Technological Availability and Employees' Well-being: A Pathway to Responsible Digitization

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Summary

Today, technologies, particularly information and communication technologies (ICTs), such as smartphones and laptops, are ubiquitous in people's everyday working and private lives leading to fundamental changes. ICTs facilitate an availability for private and work-related contacts without any temporal or spatial constraints. This dissertation addresses on the one hand risks and potential detrimental effects on individual's well-being that may arise through ICT use and have gained considerable attention in research and practice. On the other hand and foremost, responsible ICT-based solutions with regard to both availability and well-being-related physiological measures are provided that emphasize the opportunities and potential improving effects of ICTs. Thereby, the dissertation takes a pathway to responsible digitization by focusing on the individual user perceived as a human agency.

Thus, the overarching aim of the dissertation is to provide responsible ICT-based solutions for the assessment of employees' well-being, in particular regarding availability and physiological measures. To reach this overarching aim, two comprehensive empirical studies are conducted. In particular, the ICT-based Availability Management Study is aimed to shed light on employees' individual aligned availability by considering their perceptions, motives, and preferences. Therefore, results of a qualitative (n = 59) and quantitative study (n = 589) indicate that the availability preference vary depending on the life domain, the current context, and type and priority of contacts. Hence, requirements and design elements for responsible ICT-based solution that enables the user to align the actual availability with individual availability preferences are derived. Following principles of the design science research approach, the Availability-Monitor and Availability-Manager as two smartphone applications are developed as the ICT-based solution. The applications are evaluated regarding employees' stress and work-life balance in a five-week field study with 31 participants using the applications and a control group (n = 55). The evaluation results show that participants that use the applications report a significant increase in work-life balance and significant decrease in stress. Hence, ICTs could constitute a feasible solution enabling individuals to align their actual availability and, thereby, supporting their well-being.

Study 2 addresses the application of well-being-related physiological measures recorded with ICTs, particularly wearables, for organizational research. Thereby, an in-depth understanding of the opportunities but also pitfalls that arises with the application, in particular regarding methodological properties of the measures and potential measurement issues, are provided. Furthermore, two guidelines for both processing and analyzing wearable-measured physiological measures accounting for the properties and issues and the validation of wearable-measured physiological data are given. The guidelines serve as a rigorous standard of designing studies that record, process, and analyze wearable-measured physiological data. The

guidelines are exemplified with real data of an experimental comparison study with 32 participants using the Trier Social Stress Test as the experimental procedure. In this study, physiological stress measures (i.e., heart rate, heart rate variability) recorded with two wearables (i.e., wristband, breast strap) and an established stationary device are compared for validation. The results indicate that the compared wearables offer potential to record cardiovascular data and replace the stationary device. Thus, wearables could serve as an ICT-based solution to assess individuals' well-being validly and reliably.

Together, the dissertation contributes to research and practice by firstly examining responsible ICT-based solutions for the assessment of individuals' well-being. In particular, both empirical studies indicate the potential ICTs may provide to assess, regulate, and finally improve employees' well-being. Second, the methodological insights of both studies extend the methodological toolbox of organizational scholars, specifically with regard to developing and evaluating smartphone applications and applying physiological measures for research purposes. In sum, valuable methodological foundations for future research in the emerging area of ecological momentary assessment are provided that enable such studies to create a comprehensive understanding of the individual's behavior and momentary emotional states, which reflect individuals' well-being.

With illuminating the potential of responsible ICT-based solutions for individuals' well-being and, therefore, a pathway to responsible digitization, this thesis goes beyond previous research and practice that only shed light either on the detrimental or beneficial site of the double-edged sword ICTs are referred to. Thus, valuable new insights are gained that provide implications for employees as human agencies, employers and organizations, and further research considering ICTs as threefold, the research purpose, the solution, and psychophysiological measurement device in order to improve employees' well-being.

Zusammenfassung

Der steigende Grad der Digitalisierung in der Gesellschaft, und damit auch der steigende Einsatz von Technologien, verändert das Arbeits- wie Privatleben der Menschen. Insbesondere Informations- und Kommunikationstechnologien (IKT), wie Smartphones und Laptops, sind Bestandteil des täglichen Lebens geworden, was zu fundamentalen Veränderungen der Lebensbereiche führt. IKT ermöglichen es, für private und arbeitsbezogene Kontakte ohne zeitliche oder räumliche Einschränkungen erreichbar zu sein. Die vorliegende Dissertation beschäftigt sich zum einen mit den Risiken und potenziell für das Wohlbefinden der Menschen schädlichen Effekte von IKT Nutzung. Diesen Effekten wird insbesondere in derzeitiger Forschung und in der Praxis Aufmerksamkeit geschenkt. Zum anderen beleuchtet die Dissertation mögliche verantwortungsvolle IKT-basierte Lösungen in Bezug auf Erreichbarkeit und Wohlbefindens-relevante physiologische Indikatoren, welche die Chancen und möglichen positiven Effekte von IKT aufzeigen. Dabei wird ein neuer Weg hin zu einer verantwortungsvollen Digitalisierung eingeschlagen, indem der Nutzer[1] selbst in den Fokus gerückt und er als Human Agency wahrgenommen wird.

Das übergeordnete Ziel der vorliegenden Dissertation ist es daher, verantwortungsvolle IKT-basierte Lösungen zu entwickeln und zu untersuchen, die Wohlbefindens-relevante Indikatoren und Auswirkungen in Bezug auf Erreichbarkeit und physiologische Indikatoren erfassen können. Um dieses übergeordnete Ziel erreichen zu können, werden zwei umfassende empirische Studien durchgeführt. Im Speziellen ist es das Ziel von Studie 1, die Erreichbarkeit von Beschäftigten näher zu beleuchten, indem ihre Wahrnehmung, Motive und Erreichbarkeitspräferenzen berücksichtigt werden. Die Ergebnisse einer qualitativen ($n = 59$) und einer quantitativen Studie ($n = 589$) zeigen, dass sich die Erreichbarkeitspräferenz hinsichtlich des Lebensbereichs, des aktuellen Kontextes sowie dem Kontakt selbst innerhalb und zwischen Individuen variieren. Aus den Ergebnissen werden Anforderungen sowie Designelemente der zu entwickelnden IKT-basierten Lösung abgeleitet, die eine Übereinstimmung zwischen aktueller Erreichbarkeit und Erreichbarkeitspräferenzen ermöglichen soll. Nach dem Design Science Research Approach werden schließlich der Erreichbarkeitsmonitor und der Erreichbarkeitsmanager als zwei Smartphone-Applikationen entwickelt. Die Applikationen werden hinsichtlich einer Verbesserung von Stress und Work-Life Balance von Mitarbeiter in einer Feldstudie über fünf Wochen hinweg evaluiert. 31 Teilnehmer nutzten die Applikationen. Ihre Ergebnisse werden mit der einer Kontrollgruppe ($n = 51$) verglichen. Die Evaluationsergebnisse zeigen, dass sich die Work-Life Balance der Teilnehmer, welche die Applikationen genutzt haben, signifikant verbessert und der Stress sich signifikant reduziert hat. IKT stellen

[1] Aus Gründen der besseren Lesbarkeit wird auf die gleichzeitige Verwendung männlicher und weiblicher Bezeichnungen verzichtet. Personenbezeichnungen gelten stets für die weibliche und männliche Form.

daher eine leicht zugängliche Lösung dar, um Menschen eine mit ihren Präferenzen übereinstimmende Erreichbarkeit zu ermöglichen und damit ihr Wohlbefinden zu unterstützen.

Studie 2 befasst sich mit der Anwendung physiologischer Indikatoren von Wohlbefinden in der Organisationsforschung, die mit IKT, insbesondere Wearables, gemessen werden. Dabei wird ein tiefes Verständnis der daraus entstehenden Chancen, aber auch der Fallstricke, insbesondere hinsichtlich der methodischen Eigenschaften der physiologischen Indikatoren und möglicher Messprobleme, vermittelt. Es werden zwei Richtlinien zum einen für die Datenverarbeitung und Analyse von physiologischen Indikatoren sowie die Validierung physiologischen Daten, die mit Wearables gemessen werden, erläutert. Die Richtlinien dienen als strenger Standard für Studien, die physiologische Daten mit Wearables erfassen, verarbeiten und analysieren. Die Richtlinien werden mit realen Daten einer experimentellen Vergleichsstudie mit 32 Teilnehmer angewendet. Als Studiendesign wird der Trier Social Stress Test verwendet. In dieser Studie werden Stressindikatoren (d.h. Herzrate, Herzratenvariabilität), die jeweils mit zwei Wearables (Armband, Brustgurt) und einem etablierten stationären Elektrokardiogram (EKG) erfasst werden, zur Validierung verglichen. Die Ergebnisse zeigen, dass die verglichenen Wearables Potenzial bieten, kardiovaskuläre Daten valide und reliabel zu erfassen und das stationäre EKG zu ersetzen. Somit könnten Wearables als eine IKT-basierte Lösung dienen, um physiologische Indikatoren von Wohlbefinden zuverlässig zu erfassen.

Die Dissertation leistet einen wesentlichen Beitrag zur Forschung und Praxis, indem sie verantwortungsvolle IKT-basierte Lösungen zur Erfassung individueller Wohlbefindens-Indikatoren und Auswirkungen entwickelt und untersucht. Diese Lösungen können wiederum darin unterstützen, das Wohlbefinden der Menschen zu verbessern. Zudem erweitern die methodischen Erkenntnisse beider Studien das methodische Wissen in der Organisationsforschung, insbesondere im Hinblick auf die Entwicklung und Evaluation von Smartphone-Applikationen und die Anwendung und Messung physiologischer Indikatoren. Zusammenfassend werden wertvolle methodische Grundlagen für die zukünftige Forschung im Bereich des Ecological Momentary Assessment gegeben. Dieser Forschungsbereich ermöglicht durch die Erfassung momentaner emotionaler Zustände ein umfassendes Verständnis des menschlichen Verhaltens und damit auch des Wohlbefindens. Durch die Untersuchung des Potenzials von verantwortungsvollen IKT-basierten Lösungen zur Förderung des individuellen Wohlbefindens und damit eines verantwortungsvollen Weges im Umgang mit Digitalisierung, geht diese Dissertation über bisherige Forschung hinaus, die entweder nur die schädliche oder nützliche Seite des zweischneidigen Schwertes, wie IKT bezeichnet werden, beleuchtet. Sie liefert damit wertvolle Implikationen für Mitarbeiter sowie Arbeitgeber und Unternehmen und zeigt profunde Ansatzpunkte für zukünftige Forschung auf, wie das Potenzial von IKT auf dreifache Weise genutzt werden kann: als Untersuchungsgegenstand, psychophysiologisches Messinstrument und Lösung, um das Wohlbefinden der Nutzer fördern zu können.

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Darmstadt, in August 2019 Katharina Ruth Schneider

Content Overview

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List of Abbreviations

AL-Model	Allostatic Load Model
ANOVA	Analysis of Variance
ANS	Anatomic Nervous System
BOLD	Blood Oxygen Level Dependent
bpm	Beats per Minute
BVP	Blood Volume Pulse
CAR	Cortisol Awakening Response
CI	Confidence Interval
CNS	Central Nervous System
df	Degrees of Freedom
ECG	Electrocardiography
EDA	Electrodermal Activity
EGG	Electrogastrogram
EMA	Ecological Momentary Assessment
EMG	Electromyography
EPA	Extended Private Availability
ERP	Event-related Brain Potentials
ESM	Experience Sampling Method
EWA	Extended Work Availability

fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-infrared Spectroscopy
GSR	Galvanic Skin Response
HF	High Frequency of HRV
HPA Axis	Hypothalamic-Pituitary-Adrenal Axis
HR	Heart Rate
HRV	Heart Rate Variability
IBI	Interbeat Interval
ICC	Intraclass Correlation Coefficient
ICTs	Information and Communication Technologies
IgA	Immunoglobulin A
LF	Low Frequency of HRV
M	Mean
MEG	Magnetoencephalography
ms	Milliseconds
MTMM	Multitrait-Multimethod Matrix
N	Sample Size
NIBS	Noninvasive Brain Stimulation
n.s.	Non-significant
p	Significance Level
PET	Positron Emission Tomography
PNS	Peripheral Nervous System
PPG	Photoplethysmography Sensor

qEEG	Quantitative Electroencephalogram
SAM Axis	Sympathetic-Adrenal-Medullary Axis
SCL	Skin Conductance Level
SCR	Skin Conductance Response
SD	Standard Deviation
SDT	Self-Determination Theory
tDCS	Transcranial Direct Current Stimulation
TMS	Transcranial Magnetic Stimulation
TSST	Trier Social Stress Test
VLF	Very Low Frequency of HRV
WSR	Wilcoxon Signed-Rank Test

1 Introduction

“Technology is neither good nor bad – nor is it neutral” (Kranzberg’s First Law of Technology, Kranzberg, 1986).

The ubiquity of technologies and with it the increasing degree of digitization causes fundamental changes in both people’s working and private lives (Bliese, Edwards, & Sonnentag, 2017). In particular, information and communication technologies (ICTs) defined as any device and communication channel that is used for private and work-related information and communication purposes (Ayyagari, Grover, & Purvis, 2011; Day, Paquet, Scott, & Hambley, 2012) have become an integral part of everyday life. Thereby, ICTs do not only change the *way* we communicate, but also the *availability* for private and work-related contacts at any time and any place (Davis, 2002; Olson-Buchanan & Boswell, 2006). In this regard, ICTs facilitate a faster communication with short response times and without any temporal or spatial constraints. Recent research focuses mainly on changes that arise from *work-related* ICT use (Schlachter, McDowall, Cropley, & Inceoglu, 2017). However, people do not usually evaluate ICTs strictly positive or neutral, as the introductory quote indicates. In fact, their use holds both risks and opportunities for people’s well-being. This thesis focuses on potential risks and detrimental effects of ICT use, which have gained considerable attention in research and practice. Regarding ICTs, the focus is on smartphones used for communication purposes via emails, calls, and messages and wearables used for information purposes of physiological well-being indicators. Furthermore, this thesis provides approaches to emphasize the opportunities and improving effects and, thereby, potentially invert the detrimental effects to improving ones as a new pathway to responsible digitization.

The dissertation illuminates and combines two research streams: ICT-based availability and ICT-based physiological indicators of well-being. According to the first research stream, work-related ICT use, defined as employees’ availability after normally contracted working hours (i.e., extended work availability, EWA), may generate stress and work-life conflicts through two mechanisms recent research examines. EWA enhances interruptions and distractions from personal time for employees at any time and any place resulting in a unpredictability about whether and when they need to be available (Boswell & Olson-Buchanan, 2007; Dettmers, Bamberg, & Seffzek, 2016). Furthermore, it holds the potential to increase the time employees spend working, and in turn, reduces the time to recover from work (Barley, Meyerson, & Grodal, 2011). However, to be able to organize the working life flexibly and autonomously to meet the demands of private life is an important opportunity of EWA and the extended availability for private contacts at work (EPA). This may increase work-life balance and well-being (Day, Scott, & Kelloway, 2010; Mazmanian, Orlikowski, & Yates, 2013). These inconsistent findings indicate the crucial role the individual user takes with his or her individual motivation for and perception of availability. Furthermore, people set their own availability preferences for private and work-related contacts and strive to reach an alignment between their preferences and actual availability (i.e., aligned availability).

According to the second research stream, ICT-based physiological indicators of well-being, ICTs also find their way into the assessment of well-being measures, predominantly in the field of quantified self (Swan, 2013). In particular, recent advances in fitness trackers, wearables, and smartwatches give people the opportunity to be engaged in self-tracking by assessing well-being and behavioral measures. Thereby, wearables defined as technologies integrated in clothing or accessories and worn on the body are aimed gathering data from the body or the environment of the wearer and giving the wearer information about this data (Cascio & Montealegre, 2016; Tamura, Maeda, Sekine, & Yoshida, 2014; Tehrani & Michael, 2014). For instance, due to increasingly improved and more minimalistic sensors, it becomes possible to assess physiological measures, such as heart rate (HR), with wearables (Eatough, Shockley, & Yu, 2016). With physiological measures being regarded as objective measures that provide valuable insights into arbitrary physiological processes beyond the conscious awareness (Becker & Menges, 2013; Heaphy & Dutton, 2008), their measurement not only holds great potential for people's well-being but also for recent organizational research. As the essential part of health (World Health Organization, 1948), well-being is used as an umbrella term in this thesis indicating individual's psychological, physiological, and social health.

This dissertation illuminates the area of tension that ICTs create for employees' well-being today to take a pathway to responsible digitization. The overarching aim is to provide *responsible ICT-based solutions* for the assessment of employees' well-being, in particular regarding availability and physiological measures. These solutions focus on the individual user by taking a responsible pathway that perceives the user as a human agency with his or her individual motives, perceptions, and preferences. ICTs are attributed to a mediating role by facilitating availability, not causing potential detrimental effects. In this regard, they could serve as a solution for preventing detrimental and enhancing improving effects. Hence, assessing and regulating availability and well-being outcomes with ICTs may considerably contribute to improve employees' well-being. Therefore, this thesis sets two main research goals. First, the dissertation aims at shedding light on employees' individually aligned availability by considering their perceptions, motives, and preferences for availability. Thereby, the present thesis takes a closer look at the aforementioned double-edged sword of availability and illuminates the previous inconsistent findings (Bliese et al., 2017; Jarvenpaa & Lang, 2005; Lowry & Moskos, 2005). Further, by developing two smartphone applications according to the design science research approach (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007), a responsible ICT-based solution that enables an individually aligned availability and, thus, may prevent detrimental and enhance improving effects of extended availability is provided (study 1, referred to as ICT-based Availability Management Study). Second, the thesis aims at accomplishing an in-depth understanding on how organizational scholars can validly apply wearable-measured physiological measures for their research as a contribution to their methodological toolbox. To this end, this thesis introduces the topic of wearable-measured physiological data for organizational research and provides guidelines as well as an experimental comparison of wearables measuring two physiological stress measures (study 2, referred to as ICT-based Physiological Measurements Study). As a valuable result of assessing ICT-based availability and well-being, this thesis contributes to the emerging organizational research area of ecological momentary assessment (EMA) that provides a comprehensive understanding of individuals' momentary well-being.

To reach these two main research goals, the present dissertation proceeds as follows. First, the practical and empirical relevance is outlined in more detail (Chapter 1.1). Furthermore, key contributions are addressed (Chapter 1.2). The conceptual foundations and concepts that are investigated in both studies are then defined and discussed (Chapter 2.1). Three fundamental theories, the human agency perspective (Emirbayer & Mische, 1998), the self-determination theory (Deci & Ryan, 2000; Ryan & Deci, 2000), and the allostatic load model (McEwen & Stellar, 1993; McEwen & Wingfield, 2003) are outlined (Chapter 2.2). Furthermore, the thesis provides a comprehensive literature review on the current state of research on individual antecedents, outcomes, and moderators of ICT use (Chapter 3.1) and the application and wearable measurement of physiological measures in organizational research (Chapter 3.2). Moreover, the literature on the assessment of individual well-being outcomes is reviewed (Chapter 3.3). Then, key limitations of the literature are outlined (Chapter 3.4) that derive central research questions (Chapter 4) examined in the ICT-based Availability Management Study (Chapter 5) and the ICT-based Physiological Measurements Study (Chapter 6). Finally, the dissertation provides an overarching discussion on its overall contributions to both research streams, implications for organizations and employees, and further research (Chapter 7), as well as draws a conclusion (Chapter 8).

1.1 Practical and Empirical Relevance of the Thesis

The rapid advances in technologies, particularly ICTs, caused a transformation of both how people work, but also how they live (Bliese et al., 2017). People are connected with their family and friends, but also with work-related contacts, such as supervisors, colleagues, or customers, at any time and any place creating an “always on”-mentality. Simultaneously, ICTs allow more flexibility and an assessment of well-being measures and outcomes resulting in a double-edged sword. For instance, people use their smartphone as a communication tool, for example for checking work-related emails after their contracted working hours (i.e., EWA) and accept a call from their child during working hours (i.e., EPA). Besides, they have installed numerous fitness and well-being applications on their smartphone and a fitness tracker counts their steps during the day, for example. This example illustrates the variety of ICT use and its potential risks and benefits. Therefore, ICTs, their evaluation as a double-edged sword, and the evoked fundamental changes of the working and private life gain an increasing attention in recent research, organizations, and society that is further discussed in the following.

With about five billion people that own mobile devices and about half of them are smartphone users, ICTs have become ubiquitous in working and private lives (GSM Association, 2018; Statista, 2016). Regarding communication purposes of ICTs, there were 269 billion sent and received emails worldwide in 2017, 49 percent of employees in the United States stated to be checking their work-related emails every few hours in non-work times and, thereby, spend 3.1 hours on average per weekday (Adobe Campaign, 2018; The Radicati Group, 2018). In a large-scaled German survey, 83% of the 7,109 respondents use ICTs for work purposes applied at a wide variety of industries such as IT and science-oriented services, health, and production (Bundesministerium für Arbeit und Soziales, 2016). According to the European Working Conditions Surveys 2015, about a quarter of the participated employees’ worked outside their contracted working hours at least several times per month (Eurofound, 2015). In regard of ICT use, 18% of employees that participated in 2005 were contacted sometimes outside working hours by their employer, while 21% were contacted often (Arlinghaus & Nachreiner, 2014). Hence, in society, the presence of ICTs in the work place is seen as creating an “always on”-culture for employees indicating detrimental effects on their work-life balance and stress. Examples are an increase in work requirements and demands such as multitasking by managing tasks simultaneously, interruptions, and time pressure (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, 2018; Bundesministerium für Arbeit und Soziales, 2016). However, employees also report chances with respect to ICT use, in particular the increase of flexibility and autonomy as well as the sense of competence and an increase in job performance (Bundesministerium für Arbeit und Soziales, 2016).

Due to the aforementioned increase in work requirements and psychosocial stressors of the ICT-based work environment (Morschhäuser & Lohmann-Haislah, 2016), the sick days in general and in particular regarding mental disorders have continuously increased in the past decades (DAK, 2018). Behind musculoskeletal disorders with 21.8% of all sick days, mental disorders take the second place with 16.7%. Compared to 2017, the sick days of mental disorders per 100 insured persons have slightly increased again. Mostly, depressions, reactions to severe traumatic stresses, and adjustment disorders are diagnosed that result in an absenteeism rate that is about twice as high as the rate of other frequent disorders (38.1 days on average). The economic view on mental disorders also reveals the significance for important stakeholders that are the costs to employers, healthcare costs, and social welfare costs (Executive Agency for Health and Consumers, 2013). Overall, the annual costs of depression to the 27 European Union member states (i.e., EU27) were estimated to be €617 billion. Thereby, with €272 billion the major impact is on employers caused by absenteeism and presenteeism (i.e., coming to work despite illness) followed by €242 billion across the EU27 as costs for productivity losses. Furthermore, €63 billion are healthcare costs and €39 billion social welfare costs (Executive Agency for Health and Consumers, 2013). As aforementioned, it is highly likely that ICT use and its caused changes for the work and private lives of employees contribute to these developments (Morschhäuser & Lohmann-Haislah, 2016).

In order to prevent these high costs for absenteeism, presenteeism, and productivity losses (Executive Agency for Health and Consumers, 2013), organizations and governments already have started implementing interventions with regard to detrimental effects of an ICT-based work environment. For example, employees' emails can be deleted during vacations (Daimler AG, BBC News, 2014), the Blackberry servers are turned off after working hours (Volkswagen AG, BBC News, 2012), or laws were passed that support the restriction as a human right (e.g., 'right to be disconnected' in France since 2017). With regard to working hours, the Court of Justice of the European Union decided that employers in the EU are obliged to set up a system that records the time employees worked (Court of Justice of the European Union). Although these rather universal interventions are aimed to protect and, in the best case, improve the well-being of employees, they are also in the area of tension to disregard employees' individual motivation, perception, and preference (Towers, Duxbury, Higgins, & Thomas, 2006).

To monitor and improve well-being by their own, people increasingly use ICTs, in particular wearables, including smartwatches, and fitness tracker. In 2017, 1.26 Million smartwatches and 1.55 Million fitness tracker were sold in Germany that represent an increase of the market of about 27 % and 14 % compared to 2016, respectively (bitkom, 2017). As a prevention measure, health insurance funds provide bonus programs for their insured persons, if they assess their well-being outcomes (Klofta & Rest, 2015). Likewise, organizations, such as Opel, SAP, and IBM, implemented wearables (e.g., Fitbit) to track employees' activity and fitness (Klofta & Rest, 2015).

However, despite these efforts, the sick days of mental disorders still increased every year, as outlined above (DAK, 2018). By trying to prevent employees from the risks of the ICT-based work environment, the aforementioned interventions do not account for individual differences (Towers et al., 2006). In particular, individuals may differ in their preferences for ICT use and availability because of different motives and perceptions (e.g., Duxbury, Towers, Higgins, & Thomas, 2007; Ohly & Latour, 2014; Stich, Tarafdar, Cooper, & Stacey, 2017). Thus, not only the detrimental effects, but also the improving effects of ICT use, such as an increased autonomy and flexibility, are prevented (Mazmanian, 2013; Towers et al., 2006). Instead of such restricted interventions and health promotion programs, ICT-based solutions that consider the individual user and provide a comprehensive assessment of unconsciously physiological, consciously psychological, and behavioral responses seem more appropriate to better understand and promote individual's well-being (Towers et al., 2006). To this end, such a solution could enable individuals on the one hand to reflect their preferences and well-being and on the other hand to improve their well-being on their own.

In accordance with the annual trends report of the American Psychological Association, ICT-based availability as the first and ICT-based physiological indicators of well-being as the second research stream of the present thesis are rated as research trends of 2019 (Deangelis, 2018; Winerman, 2018). In particular, this thesis examines and further illuminates ICT use and wearables measuring physiological data that belongs to big data research, and the design of two smartphone applications for an aligned availability as smarter technology tools. Because of its relevance and potentials, both research streams seem more prevalent than ever in articles, reviews, and journals.

In regard of ICT use, research provides valuable first insights. Much research examines the detrimental effects of work-related ICT use on employees' stress and the work-life interface (e.g., Boswell & Olson-Buchanan, 2007; Day et al., 2012; Dettmers et al., 2016; Mazmanian et al., 2013). Moreover, work-related characteristics are investigated that refer to norms (e.g., Fenner & Renn, 2010) or availability expectations (e.g., Park, Fritz, & Jex, 2011). However, just little research takes the individual with his or her individual perception, motives, and preferences for ICT use into account. There is a lack of important results on the question why, for whom, and under what circumstances ICT use is either detrimental or improving for employees. Furthermore, person-centered interventions or ICT-based solutions that consider such results and their evaluation do not in exist in recent research.

Organizational scholars increasingly claim that the time is ripe to give physiology greater attention and enrich organizational research and theories with physiology (Ganster, Crain, & Brossoit, 2018; Heaphy & Dutton, 2008; Murray & Antonakis, 2019). Because physiological measures in organizational research offers such a great potential, there is the highest prevalence of articles applying physiological measures in management journals for now (Ganster et al., 2018; Heaphy & Dutton, 2008; Jack, Rochford, Friedman, Passarelli, & Boyatzis, 2019). The areas for application seem almost unlimited by ranging from investigating genetics of attitudes and behaviors at the work place (Arvey, Li, & Wang, 2016) to using neuroscience constructs such as quantitative electroencephalogram (qEEG) to measure leadership concepts and leader-member interactions (Waldman, Wang, & Fenters, 2019). However, the toolbox of an organizational scholar does not necessarily include a deeper understanding or in-depth knowledge of these physiological processes and their measurement with different devices (Ganster et al., 2018; Heaphy & Dutton, 2008). As a result, organizational scholars build up a hurdle of unfamiliarity that hinders them to apply physiological measures for their research (Murray & Antonakis, 2019). Because of the more feasible access, lower costs, and facilitating the requirement of a fundamentally previous knowledge, the rapid advances in wearables are promising to overcome this hurdle (Ganster et al., 2018; Ilies, Aw, & Lim, 2016; Waldman et al., 2019). However, although some research gives introductions for the application of physiological measures in organizational research, there is a lack of a clear guidance considering measurement and device issues, which is crucial to provide reliable results. In particular, little research is published that examines the validity and reliability of such newer wearables or provides a deeper discussion of device issues that come along with physiological measures recorded with wearables (i.e., wearable-measured physiological measures) (Eatough et al., 2016).

Both research streams are characterized by their interdisciplinarity, predominantly investigated in literature of organizational behavior (OB), psychology, medicine, and information systems (IS). As a result, the state of the art is heterogeneous, results are mixed and contradictory, and it may be beneficial to transfer the insights of one domain to others. Thus, research in both fields requires a more in-depth understanding with respect to the aforementioned research gaps. This thesis fills these gaps by providing a systematic literature review and two empirical studies that combine insights of all the aforementioned disciplines.

1.2 Major Contributions of the Thesis

In light of the overarching aim of the present dissertation to provide responsible ICT-based solutions for the assessment of employees' well-being as a pathway to responsible digitization, this thesis' main contributions are twofold (see Figure 1-1). The first contribution of the thesis is:

> *(1) Examining responsible ICT-based solutions for the assessment of individuals' well-being.*

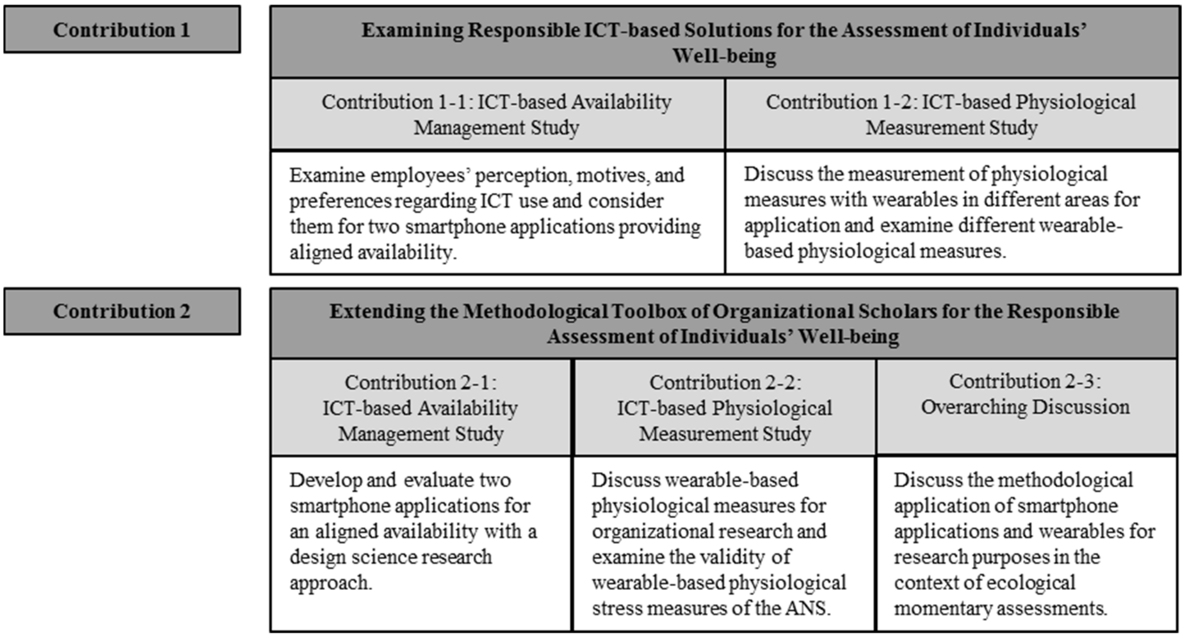
In regard of the first contribution, the ICT-based Availability Management Study firstly examines employees' individual perception, motives, and preferences regarding their ICT use, specifically their EWA and EPA. Subsequently, these individual indicators are considered for the development of two smartphone applications that, therefore, facilitate an alignment between the preferences and actual availability of employees. The ICT-based Physiological Measurements Study complements these important individual insights by discussing the measurement of individual wearable-measured physiological measures for a broad range of areas for application in organizational research. Furthermore, two physiological stress measures of the autonomic nervous system (ANS) (i.e., HR and heart rate variability, HRV) recorded with two wearables and a stationary device are examined and their data processing and analyzing procedures are discussed in detail.

Second, this thesis seeks to contribute methodically by introducing different research methods to interested scholars. Thus, the thesis' second contribution is:

> *(2) Extending the methodological toolbox of organizational scholars for the responsible assessment of individuals' well-being.*

By developing and evaluating two smartphone applications according to the design science research approach (Peffers et al., 2007), the ICT-based Availability Management Study provides a methodological framework, from which organizational scholars may benefit for their own research. In particular, while the interest in using smartphones and applications for research purposes is growing, researchers and practitioners need a method for appropriately developing such applications. The design science research approach provides such a method by suggesting an iterative development process (Peffers et al., 2007). The ICT-based Physiological Measurements Study introduces interested organizational scholars to the broad areas for application of wearable-measured physiological measures. Thereby, the study outlines the opportunities of such a method, but also potential pitfalls caused by the methodological properties and potential issues of wearable-measured physiological data that need to be considered. Furthermore, the study provides a validation protocol and an exemplary validation study of two wearables that record the aforementioned physiological stress measures. Finally, the overarching discussion of the thesis combines the methodological insights of both studies into the emerging research area of EMA. As EMA assesses emotions or stress multiple times on a momentary or daily basis (Beal & Weiss, 2003), it provides valuable insights by examining and, thereby, recognizing the meaningful within-person variability of momentary psycho-physiological processes. Recent technological advances led to a significant increase in the utility and application of EMA and facilitate to record a broad range of measures and large quantity of data (Ilies et al., 2016; Miller, 2012). Thus, the overarching discussion provides valuable implications for future EMA studies.

Figure 1-1: Contributions of the Thesis



2 Conceptual and Theoretical Background

Because both research streams of the present dissertation – ICT-based availability and ICT-based physiological indicators of well-being – are broad and inconsistent, it requires a common knowledge comprising a clear conceptual and theoretical background. In Chapter 2.1, the conceptual background of the dissertation is discussed. Further, the section explains how conceptual foundations are applied as definitions of the core concepts. Then, the theoretical background is provided in Chapter 2.2 that is constituted of the human agency perspective (Emirbayer & Mische, 1998), self-determination theory (Deci & Ryan, 2000; Ryan & Deci, 2000), and allostatic load model (McEwen & Stellar, 1993; McEwen & Wingfield, 2003).

2.1 Conceptual Background

This section outlines the conceptual foundations of central concepts. The central concepts involve (1) concepts related to ICT use, (2) concepts related to outcomes of ICT use, and (3) concepts related to physiology, wearable computing, and the assessment of individual well-being.

2.1.1 Conceptual Foundations and Definitions of Concepts related to ICT Use

In this section, the conceptual foundations and definitions related to ICT use are outlined. *ICT use* is defined as the use of any device and channel (e.g., smartphone, email, laptop) for both information and communication purposes (Ayyagari et al., 2011; Day et al., 2012). This thesis' focus is on smartphones used for communication purposes via emails, calls, and messages and wearables used for information purposes of well-being indicators. Thereby, ICT use itself is applied as an umbrella term for ICT use-related concepts. ICT use-related concepts are extended and aligned availability, boundary management and boundary management preferences as well as individual preference for and perception of availability that are defined in the next sections.

In recent literature, there is a lack of conceptual clarity what ICT use is constituted of (Schlachter et al., 2017). The concept of ICT use that is used interchangeably widely ranges from ‘smartphone use’ (Derks et al., 2015; Derks & Bakker, 2014), ‘technology-assisted supplemental work’ (Fenner & Renn, 2004), and ‘technology use at home’ (Park et al., 2011) to ‘unregulated availability’ (Pangert, Pauls, & Schüpbach, 2016), ‘extended availability for work’ (Dettmers et al., 2016), ‘constant ICT connectivity’ (Day et al., 2012), and ‘presenteeism’ as an intrusive feature of ICTs (Ayyagari et al., 2011). First studies tried to conceptualize ICT use as they applied it as an overarching umbrella term and divided ICT use into several characteristics that were investigated distinctly. For example, Day et al. (2012) examined ICT demands such as availability, ICT control, and ICT hassles and two facets of ICT support (i.e., personal assistance, resources/upgrades support). Ayyagari et al. (2011) assigned three features to ICTs, namely usability, dynamic, and intrusive features that may more or less influence stressors based on a person-technology misfit. Next to these generic conceptual foundations, much research examined ICT use differentiated according to different media and communication channels. For instance, email use is a well-investigated differentiated concept of ICT use in previous research (e.g., Barley et al., 2011; Mazmanian, 2013).

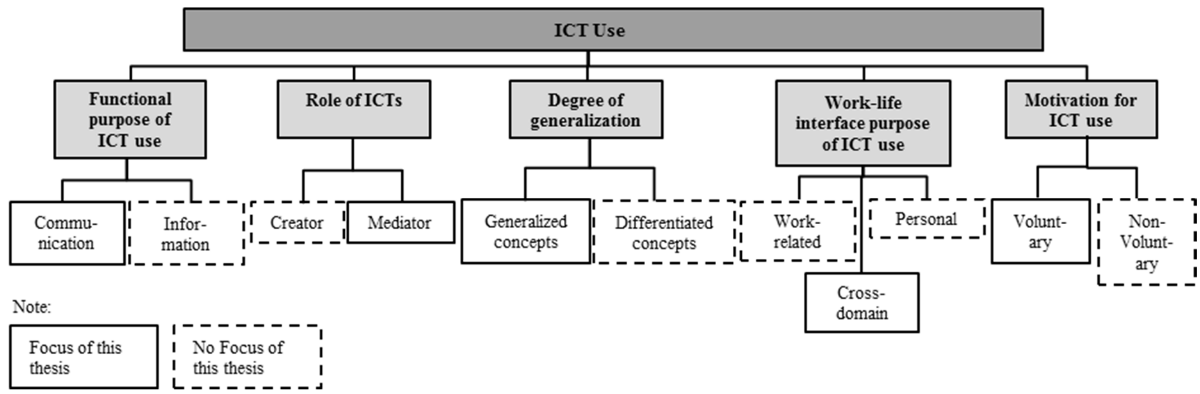
Extended and Aligned Availability

Two related concepts of ICT use are examined in the ICT-based Availability Management Study that are *extended work availability (EWA)* and *extended private life availability (EPA)*. The definitions of both EWA and EPA are based on the definition of availability for work from Bergman and Gardiner (2007, p. 401), who define availability as being “accessible in time and space and being responsive to the needs and wants of others”. By specifying time and senders, *EWA* is defined as the frequency, with which employees are accessible beyond their formally contracted working hours (i.e., after hours, at the weekend, on vacation, during illness) and responsive for the needs and wants of work-related contacts, such as their supervisor, coworkers, or customers. Similarly, *EPA* is defined as the frequency, with which employees are accessible in their formally contracted working hours (i.e., while working alone, during meetings, during breaks) and responsive for the needs and wants of private life-related contacts, such as their partner and friends.

Based on EWA and EPA, the main goal of the developed smartphone applications in the ICT-based Availability Management Study is to reach an *aligned availability*. An aligned availability is defined as the fit between EWA and EPA, its particular perceptions, and boundary management as well as availability preferences that one determines individually. Hence, beside the amount of availability, it is necessary for the concept of an aligned availability to consider further constructs to provide a comprehensive understanding. These constructs are outlined in more detail in the next sections.

To further clarify and differentiate the applied concepts from concepts of recent research and create a common understanding, four categories are outlined in the following, in which the thesis' availability concepts are classified. The categories are (1) functional purpose of ICT use, (2) role of ICTs (creator, mediator), (3) degree of generalization of ICT use (generalized concepts, differentiated concepts), (4) work-life interface purpose of ICT use (work-related, personal life-related, cross border), and (5) motivation for ICT use (voluntary, non-voluntary). Figure 2-1 depicts the classification of the categories of ICT use concepts that are examined in previous research.

Figure 2-1: Classification of ICT Use Concepts in Research and the Present Thesis



In this thesis, the availability concepts focus on the communication purpose of ICT use as it facilitates availability. Using a laptop to prepare slides for a work presentation at the week-end, for example, is out of the scope. Thereby, ICTs take a mediating role by facilitating availability and, thus, EWA, EPA, and aligned availability (Duxbury et al., 2007; Karr-Wisniewski & Lu, 2010). To this end, both availability concepts put the individual user into focus, not the technology itself. Furthermore, the availability concepts are generalized con-cepts that do not differ between particular communication channels in the consideration of availability. For instance, there is no differentiated consideration of the availability for emails and the availability for calls. Regarding the work-life interface purpose, EWA and EPA are cross-domain concepts that examine availability from the work domain within the private life domain and vice versa. The availability within each domain is not in focus of this thesis. Fi-nally, the availability concepts refer to voluntary behavior that represents employees' individ-ual motives, preferences, and expectations from others. Thus, such behavior is in contrast to for example contractual on-call work, which leads to non-voluntary ICT use and availability (Fenner & Renn, 2004). The availability concepts are further illuminated as focal constructs in the ICT-based Availability Management Study for the development of two smartphone applications for an aligned availability.

Boundary Management and Boundary Management Preferences

The conceptual foundation of boundary management is justified in the boundary theory. *Boundary management* is defined as how individuals structure the boundaries around and between their personal and work life, also referred to as domains (Ashforth, Kreiner, & Fugate, 2000; Nippert-Eng, 1996). Boundaries reflect lines around each domain that are more or less permeable and, thus, more or less related. Thereby, employees pass through a daily transition between their work and home or other places. As the definition of *boundary management preferences*, individuals manage the boundaries according to their preference that is conceptualized on a continuum ranging from keeping domains separate from another (i.e., segmentation) to merging aspects of the domains (i.e., integration) (Ashforth et al., 2000; Kreiner, 2006; Nippert-Eng, 1996). In line with this notion, 'segmenters' span an impermeable boundary around each domain to keep the domains as separate as possible. A boundary management tactic of segmenters may be to manage separate calendars or not to talk about private topics on work and vice versa. Contrarily, 'integrators' create a permeable boundary around each domain to merge aspects of the domains. Thus, they may use one smartphone for private and work-related purposes or bring colleagues home for dinner (Ashforth et al., 2000; Kreiner, 2006; Kreiner, Hollensbe, & Sheep, 2009; Nippert-Eng, 1996).

As ICT use facilitates the blurring of boundaries because employees are available for work-related purposes beyond their contracted working hours, and, thus in the private life domain, much research examines the concepts of boundary management and boundary management preferences in the context of ICT use (Boswell & Olson-Buchanan, 2007; Olson-Buchanan & Boswell, 2006). In the present dissertation, boundary management and boundary management preferences serve as complementary concepts to the availability concepts in the ICT-based Availability Management Study. Only by considering and including both into the development of two smartphone applications, an aligned individual availability can be achieved that is in line with employees' preferences.

Individual Preference for and Perception of Availability

Some qualitative and quantitative studies indicate that the individual boundary preference has an effect on ICT use (e.g., Boswell & Olson-Buchanan, 2007; Crowe & Middleton, 2012; Golden & Geisler, 2007; Park et al., 2011; Richardson & Thompson, 2012). However, maybe correlated with one's boundary preference but certainly not used interchangeably, Stich et al. (2017) examine the desired use of computer-mediated communication applications serving as a preference for the use, as a first study. This thesis transfers this concept of desired ICT use to availability as the individual preference for EWA and EPA. The *individual preference for availability*, specifically EWA and EPA, is defined as the individually determined preference that serves as a behavioral standard, with which the actual amount of availability is compared (Carver & Scheier, 1982, 1990).

