gender

Second, it has been shown that electrodermal activity has a negative relationship to the age of a person due to drying-out processes of the skin (e.g. Boucsein, 2012; Boucsein et al., 2012; Randolph and Jackson, 2010). We therefore tested our data against these empirical findings from prior work to further assure external validity of our studies. For that purpose, we first aggregated our four age groups into two distinct age sub groups (below 24 and 25-34), because the number of cases in the two extreme groups, i.e. below 21 and above 30, was only three. We then calculated the mean values, medians and standard deviations for the SCR amplitudes per breakdown event for each of the two age groups. The descriptive statistics are shown in Table 19, while the corresponding boxplots are depicted in Figure 23. Visual inspections of the medians immediately indicate that our empirical data support prior findings with regard to the negative relationship between age and electrodermal activity. That is, all means and medians of the standardized SCR amplitudes are lower for the 'older' age group. We then investigated whether these observations are also statistically significant and meaningful. We started with Study 1. Shapiro-Wilk normality tests showed that the SCR amplitudes per breakdown event are only normally distributed for the older group of subjects (W=0.89, p=0.29) but not for the subjects below 24 (W=0.82, p=0.003).[83] Therefore, a Wilcoxon rank sum test was conducted that, in turn, revealed no significant differences between the age groups (W=0.60, p=50, d=-0.28, 95% CI [-1.36, inf]).[84] In Study 2, Shapiro-Wilk normality tests indicated that the standardized SCR amplitudes were neither normally distributed for the younger (W=0.81, p=0.004) nor for the older subjects (W=0.84, p=0.03).[85] However, in contrast to

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[83] R: `shapiro.test(studies$SCRperBreakdown[studies$Study=="Study 1 (2011)" & studies$Age==1]); shapiro.test(studies$SCRperBreakdown[studies$Study == "Study 1 (2011)" & studies$Age==2]);`

[84] R: `wilcox.test(studies$SCRperBreakdown[studies$Study=="Study 1 (2011)" & studies$Age==1], studies$SCRperBreakdown[studies$Study=="Study 1 (2011)" & studies$Age==2], conf.int=T, alternative = "greater");`

[85] R: `shapiro.test(studies$SCRperBreakdown[studies$Study=="Study 2 (2012)" & studies$Age==1]);`

Study 1, a Wilcoxon rank sum test resulted in significant differences and a large effect between the age groups in Study 2 (*W*=136, *p*=0.03, *d*=-0.88, 95% CI [0.18, inf])[86] that, in turn, replicate the findings of prior work.

Table 19. Descriptive statistics of SCR amplitudes per breakdown event by gender and age group. Note: the gender statistics are based on 15 (17) female and 9 (11) male subjects in Study 1 (2); the age statistics are based on 17 (16) subjects below < 25 years and 7 (12) are 25 to 34 in Study 1 (2).

Gender / Age group	Study 1 (2011) Single-exposure to UIS services			Study 2 (2012) Repeated-exposure to UIS services			Total		
	M	*Mdn*	*SD*	*M*	*Mdn*	*SD*	*M*	*Mdn*	*SD*
Gender									
Female	3.98	4.03	1.57	5.75	3.74	5.33	4.92	3.87	4.07
Male	6.80	5.18	4.40	7.06	5.40	5.57	6.94	5.28	4.99
Age									
< 25	5.30	4.50	3.65	7.93	5.52	1.98	6.57	4.53	5.19
25 – 34	4.40	4.03	6.28	4.04	3.35	2.70	4.17	3.58	2.41

```
shapiro.test(studies$SCRperBreakdown[studies$Study=="Study 2 (2012)" & studies$Age==2]);
```

[86] R:
```
wilcox.test(studies$SCRperBreakdown[studies$Study=="Study 2 (2012)" & studies$Age==1], studies$SCRperBreakdown[studies$Study=="Study 2 (2012)" & studies$Age==2], conf.int=T, alternative = "greater")
```

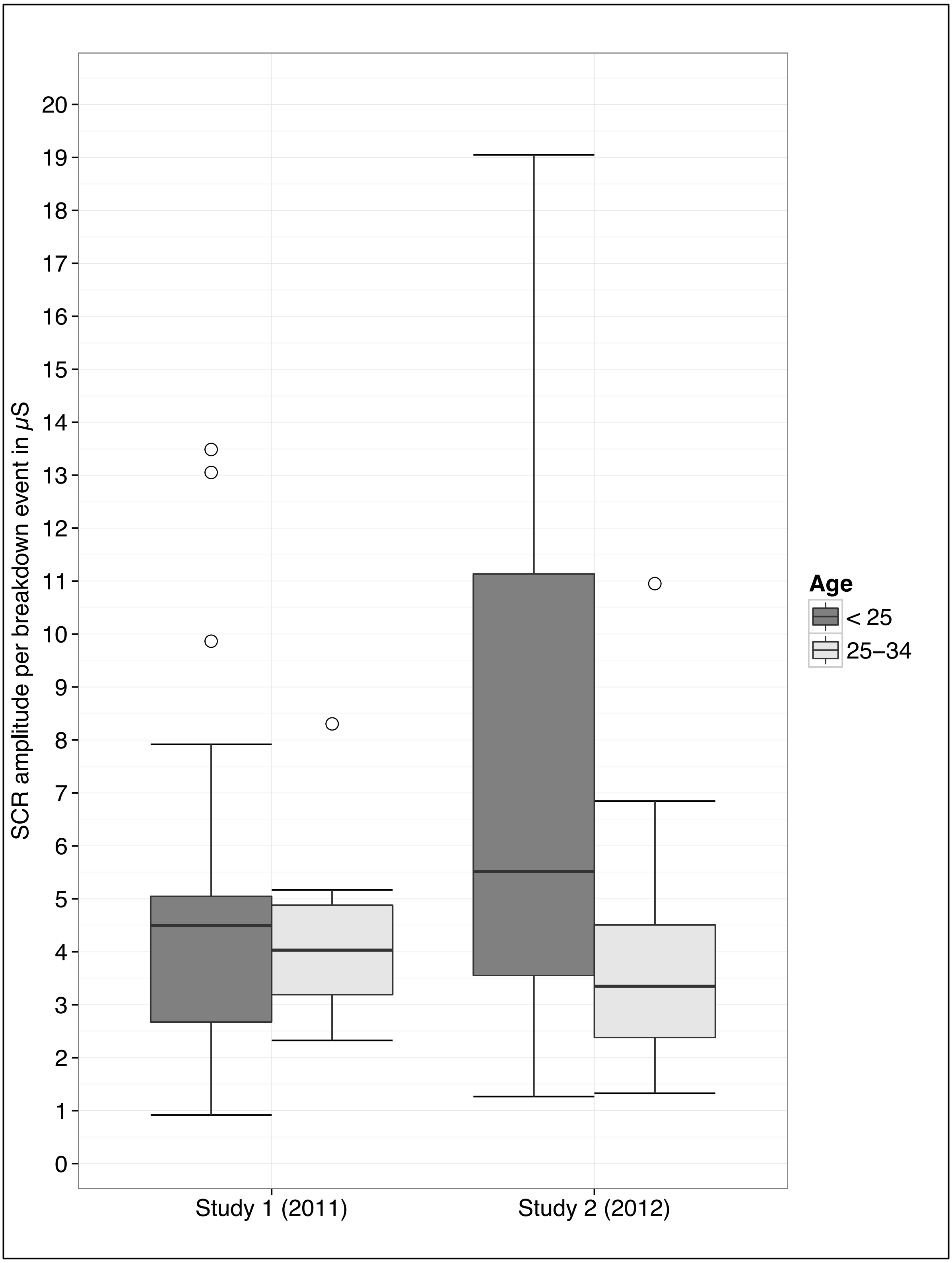

Figure 23. Boxplot for SCR amplitudes per breakdown event by study and age group

In accordance with the two findings discussed above, we next present an even more detailed view of our empirical data, which considers both gender and age effects in electrodermal reactions. A corresponding boxplot is depicted in Figure 24 and the descriptive statistics are listed in Table 20. The effects by gender and age described above are even more obvious from this detailed view, although some of the subgroups are almost too small to allow us to derive strong empirical implications. Nevertheless, against the background of this section and findings from prior work, with regard to gender and age differences in electrodermal reactions, we can conclude that the empirical data of the two studies adopted in the current work show substantial external validity. This, in turn, is a fundamental requirement in addition to the validity considerations outlined in the last section, not only for the interpretation of the results related to the hypotheses that follow in this chapter but also for the implications and generalizability of the results of the current work, as discussed in the last chapter.

Table 20. Descriptive statistics and subsample size (*n*) of SCR amplitudes per breakdown event by study, gender and age group.

	Study 1 (2011) Single-exposure to UIS services						**Study 2 (2012)** Repeated-exposure to UIS services					
	< 25			*25 – 34*			*< 25*			*25 – 34*		
	M	*Mdn*	*SD*	*M*	*Mdn*	*SD*	*M*	*Mdn*	*SD*	*M*	*Mdn*	*SD*
Gender												
Female	3.96	4.15	1.76	4.07	4.03	0.51	7.00	5.19	5.92	2.76	3.16	1.02
(*n*)		(12)			(3)			(12)			(5)	
Male	8.51	9.86	5.16	4.65	3.99	2.73	10.74	11.42	7.36	4.95	4.21	3.21
(*n*)		(5)			(4)			(4)			(7)	

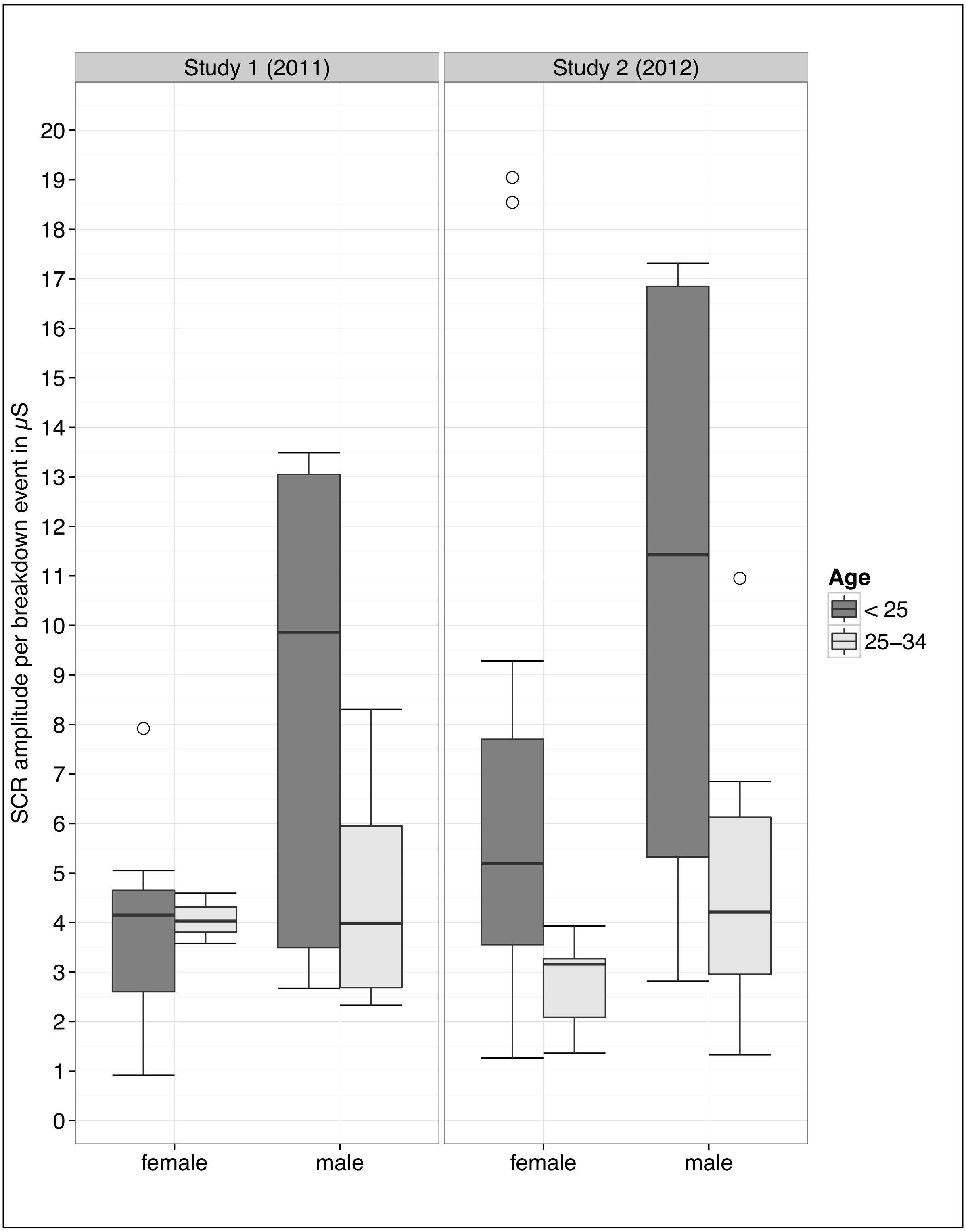

Figure 24. Boxplot for SCR amplitudes per breakdown event by study, gender and age group

5.5 PLS-SEM, sample size considerations and planned analyses

The objectives of this section are to justify the partial least squares structural equation modeling (PLS-SEM) approach as the focal statistical method used to test our hypotheses, to discuss sample size considerations with respect to the population of our studies and estimated effects, and in line with the latter objective to propose appropriate PLS-SEM analyses.

We find PLS-SEM appropriate to test our four hypotheses for the following reasons. First and foremost, the nature of the current research is rather explorative in the sense that there is, as we have seen in the literature review, only limited knowledge on the relationship of breakdown events and physiological arousal and, to the best of the author's knowledge, no existing evidence for significant electrodermal reactions in response to UIS services while subjects move around and use speech commands or touch gestures for human-computer interaction. Second, the explorative approach is also reflected by the relatively small sample sizes of both studies that can be handled by PLS-SEM algorithms. Third, PLS-SEM is also able to analyze empirical data that deviate from a normal distribution; and, in fact, as we have seen in the preceding sections, assumptions with regard to normally distributed data are violated to some degree and thus PLS-SEM seems to be appropriate. Fourth, PLS-SEM allows us to simultaneously assess both the measurement model (e.g. the factor loadings and measures of internal consistency of the three perceived ease of use items) and the structural model (e.g. the direction, strength and effect sizes of the hypothesized relationships among our constructs). Fifth, its algorithm aims at maximizing the explained variance of the dependent constructs in the structural model (e.g. task performance in the current work) and thus supports us in better understanding the impact of predicting constructs such as the frequency of breakdown events, physiological arousal or perceived ease of use. Sixth, PLS-SEM allows us to build reflective measurement models (i.e. indicators are consequences of the underlying construct. For example, the three perceived ease of use items adopted in the current work are manifestations of the construct perceived ease of use). By contrast, PLS-SEM also enables researchers to define formative measurement models, i.e. measures cause the underlying construct. For example, the time in seconds to order a ticket causes task performance. Seventh, there are PLS-SEM algorithms available which consider moderating variables and multi-group analyses that, in turn, are both concepts relevant to the current work with respect to the generalization effect between the two studies and also for the assessment of the first and third hypotheses. A detailed description of these conceptual and methodological advantages can be obtained from the corresponding literature on PLS-SEM (e.g. Chin, 1998; Chin et al., 2003; Dijkstra and Henseler, 2015; Gefen et al., 2000; Hair et al., 2014a; Hair et al., 2011; Hair et al., 2014b; Henseler et al., 2014; Peng and Lai, 2012; Ringle et al., 2012; Sarstedt et al., 2011). However, we also adopt PLS-SEM because the structure and hypothesized relationships of our research model are consistent with prior work that assesses S-O-R-like research models with PLS-SEM. Accordingly, PLS-SEM has been used not only in IS research that employs self-report instruments as the only method of data collection (e.g. Kamis et al., 2008; Xu et al., 2014a), but also in NeuroIS research related to this work that complements self-report instruments with physiological measures such as electrodermal activity (Moody and Galletta, 2015).

In line with the recommendations of Hair et al. (2014a), we now discuss sample size considerations and plan corresponding PLS-SEM analyses. With respect to the power calculation suggestions for PLS-SEM based on multiple regression analyses (e.g. Cohen, 1992; Hair et al., 2014a), our study populations allow us to detect large effects at the 5% level of significance for Study 1 (N=24, f^2=0.46) and Study 2 (N=28, f^2=0.39), with a statistical power of 80% which is common in IS research (Baroudi and Orlikowski, 1989). The power calculation is conducted with G*Power3 in the form of a sensitivity analysis for multiple regression (omnibus) and two predictors (Faul et al., 2007).[87] Moreover, we are able to identify medium effects if the empirical data is aggregated for both studies (*N*=*52,* f^2=0.18). This aggregation allows us to identify smaller effects on the inferential pathway from breakdown events to task performance via perceived ease of use, and also to test the basic hypothesized relationships of the automatic pathway via physiological arousal, while assuming, in this aggregated case, an alleviated generalization effect. Not only does that justify an aggregation of the empirical data from both studies, but also the following findings from Section 5.3: (1) We found no common method bias of the self-report data in each of the two studies and no significant differences related to the distributions of age and gender between the two sample populations; (2) Moreover, we found that subjects were quite similar with respect to their technology affinity and that there were no problems with the understandability and length of studies; (3) Only perceived alertness showed significant differences for both studies. However, aggregating the data would just increase the variance of variables related to alertness, in particular, physiological arousal. The latter is therefore not expected to be harmful with respect to the aggregation of the empirical data of the two studies if the generalization effect is not explicitly taken into account. Indeed, we will conduct a multi-group analysis to identify the generalization effect that, in turn, requires a comparison of the PLS-SEM results between the two studies without aggregating their empirical data.

Against this background, we conduct PLS-SEM analyses for each of the studies and for the aggregated data set to assess the basic relationships of the hypotheses, and we apply a multi-group analysis to test the mitigating moderation of the generalization effect. With reference to prior work (Hair et al., 2014a), Figure 25 and Figure 26 depict the path models for the two types of PLS-SEM analyses out-

[87] According to Hair et al. (2014a), the complexity of our PLS models in both studies is defined by the "maximum number of arrows pointing at a construct in the PLS path model)" (ibid., Chapter 1), i.e. in our case, two with physiological arousal and perceived ease of use predicting task performance.

lined above. The path model shown in Figure 25 includes both the measurement models, i.e. the relationship between the indicators (e.g. the three perceived ease of use questionnaire items) and their corresponding theoretical constructs of our research model (e.g. perceived ease of use), and the structural model, i.e. the relationships between the constructs.

With respect to the measurement model, and consistent with prior work (Kamis et al., 2008), we model the three questionnaire items of the perceived ease of use construct as reflective indicators because they are consequences of that construct. By contrast, electrodermal activity is measured with a single-item measure, i.e. the total SCR amplitude. As a consequence, the type (reflective or formative) of the measurement model must not be defined as its single-item indicator directly representing the construct. Correspondingly, we also model the frequency of breakdown events related to the ticket order service and the time to order a ticket as single-item indicators of UIS service breakdown events and task performance, respectively.

Regarding the structural model, the relationships of the constructs in the PLS-SEM correspond to the relationships of our research model for UIS service breakdown events, physiological arousal, perceived ease of use and task performance. By contrast, the generalization effect is assessed by a multi-group analysis due to its categorical nature given by the two studies (Sarstedt et al., 2011). In particular, we compare whether the automatic relationships between UIS service breakdown events and physiological arousal, as well as physiological arousal and task performance, differ significantly between both studies, as depicted in Figure 26.

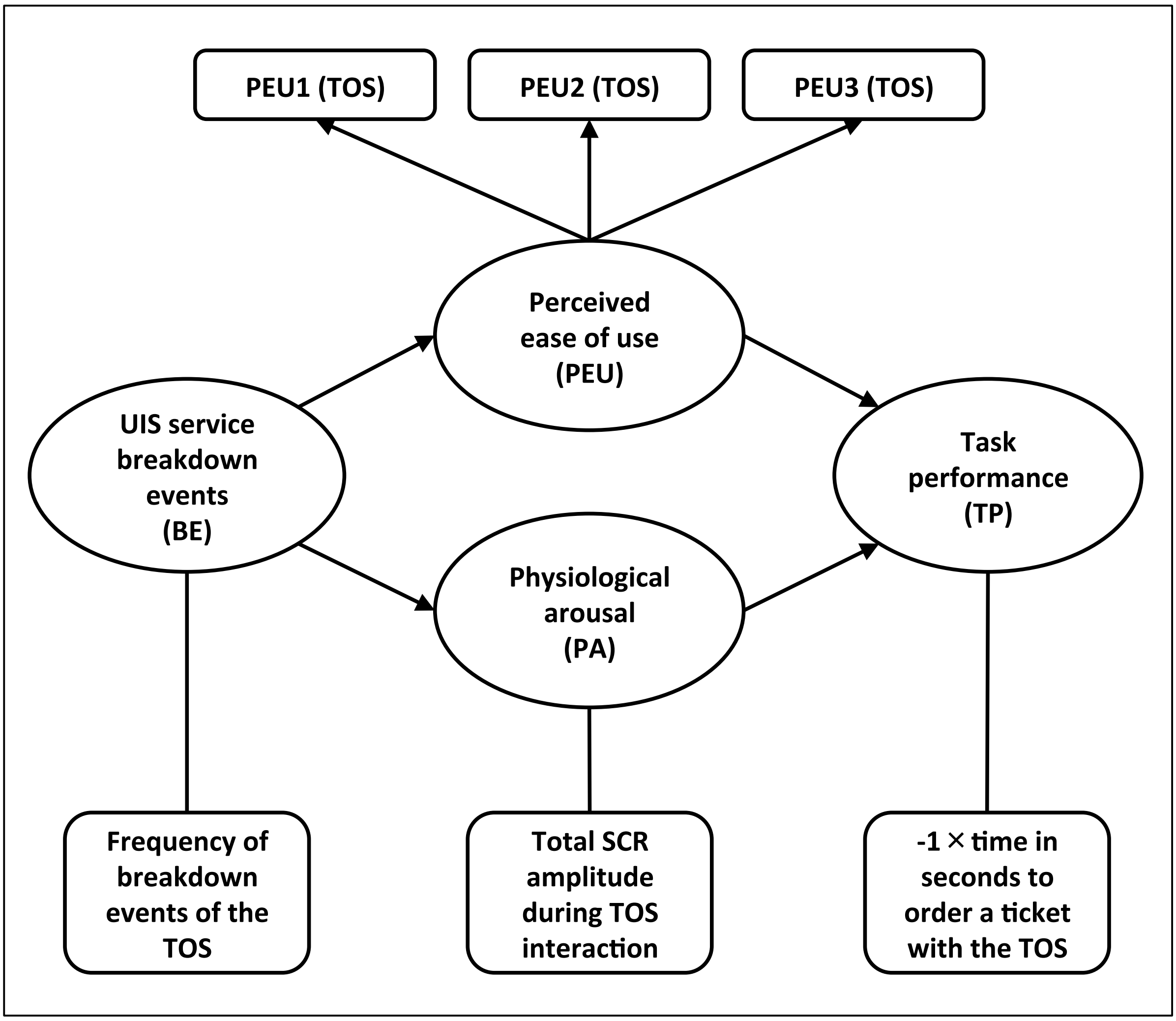

Figure 25. Measurement models and structural model for assessing the basic relationships of the hypotheses (i.e. excluding moderation effects) with PLS-SEM consisting of indicators (boxes) and manifest variables / constructs (ellipses). Note: PEU = Perceived ease of use; TOS = ticket order service.

