Live Biofeedback in Electronic Markets

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Ewa Lux

Abstract

Decisions in electronic markets are frequently made under time pressure and in competition to others. Both factors can cause the decision maker to experience high levels of arousal. Without sound emotional processing, arousal can have detrimental effects on decision making. In this thesis the use of live biofeedback to support emotion perception and thus, to facilitate emotion regulation during emotionally charged decision making is evaluated.

Based on a systematic literature review existing live biofeedback research is analyzed in Chapter 2. A transmission model for live biofeedback is developed that classifies the main components of live biofeedback applications and the flow of information in form of transmission signals. To address the identified research gaps, three experimental studies (study I-III) are designed that investigate the effects of arousal and the use of live biofeedback in electronic markets.

Study I in Chapter 3 examines how arousal affects purchasing decisions with and without social interaction to analyze the context dependence of the effects of arousal on decision making. The results reveal that in auctions, where social interaction is a key characteristic, arousal increases final prices. Purchasing decisions without social interaction, however, are not affected by arousal. As social interaction has been identified as an essential factor for arousal to affect decision making, the subsequent studies II and III investigate the effects of live biofeedback in markets experiments that involve social interaction.

Study II in Chapter 4 evaluates the effects of live biofeedback on emotional processing in the context of auction bidding. Without prior biofeedback training this novel user interface element alters decision making processes at a cognitive and affective level. Study participants, who suppress emotional expressions, experience higher levels of physiological arousal. When provided with live biofeedback, this effect is mitigated. Furthermore, participants who receive live biofeedback show increased coherence of physiological and perceived arousal.

Study III in Chapter 5 examines the use of biofeedback in a game that has frequently been used to model financial markets, that is, the beauty contest game. In this study, participants complete a training in order to familiarize with the live biofeedback prior to the experiment. The analysis reveals that live biofeedback increases arousal perception and reduces suppression of emotional expressions. Importantly, participants who receive live biofeedback yield higher decision making quality.

In summary, this thesis provides further insights into the effects of arousal on behavior and how live biofeedback affects emotional processing and decision making in electronic markets. The results of this thesis suggest that live biofeedback is a promising tool to support emotion perception, regulation, and decision making of market participants.

Contents

Chapter 1.

Introduction

> “We are merely reminding ourselves that human decisions affecting the future, whether personal or political or economic, cannot depend on strict mathematical expectation, since the basis for making such calculations does not exist; and that it is our innate urge to activity which makes the wheels go round, our rational selves choosing between the alternatives as best we are able, calculating where we can, but often falling back for our motive on whim or sentiment or chance.
>
> JOHN MAYNARD KEYNES (1936)

1.1. Emotions and Economic Decision Making

Our decisions are not only shaped by rational reasoning but also by emotions. In fact, emotions consciously and unconsciously influence our everyday decision making. This also applies if these decisions are of economic nature, e.g., when purchasing products in a supermarket or bargaining with other people – "even within such an analysis-intensive domain as financial trading emotion plays a central role" (Fenton-O’Creevy et al., 2011, p. 1056). Recent economic theory has abandoned the concept of humans being entirely rational actors and considers the influence of emotions on economic decision making. In their fundamental work on economic decision making Bechara and Damasio (2005) postulated the somatic marker hypothesis, which provides a neuroanatomical and cognitive framework for decision making. According to this hypothesis decision processes are influenced by bioregulatory processes and responses, i.e., marker signals. So far, it remains unclear, when and under which conditions emotional arousal is beneficial or detrimental for economic decision making, as several studies demonstrated that arousal affects economic decision making both, positively and negatively, in a variety of scenarios such as auction bidding (Adam et al., 2015), trading (Prechter, 2001), and investment behavior (Shiv and Loewenstein, 2005). Bechara and Damasio (2005) found that bioregulatory processes provide valuable knowledge for advantageous decision making. However, there is reason to assume that emotional arousal also influences risk assessment (Loewenstein et al., 2001), judgments (Mano, 1992), and that arousal contributes to bounded rationality (Kaufman, 1999). Ku et al. (2005) developed a competitive arousal model for decision making. The authors found that in an auction context rivalry, social facilitation, time pressure, and the uniqueness of being first fuels emotional arousal, which then impairs economic decision making. Similarly, Kocher and Sutter (2006) demonstrated that time pressure, which causes emotional arousal (Ku et al., 2005), significantly reduces decision quality in the beauty contest game, a game linked to professional investment activity (Keynes, 1936). Effects of arousal can be manifold, however, recent literature on emotional intelligence suggests that whether decision making is affected in a positive or negative manner, depends on the ability to perceive, understand, and regulate emotions (Joseph and Newman, 2010).