The aforementioned availability concepts rely only on the amount of availability representing the frequency, volume, or time spent using ICT (Stich et al., 2017). Thus, it is hypothesized that the greater the frequency, volume, or time of ICT use, the stronger the detrimental effects of it. However, beside the amount, concepts should also consider individual's perception of the amount. The findings of research regarding email use and email overload indicate that individual's perception of the email volume contributes more to the feeling of email overload than the actual email volume and, therefore, imply the importance to consider both concepts. (Dabbish & Kraut, 2006; Mazmanian et al., 2013). Building upon the conceptual foundation of the perception of email volume, the foundation can be generalized to availability. *Perception of availability*, specifically EWA and EPA, is defined as the individually determined perception of the actual amount of availability.

In the ICT-based Availability Management Study in Chapter 5, the individual preference for and the individual perception of EWA and EPA serve together with boundary management and boundary management preferences as a solution requirement for the development of two smartphone applications that enhance an aligned availability.

2.1.2 Conceptual Foundations and Definitions of Concepts related to ICT Use Outcomes

While ICT use enhances employees' flexibility when and where to work and potentially increases their work-life balance, it has likewise the potential to alleviate stress through an increased constant availability as well as work-life conflict through blurring boundaries (Lowry & Moskos, 2005). The following conceptual foundations related to individual availability outcomes concerns concepts of the work-life interface, particularly employees' work-life balance, and well-being concepts, in particular psychological stress.

Work-Life Balance

The concepts of work-life balance that serves as an outcome for a successful boundary management is related to the conceptual foundation of boundary management and boundary management preferences. In recent research, the work-life balance concept is profoundly investigated, also in the context of ICT use (e.g., Boswell & Olson-Buchanan, 2007; Derks et al., 2015; Park et al., 2011). However, work-life balance literature suffers from conceptual and definitional ambiguity, as several different conceptual foundations exist (Maertz & Boyar, 2011; Wayne, Butts, Casper, & Allen, 2017). Particularly, early research examines the key concept "work-family balance", while recent research provides a broader concept using the term “work-home/work-life balance” (Kreiner, 2006; Kreiner et al., 2009). The present thesis follows recent research by applying the broader concept of *work-life balance* integrating any work as well as any personal life domain such as family or pursuing a hobby. In the following, the conceptual and definitional foundation of the examined work-life balance concept serving as a focal outcome in the ICT-based Availability Management Study is discussed further.

Beside others, Frone (2003) provides a common definition as work-life balance is perceived as high when individuals have low work-life conflict and high work-life enrichment leading to an improving spillover of experiences or resources from one domain to the other domain. Work-life conflict is probably the most investigated concept in work-life balance research (Greenhaus & Allen, 2011). It is caused by a role conflict in that the expectations, demands and policies of the work-related role, for example as an employee, are incompatible with those of the personal role, for example as a mother or club member (Greenhaus & Beutell, 1985; Judge & Colquitt, 2004; Kreiner, 2006). Of course, such a role conflict could also occur the other way in that the requirements of the personal role interfere and are incompatible with the work-related role, referred to as life-work conflict (Greenhaus & Allen, 2011). Regarding boundary management, integrators with permeable boundaries around their domains have more the potential to perceive role conflicts as work-life conflict than segmenters (Ashforth et al., 2000). Because ICT use facilitates blurring boundaries and enhances interruptions and distractions from personal time, recent research examines the effect of mostly EWA on work-life conflict profoundly (e.g., Boswell & Olson-Buchanan, 2007; Cavazotte, Heloisa Lemos, & Villadsen, 2014; Derks & Bakker, 2014; Mazmanian et al., 2013).

However, Greenhaus and Allen (2011) provide a more recent definition of work-life balance that goes beyond of this from Frone (2003) and considers individual differences in perceiving work-life balance. Thereby, individuals set their own life role priorities reflecting their life values und preferences. Hence, they perceive balance whenever the effectiveness and satisfaction in their roles are in line with their set life role priorities. For instance, career-and-family focused individuals are aimed at being effective and satisfied in both work-related and personal roles, while career-focused individuals perceive work-life balance when they are effective and satisfied in their work-related roles given a high priority. Thus, work-life balance does not necessarily mean an equality between the domains and roles.

Following the aforementioned definition and conceptual foundation, the present dissertation defines *work-life balance* as a condition individuals perceive whenever they are effective and satisfied with the involvement of all domains that they assign with a high priority. Work-life balance serves as a focal outcome in the ICT-based Availability Management Study.

Well-being and Psychological Stress

Similar to ICT use, subjective *well-being* broadly defined as the affective and cognitive evaluation of the quality of an individual's life is also used as an umbrella term that includes various different concepts (Diener et al., 2017; Diener, Suh, Lucas, & Smith, 1999). Beside health, psychological stress is one of them indicating an impaired well-being. Similar to the concepts of work-life balance, the psychological concept of stress suffers from a lack of a clear conceptual foundation (Cooper, Dewe, & O'Driscoll, 2001). Thus, literature contains numerous different definitions and approaches for the investigation of stress. However, stress can be broadly conceptualized as either (a) an environmental feature that acts on an individual (i.e., stimulus-based definitions), (b) the individually psychological, physiological, and behavioral reaction to any environmental demand (i.e., response-based definitions), or (c) a process of cognitive and physiological reactions initiated by environmental events as the interaction of (a) and (b) (Cooper et al., 2001; Ganster & Perrewé, 2011; Ganster & Rosen, 2013). Such environmental demands or events are called *stressors*, while the individual response to a stressor is referred to as *strain* (Griffin & Clarke, 2011; Lazarus & Folkman, 1984). For this thesis, the interest is on psychosocial stressors that occur in the work environment, but not on physical stressors such as noise or chemical toxins (Ganster & Rosen, 2013).

Rooted in physics and engineering, stimulus-based definitions take stressors into focus that act as independent variables for an elicited individual response (Cooper et al., 2001). As one of the first, Selye (1936) defined stress generically as the General Adaptation Syndrome, in particular as a "non-specific response of the body to any demand" (p. 32). Selyes's definition can be assigned to the response-based definitions, which focus on stress as an outcome and, thereby, dependent variable (Cooper et al., 2001). Later, he distinguished between two categories of stress - distress as negative stress and eustress, which is also referred to as positive stress (Selye, 1974). However, to limit the definitions to either the stressors or the response, comes with several shortcomings (Cooper et al., 2001). Foremost, these definitions say little about the stress process itself that differs individually. Thus, definitions that examine the interaction between stressors and strain have arisen. Despite considering the interaction, much of these definitions are limited to investigate only two variables and a large set of moderator variables mostly without a theoretical foundation. Hence, they fail to meet the requirements of the complex and dynamic nature of the individual stress process (Cooper et al., 2001). With building upon the limitations of preceding definitions, Lazarus (1966) and Lazarus and Folkman (1984) provide an interaction based theoretical framework of stress that allows for the dynamical, individual stress process. This framework is referred to the transactional model of stress, which is outlined in the following.

While the stress literature reveals many different stress theories and models that have arisen in the past decades (Bliese et al., 2017; Ganster & Rosen, 2013), the transactional model of stress has become the most influential one (Lazarus, 1966; Lazarus & Folkman, 1984). The model offers a description of two individual processes evoked by a stressor, the primary and the secondary appraisal process. At the primary appraisal process, the individual evaluates, whether the stressor is irrelevant, positive, or dangerous. If the stressor is dangerous, the appraisal can be differentiated between challenge, threat, or harm/loss. In all three cases, the secondary appraisal process begins, in which the individual weighs up his or her own resources for coping. If the resources are insufficient, the stress reaction evolves (Lazarus, 1966; Lazarus & Folkman, 1984). Thus, stress is part of an ongoing, individual, cognitive process of transacting with the environment features, making appraisals, and coping with the issues, if possible (Cooper et al., 2001). Particularly, the transactional model of stress provides two main assumptions that also more recent theories do not contradict: (a) psychosocial stressors show their effects primarily through individuals' evaluation and perception, and (b) such cognitive processes are slotted in ahead initiating physiological processes in the central nervous system (Ganster & Rosen, 2013). Other influential theories in the context of work stress are the job demands-control model (Karasek, 1979), the job demands-resources model (Bakker & Demerouti, 2017; Demerouti, Bakker, Nachreiner, & Schaufeli, 2001), the Conservation of Resources theory (Hobfoll, 2001), as well as the Effort-Reward Imbalance Model (Siegrist, 2002). However, though these stress theories consistently reveal that physiological processes are initiated, they do not provide any detailed information about such processes (Ganster & Rosen, 2013).

Due to the increasing ubiquity of ICTs in society and the work environment, another stress concept has arisen in the early 1980s that focuses on the relationship between ICT and technology use and stress perceptions, which is referred to as technostress (Weil & Rosen, 1997). By coining this term, Brod (1984) defines technostress as "a modern disease of adaptation caused by an inability to cope with the new computer technologies in a healthy manner", with manifesting itself in "the struggle to accept computer technology" (p. 16). A Nature article continued this notion one year later and outlined that " […] it is hoped that environments that minimize stress can be designed" (Anderson, 1985, p. 6). More recently, technostress literature mostly provided by IS scholars examines antecedents (e.g., technology characteristics, Ayyagari et al., 2011) and outcomes of technostress (e.g., productivity, Shu, Tu, & Wang, 2011) as well as technostress creators (e.g., techno-overload) and inhibitors (e.g., technical support provision) (Ragu-Nathan, Tarafdar, Ragu-Nathan, & Tu, 2008). Despite the fact that the concept technostress provides interesting notions for the investigation of interactions between ICT use and stress, previous and recent literature suffers from a clear conceptual foundation that illustrates explicitly the added value of technostress compared to the aforementioned established stress concepts. Furthermore, the concept of technostress differs in literature, whether it is treated and examined as a stressor or strain. Therefore, the stress concept of the present thesis relies on the aforementioned, established stress concepts.

As the stress response occurs in three ways, psychological, physiological, and behavioral (Ganster & Rosen, 2013), the stress concept of this thesis is also threefold. First, *psychological distress* as the psychological stress concept is outlined serving as a focal outcome of availability in the ICT-based Availability Management Study. The psychological distress concept of the thesis is in accordance with the conceptual foundation of the transactional model of stress that take the transaction between the stressor and the individual strain into account (Lazarus, 1966; Lazarus & Folkman, 1984). Second, this thesis provides *physiological stress concepts*, in particular HR and HRV, that will be further illuminated in the ICT-based Physiological Measurements Study. Third, the concept of *exhaustion* is applied as it represents the long-term effect of psychological stress. Exhaustion serves as a focal outcome in the ICT-based Availability Management Study. In the following, the psychological stress concepts – distress and exhaustion – are outlined in detail, while the physiological stress concept is discussed in Chapter 2.1.3.

Psychological Distress and Exhaustion

Psychological distress is defined as an affective state that is constituted of feelings of unhappiness, depression, and anxiety (Hardy, Woods, & Wall, 2003; Warr, 1990). In particular, research has indicate a model with two orthogonal dimensions called 'pleasure' and 'arousal' (Russell, 1980; Watson, Clark, & Tellegen, 1988; Watson & Tellegen, 1985). While pleasure refers to the valence of an affective state ranging from pleased to displeased, arousal reflects the degree of activation or intensity of an affective state ranging from low to high. According to the certain level of pleasure and arousal, a certain affective state can be assigned. However, Warr (1990) provides a concept with three principal axes that takes the detailed variations of pleasure into account, because arousal alone does not represent distress. Beside the vertical axis 'arousal' with unlabeled poles and the horizontal axis 'pleasure' ranging from pleased to displeased, two further diagonal axes are introduced, 'depression' ranging from depressed to enthusiastic and 'anxiety' ranging from anxious to contented. The two diagonal axes differ in their level of arousal (Hardy et al., 2003). Assigned items of the anxiety-contentment axis are for example tense, uneasy, or relaxed, and those of the depression-enthusiasm are gloomy, miserable, or optimistic. Psychological distress serves as a focal outcome in the ICT-based Availability Management Study.

Beside psychological distress, *exhaustion* is included as a long-term concept of stress in the ICT-based Availability Management Study. The conceptual foundation of exhaustion is rooted in burnout as one of three dimensions (i.e., cynicism, inefficacy) (Maslach, Schaufeli, & Leiter, 2001). Burnout represents the prolonged individual response in these three dimensions to chronic stressors on the job. Exhaustion constitutes the stress dimension and, thus, the central quality of burnout. It is defined as "[…] feelings of being overextended and depleted of one's emotional and physical resources." (Maslach et al., 2001, p. 399). In line with his conceptual foundation, the present dissertation applies the concept of exhaustion as a focal outcome in the ICT-based Availability Management Study.

2.1.3 Conceptual Foundations and Definitions of Concepts related to Physiology, Wearables, and the Assessment of Individual Well-being Outcomes

In general, the conceptual foundation of physiology is grounded on the three nervous systems of the body, particularly the central nervous system (CNS), the automatic (ANS) and somatic nervous system, and the cellular and humoral system (Cacioppo, Tassinary, & Berntson, 2007). While the CNS is composed of the brain and the spinal cord, the ANS and somatic nervous system, also referred to as peripheral nervous system (PNS), consist of all nerves outside the brain and the spinal cord. The cellular and humoral system controls specialized neurons and endocrine glands in the brain and periphery releasing specific hormones (Schultheiss & Stanton, 2009). As research on physiology suffers from a lack of a consistent use of particular terms, this thesis uses *physiological measure* as a term for a recorded measure by a certain device. Likewise, *physiological data* is defined as the already recorded and subsequently processed, and analyzed physiological measure.

Because related to psychological and behavioral constructs, physiological measures provide valuable insights into processes of the human body beyond psychological constructs that are plagued with self-report bias and social desirability (Akinola, 2010; Cacioppo et al., 2007; Massaro & Pecchia, 2019; Murray & Antonakis, 2019). Further, physiological measures help to uncover new ways of theorizing established constructs by perceiving the human body as a valuable resource and potential source of agency (Heaphy, 2007; Heaphy & Dutton, 2008). In research, physiological measures serve as both antecedents as well as dependent variables (Heaphy, 2007). Physiological measures show a multidimensional nature consisting of the dimension time, space or location, and others (e.g., experimental condition) that, in turn, could have several subdimensions (Gratton, 2007). To this end, physiological measures differ in the time, with which they occur, and in space or location, they represent and are recorded. In particular, there is a difference between measures of the CNS that directly represent the brain and peripheral measures of the PNS located outside the brain (see also Figure 3-3). This multidimensional nature comes along with several consequences for the application of physiological measures further discussed in Chapter 6 and the guideline for wearable-measured physiological data (see Chapter 6.2).

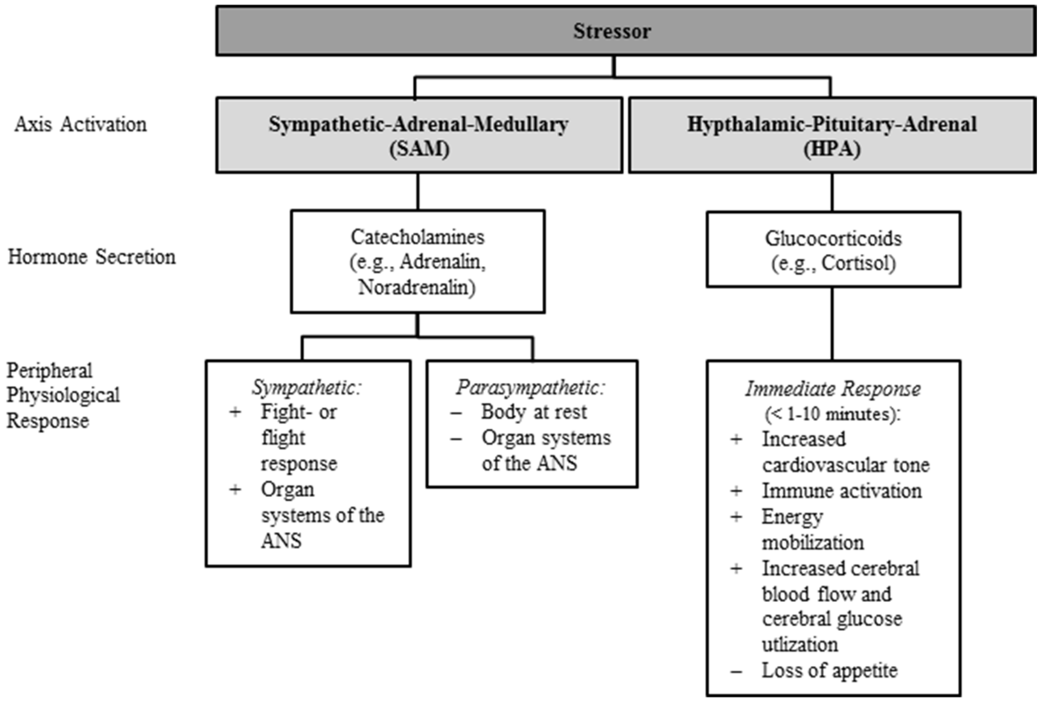
The present dissertation investigated also peripheral physiological stress measures and their measurement. The conceptual foundation of peripheral physiological measures that are often used as indicators for stress, affect, and emotions rely on a traditional discussion on the temporal order of mostly unconscious, peripheral physiological processes and conscious, cognitive processes (Christopoulos, Uy, & Yap, 2019; Mendes, 2016; Thorson, West, & Mendes, 2018). As one of the first, the James-Lange theory of emotions indicates the sequence of emotional feelings in that peripheral physiological processes precede cognitive processes that are referred to as emotions (James, 1890; Laird & Lacasse, 2014). In particular, he proposed that "[…] we feel sorry because we cry, angry because we strike […]" instead of being sorry or angry and strike (James, 1890, p. 449). However, this theory has been criticized for the fact that peripheral physiological processes are too slow to react appropriately to the environment (Cannon, 1927). More recent approaches suggest that peripheral physiological processes may act as cues for the emotional response and take thereby a dual role (Christopoulos et al., 2019). In this regard, they may precede the emotional response, but could also constitute the response itself. This thesis follows these recent approaches.

Beside the discussion about the temporal order, research arises the question to what extent do a particular physiological measure represent a particular psychological construct, such as emotion or stress (Cacioppo et al., 2007; Mendes, 2016). To specify this question, physiological measures can be assessed according to their *sensitivity* and *specificity* (Mendes, 2016). Sensitivity is referred to the extent, with which the physiological measure changes in accordance with the change of a psychological construct (e.g., an emotion state). Specificity is defined as the extent a physiological measure is related to only a particular psychological construct or a wide range of psychological construct. Although a physiological measure is highly sensitive for changes of the psychological construct, it has not necessarily a high specificity. Both, sensitivity and specificity, are crucial for the comprehensive understanding of the relationship between peripheral physiological measures and psychological and behavioral constructs. However, they can be modified by the context, in which the relationship is examined (Mendes, 2016).

Physiological Stress

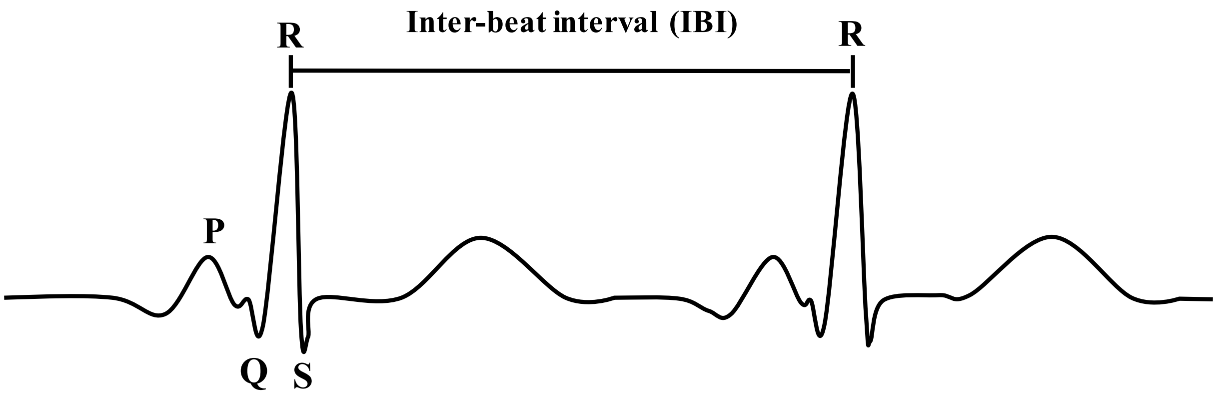
The conceptual foundation of the *physiological stress measures* in this thesis is justified in the allostatic load model, AL model for short. The AL model provides a theoretical framework on temporally structuring individual physiological processes of stress into three stages and linking stress to well-being outcomes on the long run (McEwen & Stellar, 1993; McEwen & Wingfield, 2003; see Chapter 2.2.3 for a detailed overview of the theory). Allostasis is referred to the adaption of the human body to stressors by evoking neural, neuroendocrine, and neuroendocrine-immune processes (McEwen, 1998). In particular, two axes of the CNS that are initiated within seconds by a stressor elicit these processes, the sympathetic-adrenal-medullary (SAM) axis and the hypothalamic-pituitary-adrenal (HPA) axis (Ganster et al., 2018; Ganster & Rosen, 2013; Juster, McEwen, & Lupien, 2010). The SAM axis is also referred to the sympathetic and parasympathetic nervous system as parts of the ANS (Stern, Ray, & Quigley, 2001), which are outlined in more detail in Chapter 3.2. They differ in their released hormones, particularly catecholamines from the SAM axis and glucocorticoids from the HPA axis (Sapolsky, Romero, & Munck, 2000). The released hormones initiate, in turn, peripheral physiological processes, such as an increase in HR or a suppression of the immune system (Ganster et al., 2018; Ganster & Rosen, 2013; Juster et al., 2010). If the stressor is successfully defended, the allostasis shuts down. The first stage of the AL model is referred to the allostasis, while the second stage concerns longer-term over- or underactivation of the allostasis. The third stage links negative well-being outcomes to the prolonged AL over- or underactivation of stage two. In general, the stress response can be measured in all of three stages. Figure 2-2 depicts the SAM and HPA axes schematically as the axes underlie complex neuroendocrine processes that interact within and between both axes indicating reactivity and recovery processes (Ganster & Rosen, 2013; Sapolsky et al., 2000). A more detailed overview of the neuroendocrine-immune, peripheral, and psychological processes during the stress response is provided in Figure 2-6 in Chapter 2.2.3.

Figure 2-2: The SAM and HPA Axes and the Peripheral Physiological Responses
(Own Figure based on Ganster & Rosen, 2013; Sapolsky et al., 2000)



The *physiological stress concepts* of the present thesis refer to stage one and two. In the ICT-based Physiological Measurements Study, the immediate stress response is measured with two peripheral physiological measures, *HR* and *heart rate variability (HRV)* as parts of the cardiovascular system of the ANS (Berntson et al., 1997; Berntson, Quigley, & Lozano, 2007). The main assignment of the cardiovascular system is to transport oxygenated blood from the lungs to the rest of the body and deoxygenated blood vice versa. As Figure 2-3 indicates, the electrocardiogram (ECG) with electrodes placed according to an Einthoven's lead on the limbs or on the torso is the mainly used device representing the electrical process of the heart in a specific sequence (Berntson et al., 2007). The R spikes as one particular part are relevant for the physiological measures caused by their larger magnitude. Thus, the heart period is defined as the time (in msec) between two consecutive R spikes in the ECG (i.e. R-R or inter-beat intervals, IBI, Figure 2-3). By accumulating the heart period to beats per minute (bpm) heart rate (HR) is calculated. Another prominent measure getting an increasing attention in the literature is HRV (Berntson et al., 1997; Ganster et al., 2018). Because the heart beats are varying systematically, HRV represents both sympathetic and parasympathetic activity and thus the balance between the two systems (Ganster et al., 2018) (see Chapter 3.2, 6.2, and 6.4.3 for details).

Figure 2-3: Standard ECG Signal with an inter-beat Interval (Own Figure based on Massaro & Pecchia, 2019)



Wearables for Recording Peripheral Physiological Measures

Traditionally, peripheral physiological measures are recorded with stationary devices such as the aforementioned ECG for HR and HRV. However, particularly the peripheral physiological measures of the ANS benefit from the rapid advances and dramatic improvements in wearable computing devices, wearables for short (Akinola, 2010; Bliese et al., 2017; Cascio & Montealegre, 2016; Chaffin et al., 2017; Heaphy & Dutton, 2008). *Wearables* are defined as technologies integrated in clothing or accessories and worn on the body in order to gather data from the body or the environment of the wearer and give the wearer information about this data (Cascio & Montealegre, 2016; Tamura et al., 2014; Tehrani & Michael, 2014). Wearables provide several crucial advantages compared to stationary devices, as they are easy to be worn, relatively cheap, and their application becomes affordable in the laboratory and field settings (Cascio & Montealegre, 2016; Chaffin et al., 2017). However, they also come with several perils and mostly rarely validation studies (Chaffin et al., 2017; Eatough et al., 2016). The present dissertation captures this new method recording peripheral physiological measures by discussing the advantages and perils of using wearables as well as outlining differences in measuring and processing wearable-measured physiological data in the ICT-based Physiological Measurements Study. Furthermore, the peripheral physiological stress measures HR and HRV are recorded with both two wearables and a stationary ECG in order to validate the wearable-measures physiological data in the ICT-based Physiological Measurements Study.

Ecological Momentary Assessment

To assess, for instance emotions or stress, multiple times on a momentary or daily basis, is a long traditional method called *ecological momentary assessment* (EMA; Beal & Weiss, 2003) or experience sampling method (ESM; Csikszentmihalyi & Larson, 1987). EMA provides three main advantages compared to commonly used cross-sectional studies. First, EMA takes the momentary nature of psychophysiological processes into account that vary meaningfully over time (Beal & Weiss, 2003). In this regard, EMA studies provide valuable insights by examining and, thereby, recognizing the meaningful within-person variability of momentary psychophysiological processes. Second, while examining short-lived, momentary psycho-physiological processes is usually limited to the laboratory, EMA provides the opportunity to measure such processes in field settings. Third, findings from EMA studies are less inaccurate regarding memory biases, because respondents are asked about their current state, behavior, and experiences and not reflecting states, behavior, and experiences from the past (Beal & Weiss, 2003). Similar to the relevance of wearables for recording physiological measures in organizational research, recent technological advances led to a significant increase in the utility and application of EMA (Beal & Weiss, 2003; Dimotakis, Ilies, & Judge, 2013). In particular, the use of electronic assessment devices, such as smartphones and wearables, facilitate to record a broad range of measures and large quantity of data (Ilies et al., 2016; Miller, 2012). For example, the location of a participant recorded with GPS of his or her smartphone as a behavioral measure and HR recorded with a wearable as a physiological measure can be assessed or questionnaires are sent to the respondents on their smartphones. EMA is illuminated in the overarching discussion of this thesis as a promising method for the organizational sciences that combines the findings and applied methods of the ICT-based Availability Management Study and the ICT-based Physiological Measurements Study. Furthermore, exemplary studies using EMA with electronic assessment devices are outlined in Chapter 3.3.

2.2 Theoretical Background

The present dissertation and the examined concepts and relationships are based on three theories, the human agency perspective (Emirbayer & Mische, 1998), self-determination theory (Deci & Ryan, 2000; Ryan & Deci, 2000), and the allostatic load model (McEwen & Stellar, 1993; McEwen & Wingfield, 2003). While the human agency perspective provides an individual-centered view of technology use, the self-determination theory gives insights into individuals' motivational behavior regarding ICT use. The allostatic load model offers an organizing and integrating framework for the emergence of physiological and psychological stress reactions. In the following chapters, core considerations of the theories and their particular contributions to the empirical studies of this thesis are discussed.

2.2.1 Human Agency Perspective

Considerations of the Theory

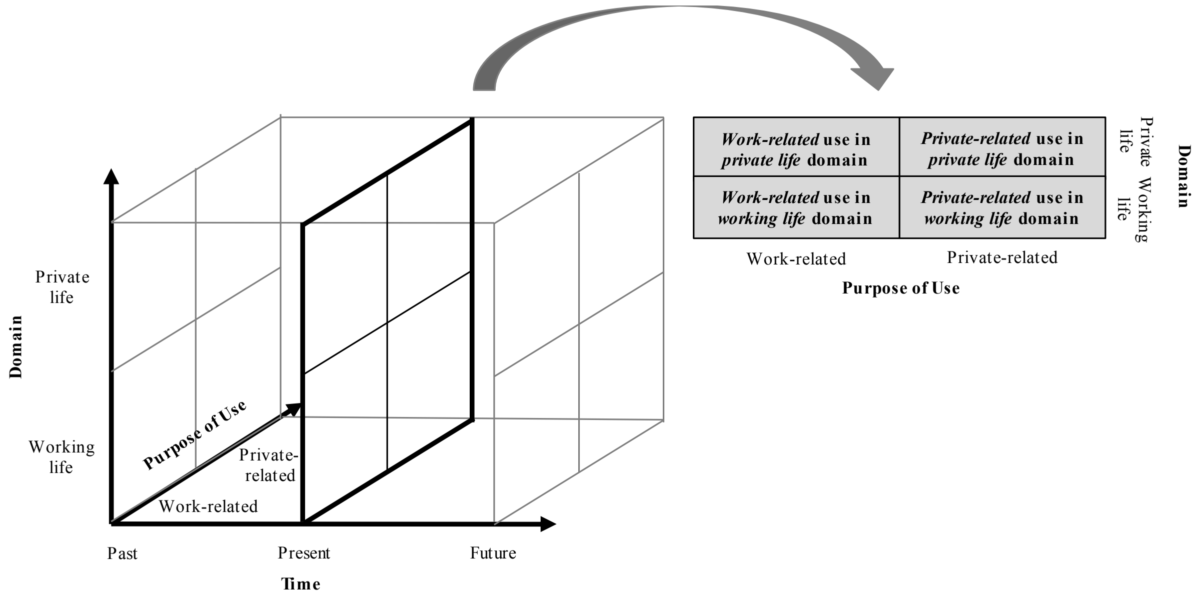
Usually classified and discussed in a sociological tradition (Emirbayer & Mische, 1998), the core considerations of the human agency perspective are transferred to organizational and management literature with the interest to explain individual and organizational behaviors and changes, also for example caused by technology use (Boudreau & Robey, 2005; Orlikowski, 1992; Schultze & Orlikowski, 2004). Thereby, the human agency perspective has the core consideration that individuals are empowered to enact freely with technologies resulting in inter-individual differences and consequences using the same technology. It considers the effect of individual choice and preferences and, thus, provides an approach to explain unpredictable actions of individuals (Cousins & Robey, 2005; Orlikowski, 1992). To better understand further applied considerations regarding technology use, the sociological view of human agency discussed by Emirbayer and Mische (1998) is outlined in the following.

According to Emirbayer and Mische (1998), human agency is defined as "the temporally constructed engagement by actors of different structural environments […]" (p. 970). Therefore, observed behavior is evoked by volition that is constituted of habit, imagination, and judgment. In particular, they postulate three constitutive elements of human agency: iteration, projectivity, and practical evaluation. These three elements represent the different temporal orientations of human agencies that concern the past, the future, and the present. Thus, the iterational element consists of routines and habits that were arise in the past based on past behavior. The projective element represents the ability to imagine prospective actions and plans. Lastly, the practical-evaluative element empowers human agencies to evaluate the present according to actual demands or ambiguities and subsequently adapt their actions to the ongoing evaluation. Thereby, the authors suggest a human capacity that takes all three elements simultaneously into account. The structural environments can be sustained or transformed by human agencies, even by the iterational element that represents habits, which are traditionally evoked by structures such as organizational norms (Boudreau & Robey, 2005).

By building upon these sociological considerations, organizational and management research uses the human agency perspective as a theoretical framework to explain individual actions in the context of changing organizational roles or structures (Boudreau & Robey, 2005). In particular, the human agency perspective is applied for job crafting (Wrzesniewski & Dutton, 2001), performance of organizational routines (Feldman & Pentland, 2003), and changes evoked by working with new technologies (Boudreau & Robey, 2005; Cousins & Robey, 2005; Tennakoon, da Silveira, & Taras, 2013). In this regard, Cousins and Robey (2005) provide an applied core consideration in that the human agency perspective "potentially explains why planned uses of technology are adjusted to balance conflicting demands emerging from practical contingencies" (p. 155). This notion supports the importance to take the individual actor with his or her own temporal elements that represents the actor's past, future, and present behavior and, thus, shifting environments into account to further understand individual outcomes despite using the same technology.

In addition to these applied considerations in the context of technology use, the human agency perspective fits closely to the boundary theory that was outlined previously (see Chapter 2.1.1 and 5) (Cousins & Robey, 2005; Tennakoon et al., 2013). Thereby, as the boundary theory outlines how individuals create their boundaries around and between the domains according to their boundary management preferences and priorities, previous experiences, and contexts (Ashforth et al., 2000), the human agency theory might serve as an overwhelming framework, in which the individuals act as human agencies to create their boundaries. Particularly, individuals are confronted with conflicts and dilemmas in regard to their boundary management and try to solve such conflicts with complex decisions and an ongoing adaption process that human agency is constituted of (Boudreau & Robey, 2005). This notion can also be transferred to the alignment of availability. Figure 2-4 presents the human agency perspective that serves as an overwhelming theoretical framework for the present thesis and is merged with relevant aspects of boundary theory. The particular contributions of this framework are discussed in the following.

Figure 2-4: The Human Agency Perspective as a Theoretical Framework for ICT Use and Boundary Theory (Own Figure based on Cousins & Robey, 2015)



Contributions from the Theory

In light of the discussed considerations, the contributions of the human agency perspective are twofold for the present thesis. First, the human agency perspective provides an important lens that justifies the pathway of responsible digitization of the thesis and in particular of both studies. Thereby, the perspective offers an explanatory approach for the inconsistent previous findings concerning ICT use by indicating to consider individual preferences and perceptions that could explain the inconsistency. Furthermore, because physiological measures are regarded as a potential source of agency (Heaphy & Dutton, 2008), the human agency perspective provides a theoretical framework for the added value of physiological measures. Therefore, both unconscious physiological and conscious cognitive and psychological measures need to be considered to comprehensively understand the human agency. Second, the human agency perspective constitutes a theoretical framework for the development of the ICT-based solution in the ICT-based Availability Management Study, in particular two smartphone applications. To this end, the applications should take into account that the individual user enacts freely with the applications probably resulting in different outcomes. In this way, they should also enable some degrees of freedom for the user. Moreover, it helps to better understand the evaluation results of both smartphone applications, in particular why the developed responsible ICT-based solution supports maybe not all users in the same way or same amount.

2.2.2 Self-Determination Theory

Considerations of the Theory

The self-determination theory (SDT, Deci & Ryan, 2000; Ryan & Deci, 2000) provides a theoretical framework about individuals motivation underlying their behavior. The theory consists of three basic psychological needs that are initial and have not to be learned and their fulfillment as satisfaction: need for autonomy, need for relatedness, and need for competence (Deci & Ryan, 2000). Need for autonomy is referred to as one's experience to feel free and have a choice concerning an activity. The desire to adapt effectively complex and changing environments is the definition of need for competence. Need for relatedness represents the desire to feel connected to others and be loved. Individuals tend to fulfill the needs because they have to be satisfied to evoke personal growth and well-being. Thus, this basic psychological need satisfaction represents the motivational mechanism that underlies individuals' behavior.

In addition to the basic psychological needs approach, SDT postulates and classifies human behavior along a continuum ranging from nonself-determined behavior as one pole to self-determined behavior as the other pole. This behavior is associated with different types of motivation (amotivation, extrinsic motivation, intrinsic motivation), and these types are assigned again to different types of regulation (non-regulation, external, introjected, identified, integrated, intrinsic) as well as loci of causality (impersonal, external, somewhat external, somewhat internal, internal).

A complete lack of self-determined behavior is associated with amotivation that occurs when individuals have no intention to behave. Accordingly, there is no regulation; the locus of causality is impersonal. In contrast to amotivation, all other forms of regulation involve either extrinsic or intrinsic motivation as any type of motivation. Is individuals' behavior self-determined, the motivation is intrinsic reflecting an intrinsic regulation as well as an internal locus of causality. In accordance with that, intrinsic motivation is reflected in that individuals act and behave because they find it interesting and do not get any reward. Between amotivation and intrinsic motivation, different types of extrinsic motivation range that differ in their types of regulation. In particular, SDT distinguishes two types of controlled extrinsic motivation (external, introjected regulation) and two types of autonomous extrinsic motivation (identified, integrated). While an external regulation as part of the controlled extrinsic motivation refers to behavior that is fully controlled by others, through for example rewards or threat of punishment, introjected regulation reflects regulation processes within an individual, but which is characterized by an inner conflict between demands and the individual's self leading to a feeling of being controlled. An identified regulation as part of the autonomous extrinsic motivation occurs, if the behavior is in line with one's values. Finally, integratedly regulated behavior is fully volitional, but still extrinsic. Figure 2-5 depicts the continuum of self-determined behavior. Additionally, for each type of regulation an example with regard to ICT use, in particular EWA, is given. Over the last decades, SDT becomes a popular theoretical framework for a large body of fundamental as well as applied research ranging from education, health care, and psychotherapy to workplace motivation designing of several technologies such as smartphone applications. Thus, SDT is a well-investigated, empirically based theory (Ryan & Deci, 2017).

Figure 2-5: The Core Concepts of the Self-Determination Theory and Examples regarding ICT Use (Own Figure based on Deci & Ryan, 2000; Ďuranová & Ohly, 2016; Ryan & Deci, 2000)

Behavior	Type of Motivation	Type of Regulation	Locus of Causality	Example regarding ICT Use/EWA
Nonself-determined	Amotivation	Non-regulation	Impersonal	No Motivation for ICT use/EWA
	Extrinsic	External	External	Expecting financial rewards
	Extrinsic	Introjected	Somewhat External	Avoiding feelings of guilt and shame
	Extrinsic	Identified	Somewhat Internal	Using ICTs for career advancement
	Extrinsic	Integrated	Internal	Using ICTs/EWA is in line with personal values and preferences
Self-determined	Intrinsic	Intrinsic	Internal	Using ICTs/EWA is fun

Contributions from the Theory

In the light of the discussed considerations, the SDT contributes to the present thesis by providing a theoretical framework that supports the understanding of important drivers of ICT use considering in the ICT-based Availability Management Study. In particular, employees may differ in their motivation for EWA and EPA either leading to detrimental effects for those with a more extrinsic motivation or improving effects for more intrinsic motivated individuals. Thus, considering employees' motivation for ICT use seems crucial to comprehensively understand their aligned availability beside boundary management and availability preferences as well as their perceptions. To this end, the SDT contributes to both important requirements for developing two smartphone applications as the responsible ICT-based solution that facilitates an aligned availability and an explanatory approach for the individual use as well as evaluation results of the applications.

2.2.3 Allostatic Load Model

Considerations of the Theory

Beside the psychological stress theories discussed in Chapter 2.1.2, the allostatic load (AL) model provide a detailed theoretical lens of the physiological processes that are elicited by a stressor (Ganster et al., 2018; Ganster & Rosen, 2013; McEwen & Stellar, 1993; McEwen & Wingfield, 2003). Thereby, the processes are depicted in a temporal sequence from short-term (seconds to minutes) to long-term (several years). This temporal sequence consists of three stages called primary, secondary, and tertiary AL processes, each with its own set of physiological markers and linked negative well-being outcomes. Figure 2-6 depicts the three stages, each with the affected body systems and its set of physiological markers or well-being outcomes.

The AL model is based on the adaption process of the human body to stressors, which is referred to as allostasis (McEwen, 1998). This process evokes immediately within seconds a release of hormones of the prior mentioned SAM (adrenalin, noradrenalin) and HPA (cortisol) axes that in turn initiates peripheral physiological processes such as an increase in HR. Each axis starts in the hypothalamus in the brain, which informs subsequently the hormone glances of adrenalin and cortisol. If the allostasis do not work normally (e.g., not shutting off after stress) or is overstimulated, this condition is called allostatic load. The allostatic load can lead to diseases and negative well-being outcomes.

The primary AL processes consist of the described initial adaptation evoked by a stressor. Thereby, stress hormones (e.g., epinephrine, cortisol) and pro- and anti-inflammatory cytokines (e.g., interleukin-6), which are important for the immune system, are released. In accordance with the stressor, psychological reactions are for example the feeling of fear, tension, or anxiety. Moreover, psychosomatic symptoms arise such as sleep disturbances, headache, and fatigue. The secondary AL processes try to adjust the allostatic load to normal ranges (i.e., set points), because of the maladaptive maintenance of the primary AL processes. According to the adjustments, different, mostly peripheral systems are involved. The immune system try to regulate itself with the release of several makers (e.g., fibrinogen, C-reactive protein, Immunoglobulin). High resting blood pressure for example symbols the cardiovascular system, while the effects arises also in the metabolic system, for example through releasing hormones such as insulin or cholesterol. As key risk factors for mental and physical negative well-being outcomes, the maintenance of the secondary AL processes over time lead to the tertiary AL processes that represent the negative well-being outcomes. Similar to the affected peripheral systems in the second stage, diseases arise regarding the cardiovascular and metabolic system (e.g., diabetes). In addition, mental disorders such as depression can emerge. Over the past decades, the AL model has become the main integrative model for describing the processes and mechanisms through which chronic exposures to stressors produce changes in mental and physical well-being.

Contributions from the Theory

As the ICT-based Availability Management Study is referred to psychological stress concepts and the ICT-based Physiological Measurements Study to physiological stress concepts, the AL model serves as an integrative model for both studies' concepts. In this regard, the model contributes to a deeper understanding of the psychological and physiological processes that are examined in the ICT-based Availability Management Study and the ICT-based Physiological Measurements Study. Particularly, as the ICT-based Availability Management Study is referred to the first and second stage of the AL model, the ICT-based Physiological Measurements Study investigates processes that are referred to only initial processes, and thus, the first stage. Thus, with being crucial for a sufficient construct validity, the AL model provides a theoretical framework for the sequential order of the examined processes and, thereby, gives valuable insights for designing EMA studies by measuring processes at the time they evolve.