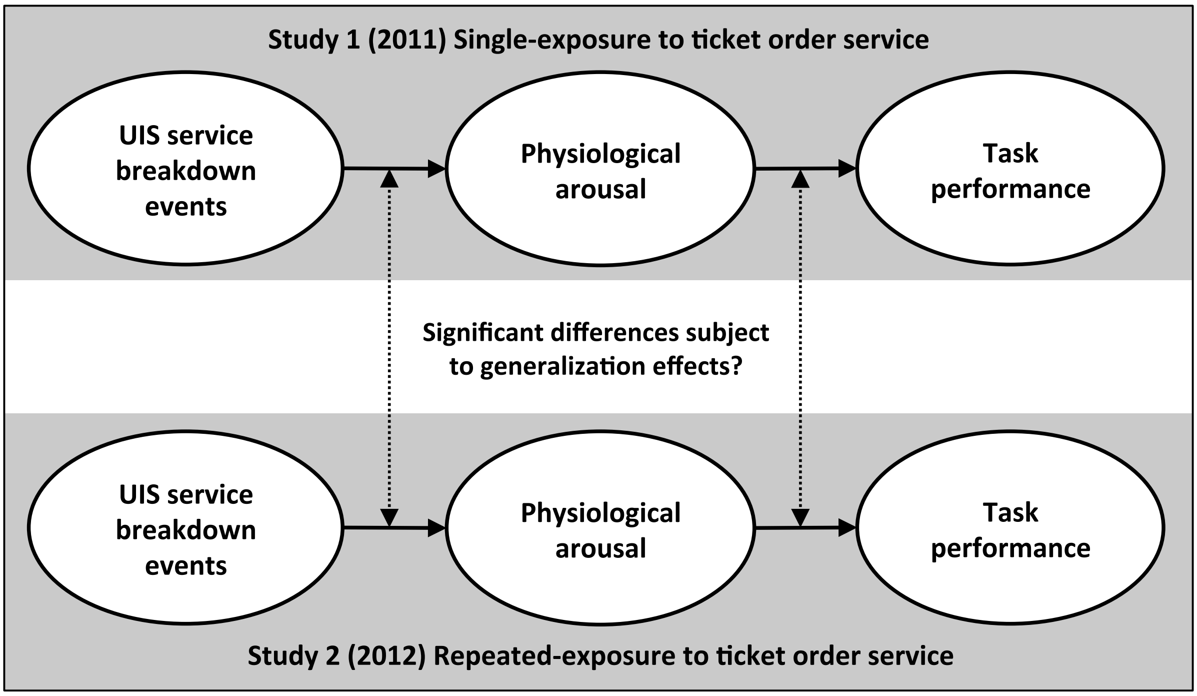

Figure 26. Categorical moderation in PLS-SEM to assess generalization effects. Note: PLS-SEM multi-group analysis is planned to assess whether there are significant differences between the relationships of both studies.

5.6 Assessment of the measurement models

This section assesses the measurement models with regard to assumptions about the raw data and quality criteria as recommended by Hair et al. (2014a). The actual results of the structural model and multi-group analyses with regard to our hypotheses are then reported in the next section of this chapter. It must be also noted that all criteria and calculations related to PLS-SEM analyses were performed by the SmartPLS 3.0 software for OS X (Ringle et al., 2015). In particular, the standard PLS algorithm was used with a maximum of 300 iterations and the path weighting scheme.[88]

[88] The standard PLS algorithm was used instead of the recently proposed consistent PLS algorithm (Dijkstra and Henseler, 2015), because (1) it is not yet assessed and adopted by a critical mass in the IS research community, (2) reported results in this work would be not consistent as the application of the multi-group analysis in the SmartPLS soft-

Although PLS-SEM can be used for empirical data that is not normally distributed, the degree of non-normality should be assessed because extreme deviations from a normal distribution mitigates the likelihood of finding significant effects (Hair et al., 2014a). We therefore conducted not only Shapiro-Wilk normality tests for all variables of the measurement model but assessed also two additional distributional measures known as skewness and kurtosis. Skewness reflects the symmetry of a distribution, while kurtosis indicates the degree to which a distribution is too peaked. Values close to zero for both measures represent a normal distribution, while deviations above 2 for skewness and above 7 for kurtosis indicate distributions that are substantially skewed and peaked (West et al., 1995). The corresponding values are listed in Table 21.[89] The results indicate that almost all variables differ significantly from a normal distribution, but only one measure (PEU3) in Study 2 lies close to the skewness threshold of two. We therefore expected no major limitations in finding significant effects due to extreme deviations from a normal distribution.

We next assessed the reliability and validity of our reflective measurement model built around the perceived ease of use construct, with respect to its internal consistency, indicator reliability, convergent and discriminant validity. First, internal consistency was assessed by composite reliability ρ_c, which should lie above 0.60 in exploratory, and above 0.70 in confirmatory, analyses. Composite reliabilities Study 1 (ρ_c=0.95), Study 2 (ρ_c=0.81) and the aggregate of both studies

ware still relies on the standard PLS algorithm, (3) with PEU2, we would have to drop an indicator important with regard to content validity due to an outer loading that is below the recommended threshold (Hair et al., 2014a), (4) our path model has only one reflective construct (i.e. perceived ease of use) and thus, any corrections of the path coefficients would be limited and, in fact, (5) in fact, the application of consistent PLS reveals no meaningful differences with respect to our hypotheses.

[89] The calculations are based on the R functions shapiro.test() of the stats package Version 3.2.2 and skewness() and kurtosis() of the e1071 package Version 1.6-7.

(ρ_c=0.93) all lie above the recommended thresholds and thus meet the requirement for internal consistency.

Table 21. Deviation from normal distribution (DN), skewness (S) and kurtosis (K) of the variables of the research model. Note: TOS = ticket order service; DN = W statistic from Shapiro-Wilk normality tests; * / ** / *** = p < .05 / .01 / .001

Construct / Measure	**Study 1 (2011)** Single-exposure to UIS services (*N*=24)			**Study 2 (2012)** Repeated-exposure to UIS services (*N*=28)			**Total** (*N*=52)		
	DN	*S*	*K*	*DN*	*S*	*K*	*DN*	*S*	*K*
Breakdown events related to the TOS*	.85**	1.07	0.29	.88**	0.72	-0.80	.88***	0.91	-0.12
Total SCR amplitude in µS during TOS use*	.94	0.49	-0.94	.82***	1.28	0.51	.86***	1.41	1.61
Perceived ease of use (PEU) of TOS									
PEU1	.85**	-0.25	-1.59	.81***	-1.14	0.35	.84***	-0.70	-0.88
PEU2	.84***	-0.50	-0.52	.88**	-0.77	-0.20	.90***	-0.64	-0.32
PEU3	.84***	-0.79	0.60	.61***	-2.14	4.05	.75***	-1.59	2.57
Task performance, i.e. time in s to order a ticket with the TOS*	.94	0.67	0.18	.87**	1.07	0.22	.95*	0.73	-0.11

Second, indicator reliability is given if the three standardized factor loadings (SFL) of the perceived ease of use construct lie above 0.708. The loadings of our empirical data all lie above this threshold, i.e. for Study 1 ($SFL_{PEU1\,/\,2\,/\,3}$ = 0.94 / 0.95 / 0.92), of Study 2 ($SFL_{PEU1\,/\,2\,/\,3}$ = 0.92 / 0.76 / 0.94) and for the aggregated values from both studies ($SFL_{PEU1\,/\,2\,/\,3}$ = 0.93 / 0.88 / 0.92). As a consequence, indicator reliability can be assumed.

Third, convergent validity of the perceived ease of use construct was assessed by the average variance extracted (AVE), which is calculated by the total mean of the squared outer loadings of the three perceived ease of use indicators. The AVE should lie above 0.50, which it does for the perceived ease of use construct in Study 1 (AVE=0.87), Study 2 (AVE=0.77) and the aggregated data set from both studies (AVE=0.83).

We finally assessed the discriminant validity of the perceived ease of use measures by using the Fornell-Larcker criterion. For that purpose, we calculated the square root of the AVE of perceived ease of use and evaluated whether it is higher than its highest correlation with any of the remaining latent variables, i.e. breakdown events, physiological arousal and task performance. The corresponding correlations and the square root of the AVE of perceived ease of use (0.94) are shown in Table 22. The correlations are all lower than 0.94, and thus discriminant validity of the perceived ease of use construct can be assumed for all study samples.

Table 22. Assessment of the discriminant validity of perceived ease of use (Fornell-Larcker criterion). Note: the diagonals represent the square root of the average variance explained; successive figures indicate the values for Study 1, Study 2 and the aggregated data set of both studies.

Construct	PEU	BE	PA	TP
Perceived ease of use (PEU)	**0.94 0.88 0.91**			
UIS service breakdown events (BE)	-0.59 -0.34 -0.44	**1**		
Physiological arousal (PA)	-0.41 -0.21 -0.26	0.57 0.39 0.43	**1**	
Task performance (TP)	-0.49 -0.38 -0.44	0.76 0.90 0.81	0.74 0.19 0.31	**1**

An assessment of the three remaining formative measurement models with regard to convergent validity, collinearity issues, and the significance of the indicators as recommended by Hair et al. (2014a) is not feasible because of their single-item structure (i.e. all outer loadings are one, per definition) and because no empirical data was collected in both Study 1 and Study 2 to be able to perform a redundancy analysis.

5.7 Evaluation of the structural model and hypotheses

The objectives of this section are the assessment of the structural model and the evaluation of the results with regard to our hypotheses. We therefore present corresponding quality criteria related to collinearity issues, path coefficients (β), (adjusted) coefficients of determination (R^2, R^2_{adj}), effect sizes (f^2), predictive relevance scores (Q^2) and q^2 effect sizes for each of the two studies and also for the aggregated sample population. Against these assessments we then tested to which degree the empirical findings support the hypothesized relationships. In order to assess the mitigating moderation effect subject to generalization phenomena, we also report the results of a multi-group analysis with the type of UIS exposure (i.e. single-exposure to UIS services in Study 1 versus repeated-exposure in Study 2) as the categorical group factor (Sarstedt et al., 2011). The following results rely on a complete bias-corrected and accelerated bootstrapping approach with 5,000 subsamples and one-sided tests for confidence intervals at the .05 level of significance (Ringle et al., 2015). Finally, critical thresholds regarding the quality criteria that are reported in the following paragraphs are derived from Hair et al. (2014a).

We first tested for any collinearity issues that might strongly bias the interpretation and discussion of any subsequent empirical findings. Correspondingly, dependent constructs should be predicted only by other constructs that are not highly correlated with each other. We therefore had to test for collinearity issues between physiological arousal and perceived ease of use, which both predict task performance in our structural model. A common criteria used to assess collinearity in PLS-SEM is the variance inflation factor (VIF). For a given predictor variable (e.g. physiological arousal), it indicates the degree to which variance is increased in a dependent variable (e.g. task performance) because of its collinearity with other predictor variables (e.g. perceived ease of use). The VIF value should not lie above 5, which would be indicative of a collinearity problem. With respect to our empirical data, the corresponding values of physiological arousal ($VIF_{Study1\ /\ 2\ /\ total}$ = 1.20 /1.05 / 1.07) and perceived ease of use ($VIF_{Study1\ /\ 2\ /\ total}$ = 1.20 /1.05 / 1.07) all lie markedly below the critical threshold, and thus we assume no collinearity issues with regard to our structural model.

We now describe and report on not only the path coefficients (*β)* and the (adjusted) coefficients of determination (R^2 and R^2_{adj})[90] but also the effect size f^2, Stone-Geisser's predictive relevance criterion (Q^2) (Geisser, 1974; Stone, 1974) and its related q^2 effect size, to better understand the quality of the structural model and to derive more fine-grained model interpretations (Hair et al., 2014a). While the path coefficient determines whether there is a positive or negative relationship between two constructs, R^2 indicates the predictive accuracy for a construct (e.g. task performance) and reflects the variance of that construct that is explained by its predictor constructs (e.g. physiological arousal and perceived ease of use). However, one has to bear in mind that comparing R^2 values can only be an approximation, as usually no adjusted values R^2_{adj} are reported which consider the complexity of a structural model (i.e. the number of predicting variables) and its underlying sample size, both of which make comparisons of predictive accuracies more comprehensible. Thus, we report in our work both R^2 and R^2_{adj}, which allows us to compare the predictive accuracies of our three structural models (i.e. from Study 1, Study 2 and the aggregated empirical data) with one another. Next, the effect size f^2 indicates whether the predicting construct has a substantial impact on the predicted construct in terms of variance explained. The values can be inter-

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[90] Path coefficients and R^2 values are the two most common quality criteria for assessing the structural model in PLS-SEM analyses.

preted as described by Cohen (1988).[91] We refer to f^2 effects close and above 0.15 as substantial. Furthermore, a dependent construct's Q^2 value indicates predictive relevance, if the structural model predicts its indicators accurately.[92] The Q^2 values should lie above zero to exhibit predictive relevance. Finally, q^2 represents the effect size to which a predicting construct contributes to a predicted construct's Q^2. Analogous to f^2 effect sizes, q^2 are interpreted.[91]

An overview of the R^2 values, R^2_{adj} values, Q^2 values and path coefficients for the aggregated data from both studies is shown in Figure 27, whereas the results for Study 1 are depicted in Figure 28, and for Study 2 in Figure 29. As a result of the multi-group analysis as proposed by Sarstedt et al. (2011), Figure 30 depicts the delta values of the two path coefficients of the automatic pathway of our research model. Additionally, the four drawings indicate whether the path coefficients or delta values are significantly greater or lower than zero. The effect sizes f^2 and q^2, along with a systematic overview of all empirical findings related to the hypotheses, are listed in Table 23. We now highlight the key findings.

First and foremost, it can be concluded that the fundamental relationships as formulated in all four hypotheses are supported for the aggregated data from both studies, as shown in Figure 27. That is, the relationship between UIS service breakdown events and (a) physiological arousal (H1)[93] is positive, significant and

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[91] That is, f^2 values of 0.02 / 0.15 / 0.35 stand for small / medium / large effects.

[92] The Q^2 values are only applicable to reflective measurement models, i.e. perceived ease of use in our case, or single-item measurement models such as for UIS service breakdown events, physiological arousal and task performance. We use the blindfolding procedure with the cross-validated redundancy approach and an omission distance of 10 in SmartPLS to derive the Q^2 values. The omission distance 10 is chosen, as recommended by Hair et al. (2014a), because the number of observations divided by 10 yields no integer value.

[93] The hypothesized mitigating moderation subject to generalization effects is assumed to be weak because the empirical data of both studies is aggregated in this case. Results

substantial (β=0.429, p<0.001, f^2=0.225, q^2=0.196), and (b) perceived ease of use (H2) is negative, significant and substantial (β=-0.440, p<0.001, f^2=0.241, q^2=0.171), while the relationship between physiological arousal and task performance (H3)[93] is negative and significant (β=-0.213, p=0.037, f^2=0.055, q^2=0.006) and the relationship between perceived ease of use and task performance (H4) is positive, significant and substantial (β=0.380, p=0.007, f^2=0.176, q^2=0.108).

Second, the subsets of the empirical data derived from Study 1 and Study 2, still support the basic relationships of all four hypotheses with reference to the direction of the path coefficients, as shown in Figure 28 and Figure 29. And even though the statistical power of these subsamples, compared to the aggregated sample data of both studies, is lower, we still find significant and substantial relationships between breakdown events and (a) physiological arousal (Study 1: β=0.565, p<0.001, f^2=0.468, q^2=0.427; Study 2: β=0.393, f^2=0.183, q^2=0.074), and (b) perceived ease of use (Study 1: β=-0.589, p<0.001, f^2=0.530, q^2=0.328; Study 2: β=-0.337, p<0.001, f^2=0.128, q^2=0.056). In addition, we find a negative and significant relationship with the largest effect of all relationships between physiological arousal and task performance in Study 1 (β=-0.655, p<0.001, f^2=0.879, q^2=0.663), and a positive and marginally significant relationship between perceived ease of use and task performance in Study 2 (β=0.359, p=0.077, f^2=0.147, q^2=0.025).

Third, empirical evidence for the hypothesized moderation in H1 and H3 can also be identified, as depicted in Figure 30. Here, we hypothesized that the strength of the relationships of the automatic pathway of our research model, and thus also the corresponding path coefficients in the structural model, are mitigated as a consequence of generalization effects. In fact, the path coefficients between UIS service breakdown events and physiological arousal (H1: β=0.565 in Study 1

with regard to the moderation will be presented later in this section and rely on a multi-group analysis that compares the path coefficients of Study 1 and Study 2 for the automatic pathway of our research model, as depicted in Figure 30.

versus β=0.393 in Study 2), and between physiological arousal and task performance (H3: β=-0.655 in Study 1 versus β=-0.116 in Study 2), are clearly weaker in the repeated-exposure Study 2 than in Study 1, where subjects were exposed only once to the ticket order service. However, only the delta of the path coefficients of the latter relationship is large enough such that it is significantly smaller than zero (β_{delta}=-0.539, p=0.007).

Fourth, with respect to the predictive accuracy of our model (R^2), there are no common thresholds among research disciplines. For example, in consumer research, predictive accuracies of 20% would be perceived as good, while in other disciplines higher predictive accuracies are to be expected (Hair et al., 2014a). We therefore compare the predictive accuracy with related NeuroIS research. With regard to Study 1, we observe a relatively high predictive accuracy of R^2_{adj} = 59.4% for task performance, which outperforms the not adjusted R^2 of 52% for the same construct reported by Moody and Galletta (2015), even though their model includes three variables predicting task performance.[94] Moreover, the predictive accuracies of physiological arousal in our aggregated sample (R^2_{adj} = 16.8%) and in Study 1 (R^2_{adj} = 28.8%) are comparable and even higher than Moody and Galletta's stress construct (R^2 = 22.9%), which is formed by four physiological measures, including electrodermal activity. Similarly, our R^2_{adj} = 59.4% for task performance in Study 1 also outperforms the reported R^2_{adj} = 21% of the same construct in the study presented by Tams et al. (2014), where task performance is predicted not only by a psychological and physiological measure of stress but also by further control variables. Even for the aggregated data of both studies, our R^2_{adj} = 20.0% for task performance would be comparable with prior work (ibid.). We therefore conclude that in particular the model of Study 1 has a high predictive

[94] Because of three predictor variables of task performance in the model of Moody and Galletta (2015), R^2_{adj} probably lies markedly below the reported R^2 of 52%.

accuracy, which is at least as high if not higher than related NeuroIS research (Moody and Galletta, 2015; Tams et al., 2014).[95]

Fifth, the Q^2 values derived from the empirical data of both studies and Study 1 indicate predictive relevance for physiological arousal (Q^2_{both}=16.4%, Q^2_{Study1}=29.9%), perceived ease of use (Q^2_{both}=14.6%, Q^2_{Study1}=24.7%) and task performance (Q^2_{both}=14.8%, Q^2_{Study1}=42.0%), as they all lie above the recommended threshold of zero. Predictive relevance is also given for physiological arousal (Q^2_{Study2}=6.9%) and perceived ease of use (Q^2_{Study2}=5.3%), but not for task performance (Q^2_{Study2}=-0.4%) for the empirical data of Study 2. The latter finding is not surprising because we assume the generalization effect to impact task performance (cf. H3), which, in turn, may mitigate the predictive relevance of task performance as a consequence of reduced variations in physiological arousal in Study 2. Indeed, the path coefficient between physiological arousal and task performance is not significant (β=-0.116, p=0.203) and both effect sizes f^2=0.015 and q^2=0.040 are close to zero.

To summarize this section by referring to the five key findings described above, and considering the systematic overview of the empirical findings listed in Table 23, we can conclude that H1 and H4 are partly supported by the empirical data, while H2 and H3 are fully supported.

[95] For the aggregated data and Study 2 we would not expect such high predictive accuracies because of the generalization effects, as hypothesized in H1 and H3.

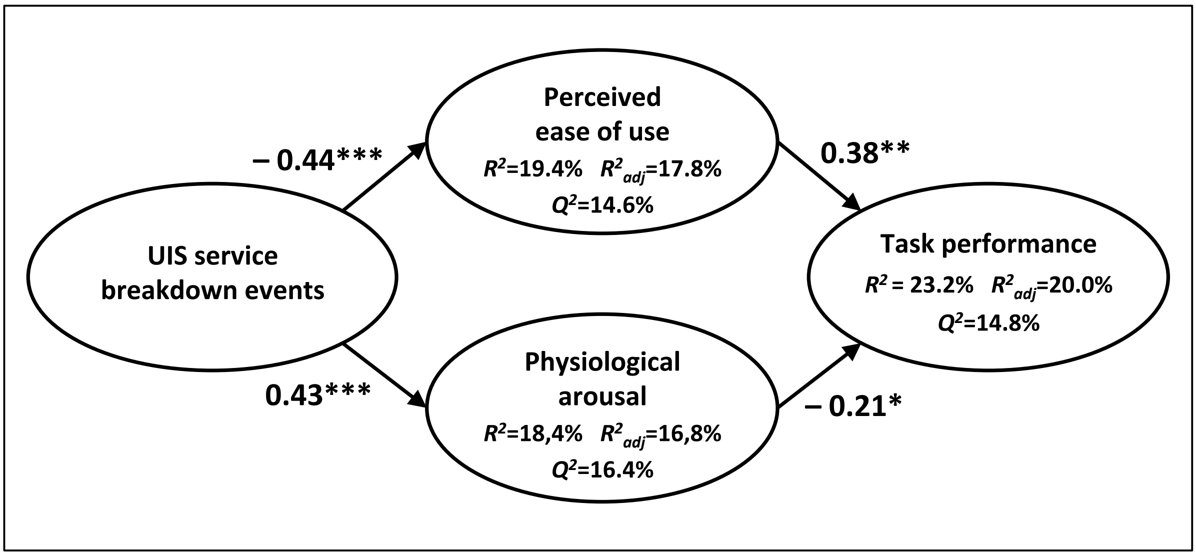

Figure 27. PLS results for both studies (*N*=52). Note: * / ** / *** = p < .05 / .01 / .001

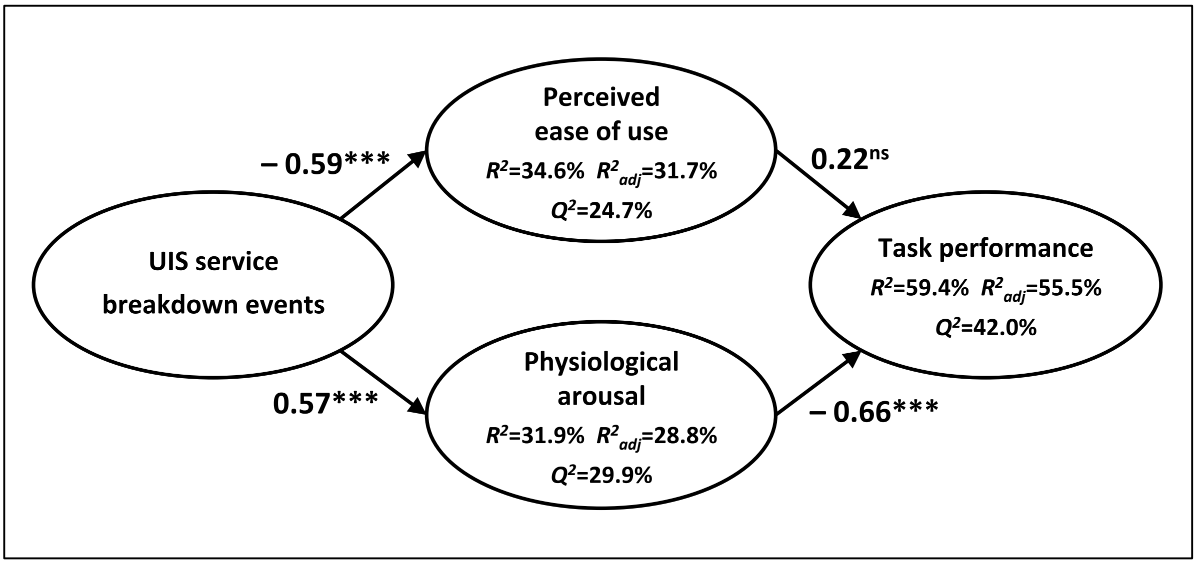

Figure 28. PLS results for Study 1 (2011, *N*=24, single-exposure to UIS services).
Note: ^{ns} / *** = p > .10 / p < .001