Emotion regulation describes the "attempts individuals make to influence which emotions they have, when they have them, and how these emotions are experienced and expressed" (Gross et al., 2006, p. 14). In fact, an emotional state is continuous, that is, a person is never without an emotional state (Zajonc, 1984) and always – automatically or controlled, consciously or unconsciously – pursues some kind of emotion regulation (Gross et al., 2006). Emotion regulation comprises processes for monitoring, evaluating, and modifying emotional reactions that can be altered to accomplish one’s goals (Thompson, 1994). Thus, to control the influence of emotions on decision making, one can try to voluntarily regulate one’s emotions. Gross (1998b) derived a process model of emotion regulation in order to differentiate emotion regulation strategies with respect to the time line of the unfolding emotional response. Before an emotion unfolds emotions can be regulated through situation selection, situation modification, attentional deployment, and cognitive change. Gross (1998b) refers to such emotion regulation strategies as antecedent-focused emotion regulation strategies as they aim at changing the antecedents of an emotion, when the emotion has not unfolded yet. Emotion regulation strategies that modulate emotional responses when behavioral, experiential, and physiological responses have already unfolded, are referred to as response-focused emotion regulation strategies (Gross, 1998b). The two most vividly discussed emotion regulation strategies are cognitive reappraisal and expressive suppression (Gross, 1998b; Gross et al., 2006; Heilman et al., 2010; Wallace et al., 2009). Suppression, a response-focused emotion regulation strategy that diminishes the expression of emotional responses, is often referred to as a detrimental emotion regulation strategy with negative effects on task performance (Wallace et al., 2009). Suppression increases physiological activation when positive or negative emotions are inhibited (Gross and Levenson, 1997) and raises the influence of emotions on behavior (Adam et al., 2016). Cognitive reappraisal is an antecedent-focused emotion regulation strategy that is defined as a cognitive change that alters the emotional impact of an emotion-eliciting situation (Gross et al., 2006). Several studies demonstrate that reappraisal can have beneficial effects on decision making (cf. Heilman et al. 2010, Miu and Crişan 2011, and Wallace et al. 2009).

The ability to voluntarily regulate emotional responses, e.g., through applying cognitive reappraisal, is facilitated through interoception, the conscious perception of physiological changes (Füstös et al., 2012; Bechara and Damasio, 2005; Dunn et al., 2010). However, coherence of actual physiological changes and their perception varies across people and time. The necessary interoceptive skills that are required to achieve coherence of physiology and perception depend on several factors such as the particular emotion, individual differences in emotional expression, physiological reactivity, and awareness of emotional responding (Mauss et al., 2005). Especially, when one experiences high levels of emotional arousal, interoception can be impaired resulting in low coherence (Barrett et al., 2001). Sze et al. (2010) found that interoceptive skills increase as people experience specialized training that promotes body awareness. To improve the perception of physiological changes and thus, to support emotion regulation, recent literature (e.g., Adam et al. 2015, Al Osman et al. 2013, Riedl and Léger 2016) proposed the application of biofeedback, the provision of real-time information about one's physiological state, in emotionally charged decision environments.