Figure 2-6: The Processes of the Allostatic Load Model (Own Figure based on Ganster et al., 2018; Ganster & Rosen, 2013)

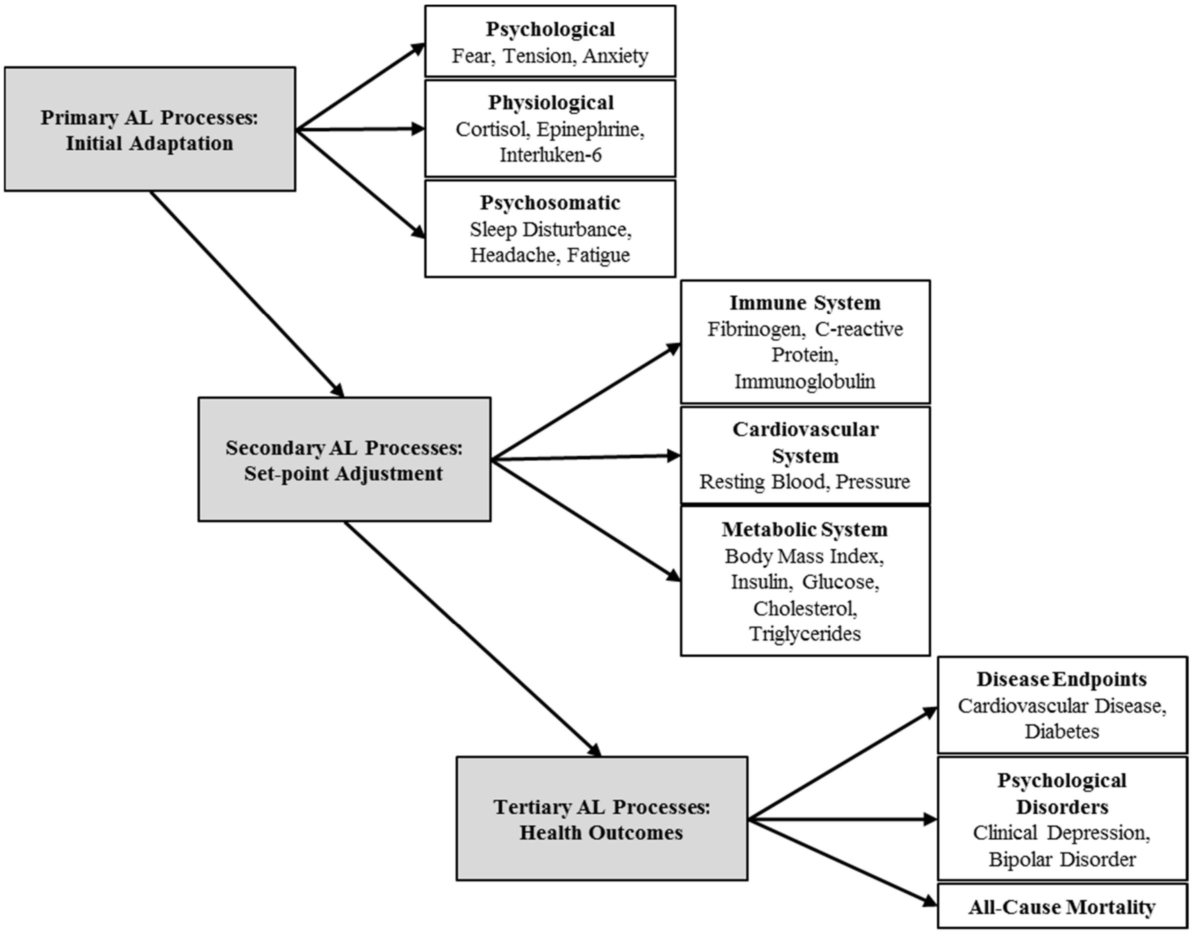


Table 2-1 provides an overview of the described theories, their core considerations, and their contributions to this thesis and the ICT-based Availability Management as well as ICT-based Physiological Measurements studies.

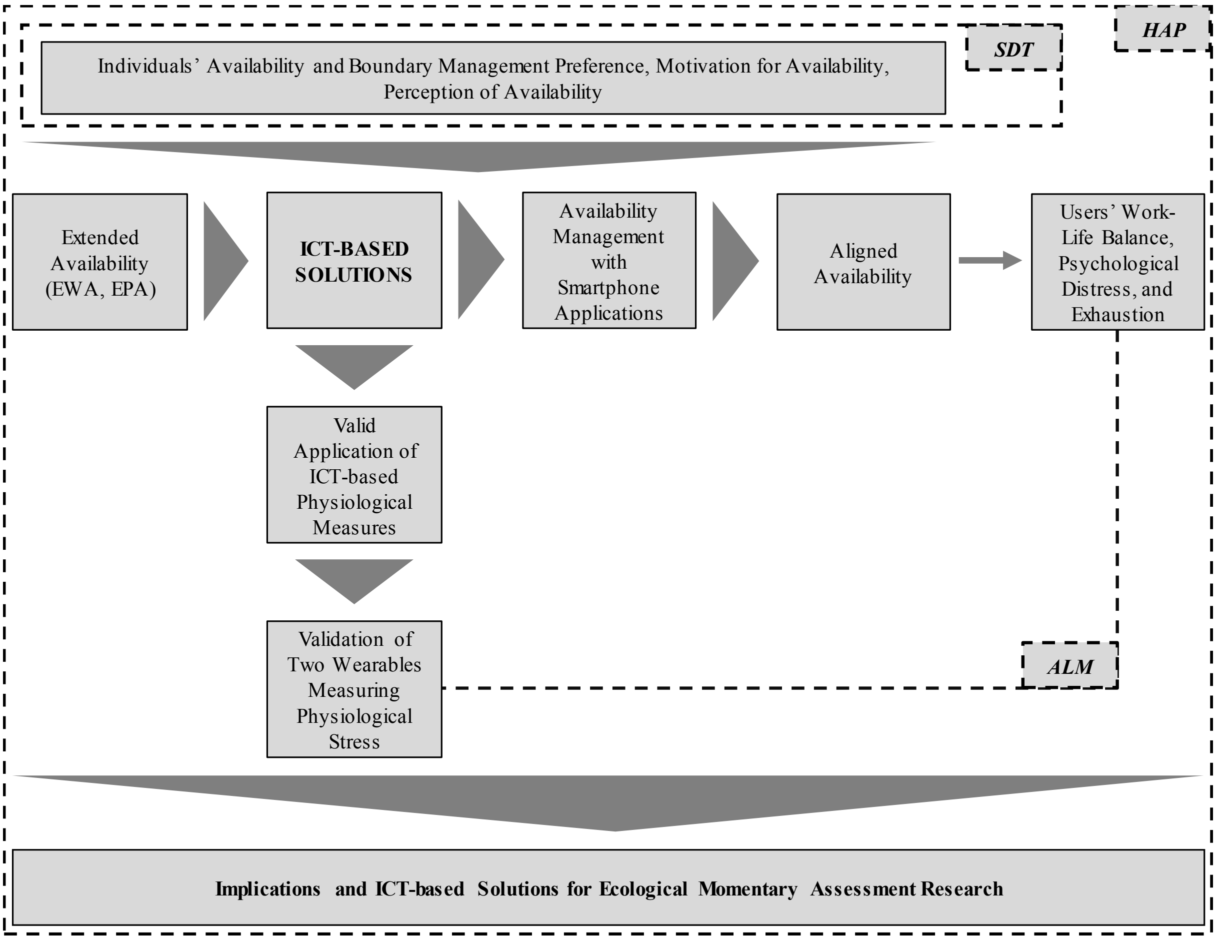
Table 2-1: Overview of the Theories and their Contributions to the Thesis

Theory	Core Consideration	Contribution to the Thesis
Human Agency Perspective (Emirbayer & Mische, 1998)	Individuals enact freely with ICTs according to their behavior in the past, present, and future resulting in inter-individual differences using the same technology.	- Enacting freely with the developed smartphone applications for availability management ➔ Enable users some degrees of freedom - Understanding the evaluation results of both smartphone applications - Highlighting the importance to consider preferences - Agency as the synergy between unconscious physiological and conscious cognitive and psychological measures
Self-Determination Theory (Deci & Ryan, 2000; Ryan & Deci, 2000)	Individuals show either non self-determined or self-determined behavior regarding ICT use according to the different types of motivation (amotivation, extrinsic, intrinsic).	- Motivation as an important driver for ICT use and availability - Considering motivation for the development of two smartphone applications beside boundary management and availability preferences and perception of availability
Allostatic Load Model (McEwen & Stellar, 1993; McEwen & Wingfield, 2003)	Individuals pass through different processes of their psychophysiological stress reactions.	- Providing an integrative model for the physiological and psychological stress concepts - Providing the sequential order of stress reactions to measure each process at the right time it evolves

2.3 Summary and Preliminary Framework of the Thesis

The aim of Chapter 2 was to clarify the conceptual and theoretical background of the thesis consisting of both research streams – the ICT-based availability and ICT-based physiological well-being indicators. Core concepts of the thesis were defined and the theoretical background with the human agency perspective, self-determination theory, and allostatic load model were outlined. Based on the defined concepts and the theoretical background a preliminary framework of the present thesis can be compiled that is depicted in Figure 2-7. Proceeding from ICT-based solutions for a responsible assessment and management of employees' well-being, Figure 2-7 shows the interplay between the ICT-based Availability Management and ICT-based Physiological Measurements studies of the thesis and their common theoretical background. Together, the framework serves as a pathway to a responsible digitization that takes the individual user into account.

Figure 2-7: Preliminary Framework of the Thesis as a Pathway to Responsible Digitization



Note: ALM = Allostatic Load Model, HAP = Human Agency Perspective, SDT = Self-Determination Theory.

To specify the preliminary framework of this thesis, a literature review on ICT-based availability and ICT-based physiological well-being indicators is conducted. The findings of previous research and their implications for the thesis' specified framework are outlined in the next Chapter 3.

3 Literature Review

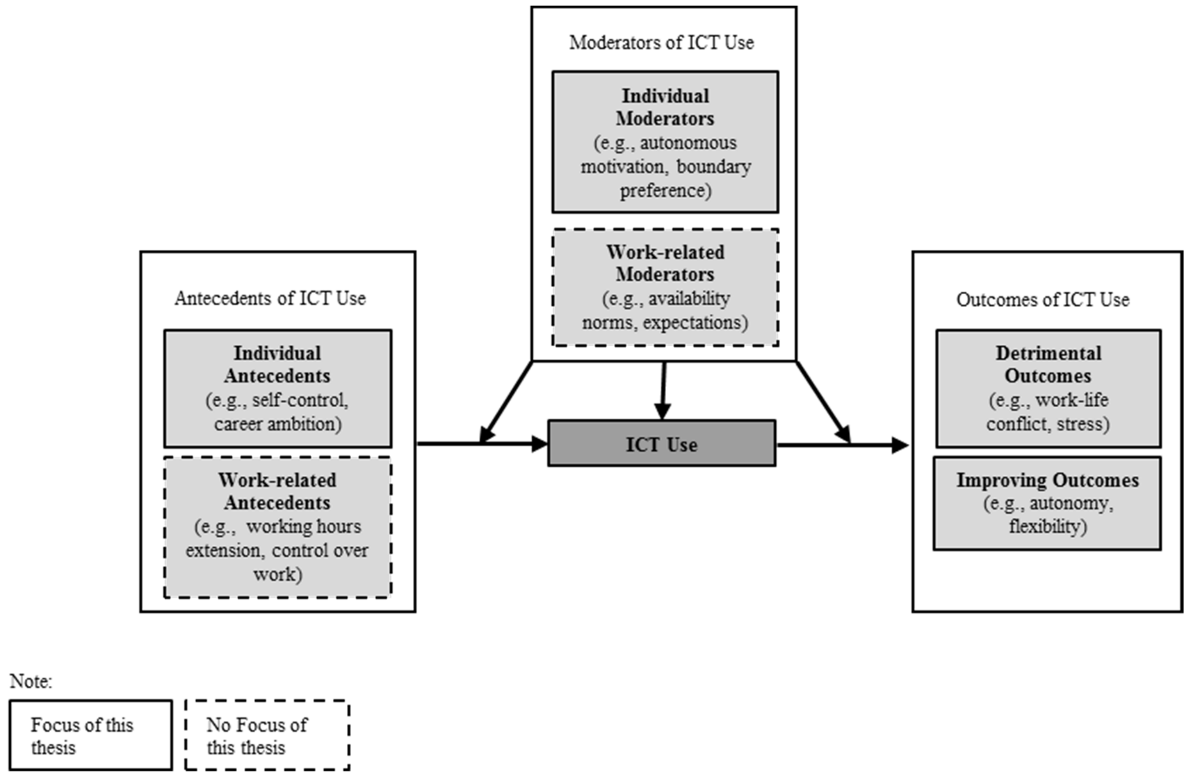
In the following chapter, a comprehensive literature review is provided for the ICT-based availability and ICT-based physiological well-being indicators literature stream. In particular, findings of previous research related to (1) individual antecedents of ICT use, its effects on employees' outcomes, and moderator variables that may buffer or enhance detrimental effects of ICT use, (2) the application and measurement of physiological measures in organizational science, and (3) the momentary assessment of individual well-being outcomes.

As both literature streams are interdisciplinary, including psychology, organizational science, information systems, and medicine, and the prevalence of studies concerning one of the two research fields is rapidly increased in the past decade, the literature review is aimed at structuring the heterogeneous literature and findings. Moreover, key findings are outlined and summarized for each research field. Finally, key limitations of previous research are discussed and their contribution to the framework of this thesis and both empirical studies are revealed.

3.1 Findings of Previous Research to Individual Antecedents, Outcomes, and Moderators of ICT Use

Research and studies that investigate ICT use, its antecedents and effects on well-being outcomes as well as moderators seem more prevalent than ever. Because the focus of the thesis is on the individual user with his or her motivation, preference, and perception, the literature was also reviewed with this focus. Therefore, a comprehensive literature research was conducted in top-tier management, OB, and IS journals in order to identify studies that examine individual variables and person characteristics as antecedents and moderators as well as individual outcomes of ICT use. As the IS literature was also part of the literature research, the concept of technostress is included in the literature review. Furthermore, first literature reviews exists that were also reviewed regarding relevant studies (i.e., Ďuranová & Ohly, 2016; Schlachter et al., 2017). Figure 3-1 provides an overview of the current state of literature regarding ICT use. As the dashed sections indicate, work-related antecedents and moderators (e.g., availability norms and expectations) were out of the scope of the literature research. It should be noted here that ICT use is applied in the following sections as the prior mentioned umbrella term as no consistent concepts are investigated in previous research. However, most reviewed research of the literature research refers to ICT-based availability, in particular EWA.

Figure 3-1: Overview of the Current Research State regarding ICT Use and Fields of the Literature Review



3.1.1 Individual Antecedents of ICT Use

Next to important work-related and organizational related antecedents such as the extension of working hours or control over work, recent research also examines individual antecedents the employee, which show ICT use, is constituted of (Ďuranová & Ohly, 2016; Schlachter et al., 2017). It should be noted that just little research has examined individual antecedents so far (Schlachter et al., 2017). However, certain demographic variables are examined, particularly in respect to the technostress literature. Findings of these studies indicate that men and younger individuals experience more technostress than women and older individuals (Ragu-Nathan et al., 2008; Schieman & Glavin, 2008; Tarafdar, Tu, Ragu-Nathan, & Ragu-Nathan, 2011). A more recent study by Shu et al. (2011) could not replicate these previous findings as only age show a significant effect, but in another direction (i.e., older individuals show higher technostress). Beyond these demographic variables, investigated individual antecedents of previous research can be broadly categorized into three categories: (1) traits towards ICT use,

(2) attitudes towards ICT use, and (3) attitudes towards work and organization. Table 3-1 lists the four categories, their assigned individual antecedents and relation to ICT use, and exemplary studies for each antecedent.

The first category concerns how employees' traits contribute to ICT use. Previous research examines a number of different traits. Fenner and Renn (2004, 2010) investigated *conscientiousness* as one of the Big Five personality dimensions as an individual antecedent for ICT use in that highly conscientious employees spend more time after hours for work-related purposes and use ICTs to facilitate their work. However, their results do not provide support for this hypothesis as no significant effect was found (Fenner & Renn, 2010). Potentially though, conscientiousness could be indirectly related to ICT use through appraisal processes (Ďuranová & Ohly, 2016). Furthermore, *polychronicity* as the ability to do tasks simultaneously is investigated as an individual antecedent (Richardson & Benbunan-Fich, 2011). In this respect, they hypothesize that polychronic individuals are more likely to show ICT use behavior due to their preferences to overlap work and private life, perform more than one task at the same time and use more than one technology. The results provide support for this hypothesis. Additionally, Richardson and Benbunan-Fich (2011) investigated *personal innovativeness with information technology* as an individual antecedent of ICT use. This construct represents one's willingness of adopting and using nee information technology and the authors hypnotized that high innovative employees tend to show higher ICT use. However, no directly significant effect was found. Some qualitative and quantitative research explores the role of *self-control* and *self-discipline* in the context of ICT use (Al-Dabbagh, Sylvester, & Scornavacca, 2014; Duxbury, Higgins, Smart, & Stevenson, 2014; Soror, Hammer, Steelman, Davis, & Limayem, 2015). According to these studies, employees with higher self-control show lower ICT use as they continuously monitor and evaluate the ICT use. Al-Dabbagh et al. (2014) provide a new concept of ICT self-discipline as "an individual's ability to control their behaviour towards use of ICTs" (p. 3). The results of these first studies provide support for a crucial role of self-control and ICT self-discipline.

Table 3-1: Overview of the Examined Individual Antecedents of ICT Use and Exemplary Studies

Category	Individual Antecedent	Exemplary Studies
Traits towards ICT use	Conscientiousness [+, n.s.]	Fenner & Renn, 2004, 2010
	Polychronicity [+]	Richardson & Benbunan-Fich, 2011
	Self-control/ICT self-discipline [-]	Al-Dabbagh et al., 2014; Duxbury et al., 2014; Soror et al., 2015
	Personal Innovativeness with information technology [+, n.s.]	Richardson & Benbunan-Fich, 2011
Attitudes towards ICT use	Perceived utility of ICT [+]	Tennakoon et al., 2013
	Computer self-efficacy	Shu et al., 2011
Attitudes towards work and organization	Career ambition [+]	Boswell & Olson-Buchanan, 2007; Fenner & Renn, 2004
	Job involvement [+]	Boswell & Olson-Buchanan, 2007; Fenner & Renn, 2004; Park et al., 2011; Park & Jex, 2011
	Workaholism [+]	Allen & Shoard, 2005; Barley et al., 2011; Middleton & Cukier, 2006
	Impression management [+]	Allen & Shoard, 2005; Barley et al., 2011

Next to traits that either encourage or hinder ICT use, study results regarding employees' attitudes towards ICT use as well as work and organization can be categorized. The second category refers to the attitudes towards ICT use, in particular to the *perceived utility of ICT* (Tennakoon et al., 2013). As a well-established construct in the technology acceptance model, perceived utility of ICT is also used for one's adoption of ICT, particularly the degree, to which individuals believe ICTs enhances and contributes to their job performance (Davis, Bagozzi, & Warshaw, 1989). In the context of ICT use, it is argued that employees, who perceive ICTs as useful in the work domain, show higher ICT use in the private life domain (Tennakoon et al., 2013). Results of the study from Tennakoon et al. (2013) provide support for this notion. Furthermore, in respect of the technostress literature, *computer self-efficacy* is examined as one's belief in his or her capability to use a computer (Shu et al., 2011; Tarafdar, Pullins, & Ragu-Nathan, 2015). According to the findings of Shu et al. (2011) and Tarafdar et al. (2015), individuals with a higher computer self-efficacy show lower technostress. In particular, computer self-efficacy positively affects the technostress creators techno-complexity and technoinsecurity in that individuals feel less unfamiliar and uncomfortable with technologies as well as less anxious to lose their job respectively.

The third category concerns employees' attitudes towards their work and organization. Compared to the other categories, much qualitative and quantitative research examines such attitudes. Probably obvious, these studies examine attitudes, which are associated with career-oriented employees that perceive ICT use as a tool to create the expression of going the extra mile, and thus, show higher EWA. In particular, *career ambition* (Boswell & Olson-Buchanan, 2007; Fenner & Renn, 2004), *job involvement* (Boswell & Olson-Buchanan, 2007; Fenner & Renn, 2004; Park et al., 2011; Park & Jex, 2011), and *workaholism* (Middleton & Cukier, 2006) are examined. Some studies give hints for ICT use as a tool for *impression management* (Allen & Shoard, 2005; Barley et al., 2011; Mazmanian et al., 2013).

3.1.2 Detrimental and Improving Outcomes of ICT Use

Unlike the overwhelming negative view in practice, recent research found rather mixed results regarding the effects of ICT use in that ICT use is regarded as a double-edged sword for employees. On one hand, ICT use had the potential to alleviate stress through an increased constant availability. On the other hand, it enhances employees' flexibility when and where to work and increasing their work-life balance (Lowry & Moskos, 2005). Jarvenpaa and Lang (2005) illustrate this notion in an empowerment/enslavement paradox. In accordance with this paradox, findings of previous research can be categorized into detrimental and improving outcomes of ICT use, in particular in respect to employees' well-being and stress as well as their work-life-interface. Table 3-2 lists both categories, their assigned subcategory, and exemplary studies for each subcategory.

Table 3-2: Overview of the Detrimental and Improving Outcomes of ICT Use and Exemplary Studies

Category	**Effects**	**Exemplary Studies**
Detrimental outcomes regarding stress	Distress	Mazmanian et al., 2013; Schieman & Young, 2013; Tarafdar et al., 2011
	Emotional exhaustion	Day et al., 2012; Xie, Ma, Zhou, & Tang, 2018
	Strain	Day et al., 2012
	Impaired well-being	Dettmers et al., 2016
	Negative health outcomes	Day et al., 2012
	Burnout	Day et al., 2012; Ferguson et al., 2016; Srivastava et al., 2015
	Depletion	Lanaj, Johnson, & Barnes, 2014
	(Impaired) Psychological detachment	Barber & Jenkins, 2014; Derks, van Mierlo, & Schmitz, 2014; Dettmers, 2017; Park et al., 2011; Richardson & Thompson, 2012
Detrimental outcomes regarding work-life-interface	Work-life conflict	Ayyagari et al., 2011; Boswell & Olson-Buchanan, 2007; Cavazotte et al., 2014; Derks & Bakker, 2014; Dettmers, 2017; Fenner & Renn, 2010; Mazmanian, 2013; Mazmanian et al., 2013

Category	Effects	Exemplary Studies
Improving outcomes regarding well-being	Increased well-being	Mazmanian, 2013; Middleton, 2007
	Sense of competence	Cavazotte et al., 2014; Mazmanian et al., 2013
	Effectiveness	Middleton & Cukier, 2006
	Productivity	Allen & Shoard, 2005; Duxbury et al., 2007
	Work satisfaction	Diaz, Chiaburu, Zimmerman, & Boswell, 2012
Improving outcomes regarding work-life-interface	Facilitator of work-life balance	Currie & Eveline, 2011; Golden & Geisler, 2007
	Flexibility	Allen & Shoard, 2005; Day et al., 2010; Duxbury et al., 2007; Middleton & Cukier, 2006
	Control	Cavazotte et al., 2014; Mazmanian et al., 2013
	Autonomy	Cavazotte et al., 2014; Mazmanian et al., 2013

The first category concerns the detrimental outcomes of ICT use either in regard of stress or employees' work-life interface. Much recent research has focused on this negative, "enslaved" site of the double-edged sword indicating detrimental effects of ICT use (Day et al., 2012). ICT use held the potential to increase the time employees spend working, and in turn, reduce the time to recover from work (Barley et al., 2011). Additionally, ICT use enhances interruptions and distractions from personal time for employees at any time and any place resulting in a unpredictability about whether and when they need to be available (Boswell & Olson-Buchanan, 2007; Dettmers et al., 2016). The consequences of these two underlying mechanisms seem quite clear and much recent research have produced empirical findings for them that will be outlined in the following.

On the one hand, ICT use is related to employees' impaired well-being (Schlachter et al., 2017). In particular, studies concluded that EWA yields an increase of employees' *stress, strain,* and *emotional exhaustion* (Day et al., 2012; Mazmanian et al., 2013; Schieman & Young, 2013; Tarafdar et al., 2011; Xie et al., 2018). Likewise, Dettmers et al. (2016) indicated positive effects of characteristics of extended work availability on *impaired well-being*.

Furthermore, ICT use affects recovery and detachment processes from work resulting in *depletion* and *impaired psychological detachment* (Barber & Jenkins, 2014; Derks et al., 2014; Lanaj et al., 2014; Park et al., 2011; Richardson & Thompson, 2012). In respect to long-term effects, some studies indicate that ICT use is related to *negative health outcomes* such as musculoskeletal or cardiovascular complaints, and *burnout* (Arlinghaus & Nachreiner, 2013, 2014; Day et al., 2012; Ferguson et al., 2016). On the other hand, employees perceive that the boundaries between their work and personal life are increasingly blurred. Blurring boundaries are not necessarily detrimental, but could lead to a conflict between employees' work requirements caused by ICT use and personal requirements caused by their family, for example (Boswell & Olson-Buchanan, 2007; Schlachter et al., 2017). Thus, much recent qualitative and quantitative research found empirical evidence for the direct detrimental effect of EWA on *WLC* (e.g., Ayyagari et al., 2011; Boswell & Olson-Buchanan, 2007; Cavazotte et al., 2014; Derks & Bakker, 2014; Fenner & Renn, 2010; Mazmanian et al., 2013).

The second category refers to the improving outcomes of ICT use either in regard of well-being or employees' work-life interface. Unlike the well investigated detrimental outcomes, little research considered ICT use as a resource indicating improving, empowering effects of ICT use (Day et al., 2010). However, directly improving outcomes of ICT use refer to an *increase in well-being*, which is indicated in qualitative studies (Mazmanian, 2013; Middleton, 2007). Further, some studies provide support that ICT use enhances positive work-related outcomes, which in turn may decrease employees' stress and, thereby, increase employees' well-being. Particularly, the *sense of competence* and *effectiveness*, *productivity*, and *work satisfaction* are examined (Allen & Shoard, 2005; Cavazotte et al., 2014; Diaz et al., 2012; Duxbury et al., 2007; Mazmanian et al., 2013; Middleton & Cukier, 2006). In regard of the work-life interface, ICT use was found as a facilitator of work-life balance, because employees are more able to meet the requirements of both the work and private life domain (Currie & Eveline, 2011; Golden & Geisler, 2007). In line with this notion, ICT use enhances *flexibility* as well as *sense of control* managing the work-life boundaries (Allen & Shoard, 2005; Cavazotte et al., 2014; Day et al., 2010; Duxbury et al., 2007; Mazmanian et al., 2013; Middleton & Cukier, 2006). Moreover, some qualitative studies reveal that *autonomy* may be positively related to EWA in that employees perceive the increased flexibility through ICT use as an evidence for their autonomy (Cavazotte et al., 2014; Mazmanian et al., 2013).

3.1.3 Individual Moderators in the Context of ICT Use

Despite these hints for both detrimental and improving effects of ICT use and, thus, the double-edged sword hypothesis, little is known about the conditions that could contribute to a better understanding of why and when employees find their ICT use improving or exacerbating. To learn more about such conditions, a pathway that takes the individual user with his or her views and preferences into account seems appropriate. However, while research focuses mainly on work-related moderators, for example job autonomy (Schieman & Glavin, 2008; Schieman & Young, 2013), organizational availability norms (Fenner & Renn, 2010), or availability expectations (Park et al., 2011), individual moderators are not yet well investigated. The importance to examine such moderators next to work-related ones is justified due to the notion that ICT use is voluntary and a consciously personal choice (Allen & Shoard, 2005; Mazmanian et al., 2013). Individual moderators can be constituted of individual motives, preferences, and perceptions regarding ICT use that can be serve as a 'filter', through which the amount of ICT use is evaluated (Ďuranová und Ohly 2016; Schlachter et al. 2017). Hence, this filter may be the cause for the finding that the same amount of ICT use lead to different effects within and between individuals (Karr-Wisniewski & Lu, 2010). Thus, examined individual moderators that may buffer the detrimental and enhance the improving effects of ICT use can be broadly categorized into four categories: employees' individual motives, preferences, and perceptions as well as others such as personality traits. Table 3-3 lists the four categories, their assigned individual moderators, and exemplary studies for each moderator.

The first category refers to the employees' motivation of ICT use and therefore to the aforementioned self-determination theory. So far, only one study shed light on the ICT use motivation in that they differentiated between *autonomous* and *controlled motivation* for employees' work-related smartphone usage in the evening (Ohly & Latour, 2014). Thereby, autonomous motivation includes intrinsic, integrated, and identified regulation, while controlled motivation represents externally and introjected regulation. According to the argumentation of the authors, autonomous motivation for smartphone usage in the evening may contribute to the fulfillment of the three basic psychological needs. For example, employees satisfy their need for competence as they complete work tasks. Contrarily, controlled motivation for smartphone usage in the evening do less or not provide the satisfaction of any basic psychological need because of feeling pressured and doing it involuntarily. The study results give support for this notion in that autonomous motivational ICT use might lead to positive experiences, while controlled motivational ICT use might lead to ones that are more negative.

Table 3-3: Overview of the Individual Moderators related to ICT Use and Exemplary Studies

Category	Individual Moderators	Exemplary Studies
Individual motives and motivation	Autonomous motivation	Ohly & Latour, 2014
	Controlled motivation	Ohly & Latour, 2014
Individual preferences	Individual boundary preference	Boswell & Olson-Buchanan, 2007; Crowe & Middleton, 2012; Derks, Bakker, Peters, & van Wingerden, 2016; Gadeyne, Verbruggen, Delanoeije, & Cooman, 2018; Golden & Geisler, 2007; Park et al., 2011; Richardson & Benbunan-Fich, 2011
	Individual preference for ICT use	Stich et al., 2017
Individual perceptions	Interpretation of ICT use	Dabbish & Kraut, 2006; Mazmanian et al., 2013
	Control perception	Ohly & Latour, 2014; Schieman & Glavin, 2008; Schieman & Young, 2013
Others	Personality traits	Krishnan, 2017; Srivastava et al., 2015
	Time management strategies	Fenner & Renn, 2010

The second category concerns individuals' preference for both boundary management as well as ICT use itself. Much qualitative and quantitative studies indicate that the *individual boundary preference*, which is defined as the preference for segmentation or integration of the work-life boundaries, has an moderating effect on ICT use (Boswell & Olson-Buchanan, 2007; Crowe & Middleton, 2012; Derks et al., 2016; Gadeyne et al., 2018; Golden & Geisler, 2007; Park et al., 2011; Richardson & Benbunan-Fich, 2011). Thus, employees with a high segmentation preference tend to perceive ICT use more negatively leading to detrimental effects compared to those with a high integration preference, which by contrast may perceive ICT use as even positively (Boswell, Olson-Buchanan, Butts, & Becker, 2016). Maybe correlated but certainty not used interchangeably, Stich et al. (2017) examine the desired use of computer-mediated communication applications serving as a *preference for ICT use* as a first study. It serves as a behavioral standard that is determined individually and with which the actual amount of ICT use is compared (Carver & Scheier, 1982, 1990). Alike the notion concerning the individual boundary preference, employees' perception of a high ICT use may be neutral or positive, if the actual ICT use is in line with their preference.

The third category refers to the individual perception of ICT use. In this regard, first studies in the context of email overload provide a promising approach that takes such individual viewpoints into account (Dabbish & Kraut, 2006; Mazmanian et al., 2013). Results suggests that the *interpretation of the email volume* contributes more to the explanation of email overload than the actual email volume itself (Dabbish & Kraut, 2006). Hence, by transferring these results on ICT use in general, to investigate the interpretation of ICT use could be an aforementioned condition that contribute to a better understanding of the double-edged effects of ICT use. Furthermore, as already discussed in the first category in this chapter regarding controlled motivation for ICT use, it seems crucial for buffering detrimental effects of ICT use that employees feel and have the *perception of controlling* ICT use according to their own discretion (Ohly & Latour, 2014; Schieman & Glavin, 2008; Schieman & Young, 2013).

Further examined moderating effects concern personality traits and individual time management strategies that represent the fourth category. The *big five personality traits* are already investigated in the context of technostress (Krishnan, 2017; Srivastava et al., 2015). The study results indicate a differentiation between individuals with certain personality traits. For instance, the relation between the technostress creators and job burnout is more positively related for individuals with high agreeableness and more negatively related for those with high extraversion. The results of Fenner and Renn (2010) and König, Kleinmann, and Höhmann (2013) provide support that certain *time management strategies*, for example setting goals and priorities or establishing a quite hour free of any ICT, buffer the detrimental effect of ICT use on WLC.

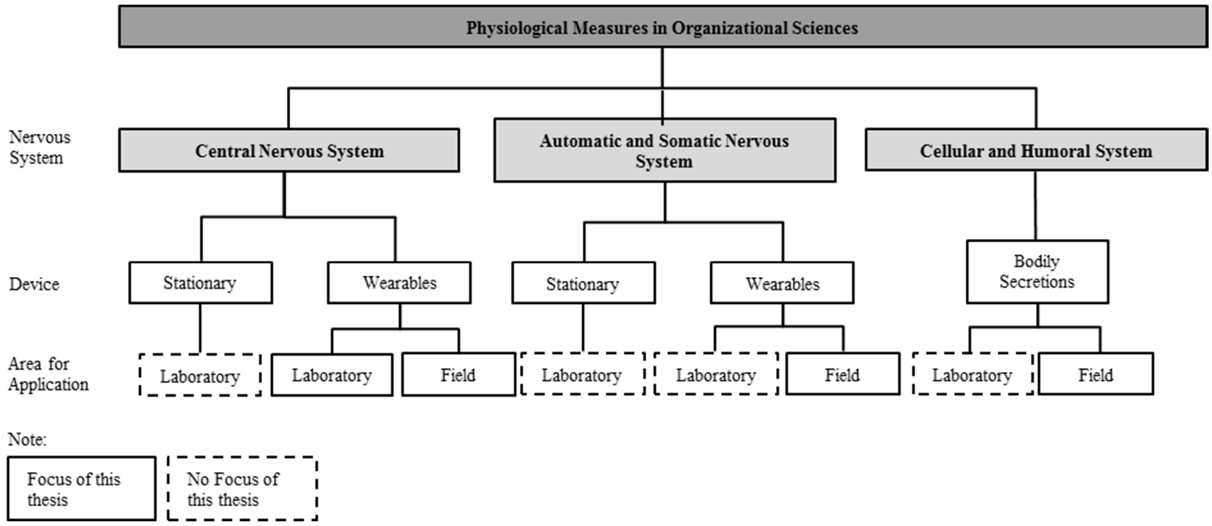
Taken together, the literature review shows that the majority of prior research on individual variables and person characteristics in the context of ICT use largely focuses on individuals' outcomes of the work-life interface and well-being. In particular, much recent research examined the detrimental outcomes of ICT use on individuals' work-life conflict and stress. Thereby, preceding studies find that, also dependent on individual antecedents, a higher amount of ICT use, predominantly EWA, reduces the time to recover and to meet the demands of the particular domain leading to work-life conflict, which, in turn, may have detrimental effects on their stress and work-life balance. However, this focus of preceding research largely disregards the conditions that could contribute to a comprehensive understanding of why and when employees find their ICT use improving or exacerbating and evaluate the same amount of ICT use differently within and between individuals. Although little research starts to investigate individual moderators that give hints for such conditions, previous research did not yet gain a comprehensive understanding of individuals' motives, preferences, and perceptions using ICTs and, in turn, the effects of ICT use that is aligned with such individual conditions. Implications for the overarching motivation for the ICT-based Availability Management Study derived from these key limitations of the research field on individual variables and person characteristics in the context of ICT use are further outlined in Chapter 3.4.

3.2 Findings of Previous Research to Physiology in Organizational Science

To apply physiological measures in studies investigating organizational research and theories is gaining a considerable attention. Therefore, the number of articles including physiological measures is fast grown in the past as already outlined in the empirical relevance section (see Chapter 1.1). A comprehensive literature research on physiology, its measurements, and application was conducted, with focusing on the application in organizational research, field studies, and wearable devices. Therefore, fundamental psychological and medical literature on physiology, official recommendations of the particular societies for physiological measures (e.g., Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), top-tier management, OB, and computer science journals, as well as top-tier methodological journals (e.g., Organizational Research Methods) were examined to identify the reviewed literature.

Figure 3-2 provides the structure and fields of the following literature review. First, in accordance with the particular nervous system the assigned physiological measures as well as stationary devices and wearables recent organizational research applies are discussed. As outlined in the conception section in Chapter 2.1.3, physiological measures can be broadly categorized by the human nervous systems, in particular (1) CNS, (2) ANS and somatic nervous system, also referred to as peripheral nervous system (PNS), and (3) cellular and humoral system. The CNS is composed of the nerves in the brain and the spinal cord and has both voluntary and involuntary parts that can or cannot be consciously influenced (Stern et al., 2001). The PNS regulates involuntary different bodily functions in the periphery with the sympathetic and parasympathetic activity, and the enteric nervous system (Stern et al., 2001). The cellular and humoral system is located in both the CNS and PNS and consists of specialized neurons and endocrine glands in the brain and periphery that release specific hormones (Schultheiss & Stanton, 2009). Second, with discussing recent studies from organizational science that applied physiological measures of the particular nervous system recorded with wearables in the field, if existing, different areas for application are provided. The dashed sections are out of the scope of the literature review, in particular experiments in the laboratory using stationary devices to record physiological measures or bodily secretions of the cellular and humoral system.

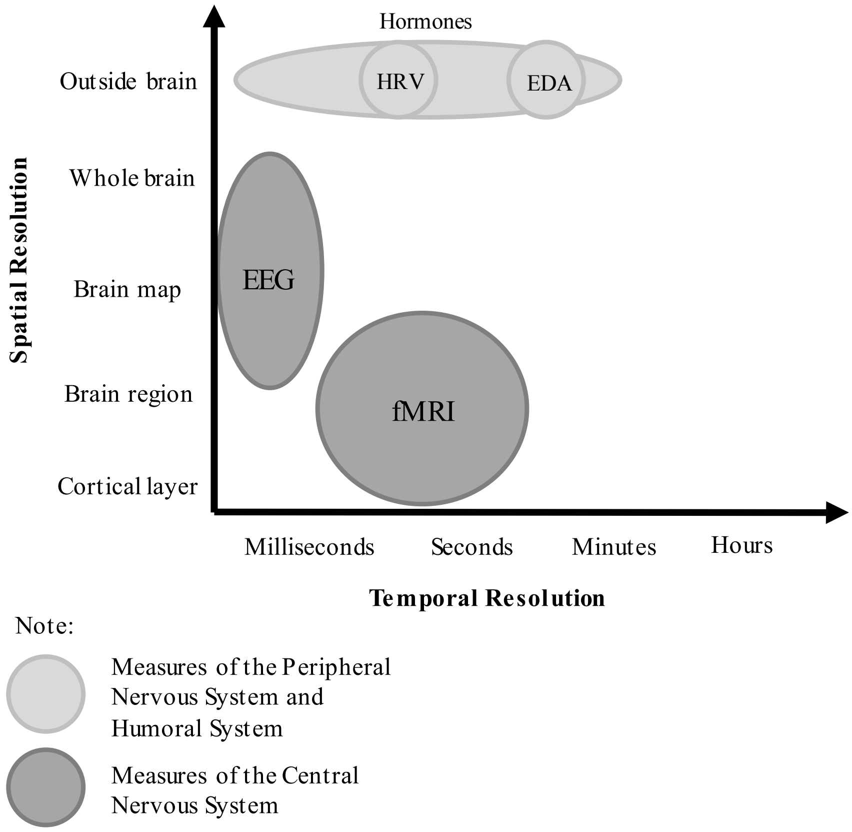
Figure 3-2: Structure and Fields of the Literature Review on Physiological Measures in Organizational Science



3.2.1 Overview of Physiological Measures, Stationary Devices, and Wearables

Associated and more detailed subcategories of the CNS, PNS, and cellular and humoral system distinguishing the human organ systems such as the brain, cardiovascular cycle and hormones (Cacioppo et al., 2007; Stern et al., 2001). Figure 3-3 provides an overview of the reviewed and commonly used physiological measures of the CNS, PNS, and humoral system, while the size of the sphere indicates the range of resolution along a given axis (Murray & Antonakis, 2019). Beside several other methodological properties of physiological measures outlined in Chapter 6.1, physiological measures are multidimensional constructs that differ in their temporal and spatial resolution (see also Chapter 2.1.3). The temporal resolution refers to the time, with which the particular physiological measure evolves ranging from milliseconds to hours (Gratton, 2007). In the aforementioned AL-model this temporal resolution is an important parameter that needs to be considered to examine physiological measures at the correct time they evolve (Ganster et al., 2018). The spatial resolution differentiates between physiological measures of the periphery such as HRV, EDA, and hormones, and measures of the CNS that directly represent the brain's functions (Murray & Antonakis, 2019). In particular, electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) are outlined in the following as the most commonly used measures of the CNS (Jack et al., 2019). For instance, EEG as an oval has a high temporal resolution with evolving within milliseconds and a variable spatial resolution depending on the examined and analyzed measures. In the following, physiological measures of each nervous system are outlined in this regard and stationary devices as well as wearables that record these measures are discussed.

Figure 3-3: Overview of the Main Reviewed Physiological Measures and their Temporal and Spatial Resolution (Own Figure based on Murray & Antonakis, 2019)



Note: EEG = Electroencephalography, EDA = Electrodermal activity, fMRI = functional magnetic resonance imaging, HRV = Heart rate variability.

Central Nervous System (CNS)

Presently, the focus of organizational scholars is on the emerging area of organizational neuroscience that investigates behavioral constructs with physiological measures representing the brain (for in-depth reviews see Becker, Cropanzano, & Sanfey, 2011; Jack et al., 2019; Senior, Lee, & Butler, 2011; Waldman et al., 2019; Waldman, Ward, & Becker, 2017). Jack et al. (2019) differentiate between observational neuroscience methods and methods that intervene on neural functions, as the latter determines the brain and neural functions as the independent, and the former as the dependent variable. Methods of the first category that refers to methods observing the neural structure and function optically with neuroimaging or neurosensing with electrodes are fMRI, positron emission tomography (PET), EEG, MEG, fNIRS, and anatomical imaging. Lesion studies, transcranial magnetic stimulation (TMS), and transcranial direct current stimulation (tDCS) are assigned to the second category that reflects methods directly manipulate neural functions. Methods of the first category are more common, with fMRI and EEG as the most commonly used methods in organizational neuroscience in recent research (Jack et al., 2019; Waldman et al., 2019). fNIRS is also discussed as a promising wearable method to assess social interactions in real life settings (Quaresima & Ferrari, 2019; Scholkmann et al., 2014). As fMRI is traditionally stationary and restricted to the scanner, EEG is a promising technique. EEG provides a more precise temporal resolution assessing the neural activity immediately compared to fMRI that measures changes in blood oxygenation as a relatively slow measure (Jack et al., 2019; Waldman et al., 2017). First wearables were developed (Jack et al., 2019; Waldman et al., 2019), for example cEEGrids (TMSi, Oldenzaal, Netherlands) or muse (InteraXon, Toronto, Canada). The cEEGrids uses sensor arrays placed around the ear as an EEG and provides recording additional physiological measures such as eye movements and cardiac electrical activity. The physiological measures of an EEG and fMRI are briefly described in the following.