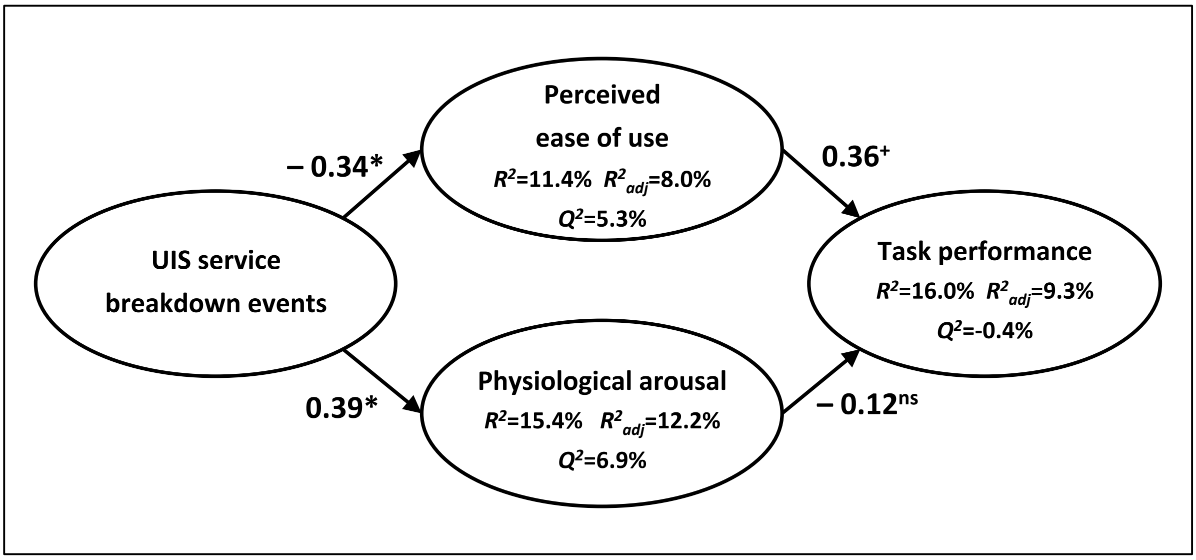

Figure 29. PLS results for Study 2 (2012, *N*=28, repeated-exposure to UIS services). Note: ns / + / * = p > 0.10 / p < .10 / .05

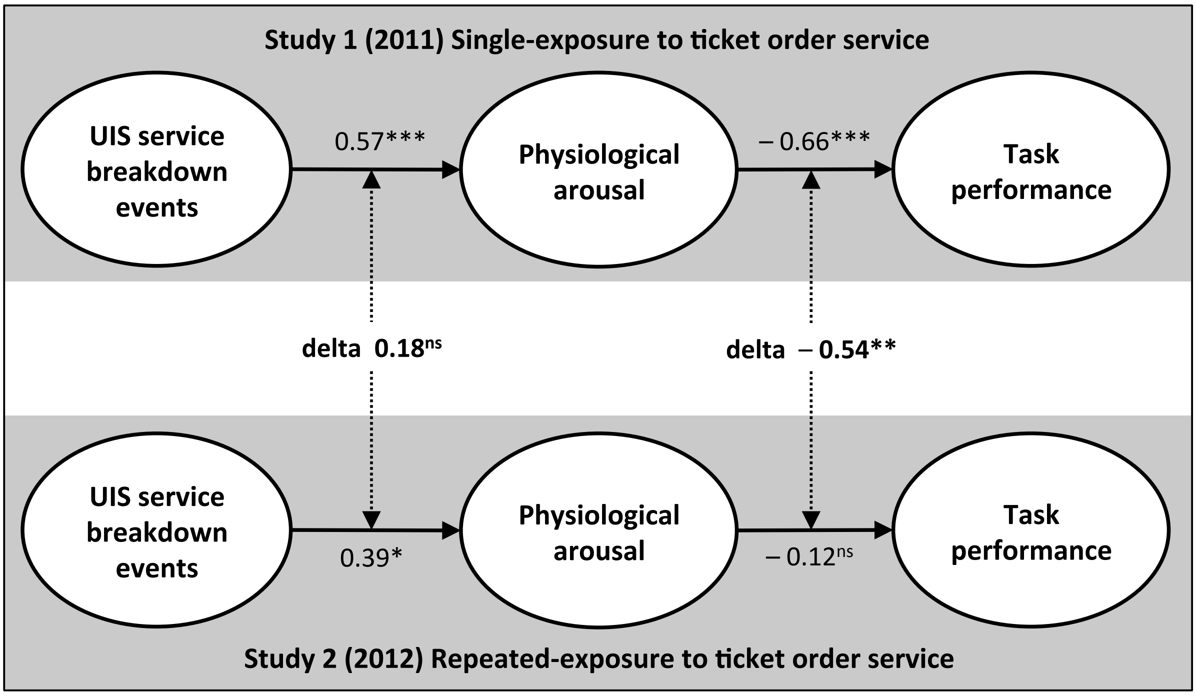

Figure 30. PLS results of the multi-group analysis of the automatic pathway of Study 1 (*N*=24) and Study 2 (*N*=28). Note: ns / * / ** / *** = p > .10 / p < .05 / .01 / .001

Table 23. Systematic overview of the empirical findings with regard to the hypotheses. Note: Subjects were exposed to the ticket order service only once in Study 1 (ST1), while they are exposed three times to the same UIS service in Study 2 (ST2); generalization effects are expected to be lower for empirical findings based on the aggregated data of both studies (ST12), and thus f^2 values are expected to be significant but not substantial in H1 and H3.

#	Hypothesis (H)	Assumption	Finding		Result
H1	The generalization effect will mitigate the positive relationship between breakdown events of a UIS service (BE) and physiological arousal (PA) for individuals who were confronted with similar services in advance.	β_{ST1} (BE➔PA) should be positive, significant and substantial.	β_{ST1} (BE➔PA) is positive, significant and substantial (β=0.565, p<0.001, f^2=0.468, q^2=0.427).	✔	Almost fully supported
		β_{ST12} (BE➔PA) should be positive and significant.	β_{ST12} (BE➔PA) is positive, significant and substantial (β=0.429, p<0.001, f^2=0.225, q^2=0.196).	✔	
		β_{ST2} (BE➔PA) should be positive.	β_{ST2} (BE➔PA) is positive, significant and substantial (β=0.393, p=0.011 f^2=0.183, q^2=0.074).	✔	
		β_{ST2} (BE➔PA) should be weaker than β_{ST1} (BE➔PA).	β_{ST2} (BE➔PA, β=0.393) is weaker than β_{ST1} (BE➔PA, β=0.565).	✔	
		Delta of β_{ST1} (BE➔PA) and β_{ST2} (BE➔PA) should be significant.	Delta of β_{ST1} (BE➔PA) and β_{ST2} (BE➔PA) is not significant (β_{delta}=0.172, p=0.215).[96]	✖	

[96] Note: β_{delta} is derived from the bootstrapping procedure and thus differs slightly from what is depicted in Figure 30 as the latter is derived from the original data.

#	Hypothesis (H)	Assumption	Finding		Result
H2	Breakdown events of a UIS service (BE) are negatively related with perceived ease of use (PEU) with respect to that service.	β_{ST1} (BE➔PEU) should be negative, significant and substantial.	β_{ST1} (BE➔PEU) is negative, significant and substantial (β=-0.589, p<0.001, f^2=0.530, q^2=0.328).	✔	Fully supported
		β_{ST12} (BE➔PEU) should be negative, significant and substantial.	β_{ST12} (BE➔PEU) is negative, significant and substantial (β=-0.440, p<0.001, f^2=0.241, q^2=0.171).	✔	
		β_{ST2} (BE➔PEU) should be negative, significant and substantial.	β_{ST2} (BE➔PEU) is negative, significant and substantial (β=-0.337, p<0.001, f^2=0.128, q^2=0.056).	✔	
H3	The generalization effect will mitigate the negative relationship between physiological arousal (PA) and task performance (TP) for individuals who were confronted with similar UIS services in advance.	β_{ST1} (PA➔TP) should be negative, significant and substantial.	β_{ST1} (PA➔TP) is negative, significant and substantial (β=-0.655, p<0.001, f^2=0.879, q^2=0.663).	✔	Fully supported
		β_{ST12} (PA➔TP) should be negative and significant.	β_{ST12} (PA➔TP) is negative and significant (β=-0.213, p=0.037, f^2=0.055, q^2=0.006).	✔	
		β_{ST2} (PA➔TP) should be negative.	β_{ST2} (PA➔TP) is negative (β=-0.116, p=0.203, f^2=0.015, q^2=0.040).	✔	
		β_{ST2} (PA➔TP) should be weaker than β_{ST1} (PA➔TP).	β_{ST2} (PA➔TP, β=-0.116) is weaker than β_{ST1} (PA➔TP, β=-0.655).	✔	

#	Hypothesis (H)	Assumption	Finding		Result
		Delta of β_{ST1} (PA➔TP) and β_{ST2} (PA➔PA) is significant.	Delta of β_{ST1} (PA➔TP) and β_{ST2} (PA➔TP) is significant (β_{delta}=-0.539, p=0.007).	✔	
H4	An individual's perceived ease of use of an UIS service (PEU) has a positive relationship with task performance (TP).	β_{ST1} (PEU➔TP) should be positive, significant and substantial.	β_{ST1} (PEU➔TP) is negative but neither significant nor substantial (β=0.219, p=0.130, f^2=0.098, q^2=0.226).	✖	Partly supported
		β_{ST12} (PEU➔TP) should be positive, significant and substantial.	β_{ST12} (PEU➔TP) is negative, significant and substantial (β=0.380, p=0.007, f^2=0.176, q^2=0.108).	✔	
		β_{ST2} (PEU➔TP) should be positive, significant and substantial.	β_{ST2} (PEU➔TP) is negative and substantial but not significant (β=0.359, p=0.077, f^2=0.147, q^2=0.025).	✖	

5.8 Assessing the higher-order construct ease of use

The final objective of this chapter is to test whether physiological arousal and perceived ease of use are complementary rather than alternative measures. We therefore address the last research question in this section. With reference to the theoretical rationale that proposes a higher-order construct ease of use consisting of physiological and psychological dimensions as described in Chapter 3, we first report on empirical findings that support this assumption. Thereafter, and in reference to the rationale of Tams et al. (2014), we assessed (1) whether physiological arousal and perceived ease of use show a rather weak relationship among each other, which would indicate that they measure different dimensions of ease of use, and (2) whether a model that includes both measures (instead of only one) adds substantial predictive accuracy and predictive relevance with respect to a theoretically related outcome measure. That outcome is task performance in our case.

First, in Chapter 3 we proposed a higher-order construct ease of use, which consists of the physiological dimension physiological arousal (measured by the total SCR amplitude during UIS service use) and the psychological dimension perceived ease of use (measured by the three perceived ease of use items).[97] In order to support the theoretical assumptions about that ease of use construct, we would assume that similar patterns of predictive accuracies and predictive relevance of physiological arousal and perceived ease of use as a consequence of UIS service breakdown events in each of the studies can be observed. And in fact, similar patterns are evident for the models of each of the studies and for the aggregated data set of both studies. That is, physiological arousal (PA) and perceived ease of use (PEU) both score rather high in Study 1 ($R^2_{adj,PA}$ = 28.8%, $R^2_{adj,PEU}$ = 31.7% and Q^2_{PA} = 29.9%, Q^2_{PEU} = 24.7%), rather low in Study 2 ($R^2_{adj,PA}$=12.2%, $R^2_{adj,PEU}$ = 8.0% and Q^2_{PA} = 6.9%, Q^2_{PEU} = 5.3%) and, consequently, in between for both studies ($R^2_{adj,PA}$=16.8%, $R^2_{adj,PEU}$ = 17.8% and Q^2_{PA} = 16.4%, Q^2_{PEU} = 14.6%). The patterns are visually depicted in Figure 31, for ease of presentation, too. Moreover, we would also expect similar patterns with regard to the strength of path coefficients between UIS service breakdown events and physiological arousal and perceived ease of use. Again, in reference to the findings reported in the last section and as shown in Figure 32, these assumptions find empirical support. We can therefore preliminary conclude that, in addition to the theoretical rationale provided in Chapter 3, the data of both studies support the assumption of a common higher-order construct referred to as ease of use.

[97] It must be noted that, due to the operationalization of physiological arousal in our work, the physiological dimension is reverse coded, i.e. a high degree of total SCR amplitudes reflects a lower ease of use score.

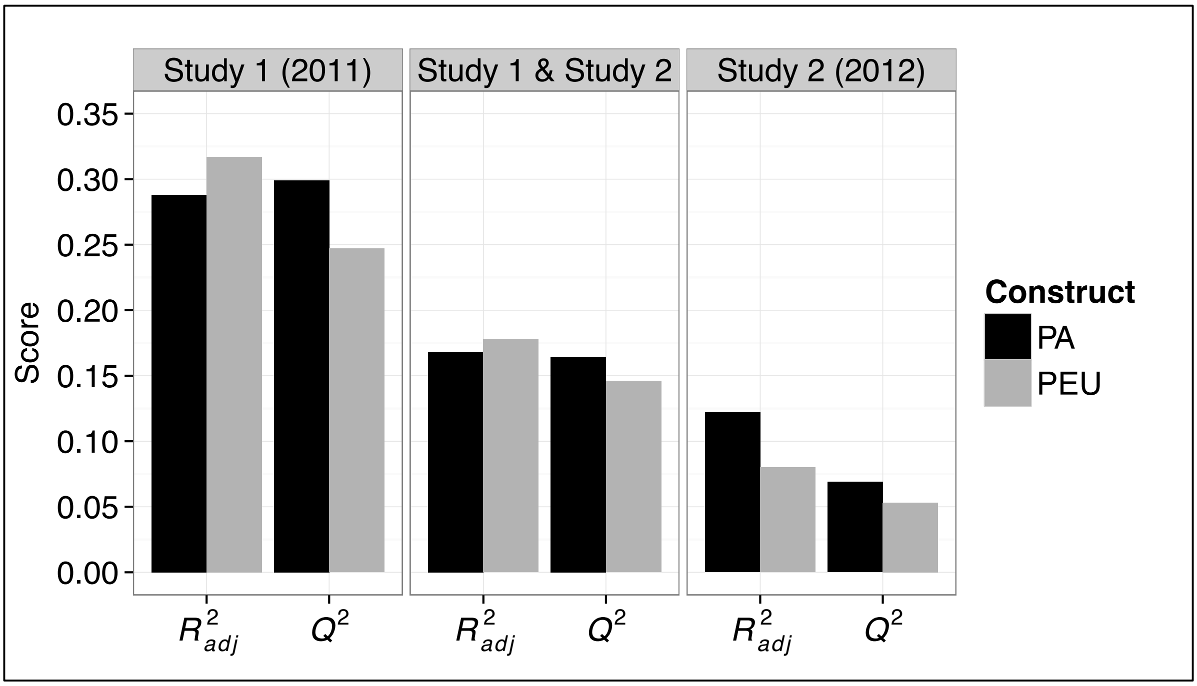

Figure 31. Adjusted predictive accuracies (R^2_{adj}) and predictive relevance scores (Q^2) for physiological arousal (PA) and perceived ease of use (PEU).

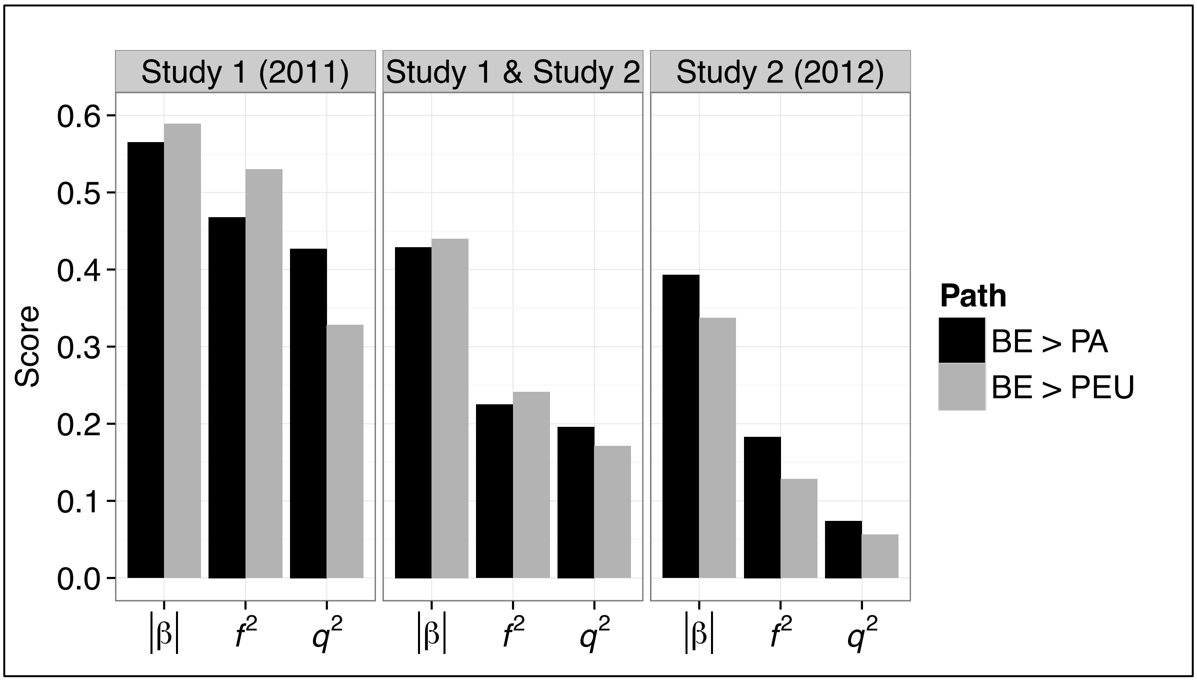

Figure 32. Absolute values (strength) of path coefficients (β), effect sizes f^2 and q^2 with respect to the relationships between breakdown events (BE) and (a) physiological arousal (PA) and (b) perceived ease of use (PEU).

Next, we tested whether physiological arousal and perceived ease of use show a rather weak relationship, which would indicate that they measure different dimensions of ease of use (Tams et al., 2014). In Section 5.6, we already reported findings that support a correspondingly weak correlation among these constructs. That is, we found no collinearity issues between both constructs in predicting task performance. This, in turn, is a first indicator for the complementary characteristics of the physiological and psychological dimension with respect to the higher-order construct ease of use. Additionally, we test the relationship between physiological arousal and perceived ease of use by building a model in which physiological arousal predicts perceived ease of use.[98] The corresponding path model with the structural components and measurement items is depicted in Figure 33. Against the background of the empirical findings of the last section and the rationale provided in Chapter 3, we would assume a negative relationship. Indeed, the empirical findings support this assumption for Study 1 (β=-0.410, p=0.016, f^2=0.203, q^2=0.119), Study 2 (β=-0.305, p=0.114, f^2=0.103, q^2=0.012), and both studies (β=-0.296, p=0.010, f^2=0.096, q^2=0.041). However, the values of f^2 and q^2 indicate only medium to small effects and, in turn, the predictive accuracies ($R^2_{adj\ Study1,\ Study2,\ Study12}$ = 13.1%, 5.8%, 6.9%) and predictive relevance scores ($Q^2_{Study1,\ Study2,\ Study12}$ = 10.6%, 1.2%, 3.9%) for perceived ease of use are rather low. As a consequence, we can conclude that physiological arousal and perceived ease of use show therefore characteristics of complementary rather than alternative measures.

[98] In this case, results related to this model are equal to results of a model that predicts physiological arousal by perceived ease of use.

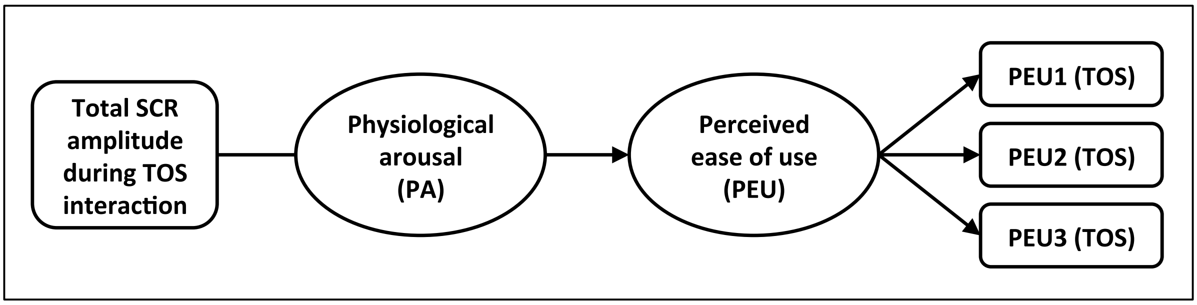

Figure 33. Path model used to test the relationship between physiological arousal and perceived ease of use. Note: TOS = ticket order service.

Finally, we evaluated whether a path model that includes both measures, i.e. the psychological and physiological measures, instead of only one, adds substantial predictive accuracy and predictive relevance with respect to the theoretically related outcome measure, which is task performance in this work. To demonstrate this behavior, we first built a baseline model, denoted as Model 1, depicted in Figure 34, which predicts task performance by perceived ease of use only. This baseline model was then assessed against four competitive models which all include the physiological component but which differ in their particular implementations, as described in the following.

Model 2, as depicted in Figure 35, is consistent with our research model and prior work, which evaluates a model with both physiological and psychological constructs (Tams et al., 2014). It consists of two separate predictor constructs, perceived ease of use and physiological arousal. It therefore represents the higher-order construct ease of use in a way that adds an additional construct and thus increases the complexity of the structural model in comparison to Model 1. This approach might be a good option for the assessment of similar models, as it is the current section's objective, but not if a researcher aims at a parsimonious structural model (Sharma and Kim, 2012), wants to address collinearity issues, or has the objective to hide model complexity by explicitly modeling higher-order constructs (Hair et al., 2014a). With Model 3a we therefore introduced an ease of use construct which consists of four reflective indicators. These are the three perceived ease of use items and the indicator of physiological arousal, i.e. the total SCR amplitude. To assure semantic consistency among the indicators, we multiplied the total SCR amplitude by minus one and modeled it as a reflective measurement item. That is, we conceptualize the higher-order construct ease of use such that the indicators all reflect the latter. One shortcoming of Model 3a, however, is its bias towards the three perceived ease of use items in relation to only one item defined by physiological arousal. We thus also built Model 3b, which aggregates the three perceived ease of sue items into one indicator.[99] The two indicators can also be modeled in terms of a formative measurement model. Model 3c reflects this implementation and implies, from a conceptual point of view, that both psychological and physiological indicators form and cause ease of use.[100] A graphical overview of Model 3a, 3b and 3c is shown in Figure 36.

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[99] We do so because the three perceived ease of use items show high indicator validity and convergent validity. Moreover, the perceived ease of use construct indicates discriminant validity. See Section 5.6 for further details.

[100] An alternative approach that also allows modeling reflective and formative relationships between perceived ease of use (PEU) and physiological arousal (PA) as lower-order components (LOCs), and ease of use (EOU) as higher-order component (HOC), represents the use of hierarchical component models (Hair et al., 2014a). As noted above, however, the number of indicators of the LOCs should be equally distributed in order to assure that no bias is present in the relationships between LOCs and the HOC. Moreover, we have calculated the following two HCMs to predict task performance (TP): HCM1 = (LOCs($PEU_{reflective}$, PA) $\leftarrow_{reflective}$ HOC(EOU)) ➔ TP and HCM2 = LOCs($PEU_{reflective}$, PA) $\rightarrow_{formative}$ HOC(TP) ➔ TP. We discovered that both models perform worse with regard to R^2_{adj} than Model 2, 3a, 3b or 3c, as reported in the following paragraphs. We therefore see no advantage to introducing and describing them in further detail with respect to this section's objectives.