1.2. Live Biofeedback for Decision Support

Biofeedback is applied to enable individuals to learn how to alter their internal physiological processes in order to improve, for instance, health, well-being, and performance (AAPB, 2011). Research on biofeedback "comprises the design, development, and testing of smart and precise instruments that measure physiological activities such as brainwaves, heart functions, breathing, muscle activities and skin temperature, and generate an appropriate feedback response" (Al Osman et al., 2013, p. 3145). If this feedback response is provided in real-time, we[1] refer to live biofeedback (LBF). From an Information Systems (IS) perspective Riedl and Léger (2016) describe LBF as a "contribution of neuroscience and physiological approaches to IS design science research" (p. 17). LBF systems support users in manifold ways that range from increased well-being (e.g., Chandler et al. 2001, Sakakibara et al. 2013), over enhanced user experience (e.g., Nacke et al. 2011, IJsselsteijn et al. 2004) and social interaction (e.g., Picard and Scheirer 2001, Roseway et al. 2015), to better decision making in an economic context (e.g., Astor et al. 2013, Fernández et al. 2013). LBF systems for everyday use can acquire a variety of biosignals such as heart rate or muscle movement by applying neurophysiological measurement techniques like electrocardiography (ECG) or electromyography (EMG) to provide, e.g., visual, acoustic, or tactile feedback response. This feedback response can be provided to the person whose biosignals are acquired, that is, self live biofeedback (SLBF), or to another person, that is, foreign live biofeedback (FLBF).

Green et al. (1970) postulated the relationship between physiological and mental processes in the body-mind loop, a psychophysiological principle which states that "[e]very change in the physiological state is accompanied by an appropriate change in the mental-emotional state, conscious or unconscious, and conversely, every change in the mental-emotional state, conscious or unconscious, is accompanied by an appropriate change in the physiological state" (p. 3) . LBF systems facilitate the perception of the physiological changes and thus, aim at supporting the voluntary control of physiological processes through emotion regulation (Riedl and Léger, 2016). Hence, LBF systems can be integrated in the concept of the body-mind loop as visualized in Figure 1.1, which is based on work by Al Osman et al. (2013) and Green et al. (1970). LBF provides information on body condition by acquiring biosignals generated by physiological processes with sensors and processes these signals to derive an adequate feedback response (Al Osman et al., 2013). LBF aims at altering mental processes to support the voluntary control of physiological processes by facilitating interoception and consequently assisting the application of emotion regulation strategies such as cognitive reappraisal.

Up to 20 years ago, LBF has mainly been studied and applied in the clinical domain (Futterman and Shapiro, 1986; Schoenberg and David, 2014), for instance for treatment of anxiety disorders, insomnia, depression, and schizophrenia. However, in recent years several studies have been conducted, for instance within the xDelia project[2], that examine the use of

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[1] *We* refers to both, the readers of this work and my co-authors.