Placing electrodes with a specific derivation technique on the scalp can be used to record brain activity with an EEG (Jack et al., 2019; Pizzagalli, 2007). The EEG makes use of the typical state of an activated neuron in the CNS as the summation of the excitatory and inhibitory potentials generates the EEG (Stern et al., 2001). EEG provides different physiological measures. First, the EEG signal can be differentiated in five frequency bands with Fourier and/or wavelet analysis methods also referred to as quantitative EEG (qEEG; Jack et al., 2019; Pizzagalli, 2007; Waldman et al., 2017; Waldman et al., 2019). The frequency bands (alpha to delta and theta band) represent different functional roles. For instance, the alpha band (8-12 Hz) represents relaxing and resting, particularly with closed eyes, while arousal, attention, sensory and mental processes are associated with the gamma band (30-44 Hz) (Pizzagalli, 2007; Waldman et al., 2019). Second, ERPs can be recorded with an EEG that represent the brain activity during the presentation and reaction on a specific external stimulus or internal mental event (Fabiani, Gratton, & Federmeier, 2007). The peaks of the ERP are named after their polarity and latency according to their ordinal number or in milliseconds, with which they are occurring (e.g., P300 as a positive peak with a latency of 300 ms). Beside qEEG and ERP, organizational scholars can use EEG to investigate whether a cognitive process is automatic or controlled and EEG hyperscanning referred to as examining relationships of signals recorded from two individuals in a social interaction (Jack et al., 2019).

The fMRI provides images of the whole brain and deep subcortical structures using the Blood Oxygen Level Dependent (BOLD) method (Wager, Hernandez, Jonides, & Lindquist, 2007).

This method is based on a signal (T_2^* signal) that depends on the oxygenation of hemoglobin and its changing concentration in the blood during the activation of a neuron. Thereby, the concentration of oxygenated hemoglobin firstly decreases but again increases because of an over-compensation in blood flow. Taken together, organizational neuroscience and its physiological measures provide a comprehensive understanding of underlying brain processes examining organizational behavior and attitudes and are, thus, an important part for organizational research. However, the application of these physiological measures requires experience and in-depth knowledge of the underlying neuronal processes, the use of the devices, and the complex data analyses (Ganster et al., 2018).

Table 3-4 provides an overview of the reviewed devices that are commonly used and their assigned physiological measures of the CNS.

Table 3-4: Overview of the Reviewed Devices and Physiological Measures of the CNS

Device	**Description [Wearable-capable]**	**Physiological Measure**
Functional Magnetic Resonance Imaging (fMRI)	Measures neural activity with changes in oxygenation level in blood that depends on the activation of a neuron [only stationary].	Functional imaging
Positron Emission Tomography (PET)	Measures neural activity (blood flow, glucose consumption, neurotransmitter receptor binding) with a radioactive tracer that is inserted into the bloodstream [only stationary].	Functional imaging Receptor binding and neurochemistry
Electroencephalography (EEG)	Measures neural activity with electrical changes recorded with electrodes placed on scalp [wearable-capable, wearables available].	qEEG: Delta, theta, alpha, beta, gamma band Event-related brain potential (ERP)
Magnetoencephalography (MEG)	Measures neural activity with magnetic fields recorded with magnetometers near scalp [wearable-capable, wearables available].	Magnetic waveforms Event-related brain potential (ERP) and fields (ERF)
Functional near-infrared spectroscopy (fNIRS)	Measures neural activity with detecting changes in near-infrared light that, in turn, reflects changes in oxygenation level in blood [wearable-capable, wearables available].	Functional imaging
Anatomical imaging	Measures static differences in brain anatomy with MRI [only stationary].	Functional imaging

Peripheral Nervous System (PNS)

The PNS is composed of the sympathetic and parasympathetic activity, and the enteric nervous system (Stern et al., 2001). While the sympathetic activity results in an improved performance of the bodily functions preparing the "fight or flight" reaction, the parasympathetic activity is its antagonist that regulates the functions to recover (see also Figure 2-2 in Chapter 2.1.3). Either one of the activities or both control each organ system of the PNS. For instance, while the cardiovascular system represents both activities, the electrodermal system is only controlled by the sympathetic activity. The enteric nervous system regulates only the gastrointestinal system. The somatic nervous system allows a voluntary control of bodily functions and parts (e.g., skeletal muscles) (Stern et al., 2001). Physiological measures of the PNS are assigned to the related organ system and, therefore, categorized into the cardiovascular system, respiratory system, electrodermal system, skeletomoter system, eyes, and gastrointestinal system. The availability of wearables that record physiological measures of the PNS is rapidly increasing (Eatough et al., 2016; Laborde, Mosley, & Thayer, 2017; Tamura et al., 2014). Particularly, the peripheral physiological measures of the PNS benefit probably the most from these advances by providing relatively cheap and easier to use wearables (Ganster et al., 2018). Examples are LifeShirt (VivoMetrics Inc., Ventura, USA) for recording physiological measures of the cardiovascular and respiratory system developed as a shirt, Empatica E4 (Empatica Inc., Boston, USA) for measures of the cardiovascular and electrodermal system as a wristband, and SMI eye-tracking glasses (SMI, Teltow, Germany) for measures of the eyes. However, while being well established in other disciplines such as social neuroscience or clinical psychology, the application of physiological measures of the PNS beside assessing stress and well-being processes is just increasing in the organizational literature (Christopoulos et al., 2019; Massaro & Pecchia, 2019; Murray & Antonakis, 2019). Each related organ system is briefly described in the following.

Cardiovascular system. As shortly outlined in Chapter 2.1.3, the main assignment of the cardiovascular system is to transport oxygenated blood from the lungs to the rest of the body and deoxygenated blood vice versa (Berntson et al., 1997; Berntson et al., 2007). Thereby, the heart pumps blood into the lungs in a specific cardiac cycle, which has two phases: diastole and systole. While in the diastole phase the heart is filled with blood, it pumps during the systole phase. During the whole cycle, the heart undergoes an electrical process reflecting its activation with a specific sequence that is depicted in Figure 2-3 (Berntson et al., 2007). The R-R intervals or IBI represent also the inverse of the instantaneous HR (iHR):

$$RR_n = \frac{1}{iHR_n} \quad (1),$$

with iHR is based on a single R-R interval (Massaro & Pecchia, 2019). By accumulating this iHR to beats per minute (bpm), HR is calculated. HRV as the variation between heart beats reflects both the sympathetic and parasympathetic activity (Berntson et al., 1997; Ganster et al., 2018). HRV is analyzed with two main methods: time domain and frequency domain analysis, though other methods are also used, in particular non-linear methods (Berntson et al., 2007; Massaro & Pecchia, 2019; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). In Chapter 6.4.3 the outlined analysis methods are exemplified with real data of the experimental comparison study. According to the time domain analysis, HRV data is analyzed with simple descriptive statistical procedures. For instance, the mean value of all recorded R-R intervals, also referred to as normal beat to normal beat intervals (NN intervals) (i.e., AVNN, in ms) or standard deviation (i.e., SDNN, in ms) can be calculated with

$$AVNN = \frac{1}{N} \sum_{j=1}^{N} RR_j \quad (2),$$

and

$$SDNN = \sqrt{\frac{1}{N-1} \sum_{j=1}^{N} (RR_j - AVNN)^2} \quad (3).$$

With using the frequency domain analysis, HRV is composed into different frequency bands mostly using a spectral analysis with a standard Fast Fourier Transform (FFT) algorithm. For the non-linear method, a Poincaré Plot is computed composing of SD_1 and SD_2 as its parameters, with

$$SD_1 = \frac{SDSD}{\sqrt{2}} \quad (4),$$

and

$$SD_2 = \sqrt{2SDNN^2 - \frac{1}{2} SDSD^2} \quad (5),$$

where SDSD is referred to the standard deviation of the difference of RR interval time series (Massaro & Pecchia, 2019).

Using a PPG sensor the blood volume pulse as the physiological measure is relevant (Tamura et al., 2014). The blood volume pulse represents the changes in the volume of blood in vessels with each heartbeat. Thus, HR and HRV can be analyzed with the blood volume pulse according to the procedures outlined in the previous ECG section. Another physiological measure is blood pressure that represents the systolic and diastolic phase of the heart. Mostly a cuff is used to measure blood pressure non-invasively (Berntson et al., 2007).

Proceeding from traditionally stationary ECG devices such as Biopac MP 36 or 150 (Biopac Systems Inc., Goleta, USA), this category may benefit from the recent advances of mobile computing and wearables probably the most (Eatough et al., 2016; Ganster et al., 2018). With an increasing development of wearables for both a commercial use and research, most wearables are wristbands using a PPG sensor measuring blood volume pulse. Additionally, breast straps can be used as an ECG-based wearable. Taken together, due to the representation of both the sympathetic and parasympathetic activity of the ANS and the presence of non-intrusive and cheap wearables, the cardiovascular system is a very promising category for organizational science. Because Biopac MP 36 as the common used stationary ECG device and two innovative wearables – an ECG-based breast strap movisens EcgMove 3 and a PPG-based wristband Empatica E4 – are essential parts of the ICT-based Physiological Measurements study (Chapter 6), they properties will be further outlined in the following.

The *Biopac MP 36* is a multifunctional device that provides up to four channels for recording a variety of physiological measures (Biopac Systems, 2019). The sample rate of Biopac MP 36 for all recorded measures is 1000 Hz. The hardware has to be connected to a PC, because the Biopac MP 36 has no data storage. The recording can be started and stopped with the Software BSL Pro. For recording cardiovascular measures with ECG, two channels are used with the SS2LB cable assembly with pinch connectors for the Ag-AgCl snap electrodes with solid gel coating. The solutions from Biopac Systems, Inc. has become the gold standard device for life science research, since it is frequently used with over 8,000 published articles only for ECG (search engine: google scholar).

The *movisens EcgMove 3* is developed by German scholars from the Karlsruhe Institute of Technology (movisens, 2018). It consists of an ECG sensor and two additional sensors (3D acceleration and pressure sensor). The movisens with its 26g and dimensions of 62x33x12 mm is placed around the chest with a belt. The sample rate of the ECG sensor is 256 to 1024 Hz. A major advantage of movisens is the battery life of the sensor with about three days while recording. The movisens' own software is used to start the sensor either immediately or at a specified time. The recorded data is stored on the movisens until it is connected to a PC, where the sensor is stopped and the data is saved. With over 100 publications in diverse research areas, such as OB (e.g., Riedl & Thomas, 2019), engineering (e.g., März & Handmann, 2018), and psychology (e.g., Kramer, Neubauer, Stoffel, Voss, & Ditzen, 2019), the application of movisens' solutions, and particularly the ECG chest belt, is getting increasing attention.

The *Empatica E4* is a MIT development by Rosalind Picard as a leading engineering scholar for affective computing with over 300 authored and co-authored scientific articles (MIT, 2019). Although only a wristband, it is equipped with several sensors as a major advantage of this device (Empatica, 2019). The Empatica E4 weighs 25g and the dimensions are 44x40x16 mm. The wristband has a 3-axis accelerometer, an infrared thermopile, a PPG and an EDA sensor. The sample rate of the PPG is 64 Hz. The PPG sensor consists of four LED lights, two green and two red LEDs. The combination of these LEDs allows a motion artefact removal algorithm. The Empatica E4 has a battery life of 20 hours in the streaming mode. To start the Empatica E4 only one button has to be pressed. The recorded data is stored on the wristband until the wristband is connected to a PC, where the data is saved. Furthermore, the Empatica E4 provides an application for the smartphone or tablet to stream real-time data. To date, over 600 publications (search engine: google scholar) refer to the Empatica E4 indicating the outstanding role this wristband plays for recent and future research applying physiological measures in the field.

All applied devices have in common that they provide raw recorded physiological data, which is not already processed and analyzed. This allows to processing and analyzing the data according to standard and replicable procedures that, in turn, are crucial to provide a rigorous data basis. As this is not ensured for every type of wearable, it is major benefit of the applied innovative wearables. Further possible issues about the applications of wearables are discussed in Chapter 6.1.2. Figure 3-4 depicts all three applied devices.

Figure 3-4: Applied Devices in the ICT-based Physiological Measurements Study Measuring Physiological Stress

a)

b)

c)

Note: a) = Biopac MP 36, b) = movisens EcgMove 3, c) = Empatica E4.

Respiratory system. The respiratory system and its measures are strongly related to the cardiac cycle by changing the heart period caused by the breath, which is called respiratory sinus arrhythmia (Lorig, 2007). Thus, the physiological measures often serve as control variables for other physiological measures such as HR or HRV. However, the respiratory system as a selective indicator for the parasympathetic activity and the voluntary regulation of breath could be of interest for organizational scholars. Two important parameters determine the respiratory system, that are, inspiration and exhalation.

Using a respiratory belt transducer, inspiration and exhalation are outputted in a waveform defining two points for a respiration cycle, the minimum peak between two cycles indicates the peak exhalation, the maximum peak the peak inspiration (Lorig, 2007). By counting the peaks per minute the frequency, also referred to as rate, is calculated. Further, inspiratory and expiratory duration or time can be measured. New wearables use inductive plethysmography and facilitate the recording of other physiological measures of the respiratory system such as the tidal volume. Based on this raw respiratory data the respiratory variability can be calculated according to a linear nonrandom or random approach, which uses either an autocorrelation coefficient or a logarithmic probability for calculating the variability (Lorig, 2007). The wearables used for the respiratory physiological measures are mostly associated with an ECG based wearable. For example, LifeShirt (VivoMetrics Inc., Ventura, USA) is a shirt that uses two additional and sewn-in belts for the inductive plethysmography and an ECG for measuring cardiovascular physiological measures. Taken together, while respiratory physiological measures are probably underestimated in research, they offer interesting insights into the parasympathetic activity that is relevant for relaxing and recovery and, thus, for evaluating interventions that probably evokes this activity (e.g., after mindfulness based trainings, Vlemincx, Vigo, Vansteenwegen, van den Bergh, & van Diest, 2013).

Electrodermal system (skin). The electrodermal system and its physiological measures are based on the organ system skin, particularly its sweat glands and their bodily function of sweating (Boucsein, 2012; Boucsein et al., 2012; Dawson, Schell, & Filion, 2007). As a response to a stimulus, the skin resistance decreases, which leads to the fact that the skin is a better conductor of electricity. Contrary to the cardiovascular and respiratory system, the electrodermal system represents only sympathetic activity. According to the degree of the sympathetic activity, the number of sweat glands producing sweat is varying. The most sweat glands are on the palm of the hands, fingers and feet. Thus, measuring EDA with two electrodes placed on the surface of the skin of these body parts is commonly used. By holding the voltage between the two electrodes constant, the skin conductance is measured in units of microSiemens (μS) (Boucsein, 2012).

Basically two types of physiological measures of the electrodermal system can be distinguished that are tonic and phasic measures (Boucsein, 2012; Dawson et al., 2007). While tonic measures indicate a basic level analyzed during the completely recording time, phasic measures as a part of the tonic level are related to spontaneous fluctuations caused by a stimulus. In addition, nonspecific phasic fluctuations can occur. Specific tonic measures are the skin conductance level (SCL) and its changes mostly ranging inter- and intra-individually from 2μS to 20μS with changes from 1μS to 3μS (Dawson et al., 2007). Typically, the SCL decreases at rest, increases during a stimulus presentation, and, in turn, decreases after the presentation. The skin conductance response (SCR) is the basic phasic measure building on other measures according to the typical sequence of SCR, which comprises latency, rise time, amplitude, and half recovery time. For example, SCR amplitude quantifies the increase of SCR following a stimulus mostly ranging from 0.1µS to 1µS averaging all trials, on which a response (> 0µS) occurs. SCR is a relatively slow measure leading to a low temporal resolution with a latency (Boucsein, 2012). Regarding the response of participants, there are intra- and inter-individual differences by also taking account those, who show no SCR response (i.e., nonresponders).

The devices for the electrodermal system mostly based on stationary devices, such as Biopac MP 36 or 150 (Biopac Systems Inc., Goleta, USA). With first wearables being developed (e.g., Shimmer3 GSR (Shimmer, Dublin, Ireland) or BIONOMADIX (Biopac Systems Inc., Goleta, USA)), the devices are flexible just to a limited extent depending on the two electrodes on the palm of the hand, fingers, or foot for recording. Accordingly, these wearables are experienced as intrusive by participants and limitedly usable for research settings that requires hand movements such as writing. The prior described Empatica E4 (Empatica Inc., Boston, USA, see also Figure 3-4) uses two electrodes, which are tightened on the wristband. Taken together, EDA is a promising physiological measure for organizational research by being a selective indicator for sympathetic activity.

Skeletomotor system (muscles), eyes, and the gastrointestinal system. The three following categories, skeletomotor system, eyes, and the gastrointestinal modality, are described shorter in the following because they are probably not of the main interest for organizational scholars. The main organ system of the skeletomotor system are muscles, which can be innervated either involuntary or voluntary (Tassinary, Cacioppo, & Vanman, 2007). Innervated muscles in the face indicating affects and emotions are profoundly investigated. Therefore, a surface electromyography (EMG) by placing electrodes on the facial muscles is commonly used in recent research (Tassinary et al., 2007). Physiological measures of the eyes such as pupil diameter or different eye movements using pupillometry could indicate parasympathetic activity (Stern et al., 2001). With new advances in wearables, the use of an eye tracker as glasses and, thus, of physiological measures in this category is getting an increasing attention in organizational research (e.g., eye tracking glasses from SMI, Teltow, Germany) (Meißner & Oll, 2017). A probably exceptional category is the gastrointestinal system, with the stomach being the organ system of interest (Stern, Koch, Levine, & Muth, 2007). The enteric nervous system of the PNS controls the muscles of the stomach that are aimed to receive and chop food preparing its transport to the intestine. Using an Electrogastrogram (EGG), this functionality can be investigated (Stern et al., 2007). Table 3-5 provides an overview of the reviewed devices and physiological measures of each organ system of the PNS.

Table 3-5: Overview of the Reviewed Devices and Physiological Measures of the PNS

Category	**Device**	**Description [Wearable-capable]**	**Physiological Measure**
Cardiovascular system	Electrocardiography (ECG)	Measures the activation of the heart cycle [Wearable-capable, wearables available].	Heart period/heart rate (HR) Heart rate variability (HRV)
	Photoplethysmography sensor (PPG)	Measures the elasticity of the arteries with the absorption of infrared light [Wearable-capable, wearables available].	Blood volume pulse Heart period/heart rate (HR) Heart rate variability (HRV)
	Cuff	Measures the systolic and diastolic phase of the cardiac cycle [Wearable-capable, wearables available].	Blood pressure
Respiratory system	Respiratory belt Respiratory inductive plethysmography	Measures the volume of the upper thorax with sensors responsive to stretch [Wearable-capable].	Frequency/rate of breathing Inspiratory/expiratory volume Inspiratory/expiratory duration/time Tidal volume Respiratory variability Random breathing variability
Electrodermal system/Skin	EDA recording system	Measures the skin conductance with two electrodes holding the voltage between them constant [Wearable-capable, wearables available].	EDA/Skin conductance Tonic: Skin conductance level (SCL) Change in SCL Phasic: Skin conductance response (SCR) Different forms of SCR, e.g., SCR amplitude

Category	Device	Description [Wearable-capable]	Physiological Measure
Skeletomotor system (Muscles)	Electromyography (EMG)	Measures muscular activity with electrodes recording voltage fluctuations that are caused by muscular tension, contraction, and movement [Wearable-capable, wearables available].	Integrated EMG: Arithmetic average of the smoothed EMG signal Root-mean-square of the raw EMG-signal
Eyes	Pupillometry	Measures the pupil size and re-activity [Wearable-capable, wearables available].	Pupil size/diameter Gaze position Eye movements Exit time of the region of interest Eye blinks
Gastrointestinal system	Electrogastrogram (EGG)	Measures gastric contractions with electrodes that record gastric slow waves and spike potentials as myoelectric components of gastric contractions [only stationary].	Gastric activity Percentage distribution of electrogastrographic power Dominant frequency and (in)stability of the dominant frequency Percentage of time with the dominant frequency

Cellular and humoral system

The cellular and humoral system is located in both the CNS and PNS and consists of specialized neurons and endocrine glands in the brain and periphery (Schultheiss & Stanton, 2009). The involved neurons and endocrine glands release specific hormones that are "messenger molecules […] that carry a signal at the speed of blood to other parts of the body" (Schultheiss & Stanton, 2009, p. 17). The different hormones are directly related to human behavior, and the evoked behavior has, in turn, an effect on the hormone level. As outlined in Chapter 2.1.3 and with regard to the AL-model (see Chapter 2.2.3), the HPA and SAM axes with their released hormones are of particular interest for previous research (Ganster et al., 2018). Beside cortisol, other hormones can also be applied. For instance, immunoglobulin A (IgA) indicates a first immune reaction caused by for example a stress reaction or the peptide hormone oxytocin effects social interactions and the relationship between a mother and her child among others (Schultheiss & Stanton, 2009). Hormones are strongly influenced by the chronobiological cycle that leads to circadian fluctuations (Schultheiss & Stanton, 2009). For instance, cortisol is higher in the morning than in the afternoon. With utilizing this fluctuation, the cortisol awakening response (CAR) representing cortisol pattern across the first hour after waking gets increasing attention in research as an indicator for chronic psychological strain (O'Connor et al., 2009). Furthermore, the menstrual cycle of female participants influence their hormone levels (Schultheiss & Stanton, 2009).

The devices recording the hormones refer to the particular bodily secretions, into which the hormones have been released, mostly blood, saliva, and urine (Eatough et al., 2016; Schultheiss & Stanton, 2009). Because participants experience saliva sampling as less intrusive than blood samples with a phlebotomist, saliva sampling has become the method of choice in this category (Schultheiss & Stanton, 2009). With oxytocin only being measured with blood samples, cortisol is beneficial, because it is released into different compartments at the same level. Thus, saliva sampling can be used to measure cortisol and IgA, for instance. Thereby, the passive drool method is commonly used, where the participant drools saliva through a straw into a vial or chews cotton swabs for a particular length of time (Eatough et al., 2016). Then, the saliva samples have to be immediately stored into a freezer. In field studies, a participant-managed system is applied, where participants sample on their own and return the samples to the researcher. As the compliance of participants is crucial for such as system, recent advances facilitate the application of digital caps that allow to record the time the cap is opened and closed and send this information to the researcher (e.g., MEMS SmartCap, Aardex Group, Belgium) (Broderick, Arnold, Kudielka, & Kirschbaum, 2004; Eatough et al., 2016). Taken together, while hormones offer interesting areas for application in organizational research, their use requires a high controlled, well-conceived study design.

3.2.2 Findings of Previous Research to Wearable-measured Physiological Measures in Organizational Science and Areas for Application

While the previous chapter indicates the opportunities of physiological measures of each nervous system for organizational research, first pioneering studies are now outlined that already applied wearable-measured physiological data for their research in the field, if existing. Thereby, the bandwidth of areas for application for organizational science is revealed.

Pioneering articles in the field of organizational neuroscience already discuss the broad range of areas for application of the CNS in detail (e.g., Becker et al., 2011; Becker & Cropanzano, 2010; Jack et al., 2019; Waldman et al., 2019). Exemplary areas for application are discussed here by reference to an exemplary study that already applied wearable-measured physiological data of the CNS in the laboratory as so far no field study exists to one’s knowledge. Waldman, Wang, Stikic, Berka, and Korszen (2015) investigated engagement neurologically with a wearable qEEG device (Advanced Brain Monitoring, Inc.) in teams solving a case problem. Additionally, the authors assessed emergent leadership as a survey measure. Their research goal was to understand the effect of leader communication on team engagement. The findings of the study provide fundamental support for the added value measuring fluid variables such as engagement physiologically and, thus, continually during the course of the problem-solving task. Furthermore, as the participants assessed the applied wearable qEEG device as non-intrusive, the findings give support for the benefits of wearables as aforementioned discussed.

Exemplary areas for application for the PNS are discussed here by reference to exemplary studies that already applied wearable-measured physiological data of the cardiovascular cycle. Vahle-Hinz, Bamberg, Dettmers, Friedrich, and Keller (2014) and Ilies, Dimotakis, and Watson (2010) applied physiological measures of the cardiovascular system, in particular HR, HRV, and blood pressure, in field studies using wearable devices (e.g., Actiheart monitor, Cambridge Neurotechnology, Cambrige, U.K.). Both studies applied the recorded physiological measures as dependent variables. The former study examined the relationship between work stress and nocturnal HRV, the latter study the relationship between positive and negative affect and HR, and negative affect and blood pressure. While the findings of the study from Ilies, Dimotakis, and Watson (2010) provide support for their hypotheses, the findings from Vahle-Hinz et al. (2014), however, were rather inconclusive, by finding no support for any hypotheses regarding nocturnal HRV. These examples reveal both the opportunities and pitfalls of wearable-measured physiological data of the PNS and provide an appropriate dealing with contradictory findings. Further discussions of areas for application of PNS measures provide Christopoulos et al. (2019) for the electrodermal system, Massaro and Pecchia (2019) for the cardiovascular system, and Akinola (2010), Ganster et al. (2018), and Heaphy and Dutton (2008) for a broader overview.

The exemplary field study from Schlotz, Hellhammer, Schulz, and Stone (2004) reveals an area for application by measuring the saliva cortisol level on weekdays compared with weekend days of 219 participants. The aim of this study was to investigate the effect of chronic work overload and worrying on work-related stress. Thereby, the participants took daily four saliva samples immediately after their awakening and 30 to 60 minutes later on six consecutive days to examine participants' CAR. The findings provide support for their hypotheses, as there was a weekend-weekday difference in CAR. Furthermore, the CAR of participants reporting higher chronic work overload and worrying more strongly increased compared to participants with lower chronic work overload and worrying.

Taken together, the literature review shows the bandwidth physiological measures of the particular nervous systems are able to provide for organizational research. Examining the brain and the sympathetic and parasympathetic activity enables organizational scholars to extend organizational theories to valuable insights that go beyond the conscious awareness of participants. Recent advances in wearables and sensors considerably facilitate the application of these physiological measures, as for each nervous system wearable devices are available using them for research purposes. The focus of much recent organizational literature was to provide an overview of the functional purposes and area for application of physiological measures. Furthermore, some pioneering studies already applied wearable-measured physiological data in field studies, predominantly with measures of the PNS examining well-being. However, this focus of preceding research largely disregards the methodological properties of physiological measures that are need to be considered in order to provide rigorous studies that apply wearable-measured physiological data. Although official recommendations exist, they did not account for recent advances in wearables, as they were composed in the last decades. Considering methodological next to functional properties could contribute to a more comprehensive understanding of how physiological measures can be effectively applied in studies and, thereby, to overcome the hurdle of unfamiliarity that organizational scholars may have. On this basis, studies could satisfy the call to apply physiological measures to a broad range of organizational research. Implications for the overarching motivation for the ICT-based Physiological Measurements Study derived from these key limitations of the research fields on physiological measures in organizational science and the assessment of well-being outcomes are further outlined Chapter 3.4.

3.3 Findings of Previous Research to the Momentary Assessment of Individual Well-being Outcomes

The examined ICT-based solutions in this thesis provide implications for future EMA research. To get familiar with recent literature on EMA, a comprehensive literature research was conducted on previous and recent research that examines the momentary assessment of individual well-being outcomes (see Table 3-6). Therefore, top-tier OB and IS journals and conference proceedings as well as recent literature reviews (e.g., Ilies et al., 2016) were used. The focus of this literature research was on EMA field studies in the context of work already using ICT-based solutions, in particular either (1) smartphone-based self-reports, (2) a combination of physiological measures and smartphone-based self-reports, or (3) a combination of physiological measures, smartphone-based self-reports, and sensor data. EMA studies that assess other outcomes (e.g., urban noise, Kanjo, 2010), are applied for medical purposes, such as health-monitoring research (e.g., congestive heart failure, Kumpusch et al., 2010), and examine measures via online or pen-and-paper surveys are excluded from the literature research and review.

As previously discussed, electronic assessment devices, in particular smartphones and wearables, considerably facilitate the application of EMA (Beal & Weiss, 2003; Ilies et al., 2016).

Thus, the number of research making use of such devices is fast grown in the past years. Thereby, smartphones take a dual role in recent research by serving as an assessment device, with which participants can easily fill out surveys or be reminded to fill out, and providing own, EMA relevant data sources with their equipped sensors (Eatough et al., 2016; Ilies et al., 2016; Miller, 2012).

The first category refers to EMA studies that applied smartphone-based self-reports examining a broad range of constructs and measures. For instance, as one of the first, Song, Foo, and Uy (2008) let the participants (i.e., dual-earner couples) fill out the surveys about their momentary mood several times per day with their smartphones. With providing a large sample size of over 5,000 people from 83 countries, the study from Killingsworth and Gilbert (2010) about momentary happiness and mind-wandering reveals the potential, smartphone-based self-reports could provide for research. In general, EMA studies with self-report data may differ in their sampling schedules (Eatough et al., 2016; Ilies et al., 2016). In particular, event-contingent, signal-contingent, and interval-contingent sampling is distinguished. While the event-contingent sampling is referred to specific events (e.g., stressful situations at work), the signal-contingent sampling is used to examine a typical day by fulfilling the survey randomly within a day. To investigate specific daily periods (e.g., beginning and end of a work day), the interval-contingent sampling is used (Ilies et al., 2016). The reviewed studies differ also in their used sampling schedules. For example, Baethge and Rigotti (2013) used a signal-contingent sampling with four daily surveys, Sonnentag and Binnewies (2013) an interval-contingent sampling with three surveys daily (i.e., beginning and end of the work day, before sleeping).

The studies of the second category applied a combination of smartphone-based self-reports and physiological measures, mostly from the cardiovascular and humoral system, for their EMA research. In particular, studies examined HR, HRV, and blood pressure in the context of stress and negative affect (e.g., Ilies, Dimotakis, & Watson, 2010; Vahle-Hinz et al., 2014), work-family conflict (Shockley & Allen, 2013), and work environments such as high workloads (Ilies, Dimotakis, & Pater, 2010) and positive work events (Bono, Glomb, Shen, Kim, & Koch, 2013). Two reviewed studies investigated positive and negative affect (Jacobs et al., 2007) and chronic work overload and worrying (Schlotz et al., 2004) on salivary cortisol. In general, all EMA studies examined the additional physiological measures as the dependent variable.

In addition to studies of the second category examining self-report and physiological measures, the third category refers to research that also used data from smartphone sensors. In particular, the acceleration sensors, microphone sensor, and calendar events were measured to investigate momentary stress (Adams et al., 2014; Kocielnik, Sidorova, Maggi, Ouwerkerk, & Westerink, 2013) and mood (Zenonos et al., 2016). All three studies were done by computer scientist that developed their own software for a smartphone-based stress and mood measurement.

Table 3-6: Overview of the Literature regarding Ecological Momentary Assessment of Individual Well-being Outcomes

Category	Author (Year)	Examined Constructs	Examined Measures
EMA studies examining smartphone-based self-reports	Song et al. (2008)	Momentary mood, spillover effects among dual-earner couples	Momentary positive and negative mood, family and work orientations, time gap for surveys between spouses for crossover effects
	Killingsworth and Gilbert (2010)	Happiness, mind-wandering, developing an application	Momentary happiness, activity, mind-wandering
	Sonnentag and Binnewies (2013)	Spillover effects of positive and negative affect from work to home, psychological detachment	Positive and negative affect, psychological detachment, sleep quality
	Baethge and Rigotti (2013)	Workflow interruptions, perceived performance	Workflow interruptions, satisfaction with performance, forgetting of intentions, irritation, mental demands, time pressure
EMA studies examining a combination of physiological measures and smartphone-based self-reports	Ilies, Dimotakis, and Watson (2010)	Stress indicators, mood	*Self-report:* Negative affect *Physiological:* HR, blood pressure
	Ilies, Dimotakis, & Pater, 2010	High workloads, well-being, distress	*Self-report:* Affective distress, workload *Physiological:* Blood pressure
	Bono et al. (2013)	Positive work events, positive reflection, stress, well-being outcomes	*Self-report:* Perceived stress, physical symptoms *Physiological:* Blood pressure
	Igic, Ryser, and Elfering (2013)	Physical well-being, posture during work (sitting vs. standing)	*Self-report:* Daily job control, time pressure, social stressors, biomechanical work strain *Physiological:* Physical activities, body height, spinal shrinkage

Category	Author (Year)	Examined Constructs	Examined Measures
EMA studies examining a combination of physiological measures and smartphone-based self-reports	Shockley and Allen (2013)	Work-family conflict, well-being outcomes	*Self-report:* Work-family conflict, family-work conflict, family-supportive supervision, work-supportive family *Physiological:* HR, blood pressure
	Daly, Delaney, Doran, Harmon, and MacLachlan (2010)	Negative affect, cardio-vascular well-being out-comes	*Self-report:* Negative affect, social interactions, activity patterns *Physiological:* HR
	Jacobs et al. (2007)	Negative emotions, stress	*Self-report:* Negative and positive affect, daily stressors, current mood *Physiological:* Salivary cortisol
	Schlotz et al. (2004)	Work overload, worry-ing, well-being out-comes	*Self-report:* Perceived chronic work overload, chronic worrying *Physiological:* Salivary cortisol (CAR)
	Vahle-Hinz et al. (2014)	Work stress, rumina-tion, sleep, cardiovascu-lar well-being outcomes	*Self-report:* Work stress, work-related rumination, restful sleep *Physiological:* HR, HRV
EMA studies examining a combination of physiological measures, smartphone-based self-reports, and sensor data	Adams et al. (2014)	Stress, stress recogni-tion	*Self-report:* Momentary stress *Physiological:* EDA *Other smartphone sensors:* Voice from microphone data
	Zenonos et al. (2016)	Mood at work	*Self-report:* Momentary mood *Physiological:* HR, HRV, skin temperature *Other smartphone sensors:* accel-eration, bespoke sensor data
	Kocielnik et al. (2013)	Stress at work, stress recognition	*Self-report:* Emotional arousal *Physiological:* EDA, skin tempera-ture *Other smartphone sensors:* accel-eration, calendar events

Taken together, the literature review shows that EMA research starts to momentarily assess well-being measures and outcomes using electronic assessment devices. In particular, smartphones and wearables are applied to assess either self-report or a combination of self-report and physiological data. Some pioneering studies already make use of additional sensor data from smartphones. However, this research is so far limited to scholars that also developed these ICT-based solutions. Hence, valuable inferences can be drawn from the findings of both empirical studies of this thesis in order to provide implications for future EMA research. These implications are further outlined in the overarching discussion of this thesis (see Chapter 7).

3.4 Synthesis: Limitations and further Research of this Thesis

As the literature review of both research fields indicates, research regarding the individual antecedents, outcomes, and moderators of ICT use and applying physiological measures in organizational science is fast growing in the past decade providing valuable first insights. However, as highly interdisciplinary research fields, the literature review shows also that both fields suffer from clear conceptual and theoretical foundations as well as consistent methodological procedures that take the rapid technological advances into account. That results in pivotal limitations further research should consider. In the following, the main results of the previous literature review are summarized for each research field and the pivotal limitations are discussed providing the motivational foundation for both studies.

With regard to individual antecedents, outcomes, and moderators preceding quantitative and qualitative research provides support that individuals differ in their traits, attitudes, motives, perceptions, and preferences for ICT use. While for example highly career-oriented employees show a high amount of ICT use (e.g., Boswell & Olson-Buchanan, 2007; Park et al., 2011; Park & Jex, 2011), employees with a high self-control trait show a lower amount (e.g., Al-Dabbagh et al., 2014; Duxbury et al., 2014). However, findings regarding the effects of ICT use on individuals' outcomes are more inconsistently as studies find support for both detrimental effects (e.g., Ayyagari et al., 2011; Day et al., 2012; Derks et al., 2014; Mazmanian et al., 2013) and improving effects (e.g., Cavazotte et al., 2014; Day et al., 2010; Diaz et al., 2012; Middleton, 2007) in the context of stress, well-being and the work-life interface and, in turn, for the double-edged sword notion. By investigating individual moderators, so far little research gets a better understanding, under which conditions ICT use effects are detrimental or improving for employees. In particular, not only the amount of emails, but also the interpretation of it is examined as an individual's perception and important driver for email overload (Dabbish & Kraut, 2006; Mazmanian et al., 2013). Furthermore, some investigated moderators are able to buffer detrimental effects of ICT use such as autonomous motivation (Ohly & Latour, 2014) and time management strategies (Fenner & Renn, 2010).

Despite these valuable findings, previous research lacks an integrative view that considers not only discrete antecedents, outcomes, or moderators of ICT use, but also the completely individual employee as a human agency. To this end, there is a lack of a comprehensive understanding for the double-edged sword of ICT use. Thereby, further research should focus more on moderators that are referred to individuals' motives, perceptions, and preferences as they provide valuable insights and contribute to such a comprehensive understanding. Furthermore, previous research so far misses to take the next logical step regarding ICT use, that is, to provide individual interventions that facilitate an alignment between the amount of ICT use, in particular availability, and individual perceptions and preferences. As recent research gives recommendations for employees, supervisors, and organizations regarding ICT use, for example to develop trainings (Boswell et al., 2016), there is a lack of mobile based interventions that consider mobile ICTs itself as a solution to manage work-life boundaries, EWA, and EPA. First smartphone applications were developed (e.g., Offtime-App, Curtaz, Hoppe, & Nachtwei, 2015), but their underlying mechanisms and efficacy are not yet well understood. Furthermore, as they only restrict availability, employees are not able to be available according to their preferences for EWA and EPA. Thus, more research is needed to shed light on mobile based interventions that considers individual preferences for an aligned availability. As the ICT-based Availability Management Study first examines employees' individual preferences, further develop and evaluate two smartphone applications that enable an aligned availability, the aforementioned considerations form the scope of the ICT-based Availability Management Study, which is outlined in more detail in Chapter 4.

Second, the literature review about physiological measures, their stationary and wearable devices, and areas for application in organizational science indicates the bandwidth of this topic. Each nervous system provides a broad range of physiological measures that, in turn, can be applied for many areas for application in the organizational science. Thereby, the application becomes more feasible because of the recent advances in wearables and sensors. In particular, because of their lower costs, feasible access with not necessarily requiring an in-depth knowledge of the devices, wearables enable organizational scholars to feasibly apply physiological measures in the field (Akinola, 2010; Cascio & Montealegre, 2016; Ganster et al., 2018). Investigating engagement in team processes with qEEG (Waldman et al., 2015), positive and negative affect with blood pressure (Ilies, Dimotakis, & Watson, 2010), and work stress with HRV (Vahle-Hinz et al., 2014) and salivary cortisol (CAR) (Schlotz et al., 2004) are exemplary studies that already applied wearable-measures physiological data in their organizational research. However, the pitfalls that come along with the application of wearables recording physiological measures are not yet well understood in recent research. For instance, because of their restrictions for low intrusion and flexibility (e.g., size of the sensors), wearables often differ in their fundamental technique, body locations, and sample rates compared to stationary devices (Ellis, Zhu, Koenig, Thayer, & Wang, 2015; Tamura et al., 2014). Thereby, recent research lacks a comprehensive understanding of wearable-measured physiological data, its properties, and methodological issues.

As one of the first, Chaffin et al. (2017) invoke the need to validate wearables that measure physical data for example via Bluetooth prior to use them for research. While official recommendations for physiological measures exists (e.g., Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996 for HRV), recent studies fail to extend such previous recommendations by newer device advances and their requirements. Furthermore, they are often designated for an audience that requires an in-depth understanding and knowledge about the physiological measures and their devices. As organizational scholars are probably new to the field and such an in-depth knowledge is not obviously part of their methodological toolbox (Heaphy & Dutton, 2008; Waldman et al., 2019), there is a need for a clear guidance about the valid application with recording, processing, and analyzing wearable-measured physiological data for organizational research. Moreover, in line with Chaffin et al. (2017), more research is needed that sheds light on the validity and reliability of wearables that record physiological measures, as it is crucial to provide valid and reliable study results of future research, from which reasonable inferences can be drawn. The aforementioned considerations form the scope of the ICT-based Physiological Measurements Study, which is outlined in Chapter 4 and Chapter 6.

4 Central Research Questions and Overview of the Studies

As the previous section indicates, recent research suffers from a lack of responsible ICT-based solutions and an in-depth methodological discussion particularly with regard to wearable-measured physiological measures. To fill these research gaps, the overarching aim of this dissertation is to provide *responsible ICT-based solutions for the assessment of employees' well-being* as a pathway to responsible digitization, in particular regarding availability and physiological measures.

Therefore, this thesis sets two main research goals:

(1) Shedding light on employees' individual aligned availability by considering their perceptions, motives, and preferences and providing two smartphone applications for an aligned availability by taking a design science research approach (*ICT-based Availability Management, study 1*).

(2) Accomplishing an in-depth understanding on how organizational scholars can validly apply wearable-measured physiological methods for their research as a contribution to their methodological toolbox (*ICT-based Physiological Measurements, study 2*).

To reach both main goals of the thesis, central research questions are derived, on which two empirical studies shed light. Figure 4-1 provides an overview of the overarching conceptual framework of the thesis.

ICT-based Availability Management Study

The first study on availability management (Chapter 5) examines employees' individual availability preference and actual availability in order to develop two smartphone applications according to the design science research approach (Peffers et al., 2007). Furthermore, the developed smartphone applications are evaluated in an empirical study. This study was a main part of the interdisciplinary research project 'Social Link' funded by the Hessen State Ministry for Higher Education, Research, and the Arts within the LOEWE Program of Excellence in Research. The study sheds light on four main research questions:

(1) How and to what extent do employees differ in terms of their availability preference and boundary management preference?

(2) Which requirements and design elements should both smartphone applications fulfill in order to provide an aligned availability?

(3) To what extent do both smartphone applications improve employees' aligned availability and, therefore, their stress and work-life balance comparing a user and control group?

(4) Which functions of both smartphone applications contribute the most to an aligned availability?

To answer the research questions, this dissertation conducts a qualitative (n = 59) and quantitative study (n = 589) regarding employees' individual availability and boundary management preference and actual boundary management strategies that further provide requirements and design elements for both smartphone applications. Following principles of design science research approach (Peffers et al., 2007), two smartphone applications – Availability-Monitor and Availability-Manager – are developed in three iterations: Deriving solution requirements from the aforementioned qualitative and quantitative study, testing the reliability and validity of the applications' design elements, and testing the applications in a simulation study. Finally, the applications are evaluated regarding employees' stress and work-life balance in a five-week field study with 31 participants using the applications and a control group (n = 55). Furthermore, the study provides a qualitative and quantitative evaluation of the perceived utility, the use as well as the assessment of the applications' different functions.

ICT-based Physiological Measurements Study

The second study about ICT-based physiological measurements (Chapter 6) investigates and discusses the application of wearable-measured physiological measures for organizational research in detail and provide, thereby, an in-depth understanding of the opportunities but also pitfalls that arises with the application. In particular, the study reveals methodological properties of the measures and potential measurement issues. Furthermore, two guidelines for both processing and analyzing wearable-measured physiological data accounting for the properties and issues and the validation of such data are given. The guidelines are exemplified with real data of an experimental comparison study. Hence, the ICT-based Physiological Measurements study is guided by three main research questions:

(5) How should organizational scholars apply wearable-measured physiological measures for their research to be able to draw reasonable inferences from their findings?