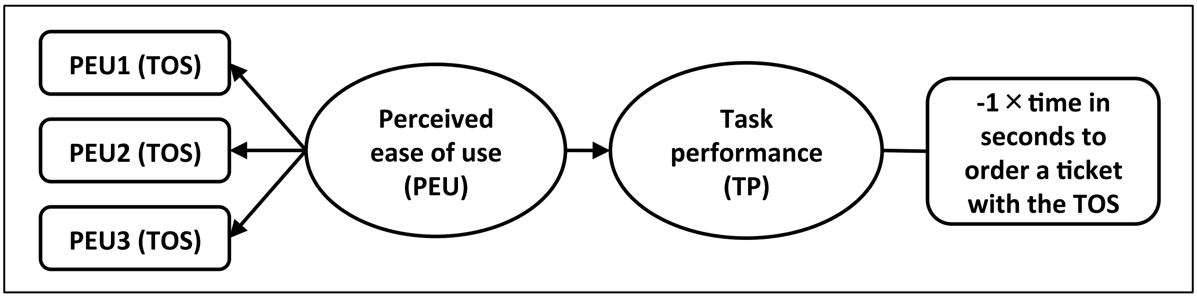

Figure 34. Baseline Model 1. Note: TOS = ticket order service.

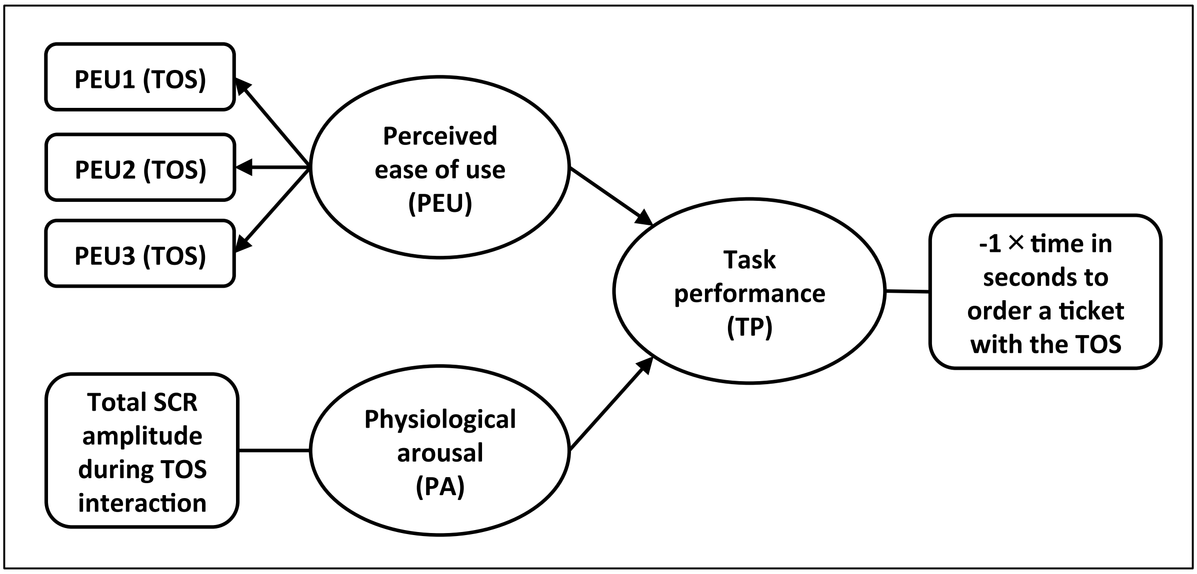

Figure 35. Two-predictor Model 2. Note: TOS = ticket order service.

We then assessed the measurement models with regard to composite reliability, standardized factor loadings (SFL), average variance extracted (AVE) and, finally, the Fornell-Larcker criterion (FLC). The results listed in Table 24 indicate that, in general, the quality of the measurement models is sufficient, in particular with regard to Study 1. However, we observe rather low SFLs in Study 2 and the aggregated empirical data of both studies for Model 3a. Because this affects only the SFLs of the total SCR amplitudes, this may be a consequence of the generalization effect and thus would be consistent with our theoretical assumption. In fact, two SFLs lie below the recommended threshold of 0.70, but above the lower threshold of 0.40, and so we do not need to consider this as a major issue, because all related AVEs lie above the recommended value of 0.50 (Hair et al., 2014a).

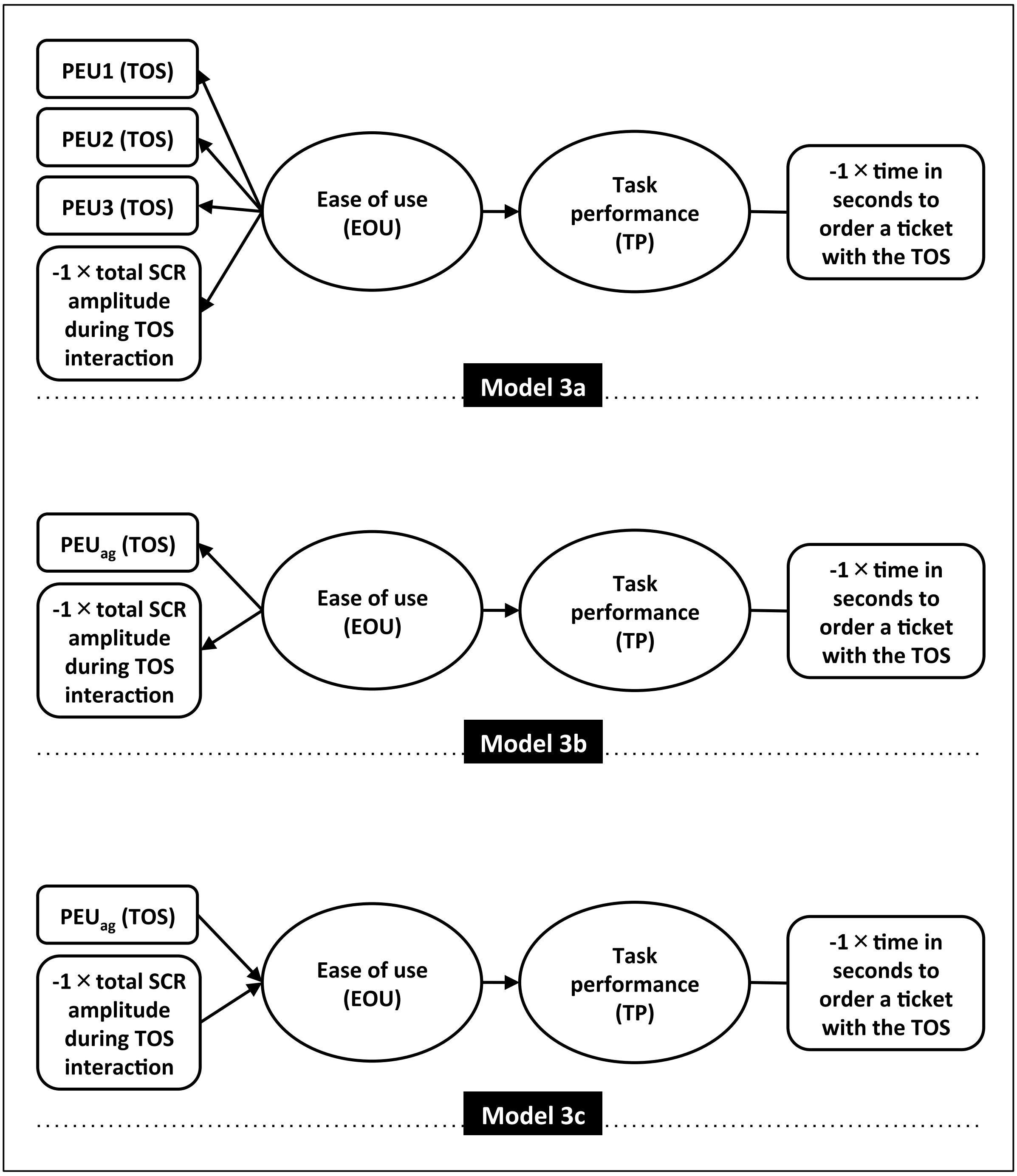

Figure 36. Three implementations of the ease of use measurement models. Note: TOS = ticket order service; ag = aggregated.

Table 24. Composite reliability (ρ_c), standardized factor loadings (SFL), average variance extracted (AVE), and Fornell-Larcker criterion (FLC) of the measurement models. Note: tSCRa = total SCR amplitude; ^{nc} = tSCRa x (-1); PEU = perceived ease of use; EOU = ease of use; PA = physiological arousal; TP = Task Performance

Model (M)		Construct assessed	ρ_c	SFL				AVE	FLC
				PEU1	PEU2	PEU3	tSCRa		
Study 1 (2011, single-exposure to UIS services, *N*=24)									
M1	PEU➔TP	PEU	.954	.944	.984	.913	–	.874	–
M2	PEU➔ TP PA➔ TP	PEU PA	.954 1	.944 –	.948 –	.913 –	– 1	.874 1	✔ ✔
M3a	EOU➔ TP	EOU	.897	.835	.885	.846	$.739^{nc}$	.686	–
M3b	EOU➔ TP	EOU	.815		.748		$.906^{nc}$	.690	–
M3c	EOU➔ TP	EOU	–		.617		$.967^{nc}$	–	–
Study 2 (2012, repeated-exposure to UIS services, *N*=28)									
M1	PEU➔ TP	PEU	.908	.930	.752	.935	–	.768	–
M2	PEU➔ TP PA➔ TP	PEU PA	.908 1	.930 –	.752 –	.935 –	– 1	.768 1	✔ ✔
M3a	EOU➔ TP	EOU	.846	.873	.764	.935	$.405^{nc}$	.596	–
M3b	EOU➔ TP	EOU	.747		.885		$.649^{nc}$	.602	–
M3c	EOU➔ TP	EOU	–		.928		$.568^{nc}$	–	–
Study 1 & 2 (*N*=52)									
M1	PEU➔ TP	PEU	.934	.936	.872	.916	–	.825	–
M2	PEU➔ TP PA➔ TP	PEU PA	.934 1	.936 –	.872 –	.916 –	– 1	.825 1	✔ ✔
M3a	EOU➔ TP	EOU	.872	.870	.866	.901	$.490^{nc}$	.640	–
M3b	EOU➔ TP	EOU	.765		.853		$.717^{nc}$	.621	–
M3c	EOU➔ TP	EOU	–		.888		.666	–	–

As a last step in the search for complementary measures, we assessed the quality criteria of the structural paths of the five models, i.e. the path coefficients and their level of significance, the effect sizes f^2 and q^2, the adjusted predictive accuracy R^2_{adj} and, finally, the predictive relevance Q^2. We choose R^2_{adj}, as the primary criterion for the assessment of the models because related work has also reported it (Tams et al., 2014). Again, R^2_{adj} is adopted instead of R^2, because the complexity of the five models varies and thus would bias the unadjusted R^2 values. We also report and discuss the models' predictive relevance Q^2, because prior work has shown that this quality criteria performs even better than R^2_{adj} in the selection of highly predictive yet parsimonious models (Sharma and Kim, 2012). The results of the quality criteria are listed in Table 25. They indicate that the R^2_{adj} and Q^2 values of the baseline Model 1 lie clearly below the values of the other models in Study 1 and, with one exception, related to Q^2 of Model 3c, also for the aggregated data set of both studies. That is, all models which include both physiological and psychological measures explain more variance in a theoretically related outcome variable than either of them alone, with respect to Study 1, if generalization effects are not present or play only an inferior role.

In order to test whether the differences R^2_{adj} and Q^2 are significant we first generated a corresponding data set and then tested for differences in the resulting distributions between the baseline model and the other four models (see also Sarstedt and Wilczynski, 2009; Sarstedt et al., 2013). That is, we first used the bootstrapping algorithm of the SmartPLS software, with 100 samples, to generate the R^2_{adj} distribution for each model. Afterwards, paired-sample t-tests were calculated to test for significant differences in the corresponding R^2_{adj} distributions.[101] We used t-tests, because visual inspection of Q-Q plots indicated normally dis-

[101] For example, to compare R^2_{adj} of Model 1 of Study 1 with that of Model 2 of Study 1 based on 100 bootstrapping samples from SmartPLS, the following R code is used:

```
t.test(Model1.Study1.R2adj, Model2.Study1.R2adj, data =
PLSbootstrapping100Samples, paired = T, alternative = "less")
```

tributed R^2_{adj} scores. To establish the data set related to the Q^2 scores, we applied the blindfolding algorithm of the SmartPLS software, with an omission distance of 10, as we did in the last section. We then divided the sum of the squared prediction errors of each blindfolding case by the proportion of the omission distance and the study's sample size (e.g. 24/10=2.4 for Study 1). This led to distributions of ten proportion scores for each model, which were then compared with each other. However, in contrast to Sarstedt and Wilczynski (2009), who analyzed a data set with more than 100 observations, we employed Wilkoxon signed rank tests for paired observations because of the non-normal distributions of our proportion scores that resulted from our blindfolding procedure.[102]

It must be noted that the empirical data from Study 2 was not used for these tests for the following reasons: (1) the path coefficients in all Study 2 models are not, or only marginally, significant at the .10 level, (2) R^2_{adj} of the baseline model is higher than in all the other Study 2 models, with the exception of Model 3a, (3) we assume generalization effects to play a major role in Study 2, and finally, (4) Model 3b and Model 3c of Study 2 show no predictive relevance, i.e. the corresponding Q^2 values lie below zero. The results for Study 1 and for the aggregated data set of both studies are listed in Table 26.

[102] For example, to compare prediction error scores related to Q^2 of Model 1 of Study 1 with those of Model 2 of Study 1, the following R code is used:

```
wilkox.test(Model1.Study1.Q2, Model2.Study1.Q2, data =
PLSblindfolding10Cases, paired = T, alternative = "greater")
```

Table 25. Quality criteria for the five models. Note: *β* = path coefficient, p = alpha error probability, ns. / + / * / ** / * equals *p*>.10 / *p*<.10 / .05 / .01 / .001, R^2_{adj} = adjusted predictive accuracy, Q^2 = predictive relevance, f^2 *and q2* = relative effect sizes with regard to R^2 and Q^2**

Model (M)		*β*	*p*	sig.	f^2	R^2_{adj} (%)	q^2	Q^2 (%)
Study 1 (2011, single-exposure to UIS services, *N*=24)								
M1	PEU➔ TP	.488	.019	*	.312	20.3	.037	3.7
M2	PEU➔ TP PA➔ TP	.220 -.654	.123 <.000	ns. ***	.099 .878	55.5	.220 .675	42.4
M3a	EOU➔ TP	.685	<.000	***	.883	44.5	.582	36.8
M3b	EOU➔ TP	.757	<.000	***	>1	55.4	.967	49.2
M3c	EOU➔ TP	.770	<.000	***	>1	57.4	.746	42.7
Study 2 (2012, repeated-exposure to UIS services, *N*=28)								
M1	PEU➔ TP	.389	.064	+	.178	11.9	.037	3.6
M2	PEU➔ TP PA➔ TP	.366 -.122	.082 .182	+ ns.	.154 .182	9.9	.036 .030	0.7
M3a	EOU➔ TP	.197	.060	+	.197	13.2	.032	3.1
M3b	EOU➔ TP	.335	.059	+	.127	7.8	.032	- 3.3
M3c	EOU➔ TP	.337	.056	+	.128	8.0	.054	- 5.7
Study 1 & 2 (*N*=52)								
M1	PEU➔ TP	.437	.001	**	.236	17.5	.167	14.3
M2	PEU➔ TP PA➔ TP	.383 -.215	.005 .035	** *	.179 .056	20.3	.110 .008	15.0
M3a	EOU➔ TP	.475	<.000	***	.292	21.1	.210	17.4
M3b	EOU➔ TP	.465	<.000	***	.277	20.1	.210	15.5
M3c	EOU➔ TP	.467	<.000	***	.278	20.2	.157	13.6

Table 26. Results of paired-sample t-tests for the comparison of R^2_{adj} and paired Wilkoxon signed rank tests for Q^2 of Model 1 with the other models. Note: *p* = alpha error probability, ns. / + / * / ** / * equals *p*>.10 / *p*<.10 / .05 / .01 / .001, *r* = effect size**

Model (M)	R^2_{adj} (%)	$R^2_{adj, delta}$	*p*	*r*	Q^2 (%)	Q^2_{delta}	*p*	*r*
Study 1 (2011, single-exposure to UIS services, *N*=24)								
M1	20.3	–	–	–	3.7	–	–	–
M2	55.5	35.2***	<.001	.829	42.4	38.9**	.005	.890
M3a	44.5	24.2***	<.001	.734	36.8	33.2**	.002	.979
M3b	55.4	35.1***	<.001	.815	49.2	45.6**	.005	.890
M3c	57.4	37.1***	<.001	.813	42.7	39.2**	.005	.890
Study 1 & 2 (*N*=52)								
M1	17.5	–	–	–	14.3	–	–	–
M2	20.3	2.8^{*}	.017	.212	15.0	0.7^{ns}	.278	.343
M3a	21.1	3.6^{+}	.074	.145	17.4	3.1^{ns}	.116	.497
M3b	20.1	2.6^{*}	.021	.203	15.5	1.2^{ns}	.348	.297
M3c	20.2	2.6^{ns}	.297	.054	13.6	-0.7^{ns}	.423	.253

The results indicate that the additional physiological construct in Model 2 and corresponding indicators in Model 3a, Model 3b and Model 3c, significantly add both predictive accuracy R^2_{adj} and predictive relevance Q^2 in the theoretically related outcome measure task performance in Study 1. By contrast, and probably due to generalization effects, we find almost no significant differences in the aggregated data set of both studies. In line with the findings of Tams et al. (2014), we therefore can conclude that also our results show empirical support for complementary rather than alternative physiological and psychological dimensions of a higher-order construct, which we called ease of use.

5.9 Summary

The objectives of this chapter were to describe the data quality and empirical findings related to the two studies which were used not only to test the hypotheses but also to answer the research questions of this dissertation. Accordingly, we first reported on a pretest, to assure the validity of the instruments and procedures carried out. We also discussed the quality of the physiological data in relation to environmental conditions and provided the rationale as to why five subjects had to be excluded from further analyses. Afterwards, we presented the demographics and descriptive statistics related to the core constructs and control variables. We then showed the internal validity of the instruments and empirical data with respect to common method variance and homogeneity considerations. We also demonstrated the external validity of our empirical findings with respect to gender and age effects, which are common to physiological measures in related work. We then introduced the PLS-SEM technique as the preferred method of analysis and conducted statistical power analyses based on the sample sizes of the studies. Thereafter, we showed that our data is non-normally distributed and that the values for skewness and kurtosis were still acceptable such that PLS-SEM can be applied. As a consequence, and in accordance with our research model, we presented a corresponding path model and showed that all quality criteria were met. Results of the structural model indicated that the first and fourth hypotheses were partially supported by the empirical data, while the second and third hypotheses were fully supported. A corresponding overview is listed in Table 27. We finally provided evidence that physiological arousal and perceived ease of use are complementary rather than alternative measures of a higher-order construct ease of use.

Table 27. Summary of results with regard to the four hypotheses.

#	Hypothesis (H)	Criteria met	Result
H1	The generalization effect will mitigate the positive relationship between breakdown events of a UIS service and physiological arousal for individuals who were confronted with similar services in advance.	80% (4/5)	Almost fully supported
H2	Breakdown events of a UIS service are negatively related to perceived ease of use with respect to that service.	100% (3/3)	Fully supported
H3	The generalization effect will mitigate the negative relationship between physiological arousal and task performance for individuals who were confronted with similar UIS services in advance.	100% (5/5)	Fully supported
H4	An individual's perceived ease of use of an UIS service has a positive relationship with task performance.	33% (1/3)	Partly supported

6 Discussion

The objectives of this final chapter are threefold: first, we discuss the research questions against the background of the empirical findings presented in the last chapter and derive theoretical and practical implications; second, we critically review this work with regard to its limitations and, consequently, outline potential contributions for future work.

The remaining sections of this chapter are therefore structured as follows. We recapitulate and discuss the four research questions, which all questioned the utility of electrodermal activity as a low-cost, noninvasive and unobtrusive in-situ evaluation measure for the design and use of UIS services. We do so with respect to electrodermal activity's sensitivity to emotional competent stimuli while individuals move, gesticulate and interact with UIS services (RQ1), its reliability under the assumption of generalization effects (RQ2), its conceptualization and relationship with existing IS constructs (RQ3), and finally, its dimensionality, i.e. whether it complements a psychological self-report measure rather than representing an alternative to the latter (RQ4). At this juncture, we present theoretical and practical implications that are derived from the examination of the research questions in combination with our empirical findings. We then outline the limitations of this dissertation particularly with regard to the retrospective methodological approach. These limitations are also used to discuss and present prospective future work. We conclude this chapter with a summary.

6.1 Sensitivity of electrodermal activity

We first wanted to know whether electrodermal activity is sensitive enough to be able to significantly respond to emotional competent stimuli while individuals move, gesticulate and interact with UIS services. Indeed, our literature review has shown that electrodermal activity is able to indicate meaningful reactions, for example as a consequence to particular website characteristics (Moody and Galletta, 2015; Sheng and Joginapelly, 2012), online auctions (Adam et al., 2012; Teubner et al., 2015), computer-based tasks (Zhou et al., 2015), computer agents (Choi et al., 2015; Pollina and Barretta, 2014), virtual environments (Chittaro and Sioni, 2015), or computer breakdown events (Riedl et al., 2013). However, we could not identify one single study in which electrodermal activity was measured while individuals were asked to freely move around and interact with UIS services by means of touch gestures and speech commands. This type of interaction, in turn, may potentially impact and reduce the signal-to-noise ratio of the measurement signal such that variations in electrodermal activity can no longer be observed, thus making it a useless research tool. Examples for this sort of noise may be hand movements during touch gestures (Boucsein, 2012; Kowatsch, 2012; Teubner et al., 2015), unintended contact with other objects (Kowatsch, 2012), or intense physical activity (Kappeler-Setz et al., 2013). We could only identify prior work in the field of marketing research, which showed significant responses of electrodermal activity while study participants were asked to search for products and walk around in a manipulated in-store environment (Groeppel-Klein, 2005).

Against this background, the empirical findings of the current work indicate that, for the very first time – to the best of the author's knowledge – electrodermal activity has been found to be sensitive enough to even detect physiological reactions while individuals move around freely, gesticulate, and use touch gestures and speech commands for the interaction with a particular UIS service. That is, we could identified a positive and significant relationship between the number of breakdown events of a ticket order service embedded in an interactive bathroom and physiological arousal measured by the total SCR amplitude (H1). In particular, empirical data of Study 1 resulted in a remarkable adjusted predictive accuracy score of R^2_{adj} = 28.8% and predictive relevance score of Q^2 = 29.9% for physiological arousal. This is astonishing, as these scores are on par with those of the already established and commonly used perceived ease of use construct (Davis, 1989; Kamis et al., 2008; Kowatsch and Maass, 2010; Venkatesh, 2000; Venkatesh and Davis, 1996), with R^2_{adj} = 31.7% and Q^2 = 24.7% in the first study. The predictive accuracy of physiological arousal even outperforms the same quality criteria of related stress constructs which were also measured physiologically in recent IS research (Moody and Galletta, 2015; Tams et al., 2014). Moreover, this dissertation also extends the findings of Riedl et al. (2013), in that it was found that breakdown events trigger not only significant physiological reactions in a desktop-based computer setting but also in the context of UIS services. In contrast to the latter research (ibid.), however, we even demonstrated that electrodermal activity varies with the amount of breakdown events, without explicitly limiting the time needed to perform a pre-defined task (i.e. to order a ticket), and for a study population that included both female and male subjects. In fact, even more female than male subjects participated in our studies, and still we identified a clear relationship between physiological reactions in response to breakdown events. Finally, as reported in the last chapter, only two out of 52 subjects (i.e. 3.8%) had to be dropped from further analyses because of measurement issues. That is, we did not identify any major challenges with respect to the technical feasibility of measuring electrodermal activity on a mobile device while subjects were freely moving around.

The following theoretical and practical implications can be derived from these results. First and foremost, the current work's empirical findings related to the first research question contribute to the design and use of UIS services such that electrodermal activity, and more particularly physiological arousal measured by the total SCR amplitude, represents a potentially new determinant of UIS service use (Dimoka et al., 2012; Dimoka et al., 2011). As it is related to the degree of cognitive effort while coping with breakdown events, electrodermal activity can be correspondingly used in the design process of UIS services in order to "enhance system utility and user friendliness and [to establish] direct usability criteria" (Dimoka et al., 2012, p. 684).