[2] www.xdelia.org

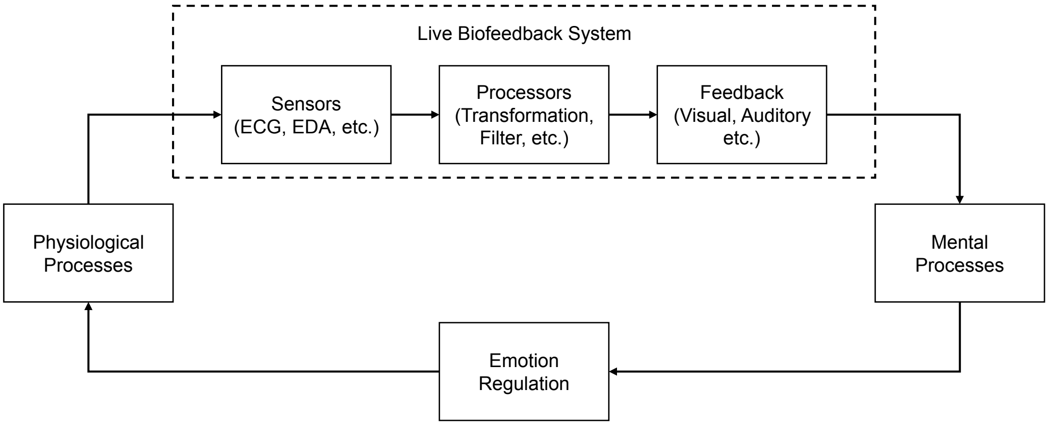

Figure 1.1.: Conceptualization of live biofeedback systems

LBF for non-clinical purposes such as decision support and serious games like the aiming game for emotion regulation training (Cederholm et al., 2011), the biofeedback training game for emotion regulation during a stressful task (Hilborn et al., 2013), or a serious game for emotion regulation in the context of financial decision making (Jercic et al., 2012). To promote future applications and research on LBF Astor et al. (2013) designed, developed, and evaluated a LBF design artifact and derived a set of design guidelines for integrating LBF in Information Technology (IT) artifacts. Several further prototypes of LBF systems for research purposes have been developed within the last decade. Fernández et al. (2013) developed a LBF system that makes individual traders as well as groups of traders more aware of their stress levels to reduce risky trading decisions. Al Osman et al. (2013) designed a LBF system that helps office workers to reduce their stress levels. With respect to consumer applications, ABN AMRO and Philips developed the *Rationalizer*, a LBF device for amateur traders that measures and reflects the user's level of arousal (Djajadiningrat et al., 2009). In recent years a variety of biofeedback applications for mobile devices became available, for instance, to increase athletic performance (e.g., *Elite HRV*, Elite HRV 2016), reduce stress (e.g., *eSense*, Mindfield Biosystems Ltd. 2016), or to monitor physiological processes in general (e.g., *BioZen*, NeuroSky 2015). Furthermore, new biofeedback-based products are currently being developed, such as headphones for improving concentration (Mindset, 2017), biofeedback patches for stress reduction (Therapeutics, 2017), and a biofeedback horror game (Reynolds, 2017).

In this thesis, the work mentioned above as well as related studies on LBF are reviewed. Based on the synthesized results of the examined studies, three further studies are conducted that investigate the role of emotions on decision making processes and how LBF can be used to alter these processes. The next Section outlines the research questions, which will be investigated in the following Chapters of this thesis.

1.3. Research Agenda

The Secretary-General of the OECD got to the heart of recent digitization processes within the economy by pointing out that "[t]he Internet is now an essential part of our lives and a critical element of the world economy" (Gurría, 2016, p. 3). As the share of Internet users increased from 6.5% of the worlds population in 2000 to 43% in 2015 (Gurría, 2016), of which nowadays 90% undertake online banking transactions and 80% – about half the OECD citizens (Wickoff, 2016) – carry out online purchases (Villarreal, 2016), decisions assisted by Information and Communication Technology (ICT) became omnipresent. They range from small everyday decisions like ordering food online to decisions that have a significant influence on our future life like searching for jobs online. Decision processes are complex and affected by our emotional state and hence, also in the field of IS the role of emotion in economic decision making is increasingly recognized. In the following Chapters, the relationship between emotional states and economic decision making is studied from an IS perspective. Situations in which emotional arousal affects decision processes are identified and it is investigated whether feedback on our physiology and thus, on the emotional arousal one experiences while making decisions, can help to make more profitable decisions.

Figure 1.2 provides an overview of the structure of this thesis. With the advances in sensor technology and real-time processing of neurophysiological data, a growing body of academic literature explores how LBF can be integrated into information systems for everyday use. While LBF has been studied primarily in the clinical domain, the proliferation of affordable mobile sensor technology enables researchers to consider LBF as a user interface element in contexts such as decision support, education, and gaming. However, the recent work on LBF (SLBF and FLBF) is highly fragmented, especially with respect to subject area, application domain, and methodology. In order to establish the current state of research on LBF, we review studies on SLBF and FLBF based on physiological data of the peripheral nervous system. The focus lies particularly on applications for everyday use. Therefore, only LBF applications for healthy subjects are included. By integrating a body of highly fragmented work from various research disciplines such as computer science, economics, IS, and psychology, we synthesize existing research, identify knowledge gaps, and suggest directions for future research. This literature review serves as the foundation of this thesis