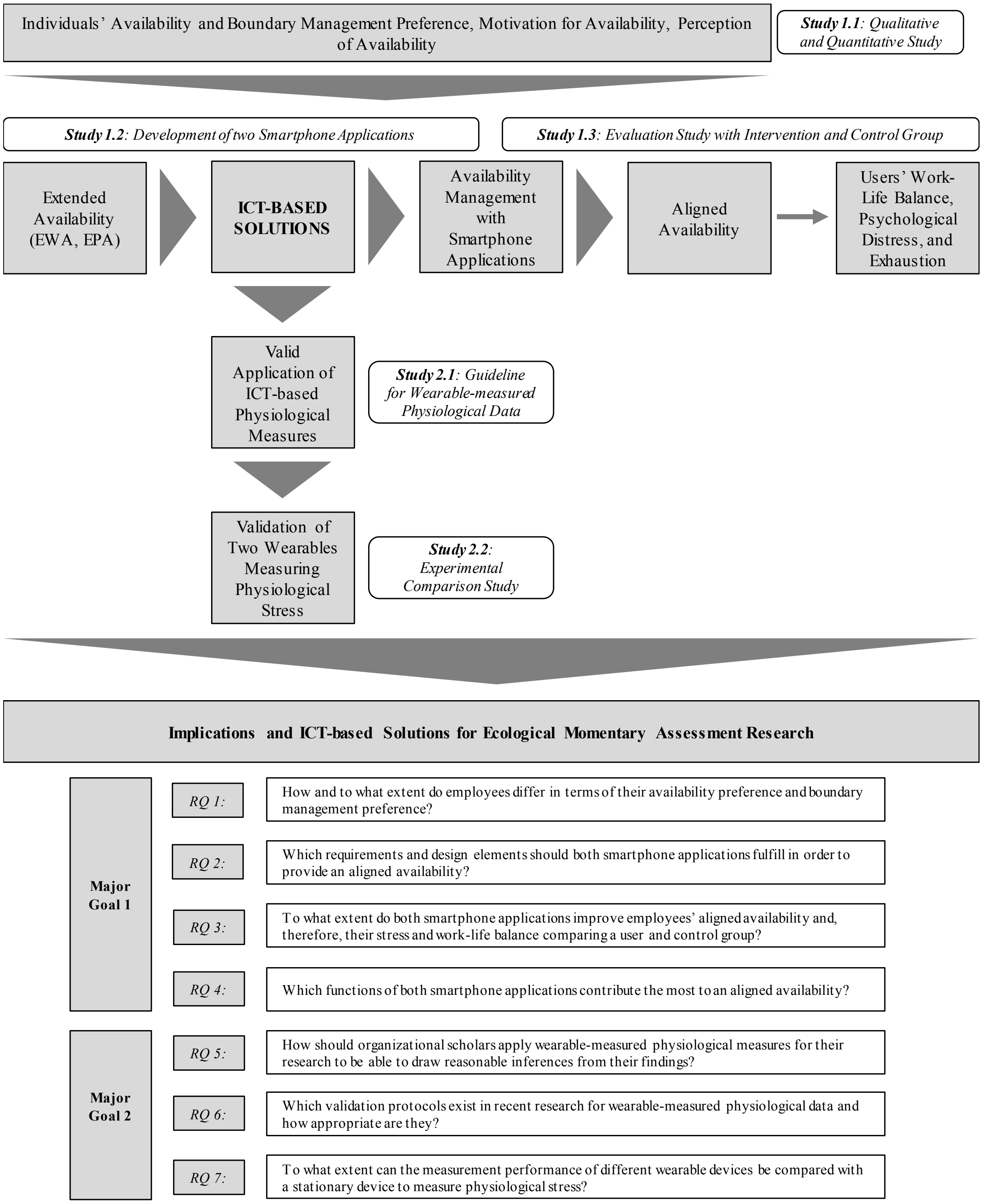
(6) Which validation protocols exist in recent research for wearable-measured physiological data and how appropriate are they?

(7) To what extent can the measurement performance of different wearable devices be compared with a stationary device to measure physiological stress?

To answer the research questions, the ICT-based Physiological Measurements Study provides an overview over the broad field of physiological measures, their methodological properties, and stationary and wearable devices applicable to record these measures. Thereby, key methodological issues for the application of wearable-measured physiological data are outlined. Furthermore, with proposing critical steps in a guideline, a rigorous standard of designing studies that record, process, and analyze wearable-measured physiological data is provided. Thereby, the discussed methodological properties and potential measurement issues are considered. Moreover, the second study examines methods used in previous research to determine the validity and reliability of physiological data with an interdisciplinary literature review. Further, these methods are evaluated regarding certain criteria, for example the previously outlined methodological properties of physiological measures, with the aim to provide appropriate methods for determining the validity and reliability of wearable-measured physiological data. Finally, a measurement comparison study is conducted with 32 participants comparing HR and HRV recorded with two wearables (PPG wristband Empatica E4, ECG breast strap movisens EcgMove 3) and an established stationary ECG-based device (Biopac MP36). This results in 96 data sets that have to be processed and analyzed according to the aforementioned procedures. Thereby, different states of physiological stress are investigated with the Trier Social Stress Test (TSST, Kirschbaum, Pirke, & Hellhammer, 1993), an established experimental procedure. The aim of this study is to exemplify the application of the proposed guidelines and the best suited methods determining reliability and convergent validity. Moreover, the findings of the experimental comparison study provide validation results for both wearables.

Together, the two empirical studies of this dissertation provide valuable contributions to the responsible assessment of individual well-being outcomes and, thereby, the extension of the methodological toolbox of organizational scholars. However, as both studies integrate findings and approaches from interdisciplinary research streams, the findings of this thesis are not limited to organizational research. Furthermore, both studies provide valuable implications, from which the research area of EMA may fundamentally benefit.

Figure 4-1: Conceptual Framework and Research Questions of the Thesis



Note: RQ = Research question

5 ICT-based Availability Management: Design and Evaluation of Availability Management Applications for an Aligned Availability [2]

As outlined in Chapter 1, information and communication technologies (ICTs) have become ubiquitous, transforming our working as well as personal lives (Ayyagari et al., 2011; Bliese et al., 2017; Sayah, 2013). Over the last decade, research in two fields, information systems (IS) and organizational behavior (OB), has identified both beneficial and harmful effects of ICT use. On the one hand, ICTs enhance users' flexibility and autonomy, which foster feelings of effectiveness and work satisfaction (Diaz et al., 2012; Middleton & Cukier, 2006) and increase individuals' ability to meet work-life demands (Towers et al., 2006). On the other hand, interactions with ICTs may result in stress, in IS literature referred to as technostress (e.g., Ayyagari et al., 2011; Tams, Hill, Guinea, Thatcher, & Grover, 2014; Tarafdar et al., 2015), and other detrimental outcomes such as feelings of overload and burnout (e.g., Barley et al., 2011; Diaz et al., 2012). Research particularly focuses on detrimental effects of the "always on" culture that has evolved over the years. ICTs prompt users to stay connected to work and personal contacts anywhere and anytime and enable to blur boundaries between work and private life domains by facilitating constant availability across these domains' boundaries (Boswell & Olson-Buchanan, 2007). The extent of individuals' availability, in turn, is found to be related to increased work-life conflict, exhaustion, and impaired recovery (e.g., Boswell & Olson-Buchanan, 2007; Derks et al., 2014; Lanaj et al., 2014) (see Chapter 3.1 for the literature review regarding ICT use).

In line with research's emphasis on the amount of ICT-based availability as a driver of detrimental outcomes, previous solutions to mitigate such outcomes focus on restricting ICT use. As mentioned in Chapter 1.1, several employers deploy interventions in order to reduce the amount of availability for work-related contacts during non-work time, such as turning off Blackberry servers after office hours (Volkswagen AG, BBC News, 2012) or offering employees to delete all incoming email while they are on holiday (Daimler AG, BBC News,

[2] This chapter is based on a published paper from Schneider et al. (2017). The study was part of the interdisciplinary project Social Link funded by the Hessen State Ministry for Higher Education, Research, and the Arts within the LOEWE Program of Excellence in Research. As the first author, I contribute leadingly to the conception and conduction of the described data collections, the data analyses, and the writing of the paper itself.

2014). Similarly, providers of ICT-based services offer applications for PCs, tablets, and smartphones that aim to help users in restricting their ICT use or, in particular, their availability. Going beyond silent or flight mode, these applications restrict the use of other applications and block calls, messages, and notifications for a time period the user specifies (e.g., Offtime; Curtaz et al., 2015).

By enabling users to regulate the amount of their availability, these applications are important first steps to mitigate detrimental effects of ICT-based availability. Nevertheless, these applications show pivotal deficits in that they do not map the complexity of individuals' availability preferences. Research on work-life balance shows that individuals vary in the degree, to which they wish to segment or integrate work and private life domains (Ashforth et al., 2000; Kreiner, 2006). These preferences should be reflected in varying degrees of preferred availability. For example, a person, who wishes to integrate both work and private lives, should prefer to be available for personal contacts during working hours and for work-related contacts during non-work time and vice versa. In fact, recent research indicates that consequences of the amount of availability depend on individuals' particular availability preferences (Stich et al., 2017).

Yet, existing applications, such as Offtime (Curtaz et al., 2015) aiming to restrict availability force individuals to make a binary decision. In particular, the user has to decide, whether they want to be available for a given time period or not. Hence, this undifferentiated regulation restricts individuals' options, for example, by not allowing being available for personal contacts and unavailable for work-related contacts at the same time and vice versa. Hence, while present applications help reducing unsolicited availability, they also bear the risk of inhibiting desired availability, thereby inducing a mismatch between actual availability and individuals' availability preferences. Therefore, they might hinder individuals from the improving effects of ICT use and availability, particularly the flexibility that comes with choosing when to be available for whom and the capability to manage different life domains more effectively (see Chapter 3.1 for the literature review of outcomes regarding ICT use). Thus, ICT-based solutions are needed that facilitate a more differentiated availability management by considering actual availability and individuals' availability preferences. To this end, they could enable individuals to align the actual availability with their preferences and, in turn, prevent the detrimental and enhance the improving effects of an aligned availability.

With the wide and still increasing dissemination of smartphones (Statista, 2016), smartphones constitute a key technology for individuals' availability and, thus, are a key starting point for developing a ICT-based solution geared to improve individuals' availability management. Thus, the goal of the first study of this thesis is to introduce and evaluate an ICT-based solution that effectively supports individuals in managing their availability in accordance with their individual availability preferences. This solution is constituted of two smartphone applications: Availability-Monitor and Availability-Manager. With going beyond preceding research and existing ICT-based solutions, the study does not only focus on regulating the amount of ICT-based availability. Instead, two smartphone applications are designed with the aim to reflect and consider the diversity and complexity of individuals' availability preferences and, thereby, facilitate a more differentiated availability management. The purpose is to enhance the alignment between individuals' availability preferences and their actual availability. Thereby, detrimental effects of the ICT-based availability identified in previous research should be prevented with perceiving a reduction in exhaustion and stress, while improving effects with perceiving an increased work-life balance be enhanced. The study is guided by four research questions (see also Chapter 4):

(1) How and to what extent do employees differ in terms of their availability preference and boundary management preferences?

(2) Which requirements and design elements should both smartphone applications fulfill in order to provide an aligned availability?

(3) To what extent do both smartphone applications improve employees' aligned availability and, therefore, their stress and work-life balance, by comparing a user and control group?

(4) Which functions of both smartphone applications contribute the most to an aligned availability?

The development of the smartphone applications follows the principles of the design science research approach (Peffers et al., 2007). To identify differences in terms of employees' availability preferences and boundary management preferences, data from both a qualitative and a quantitative study is analyzed. Then, solution objectives and requirements on both applications are derived from the studies' results. Beside the aforementioned theories in Chapter 2.2, the boundary theory (Ashforth et al., 2000) serves as an additional theoretical framework. Next, the iterative design and development process of both smartphone applications and the design elements are outlined. Afterwards, the results of a five-week field study with an intervention and a control group conducted to evaluate both applications in a real-life setting are presented. Finally, this study serves for communicating the results of the design science research process and its implications for IS and OB research as well as for organizations and individual ICT users.

5.1 Qualitative and Quantitative Study for Deriving Solution Requirements

As already discussed in the theoretical background section (Chapter 2.2), the human agency perspective and the SDT contribute to a comprehensively understanding of individuals' availability and boundary management preferences, motivation for extended availability, and perception of availability as key solution requirements. Furthermore, with integrating boundary theory into the human agency perspective (see Figure 2-4), boundary theory describes how individuals create and manage the boundaries surrounding their various life domains (Ashforth et al., 2000; Nippert-Eng, 1996). Hereby, boundaries differ in the degree, to which they are flexible and permeable (see also Chapter 2.1.1). Flexibility refers to the extent, to which boundaries are changeable and elastic. Permeability refers to the degree, to which elements of one life domain may enter another domain (Ashforth et al., 2000). According to boundary theory, individuals' boundary management preferences can be arrayed on a continuum ranging from segmentation to integration. Accordingly, individuals vary in the degree, to which they prefer thick and clear (i.e., segmentation) or thin and blurred boundaries (i.e., integration) around different life domains (Ashforth et al., 2000; Nippert-Eng, 1996). Moreover, as highlighted by Clark (2000) and Kossek and Lautsch (2012), an individual might prefer the work boundary and the private life boundary to be asymmetrical, that is to be flexible and permeable to varying degrees, as reflected, for example, in wanting a thick and clear private life boundary, but a thin and blurred work-to-life boundary.

ICTs play a central role for individuals' boundary management since they can be used as a tool to implement the desired degree of boundaries' flexibility and permeability (Kreiner et al., 2009). Individuals, who prefer greater integration may leverage ICTs to intertwine their life domains, while individuals who prefer segmentation might actively maintain thick boundaries and reduce cross-domain availability. However, at the same time, ICTs enable violations of individuals' desired boundary management (Kreiner et al., 2009). In particular, ICTs may hinder individuals from implementing their preferred degree of segmentation or integration, for example by enabling phone calls at undesired or inappropriate times, thereby representing a critical driver of an undesired blurring of boundaries. In turn, these boundary violations may have detrimental effects for the individual, such as resulting in increased work-life conflict (Kreiner et al., 2009). The goal of bot smartphone applications should therefore be twofold: They should simultaneously support ICT users in (1) creating and maintaining their preferred boundaries by ensuring desired availability and (2) preventing boundary violations by inhibiting unsolicited availability. Hereby, the smartphone applications have the potential to maintain ICT users' access to benefits of ICT-based availability, while at the same time preventing its detrimental outcomes.

To develop the smartphone applications with the aim to enable individuals to manage their ICT-based availability in accordance with their boundary management and availability preferences, it is needed to understand how individuals' different positions on the abstract segmentation-integration continuum translate into concrete availability preferences. While the theoretical background highlights the importance of individual differences in boundary management preferences, it remains unclear how these preferences affect individuals' tangible availability preferences and handling of ICT-based availability. Do individuals, who tend to segment the work domain, never want to be available for personal contacts during working hours? Does integrating work and private life imply always being connected to one's working life and at the same time accepting calls from personal contacts anytime? How do individuals, who partly integrate, partly segment their life domains prefer to be available? To answer these questions and gain a comprehensive understanding of individuals' availability preferences, findings of both the qualitative and the quantitative study are considered. Based on these findings, specific requirements for both smartphone applications for an aligned availability are derived.

Interviews with knowledge workers were conducted to better understand, which distinct availability preferences individuals exhibit and how ICT-based availability is managed to meet personal boundary management preferences. Knowledge workers are employees, whose job involves creating, distributing, and applying knowledge (Davenport, 2005). As ICT use represents a central part of their work (Wajcman & Rose, 2011), knowledge workers constitute a particularly relevant sample. The sample of the interview study consists of 59 employees from a diverse range of industries including IT, banking, and consulting. In particular, 18 top executives (4 female), 20 middle managers (9 female), and 21 employees with managerial responsibilities (10 female) with an average age of 41.9 years were interviewed.

In the semi-structured interviews, participants were asked how they use ICTs and manage their availability across work-life domains. The analysis of the transcribed interviews guided by principles of qualitative research analysis (Strauss & Corbin, 1990) suggests several important findings. First, the results confirm that individuals may manage their cross-domain availability asymmetrically. This notion is illustrated by the following interview quote: "My own cell phone is always with me but I don't check it at work. Not until the evening. Yet, I check the firm's cell phone all the time" (female, 43 years). Asymmetry exists in both directions, with some participants having higher EWA compared to EPA or vice versa.

Moreover, the interview data shows that availability preferences may not only vary across individuals and domains but also across different contexts. Hereby, participants differentiate between time-referenced contexts, such as on break, after hours, weekend, or vacation, and activity-related contexts, such as meetings, exercising, concentrated working, or family dinner. Depending on these contexts, participants state to exhibit distinct availability preferences, as illustrated by the following two quotes:

"When I am on vacation, I try to not take my smartphone with me. [On workdays,] I even check my smartphone after 10pm and reply messages. […] On weekends, I try not to do anything job-related except for Sunday evenings, when I prepare for the upcoming week" (male, 39 years).

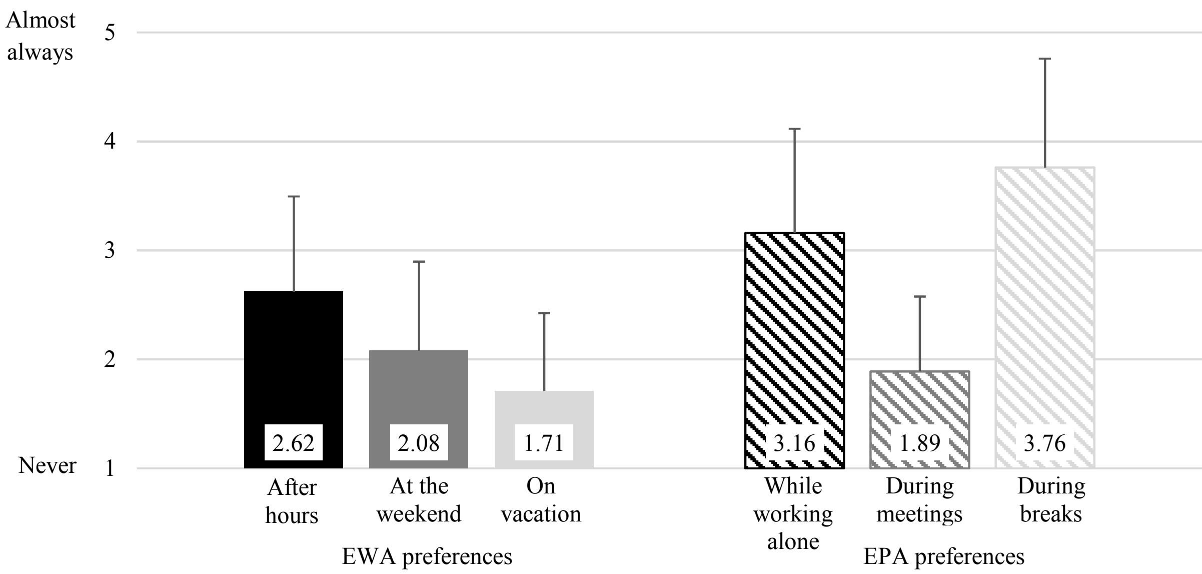
"We have this agreement that breakfast time is sacred. Dinner time is sacred, put away the phones and that's good. When someone's calling at that time, I let him know I'm at dinner, and call back later" (male, 42 years).

Finally, some participants emphasize that certain contacts, especially family members, should be able to reach them no matter what their current life domain or context is: "My family can always call me. [...] When I'm in a meeting, I quickly step outside. When 'Home' calls, I take the call, no matter if it is a trifle or someone is hurt" (male, 52 years).

To further validate the findings from the qualitative data, a quantitative survey with 589 knowledge workers is conducted representing four industries: IT (78.1%), automotive supply (17.7%), consulting (3.1%), and public administration (1.2%). 69% of the respondents are male; mean age is 45.46 years (SD = 8.98). Participants were asked to rate their cross-domain availability preferences on a scale ranging from 1 = never to 5 = almost always. On average across all participants, preferred EPA (M = 2.9, SD = 0.70) is higher than preferred EWA (M = 2.1, SD = 0.69). Moreover, cross-domain availability preferences vary largely depending on context as shown in Figure 5-1.

For a better understanding of participants' high individual preference for EWA, the motivation for their high preference in an additional analysis was explored in accordance with SDT. The reported motivation for their high EWA preference can be classified into three categories: Intrinsic motivation, extrinsic motivation, and motivated by avoidance. In the intrinsic motivation category (44%), participants reported that they are available exclusively in case of emergency indicating that these cases are frequent, they would always like to remain informed, or be sure to have everything under control. Additionally, extrinsic motivation (15%) is reported by those, who had a high EWA preference in that others are reliant on a quickly reaction or it is expected of them. In the third category motivated by avoidance (23%), participants reported that they are afraid that something could go wrong because of their non-response to calls or emails, and they would like to avoid a mountain of emails and calls when they get back to work. More than a third of these participants with high EWA preference had a managerial responsibility.

Figure 5-1: Average Availability Preferences as a Function of Context



Note: The figure depicts the mean and standard deviation.

The purpose of both smartphone applications is to enable individuals to manage their availability via ICT in accordance with their individual availability preferences by allowing desired availability and preventing unsolicited availability. The results of the two studies discussed above provide important insights into individuals' availability preferences: First, individuals differ in their availability preferences, with the extent of preferred availability depending on the life domain and potential asymmetry between EWA and EPA preferences. Second, availability preferences vary depending on context, in particular time-referenced and activity-related contexts. Third, individuals may exhibit particular availability preferences for selected contacts. These insights have important implications for the design of the applications. In more detail, they should enable individuals to adapt their availability to their personal preferences by considering life domain, context, and contact. Applications that incorporates these three aspects should allow for a more fine-grained, individually-customized availability management that, in turn, prevents detrimental effects of ICT-based availability and enhances its improving effects.

5.2 Design and Development of the Availability-Monitor and Availability-Manager

The development of both smartphone application follows an iterative process with several feedback loops. Each iteration and the resulting feedbacks contributed to further improvements. The iterations of the design science research process proceeded as follows. In the first iteration, the solution requirements derived from the properties of individuals' availability preferences discussed in the prior section are incorporated into the applications in the form of various design elements (see Table 5-1, row 1-3). In the second iteration, these design elements were tested in terms of their reliability and validity (i.e., whether they work reliably and do what they are meant to do) (Gregor & Hevner, 2013). On this basis, the applications were further improved.

Table 5-1: Criteria, Solution Requirements, and Design Elements of the ICT-based Solution

Criteria Derived from Theory and Empirical Studies	Solution Requirements	Design Elements
Individuals differ in their availability preferences, with extent of preferred availability depending on life domain	The application needs to support different availability preferences of users across different life domains	Availability modes (pre- and self-defined)
Availability preferences vary depending on different contexts	The application needs to support adaptations of availability depending on different contexts. Therefore, the application needs to "sense" the users' context	Availability modes (pre- and self-defined) Application-controlled mode switching Automatic replies Delegation
Individuals may exhibit specific availability preferences for selected persons	The application needs to support contact-specific availability preferences	Availability modes (pre- and self-defined) Contact settings (type and priority) Priority assistant
Individuals seek for transparency and control and want to track actions of the system (e.g. blocking phone calls)	The application needs to save, process and display its activities so that a user can comprehend the functionality of the application	Communication protocol *Optional* Application-controlled mode switching Feedback dashboard

Seizing on the insights and respective solution requirements derived from the qualitative and quantitative study (see Table 5-1, row 1-3), the Availability-Manager was developed first. The basic idea was that each incoming communication is examined according to a rule-based system that is designed to reflect individuals' availability preferences. Examination criteria are: (1) activated availability modus, (2) type of contact, and (3) priority of contact. Depending on the result of this examination, the communication is either patched through or blocked (i.e., the user receives neither acoustic nor visual notifications). Outgoing communication remains unaffected by the Availability-Manager.

In the third iteration, a simulation study with 15 participants in a controlled setting was conducted (Heißler, Schmitt, Maier et al., 2016; Heißler, Schmitt, & Ohly, 2016). The goal of this simulation study was to evaluate the current instantiation and the rule-based system of the Availability-Manager in terms of their utility and usability from users' point of view. Each participant of the simulation study got a smartphone with a pre-configured version of the Availability-Manager and passed through 20 different, scripted cases of incoming communication at various times and contexts. According to the rule-based system and the pre-configured settings, the incoming communication was either blocked or patched through. The participants answered several questionnaires in the course of the simulation and were interviewed afterwards regarding the usability of the application and the perceived utility of the simulated availability management. This third iteration resulted in (1) further improvements of the existing design elements of the Availability-Manager as well as (2) a fourth criterion and, thus, a fourth solution requirement (see Table 2-1, row 4). Participants of the simulation study requested more transparency and control over the activities of the application. Additional design elements were incorporated into the Availability-Manager and the Availability-Monitor as the second application was developed.

In the following section, the design elements implemented in the versions of the Availability-Manager and Availability-Monitor entered the evaluation study are outlined in more detail. It should be noted here that these versions are limited to run on devices with Android operating system (version 4.4 or higher) and solely manage incoming communication of three communication channels: calls, SMS, and email.

5.2.1 Design Elements

Availability modes. As shown in Figure 5-2, the Availability-Manager provides users with a selection of five predefined availability modes, derived from the insights regarding typical, context-specific availability preferences. Each availability mode deploys a different set of rules for the decision, which incoming communication is patched through or blocked. Hereby, the availability modes rely on two categories characterizing the contact as the sender of an incoming communication, that are the type of contact (personal, work-related, or both) and priority of contact (high or low). Table 5-2 explicates the five availability modes with their availability rules as well as the context and availability preferences, for which each mode is appropriate.

The availability modes rely on users' categorization of their contacts in terms of type and priority via the Availability-Manager. Unknown numbers and contacts that are not categorized are always patched through. To encourage users to categorize their contacts, dialog boxes were implemented, which pop up after incoming communications requesting users to categorize the particular sender.

Table 5-2: Mode Overview and Explanation of the Smartphone Applications

Mode	Context	Availability	
		Available for	Not Available for
At work	The user is currently at work	- All work related contacts - Private contacts with high priority	- Private contacts with priority normal (optional notification)
Concentrated work	The user is focused on a task	- Work related as well as private contacts with high priority	- Work related and private contacts with priority normal (optional notification)
Private	The user is off work	- All private contacts - Work related contacts with high priority	- Work related contacts with priority normal (optional notification)
Unavailable	The user is unavailable for all communication requests	- Repeated requests from contacts according to the Priority-Assistant	- All contacts (optional notification)
Available	The user is available for all communication requests	- All contacts	

In addition to the predefined modes, users can setup various personalized modes by either choosing certain communication channels (e.g., email or calls) that are blocked or selecting contacts that will be patched through, if the respective mode is activated. Users can switch availability modes manually according to their current context and availability preferences. In addition, the availability modes At work, Private and Unavailable can also be allowed to switch automatically (see application-controlled mode switching).

Application-controlled mode switching. Based on the second criterion and requirement (see Table 5-2) that the application needs to support adaptations of availability depending on different contexts and to "sense" the users' context, the modes At work, Private and Unavailable can be switched automatically. The Availability-Monitor can be taught to identify special locations by recognizing cells of the mobile network the users has tagged as work-related or private. If a user is present in a specific cell of the mobile network more frequently and for a longer time, the app posts a notification, in which the user can tag the cell immediately. The app further uses Wi-Fi connections to find cells belonging to the same logical location to reduce the number of queries to the user. As a result, the availability mode is switched either from the Private to At work mode or vice versa, if the user enters the known cell of the mobile network or Wi-Fi connection. In response to the fourth criterion (see Table 5-1), the application-controlled mode switching is an optional function. Another variation of application-controlled mode switching relies on time-based rules. Users can setup weekdays and times, to which the Availability-Manager automatically switches to the Unavailable mode.

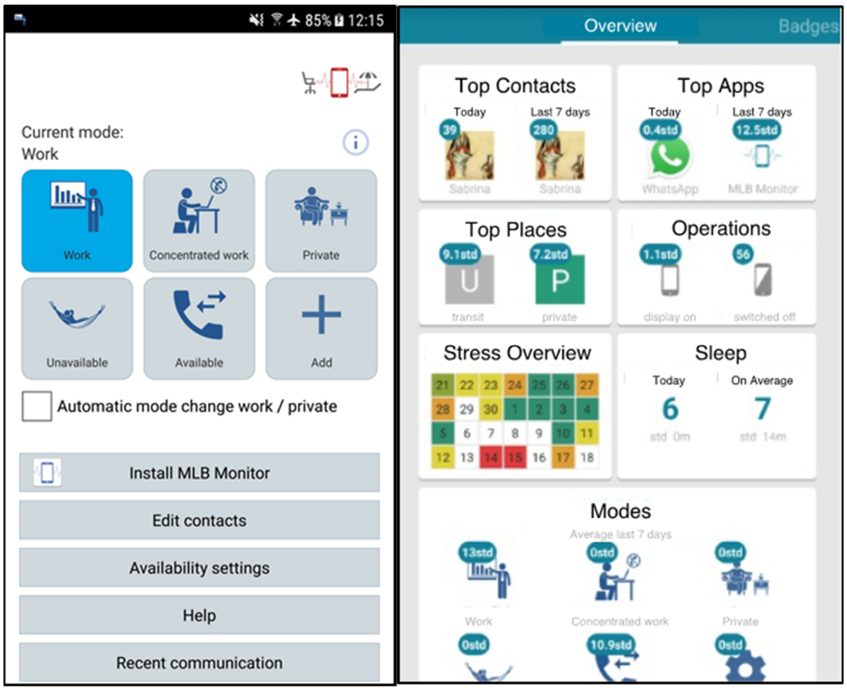
Communication protocol. Sizing on the fourth criterion and solution requirement (see Table 5-1), the Availability-Manager visualizes all activities of the application in the communication protocol. This allows users to track switches of availability modes, blocked and patched through incoming communication, and the activated availability mode.

Priority assistant. Based on the third criterion (see Table 5-1) that individuals may exhibit specific availability preferences for selected contacts, a priority assistant was implemented. The assistant allows users to setup a threshold for number of incoming communication (via calls, SMS, or email) from the same contact in a certain timespan. If the number of incoming communication from a contact surpasses this threshold, the communication is patched through, irrespective of the availability mode that is activated. Thereby, the priority assistant ensures that urgent matters do not get blocked.

Automatic replies and delegation. The Availability-Manager provides the option of automatic replies via SMS, if incoming calls are blocked. The user can customize the text of these replies for each availability mode and contact. Additionally, the reply can also contain contact information of a substitute in order to delegate the communication to this person.

Feedback dashboard. In response to the fourth criterion and solution requirement, the Availability-Monitor provides a dashboard displaying information on users' smartphone usage (see Figure 5-2). For that purpose, the Availability-Monitor logs users' communication activities transacted via the smartphone and usage of different app categories, together with other descriptive data. Furthermore, the Availability-Monitor includes a query for measuring users' perceived stress level. All this data is depicted in the dashboard to allow the user to control his or her own smartphone usage behavior and to track his or her stress level.

Figure 5-2: Screenshots of the Home Screen of the Availability-Manager and Feedback Dashboard of the Availability-Monitor



5.3 Evaluation

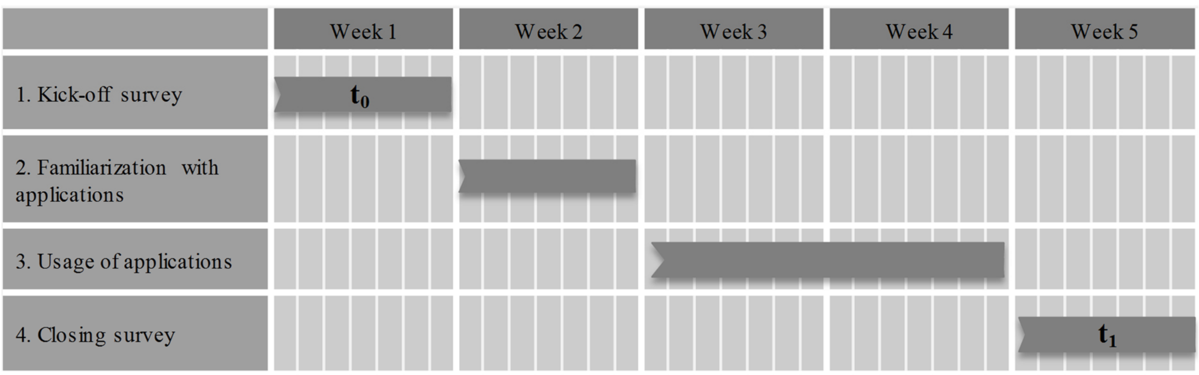
To evaluate the Availability-Manager and the Availability-Monitor in a real-life setting, a five-week field study was conducted with an intervention group, who used the applications, and a control group, who did not apply them. The key criteria for this evaluation are (1) the applications' utility from users' point of view and (2) the applications' efficacy with regard to reducing detrimental effects of availability and enhancing its improving effects. The latter is assessed in terms of changes in perceived stress, exhaustion, and work-life balance over the period participants use the applications.

5.3.1 Sample and Procedures

The evaluation study consists of four phases with two data collecting points (see Figure 5-3). In the first phase, 352 participants were contacted, who took part in the previously described quantitative study and agreed to participate in further studies, via email to complete the kick-off survey (t_0) via a web application. 152 of these 352 individuals filled-in the kick-off survey (response rate: 43.18%) and were thus considered for the next phases. At the beginning of phase 2, participants, whose private and/or firm smartphones fulfill the technical requirements to install the applications (i.e., run with Android operating systems, version 4.4 or higher), were invited to download and install both applications (Availability-Manager and Availability-Monitor). The object of phase 2 was to give participants time to familiarize themselves with the applications and make personal configurations. Therefore, no data was collected during that one-week period. Phase 3 lasted for two weeks. Participants, who had downloaded and installed the applications, were asked to apply them in order to manage their availability during the two-week period. Finally, in phase 4, all participants were asked to answer the closing survey (t_1) via a web application. 102 participants (67.11%) of the 152 individuals, who had completed the kick-off survey, filled-in the closing survey, likewise.

Of the 102 respondents, who had completed both the kick-off and the closing survey, 86 use a smartphone with Android operating system (33.3% a private, 51.0% a firm smartphone). These 86 participants constitute our final sample for evaluating the applications. The final sample includes employees from three industries: IT (81.4%), automotive supply (17.4%), and consulting (1.2%). Their average tenure is 17.70 years (*SD* = 10.02), 75.6% of them have no managerial responsibility and 98.8% are provided the possibility to work from home as part of their regular working hours (home office). 65.1% of the participants are male, their mean age is 47.74 years (*SD* = 8.18). 86.0% are in a relationship. 51.1 % of the respondents state to perceive the functions their smartphones provide as supportive for their work-life balance. Of the final sample, 31 participants downloaded and installed both, the Availability-Manager and the Availability-Monitor, and used the applications at least for two days during phase 3, thus, they constitute the intervention group. 84.0% of the participants in the intervention group used the applications at least for five days during phase 3. The control group consists of 55 participants that owned an Android smartphone, completed both the first and last survey, but did not use the applications in phase 3.

Figure 5-3: Evaluation Strategy of the ICT-based Availability Management Study



5.3.2 Measures

To compute the differences in the key outcome variables before and after the application usage phase, perceived work-life balance, exhaustion, and psychological distress were measured at two points in times, t_0 and t_1 in accordance with the temporal order of the AL model (see Chapter 2.2.3). Unless otherwise indicated, items were answered on a seven-point Likert scale, ranging from “strongly disagree” to “strongly agree”. As previously outlined (see Chapter 2.1.2), work-life balance is defined as individuals’ perception of the overall congruence between their ideal and their actual self, considering all life domains that are important to the individual. Work-life balance was measured with five items. The scale was previously validated in a study with 83 participants showing sufficient discriminant validity in its nomological net, including satisfaction with work-life balance (Valcour, 2007) and life satisfaction (Pavot & Diener, 1993). Exhaustion describes a state, in which individuals feel emotionally overchallenged and drained (see also Chapter 2.1.2). It was measured using five items from the Maslach Burnout Inventory (Maslach, Jackson, & Leiter, 1996). Psychological distress refers to a mental state characterized by negative emotions and thoughts (Selye, 1974; Warr, 1990) and was measured with six items on a seven-point scale ranging from “never” to “all the time” (Warr, 1990) (see also Chapter 2.1.2).

To assess intervention group participants’ perceptions of the applications’ utility, the extent, to which participants experienced the applications as supportive for their work-life balance, was measured with one item. Moreover, they evaluated the extent of work-life balance support for each of the applications’ different features with one item for each function and answered to three open questions to obtain feedback on the applications in more detail.

5.4 Evaluation Results

5.4.1 Efficacy of the Smartphone Applications regarding Well-being

Descriptive statistics, Cronbach’s alpha and inter-correlations of the study variables are presented in the Appendix (see Table A- 1). All measures show good internal consistency.

Paired-samples t-tests with IBM SPSS 22 are used to compare the data of t_0 and t_1 for the intervention and the control group. For both groups the mean values of work-life balance are higher, the mean values of exhaustion and psychological distress are lower at t_1 compared to t_0 (see Table 5-3). For the intervention group, differences of work-life balance (t (31) = -3.154, $p \leq .05$, d = 0.4), exhaustion (t (31) = 3.999, $p \leq .001$, d = -0.5), and psychological distress (t (31) = 4.252, $p \leq .001$, d = -0.5) before and after the application use are all significant. For the control group, differences of work-life balance (t (55) = -2.639, $p \leq .05$, $d = 0.3$) and exhaustion (t (55) = 2.003, $p \leq .05$, $d = -0.2$) are significant, yet, psychological distress did not decrease significantly (t (55) = 0.992, n.s.). In terms of effect sizes, the intervention group exhibits medium effect sizes according to Cohen's convention (1988), while for the control group effect sizes are small.

Table 5-3: Evaluation Results Comparing Intervention and Control Group

	N	*M*	*SD*	*t*	*p*	Cohen's
Work-Life Balance t_0 Work-Life Balance t_1	31	4.32 4.94	1.38 1.11	- 3.154	.004*	0.4
	55	4.58 4.92	1.12 1.22	- 2.639	.011*	0.3
Exhaustion t_0 Exhaustion t_1	31	3.61 2.99	1.28 1.22	3.999	.001**	-0.5
	55	3.66 3.39	1.11 1.23	2.003	.050*	-0.2
Psychological Distress t_0 Psychological Distress t_1	31	3.48 2.88	1.31 1.09	4.252	.001**	-0.5
	55	3.16 3.04	1.12 1.01	0.992	.326	/

Note: * $p \leq .05$; ** $p \leq .001$.

5.4.2 Perceived Utility of the Smartphone Applications and their Functions

To evaluate users' perceptions of the applications' utility, answers regarding overall and function-specific assessment of the applications together with the frequencies, with which they used the functions, were analyzed using IBM SPSS 22. Overall, 53.3 % of the participants in the intervention group reported that the applications were supportive for their work-life balance. Reasons for these perceptions of (non-)supportiveness were collected with an open question and categorized as listed in Table 5-4. Explanations for non-supportiveness of the applications were given more often than reasons for their supportiveness. The main reason for perceiving the applications as non-supportive is the missing interface to other communication platforms besides calls, SMS, and email. As many users reported that a large share of their personal communication takes place via these platforms, the applications were limited to managing only a minority of incoming communication.

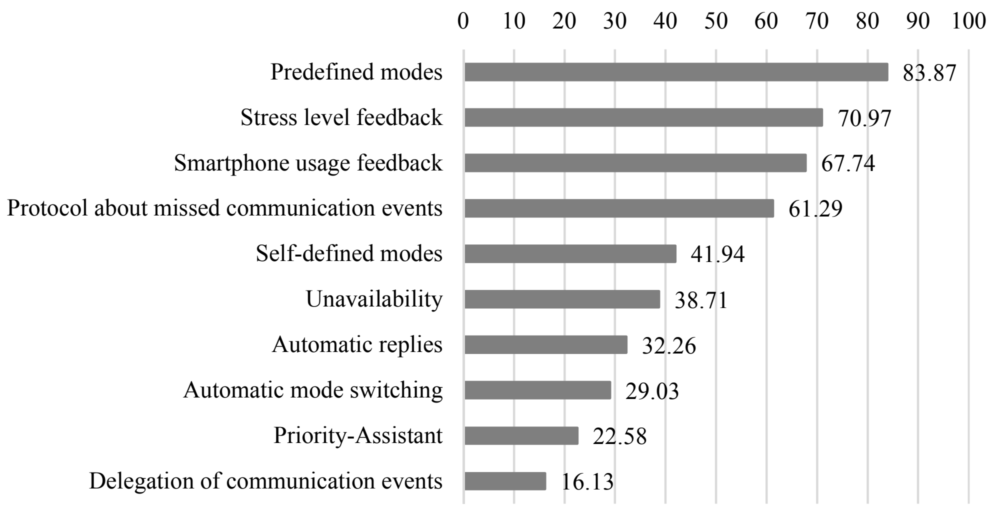
Table 5-4: Reasons for the Supportive or Non-supportive Effect of the Applications

Category	Description of the Category	Frequency of Statements
Reasons for perceiving the applications as non-supportive		
Missing or complex functionality	Users indicated that they missed functions or perceived the implemented functions as too complex (e.g., configuration of all private and work-related contacts). Most of the statements in this category refer to the applications focus on managing availability with regard to calls, SMS, and email, while other communication channels (e.g., WhatsApp, Skype Business) remain unmanaged.	15
Infrequent use	Users indicated that they did not use the applications frequently because of several external circumstances (e.g., vacation).	6
Technical difficulties	Users reported technical difficulties during use.	3
Reasons for perceiving the applications as supportive		
Self-reflection	Users reported that the feedback functions (e.g., feedback about smartphone usage) facilitated self-reflection.	3

Note: Multiple answers were possible.

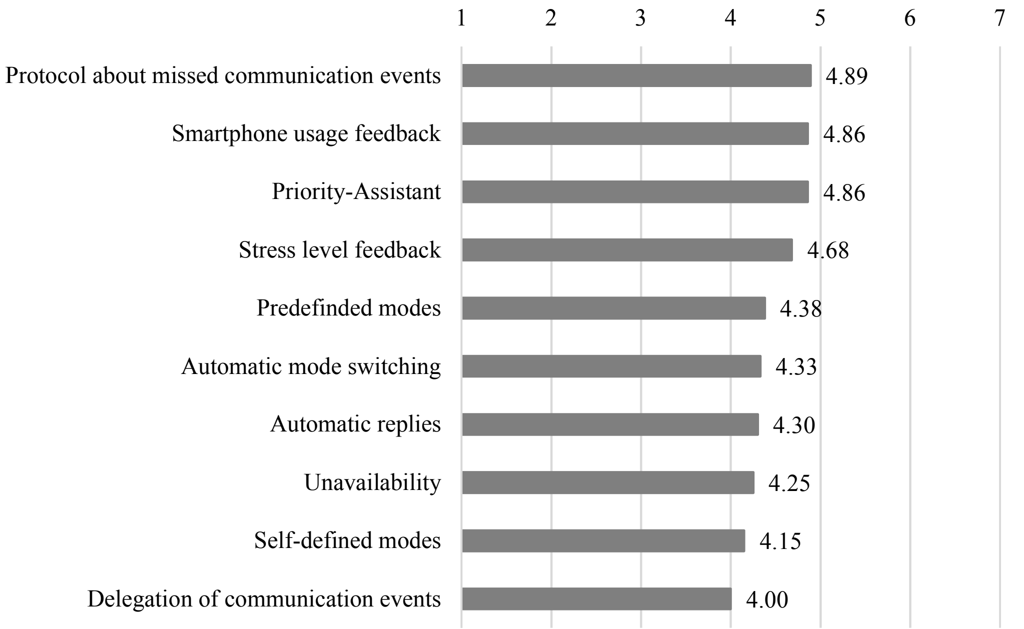
As shown in Figure 5-4, the predefined modes were the most frequently used function, followed by the feedback regarding the users' stress level and smartphone usage as well as the protocol about missed communication events. The least frequently used functions were delegation and priority assistant.