Furthermore, our empirical findings show that electrodermal activity shares only a small amount of variance with perceived ease of use, but explains significantly more variance than the latter in task performance, a theoretically related outcome construct. In line with the two-systems view of cognitive processing (Kahneman, 2003; Stanovich and West, 2000), and research opportunities in the field of NeuroIS (Dimoka et al., 2011; Tams et al., 2014), electrodermal activity is therefore probably able to capture emotional cognitive processes that are mostly hidden from consciousness and rational reasoning, and thus cannot be fully captured by self-report instruments. As a consequence, electrodermal activity adds a novel and probably highly relevant emotional dimension to the knowledge base and tool set of an IS researcher interested in empirical assessments of UIS services beyond conscious and rational processes.

Electrodermal activity can also be used as a NeuroIS measure to address common method bias if it complements self-reports or other methods of data collection such as observations of objective UIS service usage data. Accordingly, it may also represent a viable alternative to self-reports if the latter are expected to be seriously affected by various sources of measurement errors such as subjectivity, social desirability, or providing intentionally wrong answers (Dimoka et al., 2012; Dimoka et al., 2011; Pollina and Barretta, 2014).

Moreover, the findings of this present work challenge the empirical results of Riedl et al. (2013), who reported that only male subjects showed significant electrodermal reactions as a consequence of a computer breakdown if, and only if, time constraints were present while working on a computer-based task. Our results are rather consistent with the study of Moody and Galletta (2015), who found that time constraints are not significantly related to stress, a construct that was formatively measured by electrodermal activity and three other physiological measures. It should therefore be questioned, or at least carefully reconsidered, whether time pressure is either a relevant predictor, moderating or mediating variable related to variations in electrodermal activity. It may be even the case that if subjects are under time pressure, variations in electrodermal activity decrease, due to the overall high skin conductance level that, in turn, limits any further variations (Boucsein, 2012).

In contrast to Riedl et al. (2013), we also found positive and significant relationships between the amount of breakdown events and electrodermal activity, although the majority of our study participants were females and not explicitly under time pressure, as discussed above. And even though we showed that the overall physiological reactions of female subjects were lower than those of males in both studies, which is consistent with several studies employing electrodermal activity (Boucsein, 2012; Boucsein et al., 2012), this gender effect was not strong enough to negatively affect or mitigate the hypothesized basic relationships of the automatic pathway of our research model, i.e. between breakdown events of a UIS service, physiological arousal and task performance. A corresponding post-hoc analysis of our data revealed that the number of breakdown events was not, in both Study 1 (p=0.585) and Study 2 (p=0.634) dependent on gender, which even further challenges the generalizability of the findings of Riedl et al. related to gender-specific physiological reactions.[103] This implies that among time constraints also gender effects should be carefully reconsidered in future theoretical models and hypotheses.

In addition to the theoretical implications described above, we now outline several practical implications related to the first research question. First, we have shown that electrodermal activity can be used to evaluate UIS services in everyday situations while subjects are moving around and gesticulating. That is, external validity of empirical studies can even be increased by setting up evaluations "in the wild" with the help of mobile data collection devices, in comparison to

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[103] R: `fisher.test(study2011$BreakdownEvent, study2011$Gender);`
`fisher.test(study2012$BreakdownEvent, study2012$Gender);`

static and desktop-based studies that are conducted under rather clinical laboratory conditions.

Moreover, we have shown that NeuroIS researchers need not expect many technical measurement issues because of low signal-to-noise ratios. Accordingly, complete loss of physiological data can be almost neglected when planning a corresponding study.

Nevertheless, it should be taken into account that males rather than females, and younger rather than older subjects, show stronger physiological reactions (Boucsein, 2012; Boucsein et al., 2012). Hence, a balanced assignment to experimental conditions is quite important with regard to these demographic variables. Environmental conditions such as temperature and humidity, and the alertness and cultural background of subjects, should be also taken into account as important control variables so that the physiological condition of the skin and, for example, the production of sweat are comparable among study participants.

It is also recommended that subjects are given time to calm down and relax before they are confronted with potential UIS stimuli. As a consequence, electrodermal reactions are assumed not, or only slightly, to be affected by prior experiences or stimuli and thus can unfold their full potential because they are not limited to their upper physiological and natural boundaries (Boucsein, 2012).

Furthermore, subjects of our studies did not report any problems or issues such that they would have been hindered or disrupted by either the electrodes or the mobile recording device while interacting with the UIS services. This indicates that the mobile recording of electrodermal activity was perceived as being unobtrusive. The measurement of electrodermal activity in situ can therefore be recommended in future studies that require an extensive use of touch gestures or physical movements.

Another important practical implication of our work is related to the challenge of synchronizing the time between the events under examination (e.g. breakdown events of UIS services) and the physiological data. We strongly recommended using an automated trigger mechanism that transparently indicates, in the physiological data stream, when and what happens exactly during the evaluation of UIS services, so that data analyses can be automated afterwards or even implemented in real time, for example by means of a biofeedback mechanisms (Astor et al., 2013). If the recording of electrodermal activity is combined with a video stream, then the same underlying clock generator should be used.

Compared to other NeuroIS tools such as electrocardiograms or brain imaging techniques, measuring electrodermal activity is by far the cheapest method for collecting neuroscience data for the assessment of UIS services. The low costs are not only a consequence of the affordable mobile recording devices, but also of the limited personnel costs and effort required by study supervisors to manage the recording of electrodermal activity during the empirical studies. Accordingly, due to the relatively slow change of the skin conductance level and the delay of few seconds before a skin conductance response can be observed as a consequence of an emotionally-competent stimulus, a sampling rate of 1 Hz, together with a relatively low amount of data storage capacity, are sufficient enough to detect any significant reactions a NeuroIS researcher may be interested in.

In conclusion, measuring electrodermal activity with the help of a mobile device like the MBS K3, as employed in the present work, represents a low-cost, noninvasive and unobtrusive in-situ evaluation instrument that is appropriate and useful for assessing emotional phenomena related to UIS services in everyday situations. Electrodermal activity, as NeuroIS measure and predictor of UIS service use, also has its limitations, especially with respect to within-subjects designs that are potentially negatively affected by physiological habituation and generalization effects. This will be discussed in the following section.

6.2 Reliability threat because of generalization effects

Our second research question addressed the reliability of electrodermal reactions, if effects related to physiological generalization are present – for example, if subjects are exposed to a row of similar stimuli. We therefore wanted to know whether electrodermal activity still represents an appropriate measure for UIS studies that employ similar UIS stimuli as a within-subjects factor. We now briefly recapitulate the assumptions behind physiological generalization effects before we answer our second research question with the empirical data of our work, so that we can finally discuss the corresponding theoretical and practical implications.

A major threat to the reliability of physiological measures is known as habituation, which is a "decreased response to repeated stimulation" (Groves and Thompson, 1970, p. 419). Generalization, by contrast, is related to habituation, as it extends the latter to similar stimuli (Grizzard et al., 2015; Rankin et al., 2009; Stein, 1966). As determined in the current work, electrodermal responses to repeated or even similar UIS stimuli may decrease steadily with each stimuli exposure, which, in turn, results in a loss of electrodermal sensitivity and reliability. This is an important aspect, particularly with regard to design science research, because here the researcher usually adopts several build-and-evaluate loops during the design process, and therefore exposes subjects to similar stimuli (Hevner et al., 2004; Peffers et al., 2007; Winter, 2008). For example, subjects can be asked in within-subjects studies to evaluate alternative but similar IS deployments (e.g. Maass and Kowatsch, 2008b) or iterative and similar IS deployments (e.g. Kowatsch and Maass, 2013).

And although habituation and generalization effects were introduced and discussed in psychophysiological research outlets several decades ago, they were almost completely neglected in the NeuroIS literature or in outlets related to human-computer interaction, as shown by our literature review. Accordingly, we found that in 24 publications a within-subjects design was described and, surprisingly, subjects were exposed to up to 10 information retrieval tasks (Moody and Galletta, 2015), 30 auctions (Teubner et al., 2015) or even 72 computer control tasks (Randolph and Jackson, 2010). However, only in four publications was the habituation effect at least mentioned (Chittaro and Sioni, 2014a; Choi et al., 2015; Liu et al., 2008; Zhou et al., 2011), while generalization effects were not discussed at all.

In fact, the empirical findings of our second study indicate evidence for the generalization effect. That is, subjects of Study 2 were exposed to three similar instantiations of the same UIS service by means of a narrative, a mockup and an interactive mirror, and in contrast to the single-exposure Study 1, the relationship between physiological arousal and task performance measured by the total SCR amplitude was significantly mitigated, as hypothesized. And although we did not observe a significantly weaker relationship between UIS service breakdown events and physiological arousal in the repeated-exposure Study 2, compared to Study 1, a clear trend of a mitigating moderation consistent with the assumptions of the generalization effect could also be demonstrated. These findings can even be judged as substantial and rather conservative for the following five reasons. First, subjects of Study 2 perceived themselves as significantly more alert than those of Study 1. Thus, Study 2 participants may even be more sensitive than Study 1 participants, with respect to their physiological reactions in response to emotionally competent stimuli such as the UIS service breakdown events. Second, the service breakdowns were present neither in the narrative nor in the mockup instantiation of Study 2, but only when subjects interacted with the ticket order service, which was implemented and embedded in the full-size bathroom. That is, subjects of Study 2 were not able to learn and cope with the breakdown events in advance of the actual experience while interacting with the UIS service. Or, put in other words, the breakdown events themselves, in contrast to the ticket order service as such, were completely novel to Study 2 subjects. Third, the audiovisual intensity, as well as spatial and haptic resolution, of the UIS services of Study 2 were incrementally increased from (1) a textual narrative via (2) a three-dimensional mockup that was supported by an electronic slide show to (3) a full-size interactive bathroom environment. In line with prior work we would have expected this increase in sensitization to counterbalance or at least slow down the impact of physiological generalization processes (Groves and Thompson, 1970). Fourth and fifth, age and gender were almost equally distributed among the single-exposure Study 1 and the repeated-exposure Study 2, such that neither older subjects nor female subjects, i.e. both characteristics that lead to reduced physiological responses per se, were over-represented in Study 2 which, in turn, could systematically bias the results with respect to the generalization effect. In fact, there were even slightly more male subjects participating in Study 2 (39,3%) than in Study 1 (37.5%).

However, there is at least one aspect that may negatively impact the explanatory power of our findings related to the generalization effect. That is, subjects of Study 2 had to cope with somewhat fewer UIS service breakdown events (M=2.75) than Study 1 subjects (M=3.00). This means that Study 1 offered marginally more variance to be explained by physiological arousal, compared to Study 2, resulting in a theoretically stronger relationship between breakdown events and physiological arousal as actually observed. But contrary to that, mean values and standard deviations of the total SCR amplitudes were clearly higher in Study 2 than in Study 1, which brings us to the preliminary conclusion that this may be caused by the higher alertness of Study 2 participants. A theoretically sound interpretation of that aspect must be delegated to future research and a corresponding study design, as discussed later in this chapter. Nevertheless, our empirical findings generally support reduced electrodermal reactions to similar UIS stimuli, as they are expected from generalization effects. It must therefore be concluded that the utility of electrodermal activity as a NeuroIS measure is probably limited and requires careful consideration if similar UIS stimuli are employed as a within-subjects factor in corresponding study designs like that of Study 2.

Against the background of these findings, we now discuss the corresponding theoretical and practical implications. First and foremost, generalization effects may potentially mitigate the sensitivity, and consequently the reliability, of electrodermal reactions in studies that employ similar UIS services as within-subjects factor. As described above, this may be an important limitation, in particular for design science research, if subjects compare several UIS services with each other or if they evaluate similar implementations of the same UIS services, as was conducted in Study 2 of the current work. Accordingly, it is strongly recommended that NeuroIS researcher consider generalization effects when they review related work, derive their research model or discuss their empirical findings. For example, if a within-subjects design is theoretically considered to be necessary (e.g. if the amount of available subjects is limited or to identify intra-individual physiological differences), then one could address generalization by means of a mitigating moderation effect as was done in our research model. However, one has to be aware of that with an increasing number of exposures to UIS stimuli chances decrease for identifying significant physiological responses to such an extent that empirical data will no longer be able to support corresponding hypotheses (Groves and Thompson, 1970).

With respect to these theoretical considerations, the following practical implications can be derived. First, it is recommended that pretests be conducted to infer the severity of generalization effects with respect to the form and number of repeated exposures of similar UIS services. The results of these pretests should then be used to derive the final study design and an appropriate number of similar UIS services which can be compared to each other without losing too much of electrodermal activity's sensitivity. Second, a researcher may also adopt a study design in which the order of the stimuli is randomly or systematically assigned such that the exposure to the various UIS services is balanced among all study participants (Chittaro and Sioni, 2014a; Liu et al., 2008; Zhou et al., 2011). This approach could work with a limited number of UIS services which are compared to one another. However, as described above, the more UIS stimuli are evaluated by subjects, the greater are chances of failing to identify significant electrodermal reactions. Third, another subject-based approach to address generalization effects would be to control for subjects who show strong electrodermal reactions (Choi et al., 2015). These highly-sensitive subjects are assumed to show rather weak effects of habituation and generalization. Thus, they may be assigned to within-subjects designs, whereas the other "low-sensitive" subjects may be more appropriately assigned to a between-subjects design characterized by only one exposure to a UIS service stimulus. Finally, if pretests indicate the presence of strong generalization effects, the researcher may either adopt a between-subjects design, thus having to increase the test population, or he or she could replace electrodermal activity with a related psychological self-report instrument such as the self-assessment manikin (Bradley and Lang, 1994). The latter instrument would be able to capture not only the degree of perceived arousal but also emotional valence and perceptions related to feelings of dominance (ibid.). However, it must be noted that habituation or generalization effects may also bias psychological self-reports if they tap into dimensions of bodily reactions, such as perceived arousal (Grizzard et al., 2015).

We may therefore conclude by stating that electrodermal activity still represents a low-cost, noninvasive and unobtrusive in-situ evaluation instrument which is appropriate for single-exposure studies. However, it has its limitations subject to generalization effects and thus requires sound theoretical considerations and pretests with regard to study designs that employ several similar UIS stimuli as a within-subjects factor.

6.3 Conceptualizing electrodermal activity as physiological arousal

We were interested in electrodermal phenomena which are appropriate for the design and use of UIS services in such a way that they are related to IS constructs that either predict or represent consequences of service use. With respect to our third research question, we thus sought a viable conceptualization of electrodermal activity that can be related to predictors or outcomes of UIS service use. We now briefly recapitulate predictors and outcomes of IS use before motivating and discussing physiological arousal, our conceptualization of electrodermal activity.

Later we discuss the theoretical and practical implications related to our conceptualization.

To briefly remind the reader, predictors of IS use are, for example, perceived enjoyment (Kamis et al., 2008; van der Heijden, 2004), perceived ease of use or perceived usefulness (Davis, 1989; Kowatsch and Maass, 2010). By contrast, outcomes of IS use represent constructs that are related to a system's utility and success, such as intentions to purchase products or to shop at retail stores (Kamis et al., 2008; Kowatsch and Maass, 2010; Kowatsch et al., 2011; Sheng and Joginapelly, 2012), group performance (Zigurs and Buckland, 1998), task performance (Moody and Galletta, 2015; Tams et al., 2014), organizational performance (Avison and Fitzgerald, 1995; Hevner et al., 2004), website success (Palmer, 2002; Sheng and Joginapelly, 2012) or health outcomes (Agarwal et al., 2010; Kowatsch et al., 2015a; Kowatsch et al., 2014; Kowatsch et al., 2015b; Pletikosa Cvijikj et al., 2014), among others.

To derive theoretically sound assumptions about the relationship between electrodermal activity and predictors or outcomes of IS use, as outlined above, it is inevitable that we conceptualize and define electrodermal activity in such a way that it offers a concise connotation. Our literature review and marketing research, however, has shown that it is conceptualized in numerous ways and even with opposing semantics, such as cognitive absorption (Léger et al., 2014a), interest (Karran et al., 2015), fatigue (Liao et al., 2006), fear (Chittaro and Sioni, 2015), joy (Groeppel-Klein, 2005), stress (Chittaro and Sioni, 2014a; Liao et al., 2006; Moody and Galletta, 2015; Riedl et al., 2013; Schnädelbach et al., 2012) or state of relaxation (Carlbring et al., 2007). Moreover, electrodermal activity was also conceptualized by means of rather generic constructs such as arousal, physiological response or physiological activity (e.g. Bailenson et al., 2008; Chittaro and Sioni, 2014a; Chittaro and Sioni, 2014b; Harley et al., 2015; Kallinen and Ravaja, 2007; Karran et al., 2015; Kneer et al., 2016; Liu et al., 2008; Patel et al., 2014; Pollina and Barretta, 2014).

With regard to the third research question, we then conceptualized electrodermal activity by means of physiological arousal, which reflects the intensity of automatic emotional reactions. We did so for two reasons. First, we justified our choice empirically as a result of our literature review. In the majority of articles (27, 84%), authors have described electrodermal activity by referring to the strength of emotions (e.g. Carlbring et al., 2007; Choi et al., 2015; Minas et al., 2014; Randolph and Jackson, 2010; Schnädelbach et al., 2012; Teubner et al., 2015). The most common term in this regard is physiological arousal, used in 11 (34%) articles (e.g. Harley et al., 2015; Kneer et al., 2016; Lim and Reeves, 2010; Minas et al., 2014).

Second, arousal, together with valence, represent two fundamental dimensions of feelings (Kuppens et al., 2013; Russell, 1980), i.e. emotions that are experienced consciously (Damasio and Carvalho, 2013). Physiological arousal therefore represents the degree of emotional strength, but it cannot be used alone to determine specific constructs that reflect positive or negative semantics such as fear, joy or stress (Bailenson et al., 2008; Chanel et al., 2009; Kukolja et al., 2014; Liao et al., 2006; Liu et al., 2008; Sokolov and Boucsein, 2000; Zhou et al., 2011). Prior work indicates only that physiological reactions can be stronger for negative than for positive emotions (e.g. Adam et al., 2012; Bailenson et al., 2008; Sheng and Joginapelly, 2012).

We then hypothesized and demonstrated empirically that physiological arousal is sensitive to breakdown events of a particular UIS service. We theorized that physiological arousal reflects the intensity of automatic emotional reactions, which are caused by cognitive effort required to cope with breakdown events. This relationship is semantically quite close to the definition of perceived ease of use (Davis, 1989). Predictive accuracy scores and predictive relevance scores that showed similar patterns in the physiological arousal and perceived ease of use constructs also supported this close relationship. We thus proposed the higher-order construct ease of use, consisting of physiological arousal (the physiological dimension) and perceived ease of use (the psychological dimension), to make this relationship even more explicit. Our empirical findings showed also that physiological arousal, along with perceived ease of use, is related to task performance, a traditional outcome measure of IS use.

To conclude our findings with respect to the third research question, we can state that physiological arousal represents a common and viable conceptualization of electrodermal activity which is related to both perceived ease of use and task performance as a predictor and outcome of UIS service use.

The following theoretical implications can be derived. First, it is recommended to revisit theories and publications that employed arousal as one of their core constructs by means of self-report instruments (e.g. Deng and Poole, 2010; Donovan and Rossiter, 1994; Lee et al., 2012a; Vieira, 2013) or other physiological measures than electrodermal activity such as eye tracking parameters (Serfas et al., 2014), mouse cursor movements (Grimes et al., 2013; Hibbeln et al., in press), or electroencephalography (Astor et al., 2013). The corresponding research models and theories could then be used in further studies to test whether physiological arousal measured by electrodermal activity replicates or even increases variance in the arousal construct itself or in corresponding outcome variables.

Second, and analogous to the first implication, prior work that utilized the perceived ease of use construct (Venkatesh, 2000; Venkatesh and Davis, 1996; Venkatesh and Davis, 2000; Venkatesh et al., 2003) may benefit from our findings, as physiological arousal could play an additional and significant role in enhancing the explanatory power of corresponding research models or theories. One could, for example, add physiological arousal as a genuine and novel predictor in the technology acceptance model (Davis, 1989; King and He, 2006; Lee et al., 2003; Legris et al., 2003; Turner et al., 2010), or the (extended) unified theory of acceptance and use of technology (Venkatesh et al., 2003; Venkatesh et al., 2012). Another alternative would be to use physiological arousal as the physiological dimension of a novel ease of use construct that is complemented by its psychological and well-known dimension, perceived ease of use. The latter will be discussed in more detail in the next section.

Third, we have shown that breakdown events of a UIS service are a significant predictor of physiological arousal. Consistently, prior work found similar results (Riedl et al., 2013), or reported that physiological arousal is related to negative rather than positive emotions (e.g. Adam et al., 2012; Bailenson et al., 2008; Sheng and Joginapelly, 2012). Accordingly, physiological arousal is assumed to be a sensitive outcome construct on its own, as a consequence of negative events or emotions, and thus can inform or enhance theories that explain adoption behavior related to UIS services. The usage of physiological arousal as an evaluation criteria, in particular in design science research (Gregor and Hevner, 2013; Hevner et al., 2004; Riedl et al., 2014a), therefore has the potential to improve UIS service designs as it can be used to identify and eliminate features that elicit negative emotions in potential users, along with the rejection of the underlying UIS services.

Finally, the findings of the current work may also improve research models and theories related to job strain and job performance, such as the Job Demands-Resource Model (Bakker and Demerouti, 2007; Kowatsch et al., 2015b), or models related to job crafting activities (Tims and Bakker, 2010; Tims et al., 2013a; Tims et al., 2013b), because we found that physiological arousal is significantly related to task performance. For example, if physiological arousal can be measured with the help of electrodermal activity or mouse cursor movements (Grimes et al., 2013; Hibbeln et al., 2014; Hibbeln et al., in press; Kowatsch et al., 2015b), then it would be possible to detect and investigate short term relationships between job strain and task performance in knowledge workers and to design novel health interventions, as recently proposed by Kowatsch et al. (2015b).

In addition to the theoretical implications, we now discuss several practical implications with regard to our third research question. First and foremost, physiological arousal, as introduced in our research model is definitely not restricted to measures of electrodermal activity. That is, physiological arousal may be captured formatively as a combination of electrodermal activity with other physiological measures (Bailenson et al., 2008; Chanel et al., 2009; Chittaro and Sioni, 2014a; Karran et al., 2015; Kukolja et al., 2014; Liao et al., 2006; Liu et al., 2008; Moody and Galletta, 2015; Zhou et al., 2011), or may even be replaced by them (Astor et al., 2013; Tams et al., 2014). As a consequence, physiological arousal represents a flexible construct that could be adapted and operationalized such that it appropriately fits the subject of investigation.

Second, in combination with other measures, physiological arousal has the potential to detect not only the strength of emotions but also their valence (Kukolja et al., 2014; Liao et al., 2006; Liu et al., 2008; Zhou et al., 2011). This would offer important additional information which may guide a design science researcher to enhance UIS services.

Third, electrodermal activity and its alternative measures can be used to detect the degree of physiological arousal in real-time, as opposed to self-report instruments. And, in turn, a researcher may use that information to provide real-time biofeedback to the user of a corresponding UIS service. Examples would be a service that allows users to improve their self-regulation capabilities (Astor et al., 2013), or their health condition (Chittaro and Sioni, 2014a; Chittaro and Sioni, 2014b; Kowatsch et al., 2015b; Schnädelbach et al., 2012). An alternative approach would be to use that real-time data stream to detect fraudulent intents and to react correspondingly, for example, in the insurance industry (Hibbeln et al., 2014) or during security screening interviews (Pollina and Barretta, 2014).

Finally, physiological arousal can also be used as an objective UIS service log. In combination with further real-time data streams, for example, derived from tracking mouse cursor movements, physical activity, eye tracking devices, touch gestures or speech commands, the log data can be enriched and correlated with one another so as to identify and analyze problematic features and processes of UIS services. This would not only enable service providers to continuously improve existing UIS services, but also to "listen to" the physiological reactions related to customer behavior and then derive new customer needs and develop novel products and UIS services (Urban and Hauser, 2004).