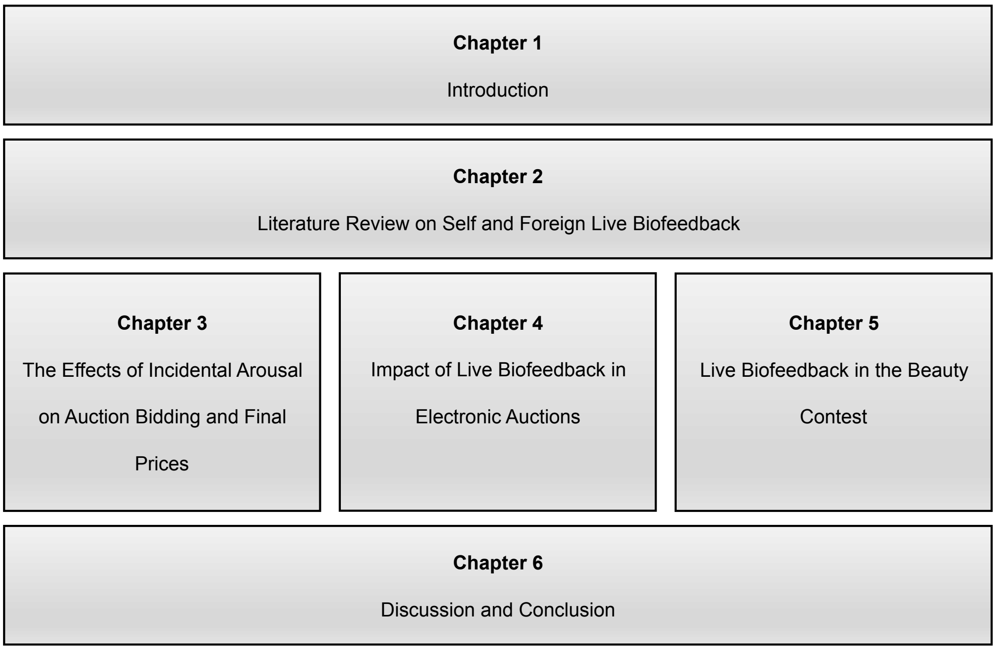

Figure 1.2.: Thesis structure

and is also meant as a reference guide for researchers and practitioners on how to integrate SLBF and FLBF into information systems. Hence, Chapter 2[3] of this thesis addresses the following research question:

RESEARCH QUESTION 1
In the emerging and fragmented field of self live biofeedback and foreign live biofeedback, (i) what is the current knowledge, (ii) what are knowledge gaps in research on live biofeedback, and (iii) how could future research close the identified gaps?

In order to investigate whether LBF can be successfully used to support emotion regulation and decision making, we first want to identify decision scenarios, where decisions are influenced by a high level of emotional arousal. One phenomenon that is considered to result in disadvantageous decision making is known as auction fever. Ku et al. (2005) define auction fever as emotionally charged behavior that can result in increased bidding prices. Despite anecdotes about auction fever, little research has examined whether arousal actually increases auction bidding. So far, it is unknown whether bidders place higher bids because they are aroused or if bidders are more aroused because they place higher bids.

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[3] Chapter 2 is based on a joint research project with Marc T. P. Adam, Verena Dorner, Sina Helming, Michael T. Knierim, and Christof Weinhardt.

To investigate this causality we isolate the effect of arousal on economic decision making and conduct a laboratory experiment in Chapter 3 of this thesis. We investigate effects of emotional arousal that is generated outside the decision context (i.e., incidental arousal) on decision behavior in two purchasing situations – an auction and a non-auction context. Thus, we want to find out, whether arousal affects purchasing decisions and whether these effects are context-dependent. We observe bidding or purchasing behavior, assess participants' perceptions, and measure physiological arousal in order to investigate under which circumstances emotional arousal that is created incidentally affect our decisions. Thus, the following research question is addressed in Chapter 3[4]:

RESEARCH QUESTION 2

Does arousal that is induced outside the decision making context affect purchasing behavior (i) in an auction and (ii) in a non-auction context?