Figure 5-4: Frequency of Use (in %) of Different Functions of the Availability-Manager and Availability-Monitor



The average evaluation of the different functions in terms of their function-specific supportiveness ranges from M = 4.00 to M = 4.89 (see Figure 5-5). The functions perceived as most supportive are the protocol of missed communication events, the feedback on smartphone usage and stress level, and the priority assistant. Beyond the functions explicitly covered with items, intervention group participants reported in an open question that the separation of personal and work-related contacts was supportive.

Figure 5-5: Average Assessment of Different Functions Supporting Users' Work-Life Balance



5.5 Implications for Research and Practice

ICT-based availability is widely regarded as a source of detrimental outcomes, such as increased work-life conflict and stress (e.g., Ayyagari et al., 2011; Barley et al., 2011; Boswell & Olson-Buchanan, 2007). Nevertheless, in cases, in which being available is in line with individuals' motives, preferences, and perceptions, ICT-based availability can be beneficial as well, for example by helping individual to manage different life domains more effectively (Diaz et al., 2012; Sayah, 2013; Towers et al., 2006). Therefore, any solutions geared at alleviating availability's detrimental effects by restricting the amount of availability concurrently bear the risk of inhibiting desired availability and, thereby, hindering individuals from the improving effects.

Against this background, the goal of the design science research presented in this study was to develop and evaluate the Availability-Monitor and Availability-Manager as two smartphone applications that effectively support individuals in managing their availability in accordance with their individual availability preferences. Thereby, an aligned availability is possible that facilitates desired availability and inhibits unsolicited availability. This research provides several implications for research on the relationship between ICT-based availability and various outcomes as well as for employers and providers of ICT.

First, this research contributes to a better understanding of individual availability preferences. In extension of boundary theory and the human agency perspective, the conducted qualitative and quantitative study provide new insights into how individuals' abstract boundary management preferences translate into tangible availability preferences. Hereby, three characteristics of individual availability preferences are of particular importance. Individuals' preferred availability vary depending on (1) the life domain, (2) their current context, and (3) the type and priority of contacts. Accordingly, availability preferences are not stable within an individual but exhibit intra-individual variability. Hence, this study adds to a more differentiated theoretical perspective on boundary management, highlighting the importance of acknowledging that availability preferences differ both across individuals and situations. Seizing on this notion, research on the consequences of ICT-based availability should consider potentially moderating effects of individual availability preferences and, hereby, account for within-person variability of these preferences. With regard to the management of individuals' availability, these results point to the need to enable individuals to adapt their actual availability to their momentary availability preferences resulting from life domain, context, and contact. The provided ICT-based solution does so by offering a selection of five predefined and additional self-defined availability modes.

Second, the results of the evaluation study indicate that availability management applications that allow a differentiated, individually and situationally adaptive management of users' availability have the potential to contribute to users' well-being. In particular, the intervention group exhibits significant increases in work-life balance and significant decreases in exhaustion and psychological distress, with medium effect sizes. If ICT-based solutions actually succeed in enhancing users' well-being, as implied by these results, they have the potential to contribute to sustaining users' well-being and capabilities in the long run and, thus, provide a pathway to responsible digitization. This is particularly important not only for ICT users but also for employers, since well-being is significantly associated with job-related outcomes such as work performance, productivity, and turnover, as prior mentioned (see Chapter 1.1 and also e.g., Tarafdar, Tu, Ragu-Nathan, & Ragu-Nathan, 2007; Tenney, Poole, & Diener, 2016; Wright & Huang, 2012).

5.6 Limitations and further Research

The study reveals several limitations that provide implications for further research as well as practitioners. As the participants' assessment of the utility of the various design elements implemented in the applications as well as their usage frequency show, receiving feedback on their ICT usage behavior and their mental state is of great importance for users. Future research is needed to investigate, to what extent the availability management facilitated by ICT-based solutions explains the positive effects. Moreover, acceptance and continuous usage of solutions like the developed smartphone applications in this study depend highly on the users' social environment. Only if supervisors, colleagues, spouses etc. are sympathetic in situations, in which users preferred to be unavailable for them, will the users adapt availability management applications and employ them continuously. Candid and mutual communication about personal availability preferences and expectations should therefore accompany the implementation of availability management tools. Employers could launch initiatives to foster both the usage of availability management applications and agreements on rules for employees' availability and unavailability at the team-level. Finally, the evaluation study reveals that user acceptance and utility perception are negatively affected by the complexity of the availability management application. Thus, providers of ICT-based availability management tools should place great emphasis on ease of use.

The findings and implications of our evaluation study need to be considered in light of its limitations. First and foremost, while the sample contains employees from three different industries and various hierarchical levels, it is too small to generalize the results. Further research is needed to test availability management applications in field studies with larger samples. Thereby, testing the transferability of the study findings, for example to other industries or employee groups, is necessary. Additionally, it should be noted that the study design was quasi-experimental, as the group assignment depended on the technical requirements to install the applications. Therefore, the participants were not randomly assigned to each group (Cook & Campbell, 1979; Coolican, 2009). Hence, the causality and internal validity of the results are restricted and further studies with randomly assigned groups are needed to validate the findings. Besides, future research may apply study designs comparing technological and non-technological interventions, such as a design with an intervention group using the application, a control group and a group attending a training about boundary and availability management. Furthermore, the results show a significant difference between work-life balance and exhaustion at t_0 and t_1 for the control group. The changes in the outcomes for the control group can be explained with their participation in the kick-off survey: Individuals of both groups – intervention and control group – filled-out this survey with questions about their well-being, their work-life balance, and exhaustion. Reflecting on their current work-life balance and exhaustion in this questionnaire may have led to reflecting on their work-life balance and exhaustion for the next weeks (Andrews & McKennell, 1980), resulting in adapting their behaviors, such as additional boundary management tactics, in order to improve their work-life balance and exhaustion. Still, this finding supports the idea of validating the results with different study designs. Lastly, another limitation of the evaluation study is the length of application usage phase. Particularly in the case of complex applications with a variety of different functions, users might need more time to gain comprehensive insights into the applications' potentials and to assess their utility profoundly.

5.7 Conclusion

The design science research presented in this study contributes to the development and dissemination of more fine-grained, differentiated ICT-based solutions for availability management. Such solutions help users in simultaneously ensuring availability when desired and preventing violations of availability preferences by inhibiting unsolicited availability. Thereby, ICTs themselves could prevent users from suffering from detrimental effects of ICT-based availability while at the same time enabling users to benefit from its advantages.

6 ICT-based Physiological Measurements: Comparing Stationary and Wearable Devices [3]

Wearable computing devices, wearables for short, open promising possibilities for organizational research as they allow to objectively measure behavioral constructs such as stress, consumer behavior, boundary spanning, or positive social interactions at work, as also outlined in Chapter 1 (Bliese et al., 2017; Cascio & Montealegre, 2016; Chaffin et al., 2017). Wearables are small, easy to be worn, and equipped with a sensor technique (Tamura et al., 2014; Tehrani & Michael, 2014). Due to the improved availability of relatively cheap wearables, their application becomes affordable, further increasing their prominence in organizational research (Cascio & Montealegre, 2016; Chaffin et al., 2017). Beside the possibility to record behavioral, physical measures such as the co-location and verbal activity via Bluetooth, infrared, and microphone sensors of wearables (Chaffin et al., 2017), a promising area for application of wearables in organizational research lies in recording physiological measures.

In general, as previously outlined in Chapter 2, physiological measures, also referred to as psychophysiology, depicts physiological processes of the human body that, in turn, reflect psychological and behavioral constructs (Cacioppo et al., 2007). Physiological measures are parts of the different human nervous systems respectively, in particular the CNS, PNS, and the cellular and humoral system. Examples of physiological measures of each nervous system are event-related brain potentials (ERPs) as a measure from the CNS, skin conductance levels (SCL) as a measure of the PNS, and cortisol levels as a measure from the humoral system (Cacioppo et al., 2007). Even genetics of attitudes and behaviors for example in work settings are already explored (Arvey et al., 2016). As measures of the cellular and humoral system are mainly recorded with non-technological devices (e.g., saliva samples, blood, hairs), the present study focusses on physiological measures of the CNS and PNS.

As aforementioned, physiological measures as implicit measures provide valuable, objective insights into arbitrary physiological human processes beyond the conscious awareness (Beck-

[3] This chapter is based on a working paper from Schneider (2019). As the single author, I designed and conducted the described data collection, the data analyses, the comprehensive literature reviews, provided guidelines, and the writing of the paper.

er & Menges, 2013; Cacioppo et al., 2007; Heaphy & Dutton, 2008; Massaro & Pecchia, 2019). Furthermore, explicit measures for example self-report measures are often plagued with self-report bias, social desirability, and retrospective (Akinola, 2010; Chaffin et al., 2017; Murray & Antonakis, 2019). Thus, organizational scholars increasingly invoke that the time is ripe to give physiological measures greater attention in organizational science and enrich organizational theories with physiological and neuroscientific techniques (Becker & Menges, 2013; Ganster et al., 2018; Heaphy & Dutton, 2008; Murray & Antonakis, 2019).

The interest of measuring physiological measures within organizational sciences is emerged in the past, resulting in a kind of hype (Ganster et al., 2018; Jack et al., 2019). Much organizational research has focused on peripheral physiological measures of the PNS that are referred to stress and well-being processes, with an upward tendency of research that examines the CNS in the last decades (Becker & Cropanzano, 2010; Ganster et al., 2018; Waldman et al., 2017). However, while some research areas of physiological measures are predominately present, others, particularly of the PNS, are absent in organizational sciences beside using them as well-being measures (Christopoulos et al., 2019; Massaro & Pecchia, 2019; Murray & Antonakis, 2019). To this end, physiological measures are not certainly included in the toolbox of an organizational scholar that comprises principally methods regarding surveys, observations, or interviews (Bono & McNamara, 2011; Heaphy & Dutton, 2008; Waldman et al., 2019). To this end, there is no deeper understanding or an in-depth knowledge of physiological processes, their mechanisms and measures as well as their recording with different devices (Ganster et al., 2018; Heaphy & Dutton, 2008). Notwithstanding, organizational scholars have to be aware of the functional properties of physiological measures related to behavioral constructs, but also methodological properties of physiological measures to design rigorous studies with an appropriate validity. The methodological properties consist of important anatomical and mathematical properties, and information about the measuring method considering that physiological measures follow their own basic rules (Heaphy & Dutton, 2008). For instance, each physiological measure has its own temporal constant referred to as the time a physiological measure evolves (Gratton, 2007). With all of that said, organizational scholars need to overcome the hurdle of their unfamiliarity with physiological measures and get to know better the expectations and hype that come along with the recent discussion in organizational sciences regarding physiological measures (Murray & Antonakis, 2019).

The rapid advances in devices, particularly regarding wearables, are promising, which allow a more feasible access recording physiological measures for organizational scholars (Akinola, 2010; Ganster et al., 2018; Heaphy & Dutton, 2008; Ilies et al., 2016; Waldman et al., 2019). In particular, wearables facilitate the requirement of a fundamentally previous knowledge of devices that record physiological measures. For instance, the use of an

ECG to record the HR of a participant requires knowledge about different types of electrodes and their placement, also referred to as lead (e.g., according to Einthoven). Recording the same physiological measure (i.e., HR), a wearable wristband can simply be put on the wrist of the participant like a watch, while no further knowledge is required. In line with this example, the peripheral physiological measures of the PNS probably benefit the most from these advances by providing relatively cheap and easy to use wearables, while neuroscientific measures still require more elaborate devices and deeper expertise to use them (Ganster et al., 2018). Thus, peripheral physiological measures of the PNS that are recorded with wearables, wearable-measured physiological data for short, are of particular interest.

Albeit the aforementioned promising notion, little research is published that examines the reliability and validity of physiological data such newer wearables record (Chaffin et al., 2017; Eatough et al., 2016). In fact, recent research comprehensively outlines the functional properties of certain physiological measures and, thereby, their existing or possibly new application to organizational research (e.g., Becker & Cropanzano, 2010 for organizational neuroscience; Christopoulos et al., 2019 for EDA). However, while this contributes to an appropriate construct validity of future studies, a deeper discussion of devices and key methodological issues, in particular regarding recent advances in wearables recording physiological measures, are provided rarely (Eatough et al., 2016). This shortfall potentially obscures the pitfalls that come along with the recording of physiological measures, and proceeding and analyzing of wearable-measured physiological data. In particular, resulting from the methodological properties of physiological measures, devices have to meet certain, crucial requirements. For example, devices should record with an appropriate sample rate (i.e., frequency in Hz) for the temporal constant of a physiological measure. Traditional, mostly stationary devices meet these requirements with a certain reliability and validity. However, wearables are not yet well understood as they are developed making a compromise between the methodological requirements and functional requirements that ensure the low intrusion and flexibility of wearables (e.g., size, power consumption). Thus, Chaffin et al. (2017) made a plea as one of the first for researchers to validate the certain sensor components of wearables that will be used for research purposes in organizational research. Thereby, the authors provide construct validation protocols for wearable-measured behavioral and physical data that reflect behavioral constructs and is recorded via Bluetooth, microphone, and infrared sensors. The second study of this thesis follows that plea by revealing the pitfalls of wearable-measured physiological data and providing standards for referring to or designing own rigorous studies that determine the reliability and convergent validity of wearable-measured physiological data.

The second study of this thesis aims at extending the aforementioned research and addressing its concerns guided by three research questions:

(1) How should organizational scholars apply wearable-measured physiological measures for their research to be able to draw reasonable inferences from their findings?

(2) Which validation protocols exist in recent research for wearable-measured physiological data and how appropriate are they?

(3) To what extent can the measurement performance of different wearable devices be compared with a stationary device to measure physiological stress?

Based on these research questions, four main research goals are pursued. With the focus on functional properties of physiological measures and the application to organizational research and audiences, which requires an in-depth knowledge about physiological measures and their devices, most preceding research fails to consider methodological properties in regard to recent advances (i.e., wearables) and introduce them to organizational scholars new to the field. In this regard, methodological issues coming along with wearable-measured physiological data are not yet well understood so far. Thus, the second study provides insight into recording physiological measures with wearables by firstly introducing interested organizational scholars to the opportunities, but also pitfalls of wearable-measured physiological data. Thereby, the focus is preliminary on main methodological properties of physiological measures, their requirements on devices, and key methodological issues of wearable-measured physiological data. Second, the aim is to provide a rigorous standard of designing studies that are recording, processing, and analyzing wearable-measured physiological data. Thereby, critical steps are proposed in a guideline, with which organizational scholars are able to increase the rigor of the research design and the use of wearable-measured physiological data considering the prior discussed methodological properties and issues. This provides a common methodological knowledge and understanding concerning wearable-measured physiological data for interested organizational scholars. As the first two goals provide context for an expanded discussion of reliability and validity of wearable-measured physiological data, the third goal of the second study of this thesis is to accomplish an empirical basis for the decision of an organizational scholar to use a certain wearable for research purposes. In particular, previous research and interdisciplinary standards about methods determining reliability and validity are reviewed and evaluated following certain criteria for the appropriate application of wearable-measured physiological data. These criteria concern the prior discussed methodological properties and key methodological issues of this kind of data. Thus, organizational scholars should be able to distinguish between rigorous studies that examine the reliability and validity of wearable-measured physiological data using appropriate methods and nonrigorous studies.

Furthermore, building upon the evaluation, appropriate methods provide a standard to design an own, rigor validation study with wearable-measured physiological data. Forth and finally, the aim is to examine the applicability of the outlined standards and, thereby, offer researchers a practical example. Therefore, a measurement comparison study is conducted with two wearables and a stationary device recording peripheral physiological stress measures (HR, HRV) according to the aforementioned AL-model in a rigor study design (TSST, Kirschbaum et al., 1993).

With all of that said, the contributions of the ICT-based Physiological Measurements study are twofold. First and foremost, the present study contributes to overcome the hurdle of unfamiliarity and high expectations that organizational scholars made cautions about applying physiological measures in their research (Murray & Antonakis, 2019). In this regard, by supporting the benefit from the more feasible access and application of wearables in organizational research, the study provides a contribution to the encouragement of organizational sciences to further use wearable-measured physiological data not only more frequently, but also with an increase of validity of their claims in their further research. Hence, organizational scholars are able to design their own rigor studies enriched with wearable-measured physiological data that provide reasonable conclusions from their findings. Second, this second study provides an integrative view that goes beyond previous research by discussing both functional and methodological properties of wearable-measured physiological data as well as theoretical standards and practical tools to adopt this data in organizational research. Further, as the present ICT-based Physiological Measurement Study gives an overview for more generic considerations, it supports the organizational scholar new to the field to overlook the broadness of the topic and, thereby, the opportunities, but also pitfalls.

Chapter 6 is structured as follows. First, methodological properties of physiological measures and their requirements regarding devices recording such physiological measures are described. To this end, it is evaluated how and to what extent wearables meet these requirements compared to traditional stationary devices. Furthermore, the opportunities and pitfalls of wearables are weighed. This section is summarized by outlining key methodological issues that need to be considered in regard to wearable-measured physiological data. Next, a guideline is proposed consisting of several critical steps of recording, processing, and analyzing wearable-measured physiological data. Then methods for determining reliability and validity are described and further evaluated with certain criteria regarding their appropriate application for wearable-measured physiological data. By applying the aforementioned guideline and methodological standard for determining the reliability and convergent validity of wearable-measured physiological data, the measurement comparison study is outlined and its results are further discussed. The chapter concludes with a discussion of further research agenda strategies.

6.1 Weighing the Pros and Cons of Wearables Regarding Methodological Properties

The purpose of the following section is to briefly describe main methodological properties of physiological measures, particularly their important anatomical and mathematical properties, and information about the measuring method. Thereby, requirements for devices, study designs, and analyzing the data with statistical methods are derived. By building upon the methodological properties and derived requirements, the properties of wearable and stationary devices are evaluated regarding how and to what extent they meet these requirements. Thereby, the opportunities and potential pitfalls of wearables are discussed and weighed against each other. Key methodological issues are outlined as a summary that need to be considered in regard to wearable-measured physiological data.

6.1.1 Methodological Properties of Physiological Measures and Derived Requirements

Table 6-1 provides a summary of the methodological properties and their requirements that are outlined in the following, respectively. In terms of recording, four key methodological properties need to be considered. First, most physiological measures of the CNS and PNS follow their own basic temporal rules regarding their time constant (Gratton, 2007). The time constant is referred to the time, a physiological measure evolves. For instance, event-related brain potentials (ERPs, see the next section for a description) recording with an EEG are fast measures evolving within milliseconds, measures of EDA evolve slowly over seconds or minutes, and HR is an intermediate measure between both extremes (see also Figure 3-3 in Chapter 3.2). The time constant depends on several factors, for example on the latency defined as the temporal distance between the presentation of a stimulus or event and the initiation of the physiological measure. Fast measures provide a good temporal resolution as the effects of different stimuli or events in rapid succession can be distinguished (Gratton, 2007). Second, while recording the signal of the physiological measure only once is often not of interest and meaningful, physiological measures are continuously recorded (Gratton, 2007; Jennings & Gianaros, 2007). Hence, this results in a large data quantity that need to be separated into recording intervals of particular interest for researchers. Third, physiological measures do not only differ in their properties between themselves, but also within regarding individual differences (Gratton, 2007). Individuals show a different amount or individual changes over time resulting in a trait-like difference (Ganster et al., 2018). The changes are dependent on the individually initial position, which is also referred to as a baseline (Gratton, 2007; Jennings & Gianaros, 2007; Massaro & Pecchia, 2019). For instance, a higher baseline (e.g., higher HR) may result in a limited increase after the presentation of a stimulus that, in turn, may affect the statistical analysis. This dependency is also called initial value dependency or principle of initial values (Jennings & Gianaros, 2007; Myrtek, 1984; Wager et al., 2007). Fourth, it needs to be considered that physiological measures are highly suggestible through other stimuli as the actual treatment stimuli (i.e., non-treatment stimuli). To this end, environmental stimuli (e.g., temperature) and individual stimuli and processes (e.g., movements, anxiety) may cause changes that the treatment stimuli do not provide.

In regard of the temporal properties, it is required for devices that the physiological measure is recorded with an appropriate sample rate (Gratton, 2007; Jennings & Gianaros, 2007). This is referred to the number of a repeating signal per second (mostly in the unit hertz, Hz). Based on the time constant of each physiological measure, there is an appropriate sample rate for the signal to record. If the sample rate is too low or too high, it arises the peril either to miss a signal or to measure noise that obscure the signal of interest (Jennings & Gianaros, 2007). For example, the risk of aliasing increases, which causes frequencies that are higher as twice the frequency of the physiological measure and, thus, noise (Gratton, 2007). To separate the continuous recording of physiological measure and large data quantity into interesting recording intervals, the devices need to provide a function to tag the beginning and end of each recording interval (Jennings & Gianaros, 2007). To this end, researchers are able to recognize the interesting intervals while processing the recorded physiological data. Prior, the recording intervals should be scheduled in the study design. Thereby, the intervals' length should be sufficient for the time constant of the physiological measure and equal, if possible. Because of the large data quantity, devices should display an appropriate battery and data storage that prevents data losses (Tamura et al., 2014; Tehrani & Michael, 2014). In terms of the individual trait-like difference in physiological measures, it is recommended to examine a combination of several physiological measures, if possible without interferences (Ganster et al., 2018; Jack et al., 2019). An important consideration for the study design regarding the initial value dependency is to schedule how, when, and how long the baseline is recorded for each participant (Gratton, 2007; Jennings & Gianaros, 2007). In terms of the suggestibility of physiological measures, the recording should be as nonintrusive as possible for the participants to prevent that the device itself affects the recording, for example by inducing fear or stress. Second, the devices should provide different additional sensors to record several complementary physiological and control measures that indicate the non-treatment stimuli.

Table 6-1: Methodological Properties of Physiological Measures and their Requirements for Devices, Study Designs, and Analyzing with Statistical Methods

	Methodological Property	Description	Requirements
Recording	Temporal properties		Recording with an appropriate sample rate for the physiological measure
	Time constant	Time, with which the physiological measure evolves (e.g., milliseconds, seconds to minutes, hours)	
	Continuous recording and large data quantity	Physiological measure is continuously recorded resulting in a large data quantity	Function to tag recording intervals
			Appropriate battery and data storage
			Scheduling appropriate recording intervals of particular interest
	Individual changes over time and initial value dependency/principle of initial values	Physiological measure shows individual differences and individual changes over time dependent on an individually initial position (i.e., baseline)	Need to record a baseline for each participant
	Suggestibility through non-treatment stimuli	Physiological measure is suggestible through other stimuli as the actual treatment	Recording as nonintrusive as possible to prevent a suggestibility through device
			Different additional sensors to record several complementary physiological and control measures (e.g., respiration, temperature)
Data Processing	Individual processing and down sampling of raw data	Data of physiological measure has to be processed and down sampled for each participant and recording interval	Access to raw data of physiological measure to process the data replicable
	Low individual data quality caused by:	Data of physiological measure shows low quality for a participant	Real time streaming mode to initially control the data quality
			Excluding the participant from additional analyses
	Missing signals	Signals of interest were missed	Recording with an appropriate sample rate for the physiological measure
			Sufficient length of recording intervals
	Moving artefacts	Data shows unacceptable values caused by movements and shifting devices	Robust devices
			Acceleration sensor to control for moving artefacts
	Wrong placement	Data shows unacceptable values or missing signals caused by a wrong placement of the device or electrodes	Easy handling of a device

Note. Black edging cells indicate a fulfillment of the requirement by a stationary device, the grayed out cells by a wearable device; the dashed lines indicate that a fulfillment by a stationary device is not ensured as a key methodological issue, the shaded cells by a wearable device.

	Methodological Property	Description	Requirements
Analyzing	Violations of assumptions for statistical methods	Physiological data violates often several assumptions of statistical tests and methods	Physiological data can be transformed according to different procedures (e.g., logarithm)
	Normal distribution	Physiological data shows rarely a normal distribution	
	Linearity	Physiological data is often not linear	
	Outliers	Physiological data shows often many and extreme outliers	
	Unrelated errors and homogeneity of variance	Physiological data correlates within the person between different measures	
	Initial value dependency/Principle of initial values	For a description see the recording section	Difference values can be computed of physiological data from the baseline and a possible treatment
	Non-relatedness (Sensitivity, specificity)	Physiological data is rarely related to other implicit or explicit measures	Awareness of the property in the analysis and study discussion

Two methodological properties need to be considered for processing. First, while raw physiological data is "characteristically fallible, large in quantity, individualistic in quality, and low in intrinsic interest" (Jennings & Gianaros, 2007, p. 819), the recorded physiological data has to be processed and down sampled for each participant and recording interval. Thereby, it is necessary to reduce the physiological data at a level of interest according to official recommendations of the particular societies and recent research (e.g., Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996 for HRV). Second, the quality of the recorded physiological data need to be controlled (Gratton, 2007; Jennings & Gianaros, 2007). A poor data quality is caused by missing signals of interest that occurs if the sample rate or the recording intervals are not appropriate for the time constant. Furthermore, data may show moving artefacts, in particular unacceptable values caused by unexpected movements of the participant, and thereby, shifting devices (Jennings & Gianaros, 2007). Unacceptable values or missing signals may also occur, if the device or the electrodes are placed wrong (Christopoulos et al., 2019).

Therefore, devices should provide researchers access to the raw physiological data (Chaffin et al., 2017). Because processing the data should follow the recommendations of recent literature and the particular societies, this requirement is crucial to ensure a replicable processing procedure in organizational research. As a requirement for controlling the data quality, devices should provide a real time streaming mode that facilitate the initially control of the data before recording. Furthermore, the quality control may also result in excluding participants from additional analyses (Jennings & Gianaros, 2007). To prevent missing signals, it is required that the devices record with an appropriate sample rate and the length of the recording intervals is sufficient for the time constant (Gratton, 2007; Jennings & Gianaros, 2007). Furthermore, the devices should be robust against movements and provide acceleration sensors to control for moving artefacts. An easy handling prevents low data quality caused by a wrong placement.

Three methodological properties need to be considered for analyzing processed physiological data. Noted here that the following section refers to physiological data that is quantitative, not qualitative such as data recorded from fMRI (Jack et al., 2019). First, physiological data often violates the assumptions for statistical methods. In particular, physiological data is rarely normally distributed, may violate the assumption of linearity, and show many and extreme outliers (Massaro & Pecchia, 2019; Wager et al., 2007). Additionally, physiological data may correlate within the person between different physiological measures and, thus, violates the assumptions of unrelated errors and homogeneity of variance (Jennings & Gianaros, 2007). Second, the prior discussed initial value dependency is another methodological property that needs to be considered for the analysis (Jennings & Gianaros, 2007; Myrtek, 1984; Wager et al., 2007). Third, physiological data is rarely related to other implicit or explicit measures such as survey measures (Akinola, 2010; Heaphy & Dutton, 2008; Semmer, Grebner, & Elfering, 2004). Besides, their relationship is characterized by the sensitivity and specificity of the physiological measure, as outlined in detail in Chapter 2.1.3.

As a requirement, the influence of these assumptions' violations and methodological properties has to be examined (Wager et al., 2007). To this end, data can be transformed according to different procedures such as logarithm and outliers can be eliminated (Wager et al., 2007). For the initial value dependency, it is required to compute difference values by subtracting the values of the baseline from values of the stimuli presentation interval (Myrtek, 1984). However, while a data transformation makes the interpretation of the results difficult, it is also recommended to occur nothing (Cacioppo, Tassinary, & Friedlung, 1990; Levey, 1980). With regard to the non-relatedness of physiological data, the organizational scholar has to be aware of that methodological property by designing the study, but also by analyzing and discussing possible contradictory study results (Akinola, 2010).

6.1.2 Properties of Stationary Devices and Wearables

Under laboratory conditions, physiological measures can be recorded using stationary devices such as functional Magnetic Resonance Imaging (fMRI) for ERP or ECG for HR and HRV. These devices have been shown to provide satisfactory reliability and validity (Berntson et al., 1997; Eatough et al., 2016; Fabiani et al., 2007; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Further, recording allows high and appropriate sample rates and a real-time transfer from the device itself to a computer (Sharma & Gedeon, 2012). Despite their methodological advantages, stationary devices come with several drawbacks (Eatough et al., 2016; Sharma & Gedeon, 2012). First, they are rather inflexible because they need a wired connection to a computer. Second, recording with stationary devices is substantially intrusive on participants because of their inflexibility and required body involvement such as placing electrodes on someone's chest for an ECG. Third, they are very expensive, which restricts the number of devices available and as such the number of participants per time.

With regard to the requirements that are derived from the methodological properties, stationary devices provide an appropriate sample rate for the physiological measure and mostly a function to tag the beginning and end of each recording interval. Because of the wired connection, no further battery and data storage as the storage of the connected PC is required that is mostly appropriate for the recording. Additionally, stationary devices provide access to raw recorded data and a real time streaming mode on the connected PC. However, most of the stationary devices are intrusive resulting in the risk to affect the physiological measure because of a suggestibility through the device itself. Furthermore, it is often not intended to record additional, complementary physiological or control measures. An example is the Biopac MP 36 (Biopac Systems Inc., Goleta, USA) that provides four channels recording a wide range of physiological measures. However, it needs to be considered that some physiological measures are sensitive to other sources of electrical current (e.g., EEG, Jack et al., 2019). Regarding moving artefacts and the peril of a wrong placement, stationary devices are mostly not robust against unexpected movements or equipped with an acceleration sensor (Laborde et al., 2017). Additionally, they require an in-depth knowledge about their hardware and software properties as well as the handling with different types of electrodes and their placement (Ganster et al., 2018; Heaphy & Dutton, 2008). Thus, stationary devices are not suited for recording physiological measures in studies – neither in laboratory nor in field settings – that require a flexible, non-intrusive device and data from a larger group of participants.

In contrast, wearables allow more flexibility as they have a wireless connection with a receiver, come with substantially lower intrusion on participants, and considerably lower costs (Akinola, 2010; Ilies et al., 2016; Tamura et al., 2014; Tehrani & Michael, 2014). Consequently, wearables are a promising solution for organizational scholars recording physiological measures in both laboratory and field settings and with large samples. In general, by developing wearables, there is the need to make a compromise between the methodological requirements of physiological measures and functional requirements that ensure the low intrusion and flexibility of wearables (e.g., size of the sensors, power consumption of the processor). Thus, beside the opportunities of wearable-measured physiological data, the use of wearables also comes with several pitfalls. First, though stationary devices and wearables record the same physiological measure, the devices often differ in their fundamental technique, body locations, and sample rates, respectively (Berntson et al., 1997; Ellis et al., 2015; Tamura et al., 2014). For example, an ECG records HR and HRV with electrodes placed on the chest and a sampling rate of 1000 Hz (e.g., Biopac MP 36, Biopac Systems Inc., Goleta, USA). In contrast, wearables recording HR and HRV are often placed at the wrist and use a photoplethysmography (PPG) sensor with a sampling rate of 64 Hz (e.g., Empatica E4, Empatica Inc., Boston, USA). This is an optical sensor, which measures the elasticity of the arteries with the absorption of infrared light as an indicator of blood volume pulse (Tamura et al., 2014). As an aforementioned compromise, the lower sample rate is often caused by lower power consumption of the processor to prolong the battery life of wearables (Ellis et al., 2015; Tamura et al., 2014). Second, the lower sample rates of wearables result in larger intervals between single measures, which increases the likelihood of missing signals affecting the results (Shaffer, McCraty, & Zerr, 2014; Tamura et al., 2014). Furthermore, as wearables often record physiological data in the periphery of the body that result in delays, the length of measuring intervals should be sufficiently high (Shaffer et al., 2014).

With regard to the requirements, wearables are robust against moving artefacts and often equipped with an acceleration sensor that supports the control of such artefacts. The handling of most wearables is easy; an in-depth knowledge is often not required. To initially control the data quality, most wearables provide a real time streaming mode. As a main advantage, wearables are developed to be as nonintrusive as possible. Furthermore, they provide the function, mostly on the wearable itself, to tag the beginning and end of each recording interval. Most wearables are equipped with several additional sensors that facilitate the recording of complementary physiological and control measures such as the temperature. However, as the aforementioned pitfalls indicate, meeting the main requirements of appropriate sample rates is not ensured for wearables. In particular, official recommendations of the particular societies often only recommend sample rates that stationary devices are able to provide. New advances in wearables are rather neglected. Furthermore, because wearables have no wired connection to a PC, their battery and data storage are dependent on the devices' conditions such as size or function range. Thus, the storage is maybe not appropriate to record the physiological measure for longer time frames, but advances in wearables will improve this constraint. Moreover, the access to raw physiological data is not ensured for wearables. On the contrary, most wearables provide their own algorithms for both recording and processing the data. Thus, only already processed data is available for organizational scholars to further analyze it. Although this may facilitate the processing procedure for organizational scholars, it arises the peril that the wearable-own algorithm, if known, is not consistent to recent research and official recommendations, or not at all replicable.

Taking together, three key methodological issues need to be considered that are crucial to provide rigor studies applying wearable-measured physiological data and, in turn, reasonable conclusions from the findings. First, one key methodological issue is that it is unclear if the wearable met the requirement of the time constant to record with an appropriate sample rate. Second, if the sample rate is too low and the length of the recording interval too short, there is a key methodological issue to have a low individual data quality caused by missing signals that are of interest for the organizational scholar. Third, if there is no access to the raw physiological data, organizational scholars have to further analyze data, of which the processing procedure is not replicable and reportable to other scholars leading to another key methodological issue. Thus, sophisticated strategies for dealing with these methodological issues are required. Taken together, the quality of wearable-measured and stationary-measured physiological data might differ substantially and lead to different results. Consequently, there is a need to proof the reliability and validity of wearable-measured physiological data, especially, compared to data measured with stationary devices. The following section summarizes the methodological procedures in a guideline.

6.2 Guideline for Wearable-measured Physiological Data

In the following section, a guideline consisted of four critical steps for applying physiological measures and wearable-measured physiological data in organizational research serving as a rigorous standard is introduced (see Figure 6-1). The guideline was conducted after a comprehensive literature research identifying recent psychological and OB, computer science, medical, and methodological literature on the application of wearables and physiological measures as well as established official recommendations of the particular societies. The aim is for the guideline to provide a common methodological knowledge by enabling organizational scholars to increase the rigor of the research design and the application of wearable-measured physiological data for their own research considering the prior discussed methodological properties and key methodological issues. Furthermore, the guideline suggests a common understanding when assessing the quality of previous and recent research applying physiological measures recorded with wearables.

6.2.1 Step 1 Planning and Designing Research

Step 1.1 Hypothesis-driven research and adequate construct validity. First and foremost, the application of physiological measures in research should be hypothesis-driven by conducting an in-depth review of existing research (Jack et al., 2019). Particularly, by identifying the construct of interest and selecting the physiological measure existing research suggests to be related to the construct, an adequate construct validity can be achieved (Ganster et al., 2018). Thereby, it needs to be considered, if a combination of several physiological measures is required (Ganster et al., 2018; Jack et al., 2019). Furthermore, scholars should be aware of the particular sensitivity and specificity of the physiological measures (Mendes, 2016). To this end, they should define how the context of the designed study modifies these properties.

Step 1.2 Determining the dependent and independent variable. It is important to determine, if the physiological measure is the dependent or independent variable (Jennings & Gianaros, 2007; Laborde et al., 2017). A physiological measure as the dependent variable may differ between groups of different experimental conditions (e.g., inducing psychological stress or not, Egizio et al., 2008). With defining different groups based on the median of recorded wearable-measured physiological data for example, data can be used as an independent variable (Thayer, Hansen, Saus-Rose, & Johnsen, 2009). The used device predetermines this decision (Jack et al., 2019).

Step 1.3 Determining the research design. Organizational scholars should follow recommendations of existing research to determine their research design (Jack et al., 2019; Jennings & Gianaros, 2007). Considering the methodological properties of physiological measures, applying a combination of a within-subjects and between-subjects design is recommended (Jennings & Gianaros, 2007). To this end, the advantage of a within-subjects design is that within-subject statistical methods show a higher sensitivity for strong correlations between values of the same subject, which is beneficial for analyzing wearable-measured physiological data. However, the peril for carryover effects of different experimental conditions arises, which may affect the results caused by the temporal resolution of the recorded physiological measure. Therefore, a between-subject design should also be implemented (Jennings & Gianaros, 2007). Furthermore, it is recommended to determine the research design carefully and as simply as possible, by using simple paradigms and convergent methods to provide main effects (Jack et al., 2019).

Step 1.4 Determining the sample size. Similar to studies with explicit measures, it is required to calculate the sample size with a given statistical power and effect size previously (Jennings & Gianaros, 2007). By performing this power analyses, organizational scholars should be aware that wearable-measured physiological data may be underpowered and Cohen's guidelines about small to large effects may probably not fit (e.g., HRV, Quintana, 2017; blood pressure, Ilies, Dimotakis, & Pater, 2010).

Step 1.5 Determining the control variables. Organizational scholars should pay particular attention to assess control variables that may confound the recording of physiological measures and, thus, the study results (Jennings & Gianaros, 2007; Kirschbaum, Kudielka, Gaab, Schommer, & Hellhammer, 1999; Laborde et al., 2017). Beside the basic demographic variables, such as age and gender, additional variables regarding participants' health, intake of medication, and actual condition (e.g., sleeping time and quality, drinking coffee) should be assessed. Additionally, scholars should gather variables regarding the environment, for example the temperature of the experimental room, as prior mentioned. If the control of these variables is insufficient prior to the experiment or study, it may be necessary to exclude participants, who not fulfill the control requirements, afterwards (Kirschbaum et al., 1999; Laborde et al., 2017).

6.2.2 Step 2 Recording

Step 2.1 Considering the appropriate sample rate and choosing the wearable device. It is crucial to consider the appropriate sample rate for the physiological measure wanted to record in the study (Gratton, 2007; Jennings & Gianaros, 2007). To this end, organizational scholars should consult recent literature that considers recent developments in wearables for the particular physiological measure in addition to the official recommendations of the particular society. Beside the sample rate, it is needed to consider that the access to raw data is ensured and also in terms of privacy and ethical concerns that arises for institutional review boards and participants (Akinola, 2010; Ilies et al., 2016). Furthermore, organizational scholars should report the applied wearable and referred validation studies. The intrusion perceived by the participants can be additionally assessed with a questionnaire (Waldman et al., 2019). Organizational scholars should also evaluate the body location, type, and robustness of the wearable sensor that fit the most to their study design to prevent data losses and artefacts in the data (Chaffin et al., 2017). It is recommended to initially control the data quality before recording.

Step 2.2 Determining the recording intervals. Four questions need to be considered for determining the recording intervals appropriately (Jennings & Gianaros, 2007). First, which length of the recording interval is appropriate for the time constant of the selected physiological measure and sample rate? Second, it is important to consider, that the length of the recording intervals should be equal. Third, how it is possible to tag the beginning and end of each recording interval is another important question? Fourth, how, when, and how long the baseline is recorded? Thereby, they should review existing literature about the common baseline procedures for the particular physiological measure. Examples are to determine only a resting baseline, Vanilla baseline, where participants perform a task with minimal cognitive load (Jennings, Kamarck, Stewart, Eddy, & Johnson, 1992), or presenting participants videos with neutral stimuli during the baseline (e.g., Piferi, Kline, Younger, & Lawler, 2000).

6.2.3 Step 3 Data Processing

Step 3.1 Conducting a quality control of the data. Although most devices and their given software apply filtering algorithms during recording that filter noise from the signal, unacceptable values are still in the data (Gratton, 2007; Jennings & Gianaros, 2007). To enhance the ratio between the signal and the noise (i.e., signal-to-noise ratio) to a maximum, these values can be filtered both automatically with filter-commands and manually with a graphical editor (Gratton & Fabiani, 2016; Jennings & Gianaros, 2007). As no algorithm seems to be perfect in filtering, it is recommended to use a visual inspection (Eatough et al., 2016). Thereby, software assists the scholar in filtering unacceptable values by firstly suggesting and subsequently filtering them. An important consideration of this step is to differentiate precisely between unacceptable values caused by artefacts and real data that deviates from the normal (Jennings & Gianaros, 2007). The quality control step may also result in excluding participants, if the quality of their physiological data is too poor.

Step 3.2 Reducing the data. Raw wearable-measured physiological data has to be reduced because of its multidimensional nature (Gratton, 2007). In particular, the multidimensional nature of recorded physiological measures causes problems for the statistical analysis, for instance, an increasing probability for an alpha error because of an increasing number of observations (Sheskin, 2007). Thus, there is the need to reduce the data with signal processing steps. Mostly, the time dimensions of physiological measures is used for signal processing. Thereby, the raw recorded physiological measure is interpreted by applying an analytic model that estimates values for the underlying structure of the data. These analytic models are mostly referred to time domain and frequency domain analysis that are outlined in more detail in Step 3.2.1 (Gratton, 2007).

Step 3.2.1 Reducing the data with time-domain and frequency-domain analysis. In the time domain analysis, time is the main dimension, as particular aspects of the time series are interpreted (Gratton, 2007). Exemplary data from the time domain analysis are maximum, minimum, and amplitude over an interval. The time domain analysis differs, whether the data is averaged and counted throughout a complete time interval (i.e., tonic) or only analyzed regarding one point in time (i.e., phasic), for example the time preceding and following a stimulus (e.g., five seconds) (Jennings & Gianaros, 2007).

If physiological measures follow a periodic structure, the frequency domain analysis is the appropriate model (Gratton, 2007). Thereby, time is replaced as the main dimension. A new data set is created, in which data represents the proportion of the fluctuations occurring at particular frequencies of the total variability over time. Then, the most represented frequency in the data can be calculated. The Fourier Transform is a commonly used analytic model of the frequency domain analysis (Gratton, 2007).

In addition to the time dimensions of physiological measures, the spatial dimensions are also of interest for some physiological measures, particularly for those of brain activity. Surface maps, 3D inference, and analysis of 3D spatial data are examples of spatial dimensions analysis (Gratton, 2007).

The official guidelines of particular societies as well as more recent research provide an overview of the commonly used data processing methods. Table 6-2 summarizes the literature for each commonly used physiological measure. For a particular physiological measure dedicated software is available that supports to process the data in accordance with the guidelines. Processing the raw data with this software facilitates the comparability and replicability of the study findings that, in turn, contribute to the rigor of the study. Organizational scholars should report the used filtering and processed algorithms in detail as the results may vary based on such decisions (Chaffin et al., 2017).