To summarize the theoretical and practical implications related to the third research question, we can state that physiological arousal can enhance research models, theories and various practical applications related to arousal, perceived ease of use and task performance, as proposed and discussed in the field of NeuroIS research (Dimoka et al., 2012; Dimoka et al., 2011; Riedl et al., 2010c).

6.4 Physiological arousal complementing perceived ease of use

With regard to our last research question, we wanted to know whether electrodermal activity and psychological self-reports are complements or alternatives of the same underlying IS construct. We now revisit the motivation for this research question and present the results of our work against the background of our findings. We will then discuss the theoretical and practical implications.

With the advent of the first NeuroIS publications it was discussed whether NeuroIS measures such as electrodermal activity are either complements or alternatives to psychological self-reports (Dimoka et al., 2012; Dimoka et al., 2011; Riedl et al., 2010a; Tams et al., 2014). Correspondingly, NeuroIS measures can be either considered "as complements, not substitutes to existing IS theories and tools." (Riedl et al., 2010a, p. 257) In line with this view, NeuroIS measures explain additional variance in related outcome constructs than a psychological self-report measure on its own. That is, physiological and psychological measures explain distinct dimensions of one focal construct. For example, prior work has shown that perceived stress and physiological stress measures complement each other (Tams et al., 2014).

By contrast, NeuroIS measures could also be considered as "alternatives for IS researchers who do not rely on self-reported measures, such as IS economists and design scientists." (Dimoka et al., 2011, p. 693) According to this view, either the psychological measure or the physiological measure represents the construct in question. It was, for example, shown that two arousal measures were consistent between self-reports and electrodermal activity for subjects interacting with a website (Sheng and Joginapelly, 2012), thus indicating that they are alternative measures to each other.

With the help of the literature review and the development of our research model we have proposed ease of use that may serve as an appropriate higher-order construct consisting of a physiological dimension (i.e. physiological arousal) and a psychological dimension (i.e. perceived ease of use). As a consequence, we can revise and further state more precisely the fourth research question as follows: Are physiological arousal and perceived ease of use complementary, or alternative, measures of ease of use?

In order to answer this question, we have adopted the approach discussed and proposed by Tams et al. (2014). That is, we assessed whether the relationship between both measures is rather weak and whether physiological arousal explains significant more variance in a theoretically related outcome measure than perceived ease of use alone. Our empirical findings presented in Section 5.8 support the view that NeuroIS measures such as physiological arousal measured by electrodermal activity are complementing related psychological self-report measures. In particular, we have shown that physiological arousal is not strongly related to perceived ease of use and that predictive accuracy and predictive relevance scores are significantly higher in the task performance construct if physiological arousal is added in addition to perceived ease of use as a predictor and no generalization effects are to be expected such as in Study 1. It has been even shown that, depending on the actual implementation of the measurement model and path model of the PLS-SEM analyses, perceived ease of use was not significantly related to task performance due to the fact that physiological arousal was a relative strong predictor.

Our results lead to the following theoretical implications. First of all, our findings with regard to the higher-order construct ease of use support the importance of adopting a two-systems view of cognitive processing when conducting NeuroIS research (Evans, 2003; Kahneman, 2003; Masicampo and Baumeister, 2008; Stanovich and West, 2000). That is, automatic processes underlying physiological reactions may not necessarily influence the inferential processes underlying the belief formation process of psychological measures such as perceived ease of use (Davis, 1989). Correspondingly and by referring to Study 1, we have shown that the relationship between physiological arousal and perceived ease of use is rather weak, but that both predictors explain significantly more variance in task performance than either measure alone. By contrast and with respect to the repeated-exposure Study 2, we also found that generalization effects may severely mitigate the physiological reactions caused by automatic cognitive processes. In particular, the latter observation indicates that the physiological dimension of ease of use changes its sensitivity dynamically, depending on habituation and generalization, i.e. learning effects in general (Grizzard et al., 2015; Groves and Thompson, 1970; Rankin et al., 2009; Stein, 1966). It is therefore recommended that this potential instability of theoretical constructs be considered with regard to their physiological dimensions. However, if both dimensions are taken together and viewed holistically, the overall higher-order construct may be more stable than the physiological dimension alone, as the physiological and psychological dimensions could compensate each other, depending on the context and impact of generalization effects.

Second, physiological arousal reflecting the bodily dimension of ease of use indicates only the strength of emotions, but it is not able to reliably detect their valence. That is, physiological arousal is sensitive to both positive and negative emotions caused by corresponding stimuli. And although it has been reported that it is more responsive to negative than positive emotions (e.g. Adam et al., 2012; Bailenson et al., 2008; Sheng and Joginapelly, 2012), it is still not possible to derive and hypothesize either a general negative or positive relationship between physiological arousal and other constructs such as perceived ease of use by means of complementary measures. It actually depends on the research context and the subject of investigation whether physiological arousal should be implemented in terms of a negative or positive indicator of a higher-order construct such as ease of use. For example, breakdown events of a UIS service, as investigated in the current work, are interpreted as negative stimuli, and thus physiological arousal was negatively related to perceived ease of use. By contrast, if a researcher is interested in the hedonic value of an IS (e.g. Chang et al., 2011; Kamis et al., 2008; Lin and Bhattacherjee, 2010; Lowry et al., 2013; van der Heijden, 2004), then physiological arousal may be a measure complementary to other constructs than perceived ease of use. Perceived enjoyment would then be an exemplary construct. However, it can also be the case that a low degree of ease use may mask other potential relationships, for example with perceived enjoyment. Accordingly, we may assume that this is one of the major reasons why Kowatsch (2012) found a negative relationship even between physiological arousal and perceived enjoyment in contrast to prior work in the field of marketing (Groeppel-Klein, 2005).

Finally, and in line with the last implication, we recommend revisiting research models and corresponding IS theories, and adding physiological arousal as the physiological dimension of related constructs such as ease of use, as shown in the current work, or other higher-order constructs such as enjoyment. With regard to the research opportunities outlined by prior work (Dimoka et al., 2012; Dimoka et al., 2011; Riedl et al., 2010c), this approach may enhance IS theories such that they are able to explain more variance in relevant outcome constructs such as job performance, online purchases or the health condition of individuals.

In addition to these theoretical implications, there are several practical implications. First and foremost, at least for the higher-order construct ease of use as conceptualized and measured in the current work, it is not possible to substitute a psychological self-report instrument with its physiological counterpart if a researcher aims at maximizing explained variance in a related outcome measure (Dimoka et al., 2011; Riedl et al., 2010a). The NeuroIS measure therefore requires additional time, effort and costs when conducting a corresponding study, because psychological self-report measures must still be adopted, revised and administered. Relative to other NeuroIS measures, however, tracking physiological arousal by electrodermal activity is the most cost-efficient approach (Dimoka et al., 2012).

Second, relying on psychological self-reports alone may only lead to suboptimal managerial decisions because some constructs of interest are not holistically represented without the physiological dimension (Tams et al., 2014). For example, technostress induced by breakdown events of IS or UIS services may not be consciously experienced, but can lead to chronic stress and, in turn, to decreased job or organizational performance in the short term and to burnout or even major depression and sickness absence in the long term (Ayyagari et al., 2011; Brod, 1984; Kowatsch et al., 2015b; Ragu-Nathan et al., 2008; Riedl, 2013; Riedl et al., 2012; Riedl et al., 2013; Tarafdar et al., 2007; Weil and Rosen, 1997). Thus, if human resource managers or team leaders are not aware of this subtle but relevant physiological dimension of arousal caused by corresponding services, they may fail to derive appropriate managerial implications and decisions such as identifying the proper source of job strain and implementing counteractive measures.

Third, it is important to consider that physiological arousal is a parameter that is continuously measured during a pre-defined period of time while subjects indicate perceived ease of use of a UIS service at a specific point in time. This asymmetry of data collection may lead to inconsistencies between both measures with respect to stimuli that are not related to the subject of investigation itself or are not observed, and thus are not under the control of the researcher or practitioner. This asymmetry may be highly relevant if physiological arousal is tracked by UIS services in field studies or productive use. For example, stimuli of the external environment – such as a joke of a coworker or a change in the temperature or humidity in the office – may lead to a high degree of physiological arousal. However, this physiological reaction is then not caused by a particular UIS service and, in turn, perceived ease of use as believed by the employee is not correlated with it. Another example would be noise or peaks in the physiological arousal signal caused by technical issues of the recording device. Thus, it is of utmost importance to make sure to control for and remove any anticipated side effects. Another, less costly approach would be to exclude any data from further analysis while a UIS service is not being used, which can be logged automatically.

And finally, a researcher or practitioner may want to react in real-time to changes of physiological arousal, for example, to personalize a website or to trigger an individual health intervention. If he or she is then not able to exclude or control for external contextual factors by using logging data of a corresponding UIS service or additional physiological parameters such as heart rate or eye tracking parameters to derive the valence of the underlying emotion (Chanel et al., 2009; Kukolja et al., 2014; Zhou et al., 2011), he or she may prompt individuals to use a self-report scale such as the visually appealing, and psychological valence dimension of the Self-Assessment Manikin (Bradley and Lang, 1994). In doing so, self-report scales can be used to complement physiological measures on demand, such that a broader basis for corresponding decision-support systems and recommender systems can be provided.

To conclude this section, we can state that our empirical findings are in line with the results of Tams et al. (2014), i.e. they support the view that NeuroIS measures are not alternatives but complements to psychometrics. Consistently, we have proposed and empirically assessed a higher-order construct ease of use that consists of physiological arousal, the physiological dimension, and complements perceived ease of use, the psychological dimension. The theoretical implications indicate that the IS researcher may consider a holistic view of existing constructs by also considering their physiological dimension, in order to enhance research models and corresponding IS theories. Regarding the practical implications, we have discussed the shortcomings of managerial decisions if a holistic view of automatic bodily reactions and the rational mind is neglected. We have also outlined the caveats related to the use of both physiological and psychological measures in field studies and productive use of UIS services.

6.5 Limitations of the current work

No empirical investigation comes without limitations. We therefore outline the shortcomings of the current work in the following paragraphs.

First and foremost, we used data from existing studies in a retrospective manner. That is, the design of the two studies conducted in 2011 and 2012 was not intended in the first place to address the research questions of the current work. And although it turned out that the data was quite homogenous among the participants of both studies (e.g. with respect to gender and age), and satisfied several important assumptions (e.g. single vs. repeated-exposure to UIS services), or even showed conservative characteristics (e.g. subjects of the repeated-exposure Study 2 were significantly more alert than those of the single-exposure study, making the identification of generalization effects even harder), the lack of a random assignment of the subjects to the single-exposure and repeated-exposure groups represents a major shortcoming.

In line with this first limitation, the amount of breakdown events of the ticket order service was not systematically manipulated due to the fact that the current work analyzed empirical data retrospectively. Although it turned out that the number of breakdown events was almost equally distributed between both studies, i.e. we found no significant differences, we could not control the frequency of breakdown events but were restricted to the observed mean values of 3.00 and 2.75 breakdown events in Study 1 and Study 2, respectively. As a consequence, the slightly lower mean value of Study 2 may potentially impact and mitigate the sensitivity of electrodermal activity in addition to generalization effects as formulated in the first and third hypotheses.

Third, we were also not able to systematically vary the frequency of and the time in between the repeated exposures to the ticket order service to better understand habituation and generalization effects (Grizzard et al., 2015; Groves and Thompson, 1970; Rankin et al., 2009; Stein, 1966; Thompson and Spencer, 1966). That is, the current work is limited in that we cannot make any assumptions about the changes over time with respect to the sensitivity of electrodermal reactions. This would offer an important theoretical and practical discussion, particularly, for the design science oriented researcher who aims at comparing alternative UIS services in empirical studies by employing on a within-subjects design.

Fourth, another shortcoming refers to the fact that the manual assessment of the video clips and coding of the breakdown events was conducted solely by the author of the current work. As a consequence, a major body of the empirical findings relies on the subjective assessment of one researcher alone. We thus cannot report corresponding quality criteria such as inter-rater reliabilities as it was done in prior work (e.g. Kowatsch, 2008; Moore and Benbasat, 1991), which would, in turn, allow us to empirically assess and discuss any potential challenges with respect to the internal validity of the manual coding process.

Fifth, the studies were conducted at different German universities and during different seasons, with more than one year in-between. Though the external laboratory conditions were kept similar in both studies with respect to the room temperature or the UIS services embedded in the interactive bathroom, potential confounding effects related to the actual time or geographic location of the two studies cannot be excluded and may also threaten the validity of the outcomes (Boucsein, 2012; Boucsein et al., 2012).

Sixth, the two empirical studies were conducted in a laboratory setting under controlled conditions and with a limited amount of rather homogenous subjects. Although these conditions assure the internal validity of the empirical findings, the generalizability of these findings and the theoretical and practical implications as discussed in the sections above are limited. For example, we cannot make any general assumptions based on our findings, in particular due to the lack of a representative study population. That is, the results are probably biased towards younger and technology-savvy students.

Another shortcoming represents the ticket order service itself, in that this UIS service was not tailored to the participants of the studies. For example, event recommendations were pre-defined, limited in their amount and not aligned to the preferences of the study participants. Thus, personal involvement in buying a corresponding ticket can be assumed to be rather low. As a result, not only subjective evaluations with respect to perceived ease of use but also physiological arousal and the general motivation of the subjects may be biased according to a "so what" attitude. The latter shortcoming may be particularly relevant in Study 2, where the overall evaluation procedure took almost one complete hour per subject.

Eighth, it is obvious that breakdown events as a consequence of interactions with a ticket order service embedded in an interactive bathroom facilitated by touch gestures and speech commands represent just a small class of UIS service failures that will be potentially relevant in the next couple of years. For example, various other classes of UIS services are offered these days for smartphones, such as mobile communication services (Mikkonen et al., 2002), social media services (Kaplan, 2012) or health intervention services (Burns et al., 2011; Kowatsch et al., 2014; Mohr et al., 2013; Pletikosa Cvijikj et al., 2014) – with their individual shortcomings or success factors (DeLone and McLean, 1992; DeLone and McLean, 2003; Petter et al., 2013; Petter and McLean, 2009). The current work is therefore also limited in providing assured answers to the research question whether electrodermal activity is a useful NeuroIS measure for the design and use of these classes of UIS services.

Ninth, several control variables were not consistently collected in both study populations, and thus it was not possible to empirically compare and assure that these variables were either equally distributed or had a significant influence on the current findings. For example, empirical data with regard to technology affinity of the subjects and prior experience with UIS services was only gathered from the subjects of Study 2. Also, additional control variables that might impact the sensitivity of electrodermal reactions were not collected in both studies. Corresponding examples include subjects' attributes related to ethnic differences (Johnson and Corah, 1963; Wesley and Maibach, 2003) and personality traits (Eysenck, 1967; Mardaga et al., 2006) or the humidity in the laboratory room (Boucsein, 2012; Boucsein et al., 2012).

And finally, the author of this work supervised the majority of the subjects in both studies. However, also two other supervisors were in charge of administering and conducting the empirical studies. Although all supervisors were instructed to adhere to the study protocol and standardized instructions, it cannot be excluded that the three supervisors influenced the subjects, and thus also the objectivity of the study procedure.

In summary, the current work has several limitations with regard to theoretical, methodological and practical aspects. Against the background of these limitations and in order to better understand and utilize electrodermal activity as a low-cost, noninvasive and unobtrusive NeuroIS measure in the context of UIS services, future research is proposed in the next section.

6.6 Future research

The section discusses potential future work that addresses the shortcomings of the current work. It also further assesses and investigates the utility of electrodermal activity as a novel emotional NeuroIS measure for the design and use of UIS services.

First and foremost, the findings of this present work should be cross-validated in a dedicated experiment in which the subjects are randomly assigned to a single-exposure condition, and at least one repeated-exposure condition, in order to better understand the nature of habituation and generalization effects in NeuroIS research. In the single-exposure condition, subjects should be asked to evaluate one UIS service, while in the repeated-exposure condition(s), at least two different implementations of the same UIS service should be assessed in a within-subjects design, as presented in this work. An alternative to the latter condition, in order to further exploit the impact of generalization effects, would be to compare implementations of two different UIS services in a study that uses a within-subjects design. In this experiment, relevant control variables should be considered in all experimental conditions, to address the limitations of the current work.

Second, and following the dual-process theory proposed by Groves and Thompson (1970), the following systematic manipulations may be considered, in addition to the experiment described above, to better understand how electrodermal reactions not only decrease over time because of habituation and generalization effects (Grizzard et al., 2015; Rankin et al., 2009), but also increase with respect to sensitization processes caused by high-intense stimuli. Initially, the frequency of stimuli can be manipulated by means of varying the time in between which subjects are exposed to UIS services. This would allow researchers to better understand when habituation and generalization effects set it, thus assisting them in planning study protocols so as to avoid or at least mitigate these effects. Exposing subjects to the same UIS service stimuli would then reveal details about the impact of habituation effects, while exposure to different but similar UIS service stimuli would offer further insights into the impact and causality of habituation effects. Then, a researcher may also systematically manipulate the intensity of UIS service stimuli to obtain insights into sensitization effects which are assumed to increase physiological reactions, allowing him or her to countervail habituation and generalization effects. For example, UIS service breakdowns may be a subtle event such as a notification about a system issue that does not hinder individuals from performing their task, and thus may barely lead to physiological reactions. By contrast, significant physiological reactions are expected as a consequence of major system failures which require individuals to wait for a UIS service, to restart it, or even to contact a first- or even second-level support team. An alternative approach to better understand sensitization effects would be to review electrodermal reactions as a consequence of various implementations of UIS services during their design process. Exposing subjects to either narratives, mockup-based implementations or even implemented prototypes of UIS services may cause different intensities of physiological reactions, which have not been investigated in this work. Personalized UIS services may also come with increased responses, compared to UIS services with pre-defined and potentially non-relevant content, as described in this present work. In summary, further investigations with regard to these classes of UIS services, under the assumption of habituation, generalization and sensitization effects, would reveal important implications for the design-science oriented researcher, while enabling decisions to be made on appropriate study protocols and control variables.

Third, the empirical findings have shown that the predictive accuracy and predictive relevancy scores were also markedly lower in Study 2 than in Study 1 for perceived ease of use. This was not expected against the theoretical assumptions underlying our research model. The perceived ease of use scores showed therefore similar patterns than those of physiological arousal indicating the presence of generalization effects, too. By contrast, relative to physiological arousal, perceived ease of use was strongly related to task performance in Study 2, which contradicts the latter finding. Thus, future research should further study the mechanisms underlying this unexpected behavior of the perceived ease use construct.

Fourth, it is recommended to assess any video material and to perform the manual coding of breakdown events of UIS services with at least two researchers, so as to increase the internal validity of the experiment and the objectivity of the data analyses. Corresponding quality criteria should also be reported then. Examples would be inter-rater reliability scores, such as the raw agreement or Cohen's Kappa.

Fifth, to further keep the objectivity of the experimental procedure stringent as possible, it is also recommended to reduce the number of different study supervisors to a minimum and to use standardized instructions and study procedures wherever possible. The latter can be achieved to a great extent by using an online survey system that not only collects self-report data as such but also guides subjects through the experimental session without subjectively biased instructions by experimenters.

Sixth, we also recommend using a survey system or a software application that sets markers during the experiment, at the beginning or end of relevant experimental steps in the physiological data stream or other observational data streams delivered by video cameras. This approach would not only further automate the data analyses but would also allow both researchers and practitioners to dynamically react to and log any anticipated or unexpected situations during the experiment. For example, a significant electrodermal reaction may trigger a pre-defined question, which is answered by the subject through text input on a smart phone or via touch gestures and speech commands, as described in Chapter 4. NeuroIS measures like electrodermal activity could even be used as novel tools for ecological momentary assessments of UIS services in longitudinal field studies beyond its application in laboratory experiments (Heron and Smyth, 2010; Stone and Shiffman, 1994).

Finally, it would be important to replicate the empirical findings of the current work in various application domains, in order to assess both their generalizability and constraints with regard to the usefulness of electrodermal activity as a novel, in-situ NeuroIS measure for the design and use of UIS services. Accordingly, we recommend investigating our research questions not only by means of UIS stimuli other than only breakdown events. Future research should also consider a more diverse or even representative study population and/or further predictor and outcome measures of IS and UIS service use that are related to electrodermal reactions. In any case, future research should also evaluate the utility of electrodermal activity for the design and use of UIS services which are realized by other physical environments or mobile devices in various application domains such as in electronic business (Hibbeln et al., in press; Kamis et al., 2008; Xiao and

Benbasat, 2007), home automation (Brush et al., 2011; Mennicken et al., 2014), online education (Huang and Lucas, 2015; McAndrew and Scanlon, 2013), sustainable energy consumption (Loock et al., 2013; Tasic et al., 2015), claims management (Baecker, 2011; Hibbeln et al., 2014), privacy and security research (Bélanger and Crossler, 2011; Kehr et al., 2015; Paefgen et al., 2012) or digital healthcare (Agarwal et al., 2010; Anderson and Agarwal, 2011; Burns et al., 2011; Kowatsch et al., 2014; Kowatsch et al., 2015b; Maass and Varshney, 2012; Marsch et al., 2014; Mohr et al., 2013).

6.7 Summary

In this concluding chapter we have discussed the four research questions against the background of our empirical findings and derived theoretical and practical implications. An overview of that discussion is provided in Table 28. We have also outlined the limitations of the current work and described potential future research.

This leads us now to the final conclusion and answer to the overall research question: Although generalization effects may decrease the sensitivity of electrodermal activity and future work is still to be done due to several limitations, we recommend the use of electrodermal activity as a low-cost, noninvasive and unobtrusive in-situ evaluation measure for the design and use of UIS services. We do so because it is conceptually related to perceived ease of use, a common and relevant predictor in the technology adoption literature, and task performance, a prominent outcome of IS and UIS service use. Conceptualized as physiological arousal, we see its value not only for design science oriented research but also for its practical application as a physiological trigger of behavioral interventions.

This work has contributed to the proposed NeuroIS research areas on the design and use of systems and outcomes (Dimoka, 2012). In line with NeuroIS research, which "…seeks to contribute to (i) the development of new theories that make possible accurate predictions of IT-related behaviors, and (ii) the design of

IT artifacts that positively affect economic and non-economic variables (e.g. productivity, satisfaction, adoption, well being)" (Riedl et al., 2010a, p. 245), this dissertation has attempted to identify a new determinant related to a predictor and outcome of UIS service use (RQ1 and RQ3), to better understand its reliability (RQ2) and dimensionality (RQ4).

Table 28. Summary of the discussion related to the four research questions (RQ)

	Question, answer and theoretical and practical implications
RQ1	**Question:** Is electrodermal activity sensitive enough to be able to significantly respond to stimuli while individuals move, gesticulate and interact with UIS services? **Answer:** In general, electrodermal activity is sensitive to physiological reactions while individuals move freely around, gesticulate, use touch gestures and speech commands for the interaction with a particular UIS service. **Theoretical implications:** (1) Electrodermal activity measured by the total SCR amplitude represents a potentially new determinant of UIS service use. (2) Electrodermal activity adds a novel physiological dimension to the knowledge base and tool set of an IS researcher interested in empirical assessments of UIS services with a focus on automatic processes that can be hidden from conscious and rational processes. (3) Electrodermal activity in combination with other methods of data collection, such as psychological self-reports, helps to address common method bias. (4) Electrodermal reactions as a consequence of breakdown events of UIS services are present independent of a subject's gender and even if a subject faces no time constraints in performing a given task. **Practical implications:** (1) Electrodermal activity can be used to evaluate UIS services "in the wild" while subjects are moving around and gesticulating.

Question, answer and theoretical and practical implications

(2) Future research does not have to consider a major extent of dropouts because of technical measurement issues.

(3) A balanced assignment of subjects to experimental conditions with regard to age and gender is recommended, because younger male subjects show stronger physiological reactions than females and older subjects.

(4) It is recommended to let subjects relax before they are exposed to UIS service stimuli, so as to increase their physiological potential for showing significant electrodermal reactions.