Table 6-2: Commonly used Physiological Measures and their Recommendations for Data Processing

Physiological Measure	**Recommendations for Data Processing**
Functional imaging with fMRI	Balthazard & Thatcher, 2015; Waldman et al., 2017
qEEG and ERP with EEG	Balthazard & Thatcher, 2015; Fabiani et al., 2007; Waldman et al., 2017
Heart Rate Variability (HRV) with ECG or PPG sensor	Berntson et al., 1997; Massaro & Pecchia, 2019; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996
Electrodermal activity with electrodes	Boucsein, 2012; Boucsein et al., 2012

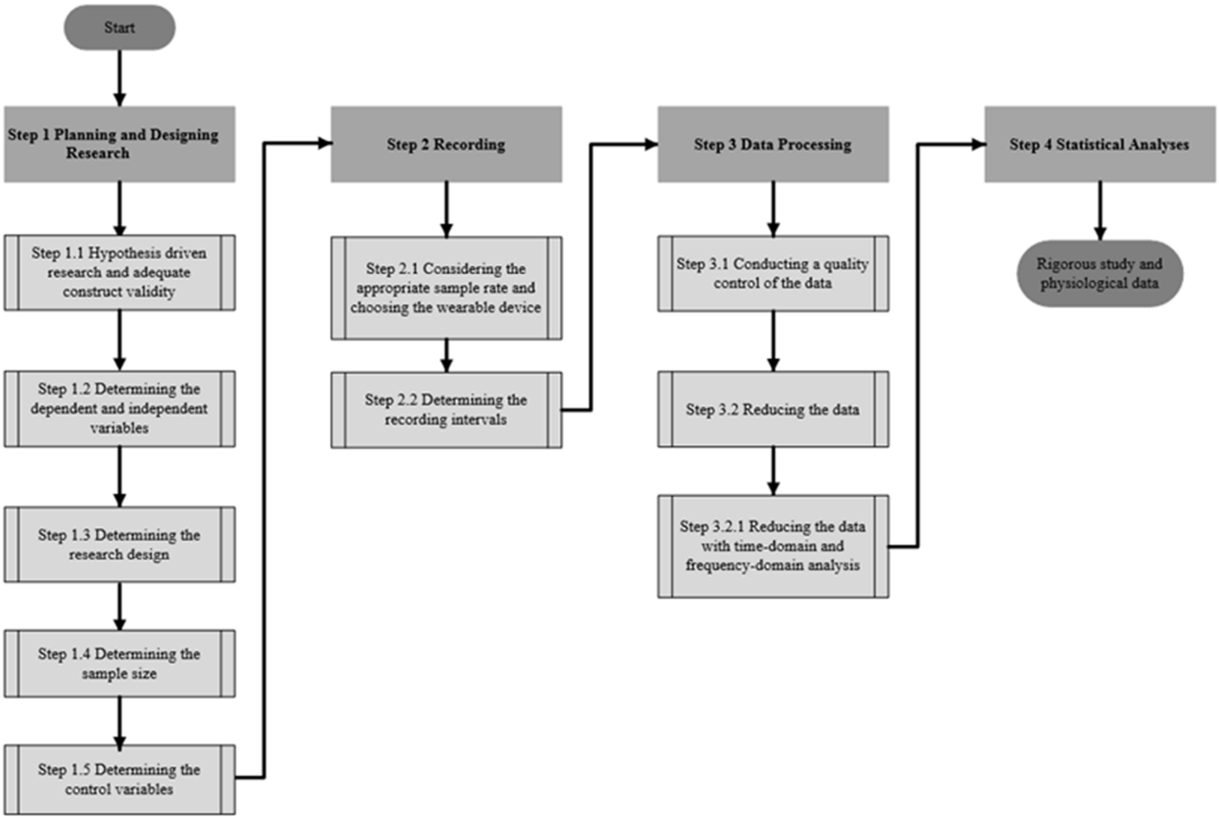
6.2.4 Step 4 Statistical Analyses

Based on the hypotheses, the appropriate statistical method should be selected. Studies applying physiological measures often record the data at several measurement time points from the same participant (Jennings & Gianaros, 2007). Thus, the statistical methods must consider the correlations between the data. To compare the mean scores of several experimental conditions or measurement time points, a repeated-measures t-test (for two groups/time points) or ANOVA (> two conditions/time points) can be applied (Sheskin, 2007). An analysis of covariance (ANCOVA) is beneficial to control for variables that are not of particular interest but may affect the physiological data (e.g., trait anxiety) (Jennings & Gianaros, 2007). To take a closer look at intra-individual differences and to account appropriately for the collinearity of the data, multilevel modeling and growth modeling can be conducted, likewise (Bliese & Ployhart, 2002; Raudenbush & Bryk, 2002). According to the literature review of Jennings and Gianaros (2007), the dominant statistical method for physiological data is analysis of variance (ANCOVA) followed by t-tests, regression, and correlation analysis. In recent research, it is often ignored to prior test the assumptions or to transform the data, although wearable-measured physiological data often misses the assumptions, as aforementioned. Additionally, nonparametric procedures are seldom used in the literature (Jennings & Gianaros, 2007). It is also recommended to control for multiple comparisons (Jack et al., 2019).

The outlined guideline was aimed to enable organizational scholars to design a rigorous study with recording, processing, and analyzing physiological measures and wearable-measured physiological data by providing them a standard for such procedures. However, in terms of the methodological issues of wearable-measured physiological data, an expanded discussion about its reliability and validity should lead in detail, as this is crucial to draw reasonable inferences from the study findings.

Figure 6-1 depicts all four steps of the guideline for wearable-measured physiological data.

Figure 6-1: Guideline for Wearable-measured Physiological Data



6.3 Overview of Methods for Determining Reliability and Convergent Validity of Wearable-measured Physiological Data

The purpose of the following section is to briefly describe common methods for determining the reliability and convergent validity of physiological data based on a review of interdisciplinary literature. Thereby, the focus is on methods that compare a new device (e.g., wearable with PPG sensor) with an established device providing sufficient reliability and convergent validity (e.g., stationary ECG). To this end, organizational scholars get familiar with the commonly used, interdisciplinary methods and should be enabled to distinguish between rigorous studies that examine the reliability and convergent validity of wearable-measured physiological data using appropriate methods and nonrigorous studies.

Existing literature does not provide a consistent approach for determining reliability and convergent validity of physiological data (Kottner et al., 2011). Instead, either statistical methods actually used for analyzing psychometric data are transferred to determine the reliability and convergent validity of physiological data (e.g., correlation analysis) or non-statistical procedures commonly used in medicine are applied. Additionally, how and to what extent these methods are appropriate and suitable for the methodological properties of physiological data in general and the key methodological issues of wearable-measured physiological data in particular are not evaluated so far. Being the first to cover the challenges of determining validity of wearable-measured data, Chaffin and colleagues (2017) provide construct validation protocols for behavioral and physical data such as the co-location and verbal activity in terms of boundary-spanning behavior recorded with Bluetooth, infrared, and microphone sensors of wearables. Kayhan and colleagues (2018) build on this research by applying a more complex research design for the validation of this data, in particular unstructured meetings. Beside specific plots for Bluetooth detection networks and analysis for speaking dominance, which are not quite appropriate for wearable-measured physiological data, they applied ANOVA, correlation analysis and Ordinary Least Squares Regression that will be part of the reviewed methods below. Additionally, Chaffin et al. (2017) provide an important notion for the validation of wearables that is also fundamental for this section. They highlighted that although available wearables change quickly due to rapid advances, the certain components do not differ substantively across different wearables recording the same measures. Thus, their focus is on the validation of certain components, not on a certain device. We follow this notion, as it is crucial for the rigor of further organizational research to refer on or design studies that determine the reliability and convergent validity of at least certain components of wearables recording physiological data (e.g., PPG sensor), if not on each applied wearable.

To structure the heterogeneous literature determining reliability and convergent validity of physiological data, methods can be broadly categorized into statistical and non-statistical procedures – each with several subcategories. Table A- 2 in the Appendix lists the categories, their subcategories, and associated test statistics, and exemplary studies using these methods for physiological data for each subcategory. In the following, each category with the methods of its subcategories is briefly introduced and subsequently evaluated. We evaluate the reviewed methods following certain criteria that concern the methodological properties and key methodological issues. In particular, the criteria are required data assumptions of test statistics and procedures, sensitivity for the methodological properties and key methodological issues, and economical applicability. At the end, we conclude by providing methods best suited for wearable-measured physiological data based on the evaluation.

6.3.1 Statistical Methods

The methods of the first category refer primary to methods that are appropriate for psychometric data differentiating between equality statistics and bivariate statistics. Hence, their hypotheses, underlying mathematical procedures and assumptions are geared to this type of data.

Equality statistics

Description of the methods. The subcategory equality statistics comprises several test statistics that have the basic analytic goal to test the equality of the mean of psychometrical data. Principally, the discussed test statistics are divided into parametric and nonparametric tests (Sheskin, 2007). While parametric tests make specific assumptions and need interval or ratio data, nonparametric tests make less assumptions and need at least nominal data. The parametric tests of this category are dependent t-test and one-way repeated measures ANOVA and their nonparametric equivalents Wilcoxon signed-rank test and the Friedman's ANOVA (Rey & Neuhäuser, 2011; Sheskin, 2007, 2011). With dependent t-test and WSR comparing the means of two groups, the one-way repeated measures ANOVA and the Friedman's ANOVA should be used to test the equality of the mean of more than two groups (Sheskin, 2007).

Bivariate statistics

Description of the methods. The analytic goal of the second subcategory bivariate statistics is to determine the reliability and convergent validity with different correlation and regression analysis. Relevant test statistics for the correlation analysis are the most frequently used and well-known Pearson's correlation coefficient (Cohen, Cohen, West, & Aiken, 2003). To test the convergent validity of multiple measures (i.e., physiological data) measured with multiple methods (i.e., devices), the multitrait-multimethod (MTMM) matrix can be compiled (Campbell & Fiske, 1959). When the correlations between the same physiological data (monotrait) measured with different devices (heteromethod) are large and significantly different from zero, convergent validity is achieved (Bagozzi, Yi, & Phillips, 1991; Campbell & Fiske, 1959). Another correlation coefficient to determine the reliability is the intraclass correlation coefficient (ICC) (Fleiss, 1986; LeBreton & Senter, 2008; McGraw & Wong, 1996; Shrout & Fleiss, 1979). Following three criteria (one- or two-way ANOVA model, random effects or mixed model, single or average measures) six different forms of ICC exist. The linear regression is also frequently used for physiological data predicting the data of one device from the data of the other (Altman & Bland, 1983; Cohen et al., 2003; Tabachnick & Fidell, 2013).

Evaluation

Data analyzed with the described methods of the category except the non-parametric tests must follow several assumptions, mainly independence of observations, normal distribution of the residuals, interval-scaled data, homoscedasticity, and linearity (Cohen et al., 2003; Field, Miles, & Field, 2013). Non-parametric tests have no distribution assumption and at least ordinal-scaled data as the required data level (Sheskin, 2007). Furthermore, the non-parametric tests are suited for studies with a smaller sample size (Sheskin, 2011). In terms of the methodological properties and issues, the methods are rather sensitive to violations leading to biased coefficients in the regression analysis, for example (Cohen et al., 2003). The sensitivity of violations of the normal distribution assumption of parametric methods decreases just if the sample size of each group is greater than thirty participants (Sheskin, 2007). Non-parametric tests exhibit lower statistical power compared to parametric tests, which leads to a higher probability for a type II error (Sheskin, 2007, 2011). Regarding the correlation analysis there is a tendency to overestimate the coefficients because physiological data of the same measure should already correlates to a certain level (Altman & Bland, 1983). Furthermore, correlation coefficients and ICC depend on the variability between and within participants and, thus, they vary between different samples. As a result, their estimates could be small although the data is reliable and valid (Altman & Bland, 1983). There is a high economical applicability of the test statistics in this category because they are standard procedures in common statistic programs like IBM SPSS.

6.3.2 Non-statistical Methods

The second category comprises non-statistical procedures that are developed for physiological data in general. These procedures are divided into simplified procedures and graphical procedures. Low or none statistical assumptions and a graphical-based analysis are features of the non-statistical procedures in this category.

Simplified procedures

Description of the methods. With the binary classification scheme the detected physiological data (e.g., IBI) are evaluated at the individual level and compared with the values from another device (Schäfer & Vagedes, 2013). Then sensitivity and specificity are computed for each device. A simplified regression procedure for physiological data is the Passing and Bablok regression following a non-parametric model (Passing & Bablok, 1983). Additional to the prediction equation similar to the linear regression, confidence intervals for the slope and intercept are calculated.

Graphical procedures

Description of the methods. The analytic goal in this subcategory is to determine reliability and convergent validity with graphical figures. Most commonly used, the Bland and Altman method is based on scatter plots that depict the difference between data of two devices against the mean of data of both devices for each participant (more detailed see: Altman & Bland, 1983; Bland & Altman, 1986, 1999). Furthermore, the mean difference, its 95% confident intervals (i.e., limits of agreement), and their 95% confident intervals for upper and lower limits of agreement are computed. The plot aims at evaluating a potentially systematic trend of deviance between the two devices, for example that the differences increase as the absolute values increase. A difference of zero indicates equality (Bland & Altman, 1999).

Evaluation

Being based on single values of each participant, the binary classification scheme has no data assumptions. As the linear regression analysis, the Passing and Bablok regression also requires linearity of the data as a necessary condition but has no distribution assumptions. For the linearity assumption, it is recommended to calculate a CUSUM test. The data for the Bland and Altman method should be normally distributed. However, the method is robust against outliers and non-normally distributed data (Bland & Altman, 1999). The economical applicability of the binary classification scheme is quite low, as the very time-consuming analysis has to be done for each participant. The economical applicability of the Passing and Bablok regression is comparable with the linear regression analysis and, thus, high. As the paper from Bland and Altman (1986) is ranked among the ten most cited statistical papers (Ryan & Woodall, 2005), the economical applicability is quite high. Compared to the test statistics of the first category it is additionally needed to compile figures.

6.3.3 Summarizing Evaluation

As the methods of each category come with several advantages but also drawbacks, it is not appropriate to select only one discussed method as the best suited for wearable-measured physiological data to determine its reliability and convergent validity. In particular, methods of the first category require more assumptions and are more sensitive for violations of their assumptions. As an advantage, these methods provide unanimous quantitative statistical criteria to determine the reliability and convergent validity and are commonly used test statistics in common statistic programs. The advantage and the disadvantages conversely pertain to the second category. Therefore, a combination of methods from both categories seems to be appropriate. Because they are less sensitive for violations of their assumptions, Pearson's correlation coefficient with MTMM matrix and ICC are selected as measures of the first category.

The Passing and Bablok regression with CUSUM-test and Bland and Altman method of the second category are selected due to their economical applicability and graphic representation of the data as a useful supplement to the unanimous quantitative statistical criteria. Table 6-3 lists the selected methods, their hypothesis to be tested for determining the reliability and convergent validity, and indicators that are relevant to confirm the hypothesis.

Table 6-3: Methods Evaluated as Best Suited for Wearable-measured Physiological Data

Category	Relevant Test Statistics	Hypothesis to be tested	Relevant Indicators for confirming the Hypothesis
Bivariate statistics	Pearson's correlation coefficient with MTMM matrix	There is a significant correlation for the validity diagonal values in the MTMM matrix (monotrait-heteromethod correlations) (H1).	*p*-value is significant
	Intraclass correlation coefficient	The ICC(A,1) for each comparison (wearable-stationary device) is significantly different from zero (H1).	Good to excellent ICC(A,1) (ICC > 0.75)
Simplified procedures	Passing and Bablok regression with CUSUM-test	The data measured with the wearable or stationary device are comparable (H1). The intercept (a) of the regression equation is zero, the slope (b) is 1. There is no significant deviation from linearity (H0).	95% confidence interval for the intercept a contains the value 0 and for the slope b contains the value 1. For the CUSUM-test the p-value is non-significant.
Graphical procedures	Bland-Altman-Plot / Bland Altman Method	Mean difference is close to zero (indicates equality), the limits of agreement are close to the mean difference.	No statistical criteria

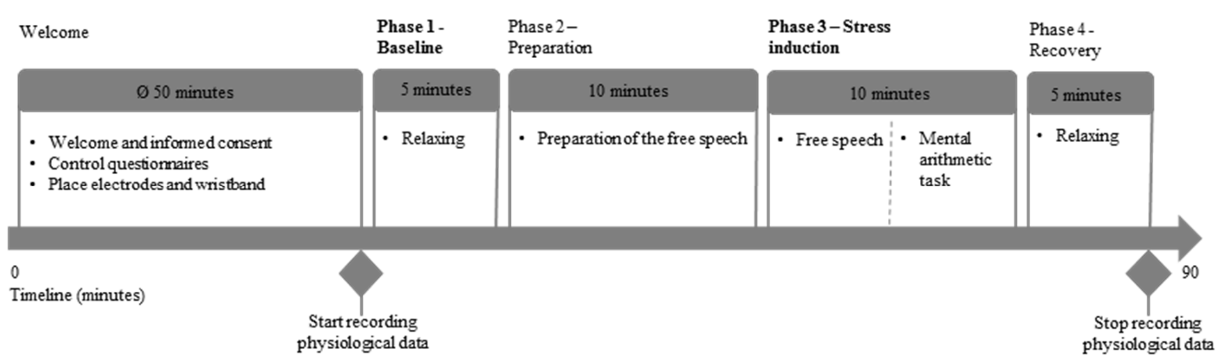
6.4 Experimental Comparison of different Physiological Measurement Devices

The experimental comparison is aimed at comparing three different devices to measure physiological arousal: a stationary device, a wearable breast strap and a wearable wristband collecting HR and HRV data measuring physiological stress. Beside the commonly used Biopac as a stationary ECG device, the innovative breast strap movisens and easy handling Empatica are used for the comparison. This experimental comparison study exemplifies the application of the proposed guideline and the best suited methods determining reliability and convergent validity as evaluated in the previous section. The results indicate the reliability and convergent validity of cardiovascular data collected with both types of wearables.

6.4.1 Step 1 Planning and Designing Research

The experimental design is a within-subject design and consists of the Trier Social Stress Test (TSST) (Kirschbaum et al., 1993). The TSST is a standardized and profoundly investigated protocol to induce psychosocial stress in individuals in a realistic scenario and serves as a gold standard for laboratory settings (Allen et al., 2017; Ganster et al., 2018; Kirschbaum et al., 1993; Kudielka, Hellhammer, & Kirschbaum, 2007). Thereby, participants are emphasized in a job applicant role, in which they have to perform a five minute long free speech followed by a five minute long mental arithmetic task in front of two evaluating observers. Other versions of the TSST were developed, for example for groups, children, and older adults (Dawans, Kirschbaum, & Heinrichs, 2011; Kudielka et al., 2007). Except the TSST for groups with slightly longer intervals, the versions do not differ in the procedure and set intervals compared to the original version. According to the original version of the TSST (Kirschbaum et al., 1993), the experiment was conducted in four phases: baseline (5 min), preparation of the speech (10 min), stress induction via TSST (speech 5 min, task 5 min), and recovery (5 min). This allocation is beneficial, because all intervals can be divided into the same length of five minutes. Figure 6-2 depicts the experimental procedure and recording intervals.

Figure 6-2: Recording Intervals of the Study and Procedure of the Trier Social Stress Test



Participants

Participants were recruited around the university by distribution of flyers and sending emails to interested participants from previous studies. Because the planned statistical methods are not included in software determining the sample size (e.g., g-power) and the effect sizes are not of particular interest for the comparison, the sample size was not calculated prior to the experiment. Instead, the determination of the sample size was guided by a comprehensive literature research on recent and previous validation studies. Thirty-two healthy adults aged between 19 to 35 years ($M = 25.53$, $SD = 4.31$) participated in the experiment. Because there were 3 data sets per participant (i.e., one for each device), 96 data sets had to be processed according to the data processing procedures outlined in Chapter 6.4.3. 17 were male and one of them was a smoker. None of them had a known cardiovascular disease. Most of participants were students from various different courses, such as psychology, computer science, and engineering. The participants received a monetary incentive of 10 €. As the study design was a within-subjects design, each participant underwent the TSST and had not to be randomly assigned to a condition.

Control Variables

In addition to the physiological data, survey data were collected (e.g., Short Stress State Questionnaire, Helton & Näswall, 2015). At the beginning, the participants were asked to fill in questionnaires about sociodemographic variables and control variables as outlined in step 1.5 of the guideline. Every participant fulfills the control requirements. Additionally, at the beginning and end of the experiment, the time and temperature in the experimental room were gathered.

6.4.2 Step 2 Recording

Stationary Device and Wearables

For cardiovascular data, it is recommended to use a sample rate of a minimum of 200 to 1000 Hz, which can be achieved by stationary devices (Berntson et al., 1997; Berntson et al., 2007; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Recent research considers newer developments indicating that also sample rates of 125 Hz and lower result in reliable cardiovascular data (Ellis et al., 2015; Shaffer et al., 2014). The physiological data in the present comparison study were recorded from three devices – as reference method, Biopac MP36 (Biopac Systems Inc., Goleta, USA), and two wearables: Empatica E4 (Empatica Inc., Boston, USA), and movisens EcgMove 3 (movisens GmbH, Karlsruhe, Germany). For a detailed description of the applied devices, see

Chapter 3.2.1. The lead of the ECG (Biopac MP36) was according to Einthoven with placing the electrodes by a qualified investigator. The participants put on the wristband Empatica E4 by themselves on the non-dominant hand. With being guided by a picture of the correct wearing position of the breast belt, the movisens was put on by the participant itself.

Recording Intervals

For cardiovascular data, it is recommended to record at least with an interval length of five minutes (Laborde et al., 2017). As the recording intervals in accordance with the TSST as the experimental procedure are not shorter than five minutes, this recommendation was followed. Two recording intervals are of particular interest, the baseline phase with an interval length of five minutes and the stress phase, where the participants performed the free speech followed by the mental arithmetic task, with an overall recording duration of ten minutes. The beginning and end of each recording interval was tagged with the function of Biopac. Afterwards, the time of each interval was transferred and combined with the data of the wearables.

6.4.3 Step 3 Data Processing

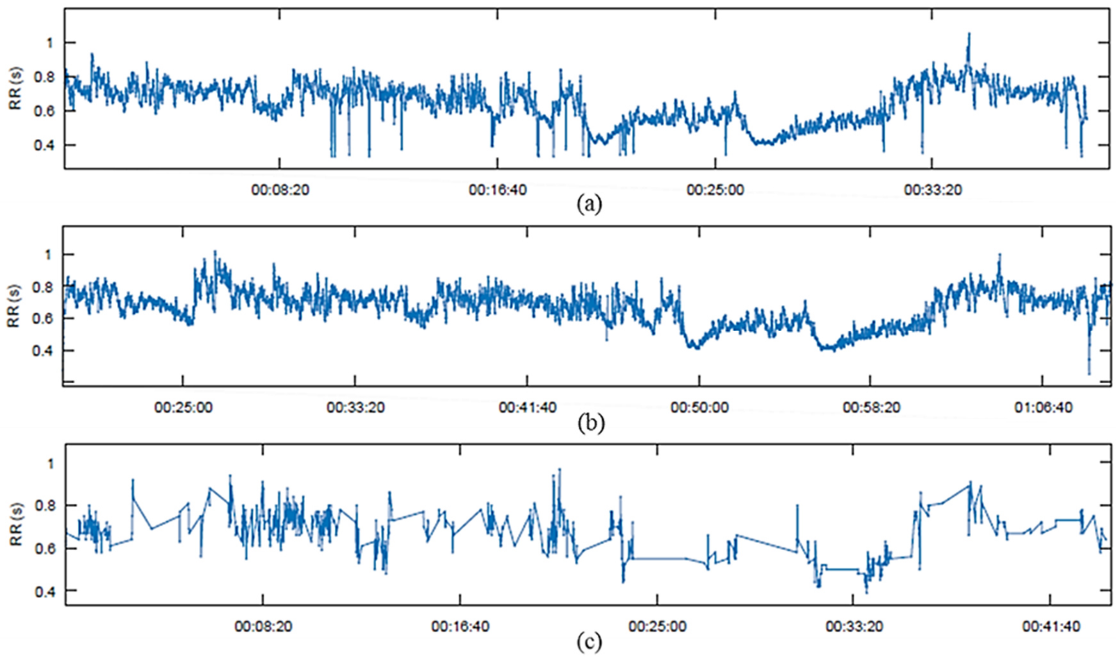
As outlined in Step 3 of the guideline, it is a major challenge during the data processing to gain reduced data that is appropriate for the statistical analysis. For example, the used stationary device Biopac MP 36 with its ECG records with 1000 Hz for five minutes (300 s), it results in 300,000 sample points. According to the sample rate of the applied Empatica E4 (i.e., 64 Hz), it results in 19,200 sample points.

Beside the differences in the sample points, Empatica E4 records blood volume pulse resulting in different raw data format as both ECGs (i.e., Biopac MP36, movisens) (Shaffer et al., 2014; Tamura et al., 2014). For Empatica E4, IBI data is available that was conducted with the individual algorithms that are optimized for the data structure. The R-R detection resulting in IBI data for Biopac and movisens follows the same procedure using their own software, respectively. From all devices, the raw data consisting of the computed IBI files in text format are used for further processing and analyzing the data.

Conducting a Quality Control of the Physiological Data

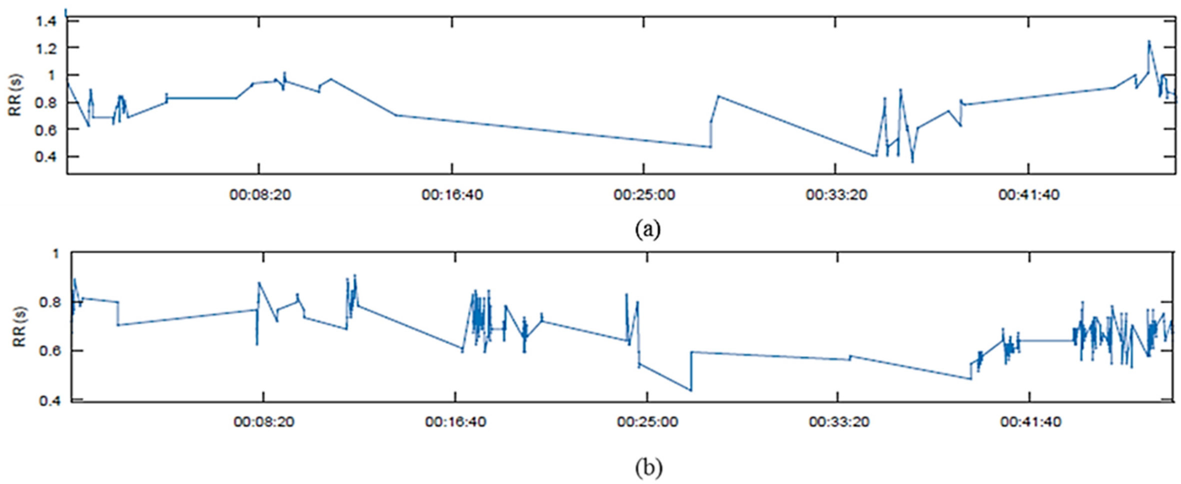
For HR, unacceptable values are below 25 bpm and above 200 bpm (Berntson et al., 1997). Concerning the data quality control step, five of thirty-two participants had to be excluded from the further data analysis to insufficient data of at least one device. On average, the excluded participants had 70% less data than the others. Additionally, one participant aborted the experiment and was also excluded. Figure 6-3 depicts a RR series measured with all three devices for one participant as an example for good data quality. The series show a similar pattern for all three devices in that the RR series is higher at the beginning during the baseline phase and lower during the stress induction phase in the last third of the series. Figure 6-4 shows RR series of two excluded participants respectively measured with Empatica E4 as an example for poor data quality. Compared with the good data quality example of Empatica E4, the missing signals of interest are obviously identifiable.

Figure 6-3: Exemplary RR Series of all three applied Devices



Note: The depicted RR series are computed during the whole length of the experiment as an example for good data quality: (a) Biopac MP 36, (b) movisens, (c) Empatica E4. Different starting points cause the different dates. Software: Kubios HRV.

Figure 6-4: Exemplary RR Series Computed from two Excluded Participants



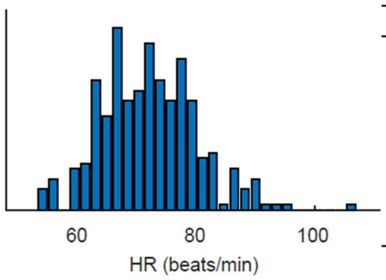
Note: The depicted RR series are computed during the whole experiment with Empatica as an example for poor data quality: (a) first participant, (b) second participant. Software: Kubios HRV.

Unacceptable physiological values of the data from the twenty-six participants included in the further data analysis were manually filtered using the software ArtIifact (Kaufmann, Sütterlin, Schulz, & Vögele, 2011).

Reducing the Physiological Data according to Time-Domain, Frequency-Domain, and Non-linear Analysis

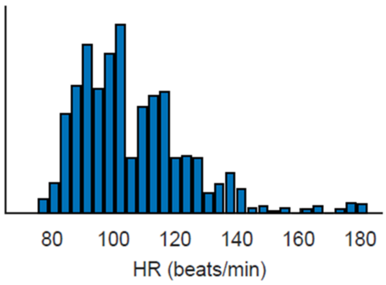
After the quality control step, HRV of the physiological data recorded with both wearables and the stationary Biopac was analyzed with Kubios HRV (Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, 2014). Neither automatic filter correction nor trend components removal was adjusted. According to the guidelines (Berntson et al., 1997; Task Force 1996), HRV is processed with three main analysis methods: time domain, frequency domain, and non-linear analysis. Figure 6-5 to Figure 6-7 provide exemplary HRV-results from one participant for all used methods. HRV data processed with time domain analysis is calculated with simple descriptive statistical procedures. In the frequency domain analysis, HRV is composed into different frequency bands (high to very low frequency) using a spectral analysis with a standard FFT algorithm. The non-linear analysis considers the non-linear features of the cardiovascular data, for example by plotting the correlation between successive R-R intervals (i.e., Poincaré Plot) and calculating their standard deviation from the line of identity, where $R_j = R_{j+1}$ (i.e., SD1, SD2).

Figure 6-5: Exemplary HRV-Results from Time Domain Analysis



Variable	Units	Value
Mean RR*	(ms)	842.8
STD RR (SDNN)	(ms)	94.2
Mean HR*	(beats/min)	72.09
Min/Max HR	(beats/min)	55.14/88.79
RMSSD	(ms)	62.2
NNxx	(beats)	80
pNNxx	(%)	25.0
RR triangular index		16.895
TINN	(ms)	458.0

(a)

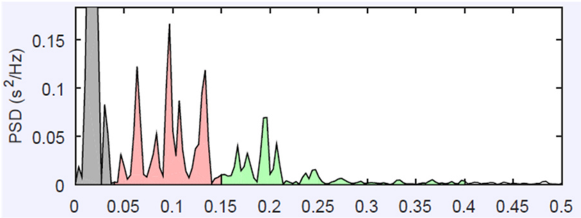


Variable	Units	Value
Mean RR*	(ms)	583.3
STD RR (SDNN)	(ms)	89.7
Mean HR*	(beats/min)	105.59
Min/Max HR	(beats/min)	80.08/166.61
RMSSD	(ms)	42.2
NNxx	(beats)	88
pNNxx	(%)	9.0
RR triangular index		20.354
TINN	(ms)	419.0

(b)

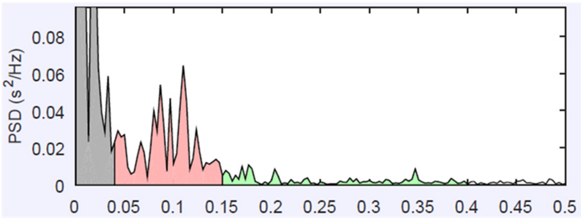
Note: The results (i.e., histogram and time domain data) were computed from one participant and the stationary ECG Biopac: (a) during the baseline phase, (b) during the stress phase. In (b) there is a relevant increase in HR (105 bpm) compared to (a) (72 bpm). Software: Kubios HRV.

Figure 6-6: Exemplary HRV-Results from Frequency Domain Analysis



Frequency Band	Peak (Hz)	Power (ms^2)	Power (log)	Power (%)	Power (n.u.)
VLF (0-0.04 Hz)	0.0133	4507	8.413	41.3	
LF (0.04-0.15 Hz)	0.0967	4389	8.387	40.2	68.5
HF (0.15-0.4 Hz)	0.1967	2015	7.608	18.5	31.4
Total		10917	9.298		
LF/HF		2.179			

(a)

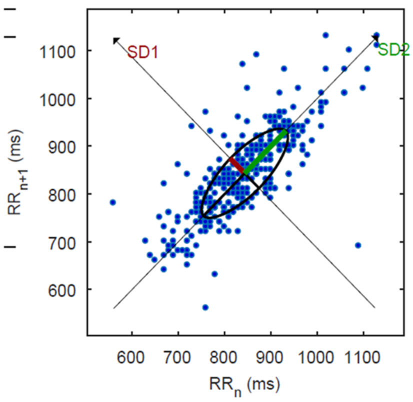


Frequency Band	Peak (Hz)	Power (ms^2)	Power (log)	Power (%)	Power (n.u.)
VLF (0-0.04 Hz)	0.0033	3961	8.284	56.9	
LF (0.04-0.15 Hz)	0.1100	2412	7.788	34.7	80.5
HF (0.15-0.4 Hz)	0.1767	585	6.372	8.4	19.5
Total		6960	8.848		
LF/HF		4.124			

(b)

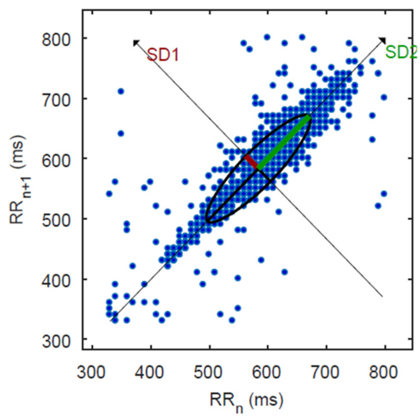
Note: The results (i.e., power spectrum and frequency domain data) were computed from one participant and the stationary ECG Biopac: (a) during the baseline phase, (b) during the stress phase. In (b) the spectrum is considerably depressed regards the total power (6,960 ms^2) compared to (a) (10,917 ms^2) indicating an increased sympathetic activation and parasympathetic withdrawal. Software: Kubios HRV.

Figure 6-7: Exemplary HRV-Results from the Non-linear Analysis



Variable	Units	Value
Poincare Plot		
SD1	(ms)	44.1
SD2	(ms)	125.7
SD2/SD1		2.853
Approximate Entropy (ApEn)		0.947
Sample Entropy (SampEn)		1.407
Detrended Fluctutation Analysis (DFA)		
Short-term fluctuations, $\alpha 1$		1.242
Long-term fluctuations, $\alpha 2$		0.943

(a)



Variable	Units	Value
Poincare Plot		
SD1	(ms)	29.9
SD2	(ms)	123.3
SD2/SD1		4.129
Approximate Entropy (ApEn)		0.954
Sample Entropy (SampEn)		0.881
Detrended Fluctutation Analysis (DFA)		
Short-term fluctuations, $\alpha 1$		1.398
Long-term fluctuations, $\alpha 2$		0.950

(b)

Note: The results (i.e., Poincaré Plot and non-linear data) were computed from one participant and the stationary ECG Biopac: (a) during the baseline phase, (b) during the stress phase. In (b) the values of SD1 (29.9 ms) and SD 2 (123.3 ms) decrease compared to (a) (SD1 = 44.1 ms; SD2= 125.7 ms) indicating an increased sympathetic activation and parasympathetic withdrawal. Software: Kubios HRV.

For reporting the following statistical analysis and procedures, three different types of data are selected, one of each main analyzing method, respectively. As data from the time domain analysis HR is selected because it is a commonly and intuitively used measure (Massaro & Pecchia, 2019), logHF as data from the frequency domain analysis because HF serves as a measure of vagal cardiac control (Parati, Mancia, Di Rienzo, & Castiglioni, 2006). SD2 as the standard deviation along the line-of-identity of the Poincaré plot is selected from the non-linear analysis because it indicates a long-term variability, is correlated with LF, and, thus, differs from the other selected HRV data providing new insights (Brennan, Palaniswami, & Kamen, 2001; Hsu et al., 2012; Melillo, Bracale, & Pecchia, 2011).

6.4.4 Step 4 Statistical Analyses

Descriptive Statistics

Table A- 3 in the Appendix presents the minimum and maximum estimates, means, and standard deviations of the study variables. The correlations will be presented in the following section, as being part of the determination of reliability and convergent validity. Normal distribution of the data was tested with the Shapiro-Wilk test. After eliminating outliers, each data was normally distributed.

Bivariate Statistics

As in the prior section evaluated, Pearson's correlation coefficient is used in a MTMM matrix with IBM SPSS 22. Because the convergent and discriminant validity of each wearable in comparison to the stationary device Biopac is of interest, the MTMM matrix provide only values for the comparison with Biopac, not for the comparison with the wearables among themselves.

The results of the Pearson’s correlation coefficients in the MTMM matrix for the baseline phase show that convergent validity is achieved in that all but one (device: Biopac, movisens; physiological data: HR) monotrait-heteromethod correlations from the validity diagonal are large and significantly different from zero (see Table 6-4, the validity diagonal values are listed in boldface). The discriminant validity criteria are not considered here, as they are not of interest for determining the convergent validity. The results of the Pearson’s correlation coefficients in the MTMM matrix for the stress phase show that three of six (50%) of the validity diagonal values indicating convergent validity are large and significantly different from zero.

Table 6-4: MTMM Correlation Matrix with three Devices (Biopac, Empatica, movisens) and three Types of Physiological Data (HR, logHF, SD2)

	Device								
	Biopac			Empatica			movisens		
Physiological data	HR	logHF	SD2	HR	logHF	SD2	HR	logHF	SD2
Baseline phase									
Biopac									
HR	1								
logHF	-.611**	1							
SD2	-.729**	.757**	1						
Empatica									
HR	**.944****	-.672**	-.771**	1					
logHF	-.477*	**.801****	.501*	-.416*	1				
SD2	-.730**	.678**	**.875****	-.674**	.551**	1			
movisens									
HR	**.368**	-.342	-.424*				1		
logHF	-.434*	**.441***	.666**				-.282	1	
SD2	-.499*	.450*	**.650****				.138	.502*	1

Stress phase									
Biopac									
HR	1								
logHF	-.346	1							
SD2	-.519*	.755**	1						
Empatica									
HR	**.898****	-.351	-.530**	1					
logHF	-.205	**.118**	.201	-.147	1				
SD2	-.365	.120	**.340**	-.350	.409*	1			
movisens									
HR	**.924****	-.270	-.434*				1		
logHF	-.259	**.155**	.310				-.101	1	
SD2	-.394	.395	**.776****				-.215	.463*	1

Note: *$p < .05$;**$p < .01$; validity diagonal values are listed in boldface.

Additionally, with being appropriate for the comparison of the each wearable with the stationary Biopac, the ICC(A,1) estimates are calculated based on a two-way mixed-effects model, absolute agreement, and single measures with IBM SPSS 22 according to following formula (McGraw & Wong, 1996),

$$ICC(A,1) = \frac{MS_R - MS_E}{MS_R + (2-1)MS_E + \frac{2}{n}(MS_C - MS_E)}, \quad (6)$$

where MS_R is the mean square for rows, MS_E is the mean square for error, and MS_C is the mean square for columns. K refers to the number of raters (i.e., two devices each) and n to the number of subjects. Table 6-5 shows the ICC(A,1) estimates, their 95% confidence interval, and their interpretation for each comparison (i.e., wearable-Biopac) and each physiological data (i.e., HR, logHF, SD2) for the baseline and stress phase. The results of the baseline phase are for all three physiological data recorded with Empatica at least good to excellent ($ICC(A,1)_{HRbaseline} = .929$, $ICC(A,1)_{logHFbaseline} = .790$, $ICC(A,1)_{SD2baseline} = .877$) and with movisens moderate ($ICC(A,1)_{HRbaseline} = .275$, $ICC(A,1)_{logHFbaseline} = .385$, $ICC(A,1)_{SD2baselone} = .404$). The moderate to excellent results of the stress phase are limited to HR and SD2 for Empatica ($ICC(A,1)_{HRstress} = .811$, $ICC(A,1)_{logHFstress} = .118$, $ICC(A,1)_{SD2stress} = .335$) and movisens ($ICC(A,1)_{HRstress} = .914$, $ICC(A,1)_{logHFstress} = .128$, $ICC(A,1)_{SD2stress} = .563$).

Table 6-5: ICC(A,1) Estimates [and 95% Confidence Intervals] and their Interpretation

	ICC(A,1)	95% CI	Interpretation
Baseline phase			
Biopac - Empatica			
HR	.929	[.840,.969]	Good to excellent
logHF	.790	[.588,.899]	Moderate to good
SD2	.877	[.742,.944]	Good to excellent
Biopac- movisens			
HR	.275	[0,.584]	Poor to moderate
logHF	.385	[.023,.666]	Poor to moderate
SD2	.404	[0,.727]	Poor to moderate
Stress phase			
Biopac - Empatica			
HR	.811	[.202,.938]	Poor to excellent
logHF	.118	[0,.498]	Poor
SD2	.335	[0,.657]	Poor to moderate
Biopac- movisens			
HR	.914	[.804,.962]	Good to excellent
logHF	.128	[0,.474]	Poor
SD2	.563	[.112,.808]	Poor to good

Simplified procedures

In the category simplified procedures, the Passing and Bablok regression and the CUSUM test for linearity are used calculated with the software MedCalc. Table 6-6 presents for each comparison and each physiological data in both baseline and stress phase the intercept, slope, their 95% confidence intervals as well as the result of the CUSUM test. The results for Empatica show comparability in that all confidence intervals of the intercept contain zero and of the slope contain one. Regarding movisens the confidence interval for SD2 at the baseline phase miss the slope criterion (b = 2.028, 95% CI = [1.140, 3.403]), the confidence interval for SD2 at the stress phase the intercept criterion (a = - 50.933, 95% CI = [-108.886; -18.597]). Beside these, the results for movisens indicate comparability, likewise. The CUSUM test for logHF at the stress phase comparing Biopac and movisens shows a significant deviation from linearity.