(5) Recording electrodermal activity with a mobile device and with electrodes attached to the edge of the hand can be recommended for future research because it was not perceived as obtrusive by the subjects of our studies.

(6) It is strongly recommended to use an automated trigger mechanism that indicates in the physiological data stream when and what happened exactly during the evaluation of UIS services.

(7) If costs are considered important in assessing UIS services, measuring electrodermal activity represents the cheapest method of collecting neurophysiological data in NeuroIS research (compared to electrocardiogram or brain imaging techniques).

RQ2 **Question:** Subject to the generalization effect of physiological responses, is electrodermal activity an appropriate measure for UIS studies that employ similar UIS stimuli as a within-subjects factor?

Answer: The utility of electrodermal activity as a NeuroIS measure is probably limited and requires careful consideration if similar UIS stimuli are employed as a within-subjects factor in corresponding study designs.

Theoretical implications:

(1) Generalization effects may potentially mitigate the sensitivity and with it the reliability of electrodermal reactions in studies, which employ similar UIS services as a within-subjects factor. Thus, physiological arousal measured by electrodermal activity might not be a stable theoretical

Question, answer and theoretical and practical implications

construct and predictor of UIS service use.

(2) If a within-subjects design is chosen, generalization effects should be considered or even explicitly incorporated into research models, for example as a moderator which mitigates relationships that include physiological arousal.

Practical implications:

(1) We recommended conducting pretests to determine the intensity of generalization effects with respect to the form and number of repeated exposures to similar UIS services.

(2) The order of UIS stimuli in a within-subjects design should be assigned randomly to subjects to countervail order effects that may also further increase the impact of generalization effects.

(3) Subjects who are highly sensitive to electrodermal reactions are more appropriate for within-subjects designs, while low-sensitive subjects should be assigned to between-subjects designs.

(4) If pretests indicate the presence of strong generalization effects, we recommend switching to a between-subjects design or to use adequate self-report instruments in addition to measurements of electrodermal activity, for example, the Self-Assessment Manikin, although generalization effects can also bias these alternative measures.

RQ3 **Question:** Which viable conceptualization of electrodermal activity can be related to predictors or outcomes of UIS use?

Answer: Physiological arousal seems to be a viable conceptualization of electrodermal activity measured by SCR amplitudes, which reflect the intensity of automatic emotional reactions. Moreover, physiological arousal is conceptually related to perceived ease of use, a relevant predictor in the technology adoption literature, and task performance, an outcome measure of IS and UIS service use.

Question, answer and theoretical and practical implications

Theoretical implications:

(1) We recommend revisiting theories and research models that employ arousal as one of their core constructs, using self-report instruments or other physiological measures to test whether physiological arousal measured by electrodermal activity replicates, or even increases, variance in the arousal construct itself or in corresponding outcome variables.

(2) Prior work which utilized the perceived ease of use construct may benefit from our findings, as physiological arousal could play an additional and significant role in enhancing the explanatory power of corresponding research models or theories (e.g. by using an ease of use construct with physiological arousal as the physiological dimension along with perceived ease of use, its psychological dimension).

(3) Physiological arousal is assumed to be a sensitive outcome construct as a consequence of negative events or emotions, and thus it can inform or enhance theories which explain adoption behavior related to UIS services.

(4) Research models and theories related to job strain and job performance can be potentially enhanced, because physiological arousal was found to be significantly related to task performance.

Practical implications:

(1) Physiological arousal is not restricted to measures of electrodermal activity. It can also be captured formatively as a combination of electrodermal activity with other physiological measures, thus representing a flexible construct that can be appropriately adapted to the subject of investigation.

(2) Physiological arousal, in combination with other measures, can be used to detect not only the strength of emotions but also their valence. It thus may guide design science researchers or practitioners in enhancing UIS services.

(3) Physiological arousal can be used by means of real-time biofeedback in corresponding UIS services.

(4) Physiological arousal can be used as an objective UIS service log which allows not only a continuous monitoring and improvement of services but

Question, answer and theoretical and practical implications	
	also to "listening in" customer behavior, to derive novel customer needs.
RQ4	**Question:** Are electrodermal activity and psychological self-reports complementary or alternative measures of the same underlying IS construct? **Answer:** With ease of use we have proposed a higher-order construct consisting of a physiological dimension (i.e. physiological arousal) and a psychological dimension (i.e. perceived ease of use). Our findings support the view that NeuroIS measures complement related psychological self-report measures rather than representing alternatives to each other. **Theoretical implications:** (1) The two-systems view of cognitive processing seems to be an appropriate theoretical lens to better understand the interplay between automatic and inferential processes. In particular, we have shown that automatic cognitive processes underlying physiological reactions may not necessarily influence inferential cognitive processes underlying the belief formation process of psychological measures, such as perceived ease of use. (2) It is impossible to derive and hypothesize either a general negative or positive relationship between physiological arousal and other constructs, such as perceived ease of use. That is, physiological arousal cannot reliably differentiate between positive and negative emotions. (3) We recommend revisiting research models and IS theories by adding physiological arousal as the physiological dimension of related constructs such as ease of use, or other higher-order constructs such as enjoyment. This approach may enhance IS theories in such a way that they are able to explain more variance in relevant outcome constructs. **Practical implications:** (1) Physiological arousal does not replace perceived ease of use but requires additional time, effort and costs when conducting a corresponding study. (2) Relying on psychological self-reports only may only lead to suboptimal managerial decisions, because some constructs of interest are not

Question, answer and theoretical and practical implications

holistically represented without the physiological dimension.

(3) Collecting physiological empirical data in real-time, and psychological data, may lead to inconsistencies between both measurements with respect to stimuli which are not related to the subject of investigation itself, or are not observed, and thus are not under the control of the researcher or practitioner.

(4) It is recommended to ask individuals on demand if physiological reactions alone cannot be automatically categorized, i.e. to use psychological self-reports to complement bodily responses.

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Appendix A: List of publications from NeuroIS.org

Table 29 contains the list of publications from NeuroIS.org from which the relevant keywords were extracted for the literature review:

Table 29. Publications from NeuroIS.org listing author (s), outlet (journal or conference), keywords and indicators that state whether electrodermal activity (EDA) was used as a measure in an original research study (EDA-OS) or whether it was just mentioned as a research tool (EDA-RT).[104] Note: * indicates articles from which keywords have been extracted by the current author because the original article did not contain any keywords.

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
1	Müller-Putz et al. (2015)	Communications of AIS	Brain, Construct, Electroencephalography (EEG), Error-related Negativity (ERN), Frequency Bands, EEG Guidelines, Neuron, NeuroIS, Spontaneous EEG, Event-related Potential (ERP), Measurement, Methodology, N200, N400, P200, P300, Research Method	–	–
2	Sénécal et al. (2015)	Journal of Internet Commerce	Automatic processing, brain, cognitive load, consumer neuroscience, controlled processing, electroencephalography (EEG), lock-in	–	–

[104] http://neurois.org/index.php?option=com_content&task=view&id=50&Itemid=49 (accessed 21 December 2015). Note: Redundant entries of the original list were removed, for example, if an article appeared as 'published' and 'forthcoming'; EDA mentioned or discussed in editorials, research-in-progress papers or literature reviews were assigned to the EDA-RT category of papers.

Appendix A

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
3	Rodger (2014)	Computers in Human Behavior	Inspiration, Adoption, Training, Emotion, Cortisol Memory	–	–
4	Turel et al. (2014)*	Psychological Reports: Disability & Trauma	fMRI, Addiction, Technology, NeuroIS, Neural Systems	–	–
5	Tams et al. (2014)	Journal of AIS	NeuroIS, Technostress, Correlation, Neuroscience, Self-reports, Triangulation	–	X
6	Vance et al. (2014)	Journal of AIS	Risk Perception, Information Security Behavior, NeuroIS, Self-reported Measures, EEG, Iowa Gambling Task (IGT), Laboratory Experiment, Security Warning Disregard	–	X
7	Léger et al. (2014c)	Journal of AIS	Eye Fixation-Related Potential, EFRP, Event-related Potential, ERP, Electroencephalography, Eye-tracking, NeuroIS, IT Use, IT impact, IS Methods	–	–
8	Riedl et al. (2014a)	Journal of AIS	Brain, Diagnosticity, Intrusiveness, Methodology, Methods, NeuroIS, Neuroscience, Nervous System, Objectivity, Psychophysiology, Reliability, Sensitivity, Validity	–	X
9	Liang and vom Brocke (2014)*	Journal of Management Information Systems	NeuroIS, EEG, EDA, EMG, fMRI, guidelines	–	X
10	Gregor et al. (2014)	Journal of Management Information Systems	Emotions in Information Systems, measurement, NeuroIS, neuroscience, nomological net	–	–

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
11	Minas et al. (2014)	Journal of Management Information Systems	Collaboration technology, electroencephalography, information processing bias, NeuroIS, virtual teams	X	–
12	Riedl et al. (2014b)	Journal of Management Information Systems	Agent, avatar, brain, cognitive neuroscience, evolutionary psychology, evolution theory, functional magnetic resonance imaging (fMRI), medial frontal cortex (MFC), mentalizing, NeuroIS, theory-of-mind (TOM)	–	X
13	Li et al. (2014)	Journal of Management Information Systems	Electroencephalography, NeuroIS, online games, software games, user–game engagement	–	–
14	Kuan et al. (2014)	Journal of Management Information Systems	Electroencephalography, emotion online, group buying, informational social influence, NeuroIS, normative social influence	–	–
15	de Guinea et al. (2014)	Journal of Management Information Systems	behavioral belief formation, cognitive beliefs, electroencephalography (EEG), emotion, IS acceptance, IS use, NeuroIS, nonlinear effects, TAM	–	–
16	vom Brocke and Liang (2014)	Journal of Management Information Systems	NeuroIS, neuroscience, research guidelines, research methods	–	X
17	Léger et al. (2014a)	Computers in Human Behavior	NeuroIS, Neurophysiological measures, End-user training, Cognitive absorption, Enactive learning	X	–

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
18	Léger et al. (2014b)	Industrial Management & Data Systems	Emotion, ERP, Expertise, Electrodermal activity (EDA), Novice, Physiology, Enterprise resource planning (ERP) system	X	–
19	Riedl et al. (2013)*	Advances in Human-Computer Interaction	ICT, technostress, gender, EDA, skin conductance	X	–
20	Astor et al. (2013)	Journal of Management Information Systems	Biofeedback, design science, decision-making processes, emotion regulation, financial decision making, IT artifacts, NeuroIS, serious games	–	X
21	Randolph et al. (2013)*	Hawaii International Conference on System Sciences	NeuroIS, EEG, mental processing, marketing	–	–
22	de Guinea and Webster (2013)	MIS Quarterly	Emotion, affect, behavior, cognition, performance, pattern, IS use, usage, heart rate, EKG, physiology, physiological arousal, automaticity, continuance, technological effects	–	–
23	de Guinea et al. (2013)	Computers in Human Behavior	Neuro IS, Multi-trait multi-method, Mono-method bias, Construct validity, Instrument validation, Electroencephalography	–	–
24	vom Brocke et al. (2013)	Journal of Computer Information Systems	Design science research, Neuroscience, fMRI, EEG, Affective computing, Neuroergonomics	–	X

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
25	Riedl (2013)	The DATA BASE for Advances in Information Systems	Adrenaline, Biology, Blood Pressure, Brain, Computer, Computerstress, Cortisol, Internet, Genetics, Heart Rate Variability, Hormone, HPA Axis, Internet, Noradrenaline, Technostress, Skin Conductance, Stress, Information Technology	–	X
26	Hubert et al. (2012)	International Conference on Information Systems	Neuroscientific research, NeuroIS, functional Magnetic Resonance Imaging (fMRI), connectivity analysis, behavioral science, cognition/cognitive science, data analysis, method	–	–
27	Sénécal et al. (2012)	International Conference on Information Systems	Brain, Cognitive Workload, Electroencephalography (EEG), NeuroIS, Online Cognitive Script, Neurophysiology	–	X
28	Zhang et al. (2012)	International Conference on Information Systems	Experiments, NeuroIS, Electronic markets, Human-Computer Interaction, Auction, Framework	–	X
29	Adam et al. (2012)	International Journal of Electronic Commerce	Auction experiments, behavioral economics, bidding, consumer behavior, Dutch auction, emotions, excitement, Internet auctions, online auctions	X	–
30	Dimoka et al. (2012)	MIS Quarterly	NeuroIS, neuroscience, neurophysiological tools, psychophysiological tools, neuroimaging	–	X
31	Dimoka (2012)	MIS Quarterly	fMRI, decision neuroscience, neuroIS, brain imaging	–	X

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
32	Riedl and Javor (2012)	Journal of Neuroscience, Psychology, and Economics	Trust, biology, hormones, fMRI, oxytocin	–	X
33	Riedl et al. (2012)*	Business & Information Systems Engineering	Technostress, NeuroIS, cortisol	–	X
34	de Guinea et al. (2012)*	Hawaii International Conference on System Sciences	NeuroIS, EKG, EEG, construct validity, mono-method bias, neurophysiology, self-reports	–	–
35	Randolph (2012)*	Hawaii International Conference on System Sciences	NeuroIS, Brain-computer interface, EEG, motor cortex, task-technology fit	–	X
36	Djamasbi et al. (2012)*	Hawaii International Conference on System Sciences	NeuroIS, attention, eye-tracking, design	–	–
37	Wegrzyn et al. (2012)	Journal of Research on Technology in Education	ADHD, brain games, engagement, focus, executive functioning, EEG	–	–
38	Brown et al. (2012)	The Kennesaw Journal of Undergraduate Research	Neuromarketing, consumer behavior, branding, taste test, EEG	–	–
39	Elkins et al. (2012)*	Hawaii International Conference on System Sciences	NeuroIS, neurophysiology, vocal response, embodied Conversational Agent, human-computer interaction	–	–

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
40	Riedl et al. (2011)	International Conference on Information Systems	Avatar, agent, brain, fMRI, mentalizing, NeuroIS, theory of mind (TOM), trust	–	–
41	Adam et al. (2011)	International Conference on Information Systems	Auctions, Electronic markets, Emotions, Experiments, Physioeconomics	X	–
42	Dimoka et al. (2011)	Information Systems Research	Cognitive neuroscience; functional brain imaging; NeuroIS; neuroeconomics; neuromarketing	–	–
43	Nunamaker Jr. et al. (2011)	Journal of Management Information Systems	Avatars, deception detection, embodied conversational agents, NeuroIS	–	–
44	Derrick et al. (2011)	AIS Transactions on Human-Computer Interaction	Embodied conversational agents, interpersonal sensors, system design	–	–
45	Liapis and Chatterjee (2011)	Conference on Design Science Research in Information Systems and Technology	Design Science, Neuroscience, Design Science Research Methodology, Human Threading, EEG, Information Systems	–	X
46	vom Brocke et al. (2011)	Conference on Design Science Research in Information Systems and Technology	Design science research, design theory, brain, neuroscience, fMRI	–	X

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
47	Randolph et al. (2011)*	International Journal of Human-Computer Interaction	NeuroIS, Brain-computer interface, BCI, electrophysical response, effective system use, mu rhythm, EEG	–	–
48	Randolph and Mourmant (2011)	ACM SIGCHI Conference on Human Factors in Computing Systems	EEG, eye-tracking, epiphany, IT entrepreneurship	–	–
49	Burkhalter and Randolph (2011)*	Society for Consumer Psychology Conference	Neuromarketing, electroencephalography, EEG, music video, television, emotional response	–	–
50	Dimoka et al. (2010)	International Conference on Information Systems	NeuroIS, Neuroscience, Functional Neuroimaging, Brain Imaging Tools	–	–
51	Benbasat et al. (2010)	International Conference on Information Systems	Online Recommendation Agents, Anthropomorphic Interfaces, Ethnicity, Gender, NeuroIS, Neuroscience, fMRI	–	–
52	Riedl et al. (2010c)	Workshop on HCI Research in MIS	Brain, Human-Computer Interaction, NeuroIS, Neuroscience	–	X
53	Loos et al. (2010)*	Business & Information Systems Engineering	NeuroIS, neuroscience, potential, design science research, cognition, technology acceptance, TAM, experimental research	–	X
54	Riedl et al. (2010a)	Communications of the AIS	NeuroIS, cognitive neuroscience, brain, neurophysiological measurements, fMRI, EEG, TMS	–	X

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
55	Riedl et al. (2010b)	MIS Quarterly	Online trust, trustworthiness, functional magnetic resonance imaging (fMRI), gender, eBay	–	X
56	Dimoka (2010)	MIS Quarterly	Trust, distrust, neuroIS, price premiums, functional neuroimaging, fMRI, cognitive neuroscience	–	–
57	Randolph and Jackson (2010)	ACM Transactions on Accessible Computing	User interfaces, human factors, design, performance, user profiles, individual characteristics, brain-based interfaces, brain-computer interface, direct-brain interface, galvanic skin response, functional near-infrared, assistive technology	X	–
58	Dimoka et al. (2009a)	International Conference on Information Systems	Cognitive Neuroscience, IS Economics, TAM, Brain Imaging Tools, NeuroIS	–	–
59	Riedl (2009a)	Information Management und Consulting	Cognitive Neuroscience, Brain, functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG), Brain-Computer Interaction System	–	–
60	Riedl (2009b)	NeuroPsychoEconomics	Neuroeconomics, Business information systems, Theory	–	–
61	Dimoka and Davis (2008)	International Conference on Information Systems	NeuroIS, Cognitive Neuroscience, Technology Adoption, TAM, Brain Imaging, fMRI	–	–

#	Author(s) (Year)	Journal / Conference	Keywords	EDA-OS	EDA-RT
62	Dimoka et al. (2007)	International Conference on Information Systems	Cognitive Neuroscience, Functional Neuroimaging, Brain Imaging, Neuroeconomics	–	–
63	Randolph et al. (2006a)	International Conference on Information Systems	Brain-computer interface, biometric interface, assistive technology, mu rhythm, control, locked-in syndrome	–	X
64	Moore et al. (2005a)	International Conference on Information Systems	Assistive technology, augmented communication, biometric interface	–	X
65	Randolph et al. (2005)	International Conference on Human-Computer Interaction	Biometric interface, galvanic skin response, characterization of controllability	X	–
66	Moore et al. (2004)	Americas Conference on Information Systems	User profiles, personalization, augmentative and assistive communication, conversational prediction	–	X

Appendix B: Publications utilizing parameters of electrodermal activity as a result of the literature review

Table 30 gives an overview of the publications that showed up according to the search terms and search strategy of databases outlined in Section 2.7.

Table 30. Publications utilizing parameters of electrodermal activity with an indicator that states whether electrodermal activity (EDA) was used as a measure in an original research study (EDA-OS). Note: * indicates that EDA was used in the described study. However, no empirical data or statistical tests were provided, and thus this paper was dropped from the list of relevant publications.

#	Outlet Author(s) (Year)	Title	EDA-OS
	European Journal of Information Systems		
	Information Systems Journal		
	Information Systems Research		
	Journal of AIS		
1	Teubner et al. (2015)	The Impact of Computerized Agents on Immediate Emotions, Overall Arousal and Bidding Behavior in Electronic Auctions	X
2	Vance et al. (2014)	Using Measures of Risk Perception to Predict Information Security Behavior: Insights from Electroencephalography (EEG)	–
3	Riedl et al. (2014a)	Towards a NeuroIS Research Methodology: Intensifying the Discussion on Methods, Tools, and Measurement	–
	Journal of Information Technology		
	Journal of MIS		
4	Moody and Galletta (2015)	Lost in Cyberspace: The Impact of Information Scent and Time Constraints on Stress, Performance, and Attitudes Online	X

#	Outlet Author(s) (Year)	Title	EDA-OS
5	Liang and vom Brocke (2014)	Special Issue: Neuroscience in Information Systems Research	–
6	Twyman et al. (2014b)	Autonomous Scientifically Controlled Screening Systems for Detecting Information Purposely Concealed by Individuals	–
7	Minas et al. (2014)	Putting on the Thinking Cap: Using NeuroIS to Understand Information Processing Biases in Virtual Teams	X
8	vom Brocke and Liang (2014)	Guidelines for Neuroscience Studies in Information Systems Research	–
9	Twyman et al. (2014a)	A Rigidity Detection System for Automated Credibility Assessment	–
10	Riedl et al. (2014b)	Trusting Humans and Avatars: A Brain Imaging Study Based on Evolution Theory	–
11	Astor et al. (2013)	Integrating Biosignals into Information Systems: A NeuroIS Tool for Improving Emotion Regulation	–
	Journal of Strategic Information Systems		
	MIS Quarterly		
12	Dimoka et al. (2012)	On the Use of Neurophysiological Tools in IS Research: Developing a Research Agenda for NeuroIS	–
13	Lee et al. (2012b)	Can Online Wait Be Managed? The Effect of Filler Interfaces and Presentation Modes on Perceived Waiting Time Online	–
14	Riedl et al. (2010b)	Are There Neural Gender Differences in Online Trust? An fMRI Study on the Perceived Trustworthiness of eBay Offers	–

#	Outlet Author(s) (Year)	Title	EDA-OS
	AIS Transactions on Human-Computer Interaction		
15	Sheng and Joginapelly (2012)	Effects of Web Atmospheric Cues on Users' Emotional Responses in E-Commerce	X
	ACM Transactions on Computer-Human Interaction		
16	Da Silva et al. (2015)	Introduction to the Special Issue on Physiological Computing for Human-Computer Interaction	–
17	Slovák and Fitzpatrick (2015)	Teaching and Developing Social and Emotional Skills with Technology	–
18	Reeves et al. (2015)	The Challenges of Using Biodata in Promotional Filmmaking	–
19	Zhou et al. (2015)	Measurable Decision Making with GSR and Pupillary Analysis for Intelligent User Interface	X
20	Karran et al. (2015)	A Framework for Psychophysiological Classification within a Cultural Heritage Context Using Interest	X
21	Benford et al. (2015)	The Ethical Implications of HCI's Turn to the Cultural	–
22	Schnädelbach et al. (2012)	ExoBuilding: Physiologically Driven Adaptive Architecture	X
23	Li et al. (2012)	Using context to reveal factors that affect physical activity	–
	International Journal of Human-Computer Studies		
24	Felnhofer et al. (2015)	Is virtual reality emotionally arousing? Investigating five emotion inducing virtual park scenarios	X
25	Choi et al. (2015)	Physiological evidence for a dual process model of the social effects of emotion in computers	X
26	Kukolja et al. (2014)	Comparative analysis of emotion estimation methods based on physiological measurements for real-time applications	X

Appendix B

#	Outlet Author(s) (Year)	Title	EDA-OS
27	Chittaro and Sioni (2014a)	Affective computing vs. affective placebo: Study of a biofeedback-controlled game for relaxation training	X
28	Zhou et al. (2011)	Affect prediction from physiological measures via visual stimuli	X
29	Lim and Reeves (2010)	Computer agents versus avatars: Responses to interactive game characters controlled by a computer or other player	X
30	Chanel et al. (2009)	Short-term emotion assessment in a recall paradigm	X
31	Liu et al. (2008)	Physiology-based affect recognition for computer-assisted intervention of children with Autism Spectrum Disorder	X
32	Bailenson et al. (2008)	Real-time classification of evoked emotions using facial feature tracking and physiological responses	X
33	Liao et al. (2006)	Toward a decision-theoretic framework for affect recognition and user assistance	X
	Computers in Human Behavior		
34	Kneer et al. (2016)	Fight fire with rainbows: The effects of displayed violence, difficulty, and performance in digital games on affect, aggression, and physiological arousal	X
35	Harley et al. (2015)	A multi-componential analysis of emotions during complex learning with an intelligent multi-agent system	X
36	Chittaro and Sioni (2015)	Serious games for emergency preparedness: Evaluation of an interactive vs. a non-interactive simulation of a terror attack	X

#	Outlet Author(s) (Year)	Title	EDA-OS
37	Pollina and Barretta (2014)	The effectiveness of a national security screening interview conducted by a computer-generated agent	X
38	Patel et al. (2014)	Receptive to bad reception: Jerky motion can make persuasive messages more effective	X
39	Léger et al. (2014a)	Neurophysiological correlates of cognitive absorption in an enactive training context	X
40	Chittaro and Sioni (2014b)	Evaluating mobile apps for breathing training: The effectiveness of visualization	X
41	Amichai-Hamburger et al. (2014)	The future of online therapy	–
42	Kallinen and Ravaja (2007)	Comparing speakers versus headphones in listening to news from a computer – individual differences and psychophysiological responses	X
43	Carlbring et al. (2007)	Applied relaxation: an experimental analogue study of therapist vs. computer administration	X
	Personal and Ubiquitous Computing		
44	Kanjo et al. (2015)	Emotions in context: examining pervasive affective sensing systems, applications, and analyses	–
45	Sysoev et al. (2015)	Noninvasive stress recognition considering the current activity	–
46	Gravenhorst et al. (2015)	Mobile phones as medical devices in mental disorder treatment: an overview	–
47	Sas and Chopra (2015)	MeditAid: a wearable adaptive neurofeedback-based system for training mindfulness state	–
48	Niforatos and Karapanos (2015)	EmoSnaps: a mobile application for emotion recall from facial expressions	–
49	Kappeler-Setz et al. (2013)	Towards long term monitoring of electrodermal activity in daily life	X

#	Outlet Author(s) (Year)	Title	EDA-OS
50	Arnrich et al. (2013)	Mental health and the impact of ubiquitous technologies	–
51	van den Broek (2013)	Ubiquitous emotion-aware computing	–
52	Atz (2013)	Evaluating experience sampling of stress in a single-subject research design	–
53	Repetto et al. (2013)	Virtual reality and mobile phones in the treatment of generalized anxiety disorders: a phase-2 clinical trial	X
54	Terzis et al. (2013)	Measuring instant emotions based on facial expressions during computer-based assessment	–
55	Maly et al. (2013)	An evaluation tool for research of user behavior in a realistic mobile environment	–*
56	Gartenberg et al. (2013)	Collecting health-related data on the smart phone: mental models, cost of collection, and perceived benefit of feedback	–
57	Barakova et al. (2013)	Trends in measuring human behavior and interaction	–
58	Ivonin et al. (2013)	Unconscious emotions: quantifying and logging something we are not aware of	–
59	Gaggioli et al. (2013)	A mobile data collection platform for mental health research	–
60	Marin-Perianu et al. (2013)	A performance analysis of a wireless body-area network monitoring system for professional cycling	–
61	Beun (2013)	Persuasive strategies in mobile insomnia therapy: alignment, adaptation, and motivational support	–
61	Bates and Marquit (2011)	Space psychology: natural elements in habitation design	–
61	Schumm et al. (2010)	Unobtrusive physiological monitoring in an airplane seat	–*

#	Outlet Author(s) (Year)	Title	EDA-OS
62	Maglogiannis et al. (2010)	Pervasive technologies for assistive environments: special issue of PETRA 2008 conference	–
63	Benoit et al. (2009)	Multimodal focus attention and stress detection and feedback in an augmented driver simulator	–*
64	Ståhl et al. (2009)	Experiencing the Affective Diary	–*
65	Sumi et al. (2007)	Collaborative capturing, interpreting, and sharing of experiences	–

Appendix B

Appendix C: Promotion cards of the studies

Figure 37. Promotion card of Study 1

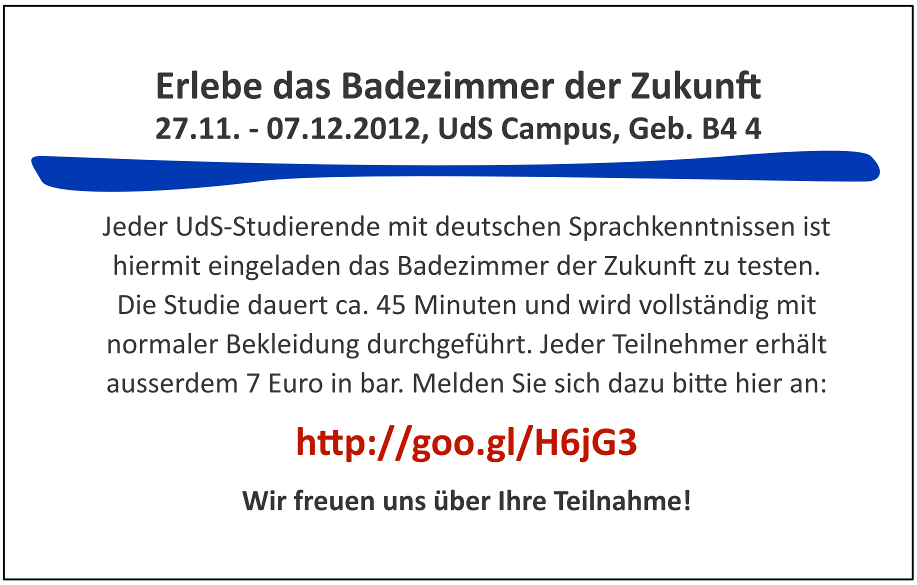

Figure 38. Side 1 of the promotion card of Study 2

Figure 39. Side 2 of the promotion card of Study 2

Appendix D: Instructions for the supervisor of the studies

Study 1 (2011): Please note that only the narrative (denoted as "Situation 1 / Group A" in the instructions) with the ticket order service is relevant to the current work. Furthermore, setting markers with the MBS K3 by the subject and / or study supervisor is also not relevant with regard to the current work. It was meant to be a sanity check for the data analysis to test whether all steps during the study were conducted.

Studie „Das interaktive Bad"

Instruktionen für Studienleiter

Ablauf:

1. Der Teilnehmer wird freundlich begrüßt und kurz in den Ablauf der Studie eingewiesen. Dauer: max. 1 Min.

2. Der Studienleiter erklärt kurz die Funktion des K3, bittet dann den Teilnehmer sich die Hände mit Seife zu waschen (die Hände müssen für korrekte Funktion des K3 fettfrei sein) und befestigt anschließend die Elektroden an die linke Hand (Kanal 1) und rechte Hand (Kanal 2) des Teilnehmers (bzw. überlässt dies dem Teilnehmer). Die Elektroden werden mit dem K3 verbunden. Der 2-Kanal-Test wird durchgeführt und dann die 2-Kanal-Aufzeichnung gestartet. Dauer: max. 4 Min.

3. Der Teilnehmer wird abwechselnd Gruppe A (Situation 1) bzw. Gruppe B (Situation 2) zugeordnet. Entsprechend der zugewiesenen Gruppe liest der Studienleiter die entsprechende Situation vor und erklärt dabei die Funktionsweise im Bad (z.B. Interaktionen wie das Starten / Beenden der angebotenen Dienste, etc.). Der Studienleiter weist dabei darauf

hin, dass die Informationen und Dienste in dieser Studie nur exemplarischen Charakter haben, d.h. das zukünftige Produkt wäre natürlich personalisierbar und die Informationen aktuell. Dauer: max. 5 Min.

4. Nach der Demonstration wird die Kamera-Aufzeichnung mit der Fernbedienung gestartet. Es wird zudem ein Marker auf dem K3 durch Doppelklick auf den Taster vorne gesetzt (dies kann der Teilnehmer selbst machen, es muss nur darauf geachtet werden, dass der Marker gesetzt wurde. Der Teilnehmer soll nun selbst die Situation mit Hilfe des Studienleiters durchspielen. Dann wird wieder ein Marker gesetzt. Danach spielt der Teilnehmer noch ein- mal die Situation ohne die Hilfe des Studienleiters durch. Danach wird nochmals ein Marker gesetzt und die Videoaufzeichnung wird beendet. Dauer: max. 5 Min.

5. Der Teilnehmer darf nun den Fragebogen für die entsprechende Gruppe ausfüllen. Danach wird die K3-Aufzeichnung beendet. Dauer: max. 13 Min.

6. Nach dem Ausfüllen des Fragebogens entfernt der Studienteilnehmer die Klebeelektroden, dankt dem Teilnehmer, gibt ihm 5 EUR und lässt dies durch Name und Unterschrift auf der entsprechenden Liste quittieren. Dauer: max. 2 Min.

7. Falls noch Zeit übrig ist, soll ein Kurzinterview mit Hilfe des Kurz-Interview Leitfadens durch- geführt werden. Anschließend bedankt sich der Studienleiter für die Teilnahme und wünscht dem Teilnehmer noch einen schönen Tag. Dauer: max. 5 Min.

8. Es muss auf jeden Fall darauf geachtet werden, dass auf dem ausgefüllten Fragebogen Tag und Uhrzeit der Teilnehmer-Session vermerkt wird, ansonsten ist eine Korrelation der Fragebogenergebnisse mit dem K3 nicht möglich.

Weitere Hinweise:

- Es muss darauf geachtet werden, dass der Teilnehmer nicht zu lange für die einzelnen Stationen benötigt (d.h. Small-Talk am besten am Ende im Rahmen des Kurzinterviews).

- Fragen des Teilnehmers dürfen immer beantwortet werden.

- Wenn der Teilnehmer den Einsatz des MBS K3 nicht möchte, ist dies kein Problem.

- Es muss darauf geachtet werden, dass jeden Morgen die Uhren des Videos mit denen des MBS K3 synchronisiert werden.

Study 2 (2012): Please note that setting markers with the MBS K3 by the subject and / or study supervisor is also not relevant with regard to the current work. It was meant to be a sanity check for the data analysis to test whether all steps during the study were conducted.

Studie „Das Badezimmer der Zukunft“

Instruktionen für Studienleiter

1. Proband wird begrüsst und entfettet die Handflächen für die Klebeelektroden und wird mit dem K3 ausgestattet sofern er damit einverstanden ist. Die Messung des Hautleitwerts wird getestet und gestartet. Dauer: max. 5 Min.

2. Proband liest kurze Einweisung in die Studie (Dauer: max. 1 Min.), dann folgt das Entspannungsvideo 1 (Dauer: 3 Min.); K3-Marker setzen Proband liest sich die vorgegebene Situation[105] durch (Dauer: max. 0,5 Min.) Proband füllt den Online-Fragebogen zur Situation aus (Dauer: max. 5 Min.).

3. Entspannungsvideo 2 (Dauer: 1 Min.) > danach K3-Marker setzen lassen und gleichzeitig Video starten Mündliche Erklärung der Situation 1 mit dem Bad-Modell durch den Instrumentalleiter (Dauer: max. 3 Min.) danach K3-Marker setzen. Proband füllt den Online-Fragebogen zum Bad-Modell aus (Dauer: ca. 5 Min.) > währenddessen wird das Video beendent.

4. Proband schaut sich Entspannungsvideo 3 an (Dauer: 2 Min.), währenddessen wird das Stativ im Bad aufgestellt. Nach dem Video wird wieder

[105] The narrative outlined in the current work.

ein K3-Marker gesetzt.

5. Entsprechend Situation 1 weist der Studienleiter den Teilnehmer in die Funktionsweise des interaktiven Bades ein (z.B. Interaktionen mit den angebotenen Dienste, etc.). Der Studienleiter weist dabei darauf hin, dass die Informationen und Dienste in dieser Studie nur exemplarischen Charakter haben, d.h. das zukünftige Produkt wäre natürlich personalisierbar und die Informationen aktuell. Dauer: max. 5 Min.

6. Nach der Demonstration wird die Kamera-Aufzeichnung gestartet. Es wird zudem ein Marker auf dem K3 durch Doppelklick auf den Taster vorne gesetzt (dies kann der Teilnehmer selbst machen, es muss nur darauf geachtet werden, dass der Marker gesetzt wurde. Der Teilnehmer soll nun selbst die Situation mit Hilfe des Studienleiters durchspielen. Dann wird wieder ein Marker gesetzt. Danach spielt der Teilnehmer noch einmal die Situation ohne die Hilfe des Studienleiters durch. Danach wird nochmals ein Marker gesetzt und die Videoaufzeichnung wird beendet. Dauer: max. 5 Min.

7. Der Teilnehmer darf nun den Online-Fragebogen zum interaktiven Bad ausfüllen. Danach wird die K3-Aufzeichnung beendet. Dauer: max. 13 Min.

9. Nach dem Ausfüllen des Online-Fragebogens entfernt der Studienteilnehmer die Klebeelektroden, dankt dem Teilnehmer, gibt ihm 7 EUR und lässt dies durch Name und Unterschrift auf der entsprechenden Liste quittieren. Dauer: max. 2 Min.

10. Falls noch Zeit übrig ist, soll ein Kurzinterview mit Hilfe des Kurz-Interview Leitfadens durchgeführt werden. Anschließend bedankt sich der Studienleiter für die Teilnahme und wünscht dem Teilnehmer noch einen schönen Tag. Dauer: max. 5 Min.

11. Es muss auf jeden Fall darauf geachtet werden, dass der Online-

Fragebogen abgeschickt wurde, damit er vollständig ausgefüllt erkannt wird und später ein Abgleich mit den Daten des MBS K3 nicht sowie des Videos möglich ist.

Weitere Hinweise:

- Es muss darauf geachtet werden, dass der Teilnehmer nicht zu lange für die einzelnen Stationen benötigt (d.h. Small-Talk am besten am Ende im Rahmen des Kurzinterviews).
- Fragen des Teilnehmers dürfen immer beantwortet werden.
- Wenn der Teilnehmer den Einsatz des MBS K3 nicht möchte, ist dies kein Problem.
- Es muss darauf geachtet werden, dass jeden Morgen die Uhren des Videos mit denen des MBS K3 synchronisiert werden.

Appendix E: Study information for participants

Study 1 (2011):

Studie „Das interaktive Bad“

Informationsblatt

Liebe(r) Teilnehmer(in),

herzlichen Dank für Ihr Interesse an der Studie „Das interaktive Bad“. Im Rahmen dieser Studie haben Sie die Möglichkeit Informations- und Kommunikationsdienste in einer interaktiven Badumgebung zu testen und zu bewerten.

Die Teilnahme dauert ca. 30 Minuten und besteht aus drei Teilen:

1. Zunächst lernen Sie kurz die interaktive Badumgebung kennen.

2. Danach dürfen Sie selbst die Badumgebung anhand von Alltagssituationen testen.

3. Schließlich bewerten Sie die Badumgebung mit Hilfe eines Fragebogens.

Sie dürfen jederzeit während der Studie Fragen stellen. Alle erhobenen Daten werden vertraulich behandelt und nur anonym ausgewertet. Am Ende der Studie erhalten Sie eine Aufwandsentschädigung von 5 Euro in bar.

Aber nun viel Spaß bei der Teilnahme!

Appendix E

Study 2 (2012):

Universität St.Gallen

Studie
Das Badezimmer der Zukunft
2012

Liebe(r) Teilnehmer(in),

herzlichen Dank für Ihr Interesse an der Studie „Das Badezimmer der Zukunft". Im Rahmen dieser Studie haben Sie die Möglichkeit Informations- und Kommunikationsdienste in einer interaktiven Badumgebung zu testen und zu bewerten.

Die Teilnahme dauert ca. 45 Minuten und umfasst drei Teile:

1. Zunächst lernen Sie das Badezimmer anhand einer Alltagssituation kennen.

2. Danach dürfen Sie das Badezimmer selbst testen.

3. Dazwischen bewerten Sie das Badezimmer mit Hilfe dieses Online-Fragebogens.

Sie dürfen jederzeit während der Studie Fragen stellen. Alle erhobenen Daten werden vertraulich behandelt und nur anonym ausgewertet. Am Ende der Teilnahme erhalten Sie eine Aufwandsentschädigung von 7 Euro in bar.

Aber jetzt viel Spass. Bitte klicken Sie auf "Weiter".

Figure 40. Information for participants of Study 2 (2012)

Appendix F: Constructs and questionnaire items

In Table 31 lists all constructs and questionnaire items of both studies as published in the prior work of the author (Janzen et al., 2011a; Kowatsch, 2012; Kowatsch and Maass, 2013; Kowatsch et al., 2013; Maass et al., 2012).

Table 31. Constructs and questionnaire items of both studies. Note: Seven-point Likert scales ranging from strongly disagree (0) to strongly agree (7), with neither being the neutral anchor (4) apply to the items if not stated otherwise; * either weather information service, event recommendation service or ticket order service; + 10-point Likert scale ranging from extremely sleepy (1) to extremely alert (10); items are formulated for the evaluation of the full-size interactive bathroom prototype, i.e. the formulation of items for the narrative and mockup with doll and slides differed slightly and was termed prospectively (e.g. "Using the * in the bathroom would be fun")

#	Construct Questionnaire Item	Study 1 (2011)	Study 2 (2012)
	Perceived enjoyment (PEN)		
PEN1	Using the * in the bathroom was fun.	X	X
PEN2	My attitude toward using the * in the bathroom is positive.	X	–
PEN3	Using the * in the bathroom was a pleasant experience.	X	X
PEN4	Using the * in the bathroom was very interesting.	X	X
	Perceived usefulness (PU)		
PU1	Using the * in the bathroom would increase my effectiveness.	X	X
PU2	Using the * in the bathroom would increase my efficiency.	X	X
PU3	Using the * in the bathroom would increase my overall performance.	X	–
PU4	I would find the * useful in the bathroom.	X	X

#	Construct Questionnaire Item	Study 1 (2011)	Study 2 (2012)
	Perceived ease of use (PEU)[106]		
PEU1	Using the * was easy for me.	X	X
PEU2	My interaction with the * was clear and understandable.	X	X
PEU3	Learning to use the * was easy for me.	X	X
PEU4	It was easy for me to become skillful at using the *.	X	–
	Perceived ease of use (IU)		
IU	I would use the * in the bathroom.	X	X
	Intention to pay (IP)		
IPOnce	If you actually had the money, how likely is it that you would pay for the * at a fixed price?	X	–
IPMonthly	If you actually had the money, how likely is it that you would pay a monthly fee for the *?	X	–
IPPerUse	If you actually had the money, how likely is it that you would pay a pay-per-use fee for the *?	X	–
	Situation Service Fit (SSF)		
SSF1	The * fits well into the situation I just played through.	X	X
SSF2	Using the * in the bathroom would fit well to my behavior.	X	X
SSF3	I found that the modality of content presentation fits well to the *.	X	X
SSF4	I found that the spatial placement of the contents fits well to the *.	X	X
	Interactivity (INT), Relevancy (REL) and Satisfaction (SAT)		
INT	I find this * static (1) ... interactive (7).	–	X

[106] Was only asked after interaction with the full-size interactive bathroom (cf. Chapter 3).

#	Construct Questionnaire Item	Study 1 (2011)	Study 2 (2012)
REL	I find this * irrelevant (1) ... relevant (7).	–	X
SAT	Using this * is frustrating (1) ... satisfactory (7).	–	X
	Technology Affinity (TA)		
TA1	It is easy for me to use new technologies.	–	X
TA2	I am open towards new technologies.	–	X
	Alertness (ALE): Karolinska Sleepiness Scale^{+}	–	X
ALE	Please indicate the degree which best reflects your mental alertness while you were in the bathroom.	X	X
	Demographics		
GEN	Gender: Are you female or male?	X	X
AGE	Age: How old are you? < 20, 20-24, 25-29, 30-34, > 34	X	X
	Further variables		
UND	Understandability of the instructions: I found that the instructions of the study were easy to understand.	–	X
LEN	Length of the study: The study was too long.	–	X

Appendix F

Appendix G: Extraction of SCR amplitudes by means of nonnegative deconvolution

In the current work, we adopted the approach proposed by Benedek and Kaernbach (2010b), which applies nonnegative deconvolution to the original electrodermal activity signal to extract distinct SCR amplitudes. For the extraction of the SCR amplitudes we used MathWorks MATLAB Version R2015a for OSX and the Ledalab plugin V.3.4.7.[107] The procedure of the extraction was three-fold.

First, we applied a spline interpolation in R to the raw data such as to smooth and upscale the data to 32 samples per second.[108]

Second, a visual inspection of the skin conductance recordings was performed in order to identify and remove any cases where the neurophysiological signal was not recorded correctly (Boucsein, 2012).

Finally, we applied the Ledalab script as shown in Table 32 to the electrodermal activity data to derive the SCR amplitudes. The root-mean-square error (RMSE) of the difference between the upSampledData and the reconstructed data as described by Benedek and Kaernbach (2010b) is then used as goodness of fit index. For Study 1 (*M*=0.047, *SD*=0.062) and Study 2 (*M*=0.088, *SD*=0.228), the RSMEs lie slightly above the values of prior work (*M*=0.019, *SD*=0.01) (ibid.).

[107] http://www.ledalab.de, accessed November 1st 2015

[108] R: `upSampledData = spline(rawData,n = 32 * length(s.rawData))$y`

Table 32. LedaLab parameters for the extraction of electrodermal reactions

#	Script code	Comment
1	`Ledalab(`	Name of the function
2	`'/Path/to/Study',`	Path to the raw data
3	`'open','text2',`	Definition of the file type
4	`'analyze','DDA',`	Type of decomposition analysis,
5		here: Discrete Decomposition
6		Analysis
7	`'optimize', 2,`	Parameter to be considered for
8		optimization approach (2 is default)
9	`'overview', 1,`	decomposition results are saved to
10		an image file.
11	`'export_scrlist',`	This option will export the list of
12	`[.01 2])`	SCRs with a minimum amplitude of .01 µSiemens to a text file.

Appendix H: Rotated factor matrix for perceived ease of use and technology affinity

Table 33 shows the rotated factor matrix for perceived ease of use and technology affinity as a result of a confirmatory factor analysis with principal components extraction and varimax rotation. The calculations were carried out with the Mac Version of IBM SPSS Statistics Version 21.

Table 33. Rotated factor matrix for perceived ease of use (PEU) and technology affinity (TA).

Item	Factor 1 (PEU)	Factor 2 (TA)
PEU1	**.915**	.188
PEU1	**.834**	.236
PEU1	**.773**	.431
TA1	.296	**.889**
TA2	.234	**.908**

Appendix H

Curriculum Vitae

Tobias Kowatsch, born August 28th 1980 in Donaueschingen, Germany

Basic Education

1991 – 2000	Fürstenberg Gymnasium Donaueschingen, Germany
07/2000 – 08/2001	Basic military service

Higher Education

10/2001 – 08/2005	Computer Science in Media at Hochschule Furtwangen University (HFU) Degree: Diplom-Informatiker (FH)
09/2005	English language course at Aspect, Edinburgh, Scotland Level achieved: Higher Intermediate (48 lessons)
03/2006 – 08/2007	Computer Science in Media at Hochschule Furtwangen University (HFU) Degree: Master of Science
02/2011 – 03/2011	Introduction to R for Academic Statistical Analyses, Virginia Commonwealth University, School of Business Foundation, USA
09/2011 – 07/2012	Business Informatics at Saarland University, Germany Degree: Master of Science
09/2012 – 07/2016	PhD student in Business Innovation at the University of St. Gallen, Institute of Technology Management (ITEM-HSG) St. Gallen, Switzerland

Work Experience

09/2002 – 02/2003	IBM Deutschland GmbH, Learning Solution Development Services Full-time position: project manager and courseware engineer
03/2003 – 12/2003	IBM Deutschland GmbH, Business Consulting Services Part-time position: IT instructor and courseware engineer
03/2003 – 11/2005	tele-akademie at Hochschule Furtwangen University (HFU) Part-time position: Online instructor for *Java for Beginners*, *Advanced Java Programming* and *Dynamic Websites with JSP*
03/2004 – 09/2004	artCONCEPT GbR, Bad-Dürrheim – Biesingen, Germany Full-time position: marketing assistant
11/2005 – 01/2006	Social volunteer in Westlake, Cape Town, South Africa
09/2007 – 01/2009	Research Center for Intelligent Media at HFU Full-time position: research associate in SmaProN
09/2007 – 08/2011	Instructor for Empirical Social Research at HFU
02/2009 – 12/2012	Institute of Technology Management at University of St. Gallen Full-time position: research assistant
01.2012 – 12.2014	Instructor for a NeuroIS workshop at Saarland University
since 01/2013	Scientific Director of the Health-IS Lab (www.health-is.ch) at the Institute of Technology Management, University of St. Gallen and the Department of Management, Technology and Economics, ETH Zurich