Table 6-6: Estimates for the Intercept and Slope [and 95% Confidence Intervals] of the Passing and Bablok Regression Analysis and Results of the CUSUM Test for Linearity

	Intercept	95% CI	Slope	95% CI	CUSUM test
Baseline phase					
Biopac - Empatica					
HR	-1.439	[-4.428,0.579]	1.014	[0.987,1.050]	No deviation from linearity
logHF	0.642	[-0.291,1.606]	0.934	[-0.777,1.086]	No deviation from linearity
SD2	2.693	[-8.532,13.633]	0.971	[0.845,1.129]	No deviation from linearity
Biopac- movisens					
HR	-76.511	[-309.911,-22.768]	1.990	[1.325,4.877]	No deviation from linearity
logHF	-0.509	[-5.695,2.759]	1.096	[0.635,1.953]	No deviation from linearity
SD2	-56.375	[-150.050,13.561]	2.028	[1.140,3.403]	No deviation from linearity
Stress phase					
Biopac - Empatica					
HR	-7.037	[-35.156,13.470]	1.019	[0.819,1.287]	No deviation from linearity
logHF	-0.100	[-14.329,3.623]	0.981	[0.361,3.364]	No deviation from linearity
SD2	29.800	[-34.149,66.035]	0.617	[0.202,1.334]	No deviation from linearity
Biopac- movisens					
HR	-8.103	[-30.822,5.985]	1.093	[0.960,1.310]	No deviation from linearity
logHF	-3.791	[-33.393,1.330]	1.681	[0.824,6.496]	Deviation from lineari-ty
SD2	-50.933	[-108.886,-18.597]	1.784	[1.376,2.455]	No deviation from linearity

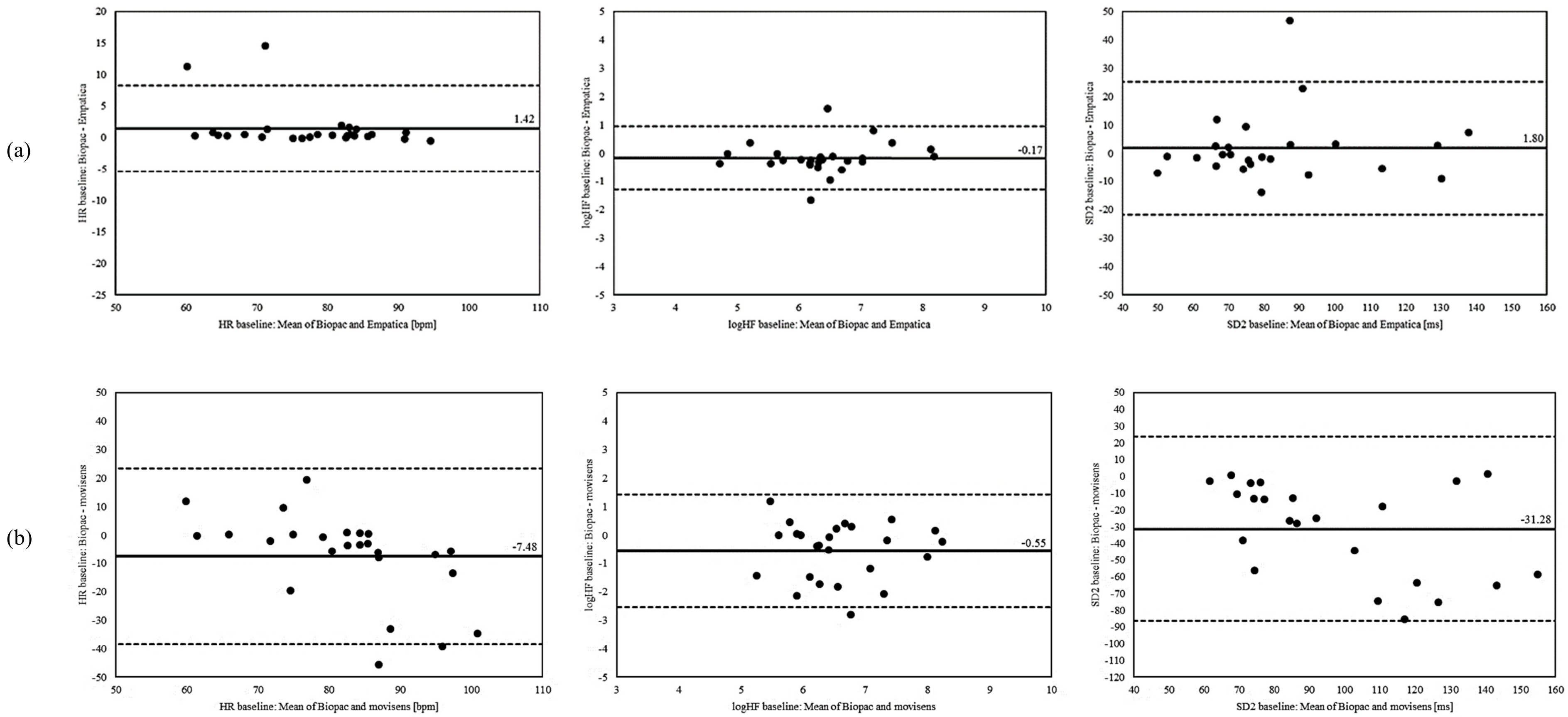
Graphical Procedures

In the category graphical procedures, the Bland and Altman method is applied by plotting the difference of each device comparison against the mean of both devices in scatter plots (see Figure 6-8 and Figure 6-9). Table 6-7 presents for each comparison and each physiological data in both baseline and stress phase the mean difference, its 95% confidence interval as well as the limits of agreement (mean difference ± 1.96 *SD*) and their 95% confidence interval, respectively. The results for Empatica indicate a good agreement, in particular for HR in the baseline phase and logHF in both phases in that their mean difference is close to the equality line zero and their upper and lower limits of agreement are close around the mean difference line (mean difference$_{\text{HRbaseline}}$ = 1.419 bpm, mean difference$_{\text{logHFbaseline}}$ = -0.166, mean difference$_{\text{logHFstress}}$ = 0.205). However, for SD2 in the baseline phase and stress phase, the mean difference is also close to zero but its limits of agreement are large indicating uncertainty (upper limit of agreement$_{SD2baseline}$ = 25.301 ms, lower limit of agreement$_{SD2baseline}$ = 21.701 ms). Overall, the mean differences of almost all physiological data are positive indicating that the results of Empatica *underestimate* the results of Biopac. The Bland and Altman method for movisens show good agreement for logHF in the baseline and stress phase (mean difference$_{logHFbaseline}$ = -0.552, mean difference$_{logHFstress}$ = -0.532), and HR in the stress phase (mean difference$_{HRstress}$ = - 2.126 bpm). The other physiological data is away from zero and the limits of agreement are large indicating uncertainty. Overall, the mean differences of all physiological data are negative indicating that the results of movisens *overestimate* the results of Biopac.

Table 6-7: Estimates for the Mean Difference [and 95% Confidence Intervals] and the Upper and Lower Limits of Agreement [and 95% Confidence Intervals] of the Bland and Altman Method

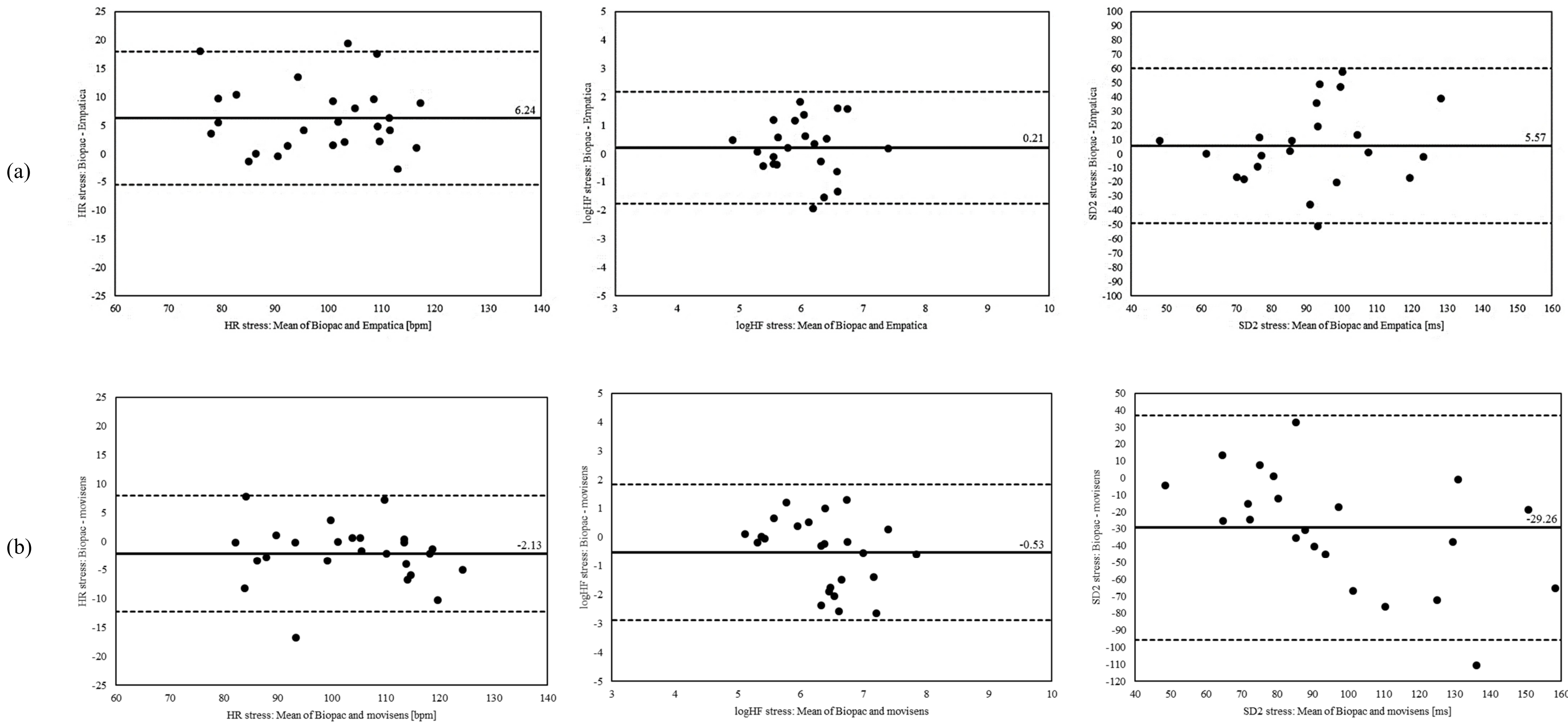
	Mean Difference	95% CI	Limits of Agreement			
			Upper	95% CI	Lower	95% CI
Baseline phase						
Biopac - Empatica						
HR	1.419	[0.022,2.816]	8.198	[5.779,10.616]	-5.359	[-7.778,-2.941]
logHF	-0.166	[-0.395,0.064]	0.948	[0.551,1.345]	-1.279	[-1.676,-0.882]
SD2	1.800	[-3.149,6.749]	25.301	[16.727,33.874]	-21.701	[-30.274,-13.127]
Biopac - movisens						
HR	-7.480	[-13.977,-0.984]	23.365	[12.112,34.619]	-38.326	[-49.579,-27.073]
logHF	-0.552	[-0.969,-0.134]	1.432	[0.709,2.156]	-2.536	[-3.259,-1.812]
SD2	-31.278	[-43.428,-19.128]	23.791	[2.718,44.863]	-86.348	-107.420,-65.275]
Stress phase						
Biopac - Empatica						
HR	6.240	[3.820,8.661]	17.987	[13.796,22.178]	-5.506	[-9.698,-1.315]
logHF	0.205	[-0.230,0.641]	2.180	[1.425,2.936]	-1.769	[-2.525,-1.014]
SD2	5.568	[-6.760,17.896]	60.066	[38.670,81.462]	-48.930	[-70.326,-27.533]
Biopac - movisens						
HR	-2.126	[-4.245,-0.007]	7.936	[4.265,11.606]	-12.187	[-15.857,-8.516]
logHF	-0.532	[-1.041,-0.022]	1.833	[0.950,2.716]	-2.897	[-3.780,-2.013]
SD2	-20.057	[-32.772,-7.343]	34.690	[12.606,56.774]	-74.804	[-96.888,-52.720]

Figure 6-8: Bland and Altman Plots of the Comparisons in the Baseline Phase



Note: The plots are depicted for three types of physiological data (HR, logHF, SD2) measured with (a) Biopac and Empatica and (b) Biopac and movisens in the baseline phase. The solid line indicates the mean of difference, the two dashed lines the upper and lower limit of agreement.

Figure 6-9: Bland and Altman Plots of the Comparison in the Stress Phase



Note: The plots are depicted for three types of physiological data (HR, logHF, SD2) measured with (a) Biopac and Empatica and (b) Biopac and movisens in the stress phase. The solid line indicates the mean of difference, the two dashed lines the upper and lower limit of agreement.

6.5 Summary and Discussion of the Results

Based on this set of results, taken as a whole, it can be concluded that although the results show consistently no perfect reliability and convergent validity for all comparisons, respectively, the wearables offer potential to record cardiovascular data in different states of arousal and to replace the stationary device Biopac. In particular, Empatica shows good results for all physiological data of the baseline phase, with being more unreliable in the stress phase caused by its tendency to underestimate the cardiovascular data. For movisens the results are reverse in that the physiological data were recorded more reliably in the stress phase, by overestimating the cardiovascular data in the baseline phase. Additionally, these biases seem to have a greater impact on wearable-measured physiological data that was processed with the frequency domain and the non-linear analysis for HRV (i.e., logHF, SD2). These findings are in line with previous research in terms of finger PPG sensors and probably caused by the underlying recording process of peripheral PPG sensors as previously discussed (Eatough et al., 2016; Schäfer & Vagedes, 2013).

The exemplary comparison study reveals two main important considerations for further research. First, the proposed and applied guideline for designing studies with physiological measures and recording, processing, and analyzing wearable-measured physiological data provide a rigorous standard for the present and further studies. Thereby, it is important for organizational scholars to report any decision they made based on the guideline's steps to contribute to a replicable understanding. For instance, the TSST was introduced as a standardized and profoundly investigated protocol to induce psychosocial stress as the study design and described the recording intervals associated with the TSST phases in detail. Of course, the experimental comparison study is not without limitations that, in turn, support the importance of the proposed guideline. Participants had to be excluded due to sufficient data losses caused by moving artefacts and wrong placements as aforementioned. Thereby, it was missed to initially control the data quality of the both wearables before recording, for example with the Empatica's real time streaming mode. Thus, as organizational scholars should learn from such mistakes, such crucial suggestions were outlined in the guideline.

Second, the results of the exemplary comparison study provide support for the notion that to determine the reliability and convergent validity of wearable-measured physiological data is crucial to provide reasonable findings. To this end, it is important to consider that for instance PPG sensors of wristbands (e.g., Empatica), are prone to underestimate the cardiovascular data, predominantly in phases of high arousal. Furthermore, in terms of distinguishing between rigorous and nonrigorous studies validating wearable-measured physiological data or designing own validation studies, to apply only one method for determining is not appropriate because it could lead to a wrong conclusion. For example, *ICC(A,1)* estimates are lower for several comparisons indicating lower reliability compared to the other statistical and non-statistical procedures. Thus, the suggestion to combine statistical and non-statistical procedures reviewed from interdisciplinary literature and evaluated with certain criteria contributes to more rigorous validation studies.

6.6 Conclusion

Due to their flexibility, substantially lower intrusion on participants, and considerably lower costs compared to traditionally stationary devices, wearables constitute a promising solution for organizational scholars recording various types of physiological data for various areas for application. Therefore, interested organizational scholars were introduced to the opportunities of physiological data and wearables by providing an overview of physiological data in general and devices applicable to record this data and presenting pioneering studies already applied wearable-measured physiological data. Hence, organizational scholars may get inspired and increasingly apply this data for their own research. However, developing and introducing standards for the application of wearable-measured physiological data in organizational research is a necessary condition, because the use of wearables to record physiological data comes with several pitfalls. To this end, organizational scholars have to be aware of the methodological properties of physiological measures and key methodological issues of wearable-measured physiological data outlined in the following sections. By following the proposed guideline, considering the developed methodological knowledge, and methodological discussion for deciding for an already validated wearable or validating a certain sensor technique by themselves, organizational scholars could make valuable contributions. First, they contribute to the standardization applying physiological measures in organizational research that, in turn, provide support for overcoming the hurdle of unfamiliarity and high expectations that organizational scholars made cautions about applying physiological measures in their research. Second, organizational scholars are enabled to design their own rigor studies enriched with wearable-measured physiological data that draw on reasonable conclusions from their findings.

The second study of this thesis concludes with a brief discussion of future research agenda strategies. First, due to the rapid advances in wearables, it becomes increasingly possible to apply wearable-measured physiological data in real life settings with the lowest intrusion for participants. Proceeding from the high intrusive, non-flexible stationary devices to lower intrusive wearables with more flexibility, future advances will develop devices that record physiological measures almost undetectable for participants (Waldman et al., 2019). While such advances open promising opportunities for organizational research integrating physiological measures as standard methods in their toolbox, several crucial questions arise that further research needs to consider. For instance, how and by whom are the extremely large data sets processed and analyzed? The guidelines from the particular societies, mostly compiled in the last decades, do not nearly give answers to these questions. Instead, findings from other methods such as big data analysis should be transferred and integrated (George, Haas, & Pentland, 2014).

Second, with the increased use of commercial wearables and other electronic assessment devices such as smartphones producing ‘self-quantification data’, it is possible for organizational scholars to make use of and integrate these methods in their research (George et al., 2014; Ilies et al., 2016). Such discussions are mainly led in terms of EMA research (Beal & Weiss, 2003; Ilies et al., 2016). The implications for EMA research are discussed in more detail in the next chapter (Chapter 7). Beside the possibility to assess a rich set of behavioral, physiological, and psychological measures, smartphones are also a useful tool, for example to complete surveys from them (Ilies et al., 2016). However, thereby, the aforementioned methodological properties and issues still need to be considered.

The ICT-based Physiological Measurements Study tried to contribute to take the next step towards the active role organizational scholars should take in the development of wearables and enrichment of organizational theories and studies with valuable insights of the human brain and body that physiological measures provide.

7 Discussion

ICTs are ubiquitous in people's everyday working and private lives. They change the way people communicate by being available for private and work-related contacts at any time and any place. While this "always on"-mentality comes with several risks resulting in detrimental effects for individuals, such as an increase in stress and work-life conflict, ICT use also provides opportunities that are crucial for people's well-being. With further illuminating this double-edged sword notion, it needs to be considered that the individual has his or her individual availability preference consisting of individual motives for and perception of the actual availability in order to provide an aligned availability. To this end, ICTs themselves could serve as a solution for preventing detrimental and enhancing improving effects. Assessing and regulating availability and well-being outcomes with ICTs may considerably contribute to improve employees' well-being. In response to these notions, the aim of this thesis was to examine and provide responsible ICT-based solutions for the assessment of well-being as a pathway to responsible digitization, in particular regarding availability and physiological measures. To reach this main goal, two empirical studies were conducted that on the one hand examined employees' aligned availability and developed and evaluated two smartphone applications to provide an aligned availability (ICT-based Availability Management Study), and on the other hand established an in-depth understanding of wearable-measured physiological measures and validated two wearables measuring two physiological stress measures (ICT-based Physiological Measurements Study). In the following, main findings of both conducted studies and inferences drawn from their findings are outlined. Moreover, the integrated findings of both studies provide implications for practice and research, in particular for the research area of EMA. Finally, the overall limitations of this thesis are presented. They lead to directions and implications for future research examining and further illuminating the risks and opportunities that ICTs create for people's well-being today.

7.1 Main Findings

In light of the main goal to examine and provide responsible ICT-based solutions for the assessment of well-being, the two empirical studies were conducted. The aim of the ICT-based Availability Management Study was to shed light on employees' individual aligned availability by considering their perceptions, motives, and preferences and to provide two smartphone applications for an aligned availability by taking a design science research approach (Peffers et al., 2007). The first study of this thesis firstly examined and subsequently considered employees' individual availability preference and actual availability in order to develop two smartphone applications according to the design science research approach (Peffers et al., 2007). Furthermore, the developed smartphone applications were evaluated in an empirical study. Thereby, four main research questions were investigated:

(1) How and to what extent do employees differ in terms of their availability preference and boundary management preference?

(2) Which requirements and design elements should both smartphone applications fulfill in order to provide an aligned availability?

(3) To what extent do both smartphone applications improve employees' aligned availability and, therefore, their stress and work-life balance comparing a user and control group?

(4) Which functions of both smartphone applications contribute the most to an aligned availability?

To answer the research questions, results of a qualitative and quantitative study from a larger project were analyzed regarding employees' individual availability and boundary management preference and actual boundary management strategies. The results indicated that the availability preference vary depending on (1) the life domain, (2) their current context, and (3) type and priority of contacts. Accordingly, the preference differs between both individuals and particular situations. Based on these results, requirements and design elements for both smartphone applications that provide an aligned availability were derived. As a main design element that considers all three variation factors of availability preference, availability modes were implemented that rely on the life domain and current context of the user. Furthermore, a different set of rules is deployed that accounts for the type and priority of contacts regarding incoming communication. Following principles of the design science research approach and derived design elements, the Availability-Manager and Availability-Monitor as two smartphone applications were developed in three iterations: Deriving solution requirements from the aforementioned qualitative and quantitative study, testing the reliability and validity of the applications' design elements, and testing the applications in a simulation study. Finally, the applications were evaluated regarding employees' stress and work-life balance in a five-week field study with an intervention and control group. The evaluation results showed that using the applications led to a significant increase in work-life balance and significant decrease in psychological distress and exhaustion. Furthermore, the qualitative and quantitative evaluation of the perceived utility, the use as well as the assessment of the applications' different functions revealed that the majority of users in the intervention group reported that the applications were supportive for their work-life balance. The availability modes were used most frequently. Although all functions were evaluated quite similar, the functions perceived as most supportive were the protocol of missed communication events, the feedback on smartphone usage and stress level, the priority assistant, and separation of personal and work-related contacts. Together these findings indicated that (1) individuals differ in their availability preference and, therefore, alignment of availability, and (2) ICTs constitute a feasible solution enabling individuals to align their actual availability with their preferences and, thereby, supporting their well-being.

The second study was aimed to accomplish an in-depth understanding on how organizational scholars can validly apply wearable-measured physiological measures for their research as a contribution to their methodological toolbox. To this end, the study discussed the application of wearable-measured physiological measures for organizational research in detail. Thereby, an in-depth understanding about the opportunities but also pitfalls that arises with the application, in particular regarding methodological properties of the measures and potential measurement issues, was provided. Also, two guidelines for both processing and analyzing wearable-measured physiological measures accounting for the properties and issues as well as the validation of wearable-measured physiological data are given. Both guidelines were exemplified with real data of an experimental comparison study. Hence, the ICT-based Physiological Measurements Study was guided by three main research questions:

(5) How should organizational scholars apply wearable-measured physiological measures for their research to be able to draw reasonable inferences from their findings?

(6) Which validation protocols exist in recent research for wearable-measured physiological data and how appropriate are they?

(7) To what extent can the measurement performance of different wearable devices be compared with a stationary device to measure physiological stress?

To answer the research questions, the second study of this thesis gave an overview over the broad field of physiological measures, their methodological properties, and stationary and wearable devices applicable to record these measures. One key methodological property of physiological measures is that they follow their own temporal rules according to their time constant. The time constant is referred to the time, a physiological measure evolves. Thus, devices should record the physiological measure with an appropriate sample rate. This device requirement is ensured for traditional stationary devices, but not necessarily for wearables. Accordingly, certain measurement issues arose that needed to be considered in the guidelines of the study. Furthermore, with proposing critical steps in a guideline, a rigorous standard of designing studies that are recording, processing, and analyzing wearable-measured physiological data was provided. Thereby, the discussed methodological properties and potential measurement issues were considered. By following this guideline, organizational scholars are enabled to apply wearable-measured physiological measures in a way they could draw reasonable inferences from their findings. Furthermore, an interdisciplinary literature review about methods used in previous research to determine the validity and reliability of physiological data was conducted. The review revealed that previous research provided no standard procedures for the determination. Instead, the literature was heterogeneous and needed to be categorized into statistical and non-statistical procedures. In addition, the reviewed methods were evaluated regarding certain criteria, for example the previously outlined methodological properties of physiological measures, with the aim to provide appropriate methods for determining the validity and reliability of wearable-measured physiological data. Based on the evaluation results, a combination of methods from both categories was determined as the most appropriate measures. Finally, an experimental comparison study was conducted comparing HR and HRV recorded with the PPG wristband Empatica E4 and ECG breast strap movisens EcgMove 3 as wearables and the established stationary ECG-based device Biopac MP36. Thereby, different states of physiological stress were investigated with the TSST, an established experimental procedure. The aim of this study was to exemplify the application of the proposed guideline and the best suited methods determining reliability and convergent validity. Although the results showed consistently no perfect reliability and convergent validity for all comparisons, respectively, they indicated that the wearables offer potential to record cardiovascular data in different states of physiological stress and to replace the stationary device Biopac. Together, these findings provided (1) rigorous standards for future research applying wearable-measured physiological measures validly and reliably, and (2) a validation of two wearables and, thereby, a recommendation to apply them in future research.

By integrating the aforementioned findings, taken as a whole, both studies underline the important role that ICTs are able to take for individuals' well-being as well as research. In particular, the findings indicate that they can serve not as the cause of detrimental effects but as a solution to more feasibly assess and regulate individuals' well-being. Thereby, both studies contribute methodologically by extending the methodological toolbox of organizational scholars, respectively. Furthermore, both studies provide valuable implications for the research area of EMA that are further outlined in the following chapter.

7.2 Research Implications of the Thesis

The overall contributions of this dissertation are twofold, as already outlined in Chapter 1.1. In more detail, the thesis contributes to research and practice by *examining responsible ICT-based solutions* for the assessment of individual's well-being and *extending the methodological toolbox* of organizational scholars. Furthermore, with combining the methodological insights of both studies into the emerging research area of EMA, valuable implications for future EMA studies are provided. In addition to the particular implications derived from the two studies in Chapter 5 and 6, respectively, the following section illuminates the overall contributions in more detail and discusses implications for research, in particular for EMA research, on a superordinate level. Thereby, the implications are differentiated between theoretical/conceptual implications and methodological implications.

This dissertation provides three important theoretical/conceptual implications. First, the comprehensive reviews of conceptual and theoretical foundations (Chapter 2.1 and 2.2) and recent literature (Chapter 3) bring together various different disciplines such as organizational behavior, psychology, medicine, and information systems. As the state of the art is therefore heterogeneous and results are mixed and contradictory, the reviews contribute to a more structured overview of the different research streams. To this end, future research could benefit from important findings and valuable notions other domains already provide. For instance, as technostress is predominantly examined by IS researchers, findings of availability research from psychology and organizational behavior or valuable notions of profoundly investigated stress theories are rather neglected though beneficial. Moreover, although psychologists apply physiological measures in their research for several decades, organizational and IS research, for example regarding technostress, are just about to introduce such measures to their research with an upward tendency (Murray & Antonakis, 2019; Riedl, 2013). As these examples illustrate, there is a need to consider research and literature from other disciplines examining similar concepts and theories not only to provide a more consistent and comprehensive conceptual understanding, but also to benefit from the conceptual and methodological knowledge and experiences of other disciplines. Thus, this thesis takes a first step to initially reveal this need to scholars, who maybe get inspired considering this for their own research.

Second, based on the discussed conceptual foundations, the examined concepts of the present thesis constitute an extension of concepts previous research investigated. In particular, this thesis acknowledges the important role of individuals' perception, motives, and preferences regarding their extended availability for work-related and private contacts. In more detail, individuals set their availability preferences not generically; instead, the preference differs regarding the life domain, context, and contacts. Furthermore, aligned availability is introduced as a new construct previous research neglected. Moreover, with its focus on methodological properties of physiological measures in regard to recent device advances introducing them to scholars new to the field, this thesis offers a conceptual contribution that previous research did not provide. By considering all three facets of a stress reaction in the stress concept, in particular psychological, physiological, and behavioral, this thesis further provides a comprehensive conceptual approach for future research examining stress. Taken together, this thesis contributes to research by applying differentiated, responsible constructs future research can build upon.

Third, this thesis contributes to the theoretical understanding of the human agency perspective (Emirbayer & Mische, 1998). In this regard, the dissertation further illuminated the human agency perspective by examining the individual aligned availability and physiological measures. Hence, this thesis acknowledged the need to consider both unconscious physiological and conscious cognitive and psychological processes to comprehensively understand the human agency. Further, this thesis provided empirical support that the individual user enacts freely with the responsible ICT-based solution, as it serves as a theoretical underpinning for the evaluation results of the smartphone applications developed and evaluated in the ICT-based Availability Management Study. Together, the findings emphasized that the human agency perspective provides an important lens that justifies the pathway to a responsible digitization future research should take.

With regard to the methodological implications, this dissertation provides three main implications that all three strive to extend the methodological toolbox of scholars and thereby contribute to research. First, the design science research approach, with which both smartphone applications were developed in the ICT-based Availability Management Study, served as a promising approach for interdisciplinary research (Peffers et al., 2007). In particular, because of its iterative procedure, technological but also non-technological requirements that are derived from user feedback for example can be repeatedly considered. While the interest using smartphones and applications for research purposes is growing as the EMA literature review indicated (see Chapter 3.3), researchers developing such applications can benefit from the design science research approach exemplified in the ICT-based Availability Management Study. Moreover, not only the development process, but also the developed smartphone applications themselves and, in particular, the assessed user measures provide a contribution to research. In more detail, to the best of one's knowledge, this is the first study in the context of extended availability that examined both the use of smartphone applications as an ICT-based solution, and momentary availability, well-being relevant measures of the users. Although studies investigating ICT use and availability with a daily diary design increase in recent literature (e.g., Derks et al., 2014; Derks & Bakker, 2014; Lanaj et al., 2014), they did not exploit the potential of smartphones and their sensors. Accordingly, this thesis highlights this potential and the need to take an active role in the development of smartphone applications using them for EMA research.

Second, this thesis, in particular the ICT-based Physiological Measurements Study, outlines the great potential of physiological measures for organizational research to interested scholars. As the toolbox of an organizational scholar principally comprises methods regarding surveys, observations, or interviews (Bono & McNamara, 2011; Heaphy & Dutton, 2008; Waldman et al., 2019), this thesis contributes to the extension to unconscious, implicit measures that are not plagued with self-report bias and other biases (Akinola, 2010; Chaffin et al., 2017; Murray & Antonakis, 2019). Thus, with providing valuable insights into the valid and reliable application of wearable-measured physiological measures, the thesis was able to facilitate organizational scholars the overcoming of the hurdle of their unfamiliarity with physiological measures and devices. Together, this thesis provides a contribution to the encouragement of organizational sciences to further apply wearable-measured physiological measures and, thereby, enrich research and theories with these measures not only more frequently, but also with an adequate construct validity, convergent validity, and reliability serving as a rigor standard.

Third and finally, by combining the aforementioned methodological insights of both studies, the dissertation contributes to the emerging research area of EMA, particularly as methodological foundations future research may build upon in two ways. On the one hand, this thesis highlights promising methods for the assessment of availability and well-being for EMA research, with providing two smartphone applications and validated wearables. Thereby, all facets, in particular psychological, physiological, and behavioral, were considered. Thus, on this basis, future EMA research could apply one or both methods for their studies or get inspired to develop similar ones. Particularly for research examining availability and work-related ICT use, which so far rather neglected such methods, this thesis and its applied methods could serve as an inspiration. On the other hand, the present thesis fundamentally supports the valuable findings pioneering EMA studies provided that applied a combination of physiological measures, smartphone-based self reports, and other sensor data (Adams et al., 2014; Kocielnik et al., 2013; Zenonos et al., 2016). Thereby, such studies are not able only to examine and recognize the meaningful within-person variability of momentary psychophysiological processes such as EMA studies that used only smartphone-based self-report data or a combination with physiological measures (Beal & Weiss, 2003). Instead, they accomplish to create a comprehensive understanding of the individual's behavior. Hence, this research may provide valuable insights for broad areas of application, but especially for the assessment of individual's well-being. Together, this thesis gives the pivotal implication to future research and interested scholars to make reasonable use of ICTs that fundamentally facilitate the application of such research and provides a feasible way to measure a broad range of interesting variables with large data quantities.

7.3 Practical Implications of the Thesis

In addition to implications for research, there are important practical implications for organizations, employers, managers, and individual employees that stem from this dissertation. In practice, the overwhelmingly negative view on ICTs leads to interventions that are implemented in order to prevent employees from the detrimental effects of ICT use. However, by trying to prevent employees from these risks, such interventions do not account for individual differences regarding for instance employees' preference for availability. Thereby, improving effects of ICT use such as an increased autonomy and flexibility are eliminated. Thus, this thesis' implications reveal a more optimistic view on ICT use that goes beyond such restricted interventions and brings the individual employee into focus. Therefore, three overall levers for organizations and employees are outlined in the following that are aimed to elucidate the importance to enable individuals to on the one hand reflect their preferences and well-being and on the other hand to improve their well-being on their own.

First, although ICT use is of course also determined from norms (Derks et al., 2015; Fenner & Renn, 2010) and expectations of others (Park et al., 2011), employees should first be empowered to determine their own individual preferences for their ICT use, extended availability, and boundary management regarding both the work and private life domain. For this purpose, organizations could offer workshops and training interventions that brings the employees' individual preferences into focus. Additionally, managers that first should be sensitive for this topic in managerial training programs could address this in team meetings. For instance, Boswell et al. (2016) give detailed recommendations for the development of trainings in the context of ICT use for different audiences. That way, organizations and managers can create and reinforce a transparent availability culture that enhances a healthy work-related ICT use. Within this culture, it should also become established to reach agreements according to one's individual preference with all important stakeholders, such as managers, colleagues and customers of the work domain, and family and friends of the private life domain. As this thesis indicates, the preferences can be differentiated between the life domain, context, and particular contacts. Also, the importance of the issue, with which the employee is contacted, the time of contacting (e.g., after hours, on weekends, on vacations), and the communication channel (e.g., email, calls, messages) are conditions that should be determined in an agreement. Implementing responsible ICT-based solutions in organizations, for example a smartphone application with functions similar to the developed Availability Manager, could support employees to implement their preferences and agreements for assuring an aligned availability and healthy ICT use. Thereby, organizations could provide a pathway to responsible digitization.

Second, organizations should empower employees to more autonomy as for their ICT use and seek ways to aid them in implementing autonomy strategies into everyday practice. For instance, such autonomy strategies could be more dynamic next to the stable concept of autonomy in the workplace by depending more on practices and work conditions as on professional status or job design (Mazmanian et al., 2013). Thereby, as other studies demonstrated that the restriction of control over nonwork activities is crucial for impaired well-being in the context of EWA (Dettmers et al., 2016), autonomy regarding ICT use could support them to be in control over both availability and nonwork activities in their leisure time. In this way, a sufficient and healthy recovery and work-life balance can be ensured.

Third, this thesis gives practical implications for an improved health care management in organizations. To prevent sick days that cause high costs for organizations, and, in particular, human resources could benefit from assessing and monitoring employees' health continuously. Thereby, organizations are able to identify detrimental, well-being-related work environments and make more informed decisions about implementing interventions that are suited to improve these detrimental environments into supporting ones. As shown in an illustrative example from Soma Analytics, that offers the Kelaa App for employees and a related Kelaa Dashboard for the particular organization this is promising for organizations (Soma Analytics, 2019). The aim of this application is to record stress of the employee using several different smartphone sensors and report the analyzed data to the user with a personal dashboard and also to the organization in an aggregated and anonymous form. For instance, the Kelaa App records sleep time and sleep quality with the motion sensor of the smartphone and emotional states and stress levels by interpreting the voice frequency of every call employees make. In addition, the app also analyses the way employees use their smartphone. If, for example, an employee looks at his or her smartphone very frequently and at short intervals this provides information about the employee's stress level. In this way, large amounts of personal data about the employees are collected, which an algorithm can analyze. Alongside Soma Analytics, several providers mostly of commercial wearables (e.g., Fitbit, Jawbone) already cooperate with organizations such as Opel and IBM making it possible to track employees' activity and fitness, likewise (Klofta & Rest, 2015).

Although these examples seem promising for organizations, this thesis also revealed the perils that arise with such applications, especially regarding data privacy. Therefore, there is a fundamental risk that valuable personal data may be misused for other purposes by both the system provider and the employer or passed on to third parties. Examples could be the dismissal of employees, who tend to higher stress levels, or the misuse of well-being-related data to disclose insured persons, who are particularly at risk, or to demand higher contributions from them. Thus, to restrict these perils, this thesis recommends the application of smartphone-based and wearable-measured psychophysiological data in a more limited scenario. Moreover, this type of data could contribute to the job hazard analysis that organizations have to make by law. Thereby, as organizations commonly used self-reports for this analysis, they could enrich the assessment with this data to provide a comprehensive understanding of their employees' well-being. On this basis, health promotion programs and interventions could be implemented in a more specific way in order to promote employees' well-being as they fit more closely to their needs and requirements.

7.4 Overall Limitations and Recommended Areas for Future Research

Overall, this dissertation provides a contribution to research and practice on ICTs assessing employees' well-being and, thereby, various implications. However, this thesis is not without overall limitations that future research should consider in addition to the thesis' contributions and implications.

As a methodological contribution, this thesis provides methodological foundations for EMA research by examining availability, well-being outcomes with smartphone applications as well as physiological stress measures with wearables. These measures and outcomes were investigated separately in different empirical studies. Therefore, future research should apply a more holistic approach by integrating both methods following pioneering EMA studies (Adams et al., 2014; Kocielnik et al., 2013; Zenonos et al., 2016). To this end, future studies might examine the effects of availability on stress-related outcomes with a combination of smartphone-based sensor and self-report data, and physiological measures, such as HR and HRV. On this basis, the improving effects of an aligned availability by managing the actual availability of employees according to their preferences could be profoundly investigated.

With regard to the examined concepts, this thesis' focus was on extended availability, self-report data of employees' well-being, as well as physiological, cardiovascular stress measures (i.e., HR, HRV). Although this data has already provided valuable insights for the outlined research questions of this thesis, they do not tap the full potential of the methods. For instance, with the Availability Monitor it is possible to assess the smartphone use, for example regarding the time employees handle their smartphone. Additionally, with the validated Empatica E4, EDA data can be recorded simultaneously to cardiovascular data. As the thesis' investigated methods may be applied in future EMA research, future studies might expand the methods by recognizing all possible measures. However, it should be noted here, that it is not worthwhile for future research to implement as much measures, as the applied methods are able to record. Instead, the application should be always hypotheses- and theory-driven to provide an appropriate construct validity (Ganster et al., 2018; Jack et al., 2019).

Both studies of this thesis reveal limitations with respect to the study design. In particular, although both studies examined the methods and measures at different time points, they are limited to relatively short time frames (several hours to five weeks). Furthermore, while the ICT-based Availability Management Study conducted a field study, the findings of the ICT-based Physiological Measurements Study relied on an experimental study in the laboratory. Thus, as both examined methods are suited to apply them covering longer time frames in the field, future studies could conduct longitudinal studies. Therefore, they could assess availability and stress of employees over a period of several months or even years leading to a large quantity of data also referred to as big data. For instance, the study from Killingsworth and Gilbert (2010) examining momentary happiness and mind-wandering with smartphone-based self-report data over several years provides a large sample size with over 5,000 people from 83 countries. However, with regard to such longitudinal studies, the challenge to deal with big data arises. The question is, how and by whom are the extremely large data sets processed and analyzed? Even the extended toolbox of organizational scholars seems not appropriate to fully answer this question. Instead, big data analysis has to be transferred and integrated to take up this methodological challenge (George et al., 2014). Therefore, an interdisciplinary research approach consisting of the addressed disciplines seems indispensable.

8 Conclusion

The ubiquity of ICTs in peoples working and private lives comes with fundamental changes for individuals' well-being. These changes are not only beneficial or improving, but they are also not only detrimental for individuals. That is why ICT use is justifiably seen as a double-edged sword in research and society. However, the aim of this dissertation was not to shed light on either the beneficial or the detrimental side of the sword, but on the user him- or herself as a human agency, in order to take the pathway towards a responsible digitization. Thereby, ICTs are not the causer; instead, they could serve as solutions providing a momentary assessment of individual's well-being. To this end, this thesis not only illustrates the potential benefits of such ICT-based solutions for individuals' well-being by developing two smartphone applications that facilitate an availability management with the aim of an alignment between actual availability and individual availability preferences, but also validates wearables that measure important physiological stress measures. ICT-based solutions also come with several perils, which future research should consider and further reveal. To conclude with Kranzberg's first law of technology (1986), technology may probably never be good, or bad, or neutral, even if restricted. It depends on the user with his or her individual motives, preferences, and perceptions for technology. Thus, this thesis supports (1) employees to see themselves as human agencies that know the best for their own healthy ICT use, (2) employers to recognize that and empower their employees to work on their own healthy ICT use, and (3) future research to perceive ICTs in three ways, the research purpose, the solution, and psychophysiological measurement device in order to gain a comprehensive understanding of employees' well-being.

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Appendix

Table A- 1: Descriptive Statistics, Cronbach's Alpha, and Bivariate Correlations between the Study Variables of the ICT-based Availability Management Study

	M	*SD*	α	1	2	3	4	5	6
1 Life balance t_0	4.53	1.24	.948	-					
2 Exhaustion t_0	3.55	1.18	.911	-.485**	-				
3 Stress level t_0	3.23	1.18	.893	-.633**	.699**	-			
4 Life balance t_1	4.94	1.15	.946	.643**	-.269**	-.331**	-		
5 Exhaustion t_1	3.16	1.26	.891	-.468**	.709**	.586**	-.387**	-	
6 Stress level t_1	2.89	1.04	.849	-.489**	.574**	.668**	-.490**	.668**	-

Note: ** $p \leq .001$; $N = 86$

Table A- 2: Category System for the Reviewed Methods and Procedures Determining Reliability and Convergent Validity (ICT-based Physiological Measurements Study)

Category	**Subcategory**	**Test Statistics**	**Exemplary Studies using Physiological Data**
Statistical Methods	Equality statistics	*Parametric:* Dependent t-test One-way repeated measures ANOVA *Non-parametric:* Wilcoxon signed-rank test Friedman's ANOVA	Giardino, Lehrer, & Edelberg, 2002 Khandoker, Karmakar, & Palaniswami, 2011
	Bivariate statistics	*Correlation:* Pearson's correlation coefficient with MTMM matrix Intraclass correlation coefficient *Regression:* Linear regression	Vanaelst et al., 2012
Non-statistical Methods	Simplified procedures	Passing and Bablok regression with CUSUM-test	Johansson, Öberg, & Sedin, 1999
	Graphical procedures	Bland and Altman Plot and Analysis	Heilman & Porges, 2007

Table A- 3: Descriptive Statistics of the Study Variables of the ICT-based Physiological Measurements Study

	Min	Max	*M*	*SD*	*N*
Baseline phase					
Biopac					
HR	61.35 bpm	94.29 bpm	78.22 bpm	9.15 bpm	26
logHF	4.54	8.21	6.30	0.93	26
SD2	46.30 ms	141.50 ms	84.19 ms	24.40 ms	25
Empatica					
HR	54.52 bpm	94.81 bpm	76.80 bpm	10.32 bpm	26
logHF	4.85	8.25	6.50	0.85	26
SD2	53.30 ms	134.80 ms	83.78 ms	24.10 ms	26
movisens					
HR	53.95 bpm	118.18 bpm	86.10 bpm	16.62 bpm	25
logHF	4.87	8.39	6.85	0.96	25
SD2	63.00 ms	184.40 ms	113.37 ms	36.15 ms	24
Stress phase					
Biopac					
HR	79.76 bpm	121.80 bpm	101.66 bpm	13.03 bpm	26
logHF	5.14	7.55	6.16	0.78	25
SD2	52.80 ms	147.80 ms	93.77 ms	25.63 ms	23
Empatica					
HR	66.95 bpm	116.15 bpm	95.42 bpm	13.48 bpm	26
logHF	4.65	7.31	5.92	0.76	24
SD2	43.40 ms	146.30 ms	91.25 ms	24.05 ms	25
movisens					
HR	80.23 bpm	126.77 bpm	104.48 bpm	13.41 bpm	25
logHF	5.10	8.53	6.68	1.07	25
SD2	50.90 ms	191.40 ms	113.36 ms	40.92 ms	24