Having identified that arousal drives decision behavior in a purchasing task that comprises social interaction, we investigate how LBF interacts with decision processes on a physiological, cognitive, and behavioral level. Based on the psychophysiological concept of the body-mind loop and empirical findings of the extant auction literature, we develop a research model that describes the pathways in which LBF affects the emotion-generative process in the context of auctions: expressive suppression of emotions comes at the cost of increased physiological arousal, which in turn influences the perceived arousal. Both, physiological and perceived arousal influence bidding prices of the auction. We designed a study where LBF is integrated into an information system for auction bidding. We used an ascending open-outcry auction (i.e., English auction) with a soft-close end as this auction format is known to fuel emotional arousal through rivalry, social facilitation, time pressure, and the uniqueness of being first (Ku et al., 2005). We investigated behavioral measures, self-report measures and physiological measures to answer the following research question in Chapter 4[5]:

RESEARCH QUESTION 3

Does live biofeedback influence (i) physiological arousal, (ii) perceived arousal, and (iii) bidding prices in an electronic English auction?

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[4] Chapter 3 is based on a joint research project with Marc T. P. Adam, Gillian Ku, Adam D. Galinsky, and J. Keith Murnighan.

[5] Chapter 4 is based on joint research projects with Marc T. P. Adam, Fabian Both, Verena Dorner, Anuja Hariharan, Jella Pfeiffer, and Christof Weinhardt.

After we studied how LBF affects decision processes in electronic auctions, a context that is well-known to fuel emotional arousal, we turn to a further market scenario as decision makers experience high level of arousal due to rivalry, social facilitation, time pressure, and the uniqueness of being first in a variety of settings (Ku et al., 2005). For instance when buying or selling stocks, traders are often exposed to severe time pressure and experience high levels of emotional arousal (Fenton-O'Creevy et al., 2011). In the article *The stock market and the beauty contest* by Keynes (1936) the beauty contest game (also known as the guessing game) was linked to professional trading activity. Kocher and Sutter (2006) demonstrated that in this game the decision quality in terms of distance to equilibrium and payoff is reduced when the decision maker faces time pressure. Based on these findings, we investigated whether LBF can increase decision quality in a beauty contest game under time pressure. The following research question is addressed in Chapter 5[6]:

RESEARCH QUESTION 4
Does live biofeedback improve decision making quality under time pressure?

Finally, the findings of this thesis are summarized in Chapter 6. We discuss implications for researchers and practitioners, give an outlook for further research on LBF in IS and related areas, and provide a concluding note for this thesis.

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[6] Chapter 5 is based on joint a joint research project with Marc T. P. Adam, Verena Dorner, and Christof Weinhardt.

Chapter 2.

Theoretical Background and Overview of Live Biofeedback Literature

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> "Our everyday experiences leave little doubt that our emotions can influence the decisions we make, much as the outcome of our decisions can influence the emotions we experience.
>
> NORBERT SCHWARZ (2000)

2.1. Introduction to Self and Foreign Live Biofeedback

In recent years, the interdisciplinary research field of Neuro-Information Systems (NeuroIS) has contributed to a deeper understanding of the cognitive and affective processes of users interacting with Information Technology (IT) (Riedl et al., 2010). In their summary of ten key contributions of NeuroIS to IS research and practice, Riedl and Léger (2016) concluded that one of these contributions are biofeedback systems as a specific category of "neuro-adaptive Information Systems" (Riedl et al., 2014, p. ii). Neurophysiological measurements can provide users with indicators that improve awareness and control of their cognitive and affective processes and thus, support emotion regulation training and facilitate behavior change (Astor et al., 2013; Riedl and Léger, 2016). LBF systems provide users with real-time feedback about their own (self live biofeedback or SLBF) or another person's (foreign live biofeedback or FLBF) current physiological state; information that users of biofeedback technology may have limited access to otherwise (Allanson and Fairclough, 2004; Astor et al., 2013). So far, LBF has been studied primarily in the clinical domain[1], e.g., for the treatment of mental health disorders (Monastra et al., 2002; Zucker et al., 2009). But since the proliferation of affordable mobile sensor technology has made non-health-related innovative applications of LBF systems technologically and economically feasible (Al Osman et al., 2013, 2016), researchers have begun to employ LBF as a user interface (UI) design element in application domains such as education and gaming to enhance, e.g., stress management and user experience.

However, the body of literature on the use of LBF as a UI design element in human-computer interaction (HCI) for healthy subjects in non-clinical domains is highly fragmented. This Chapter aims at facilitating the integration of LBF in information systems for everyday use by reviewing and synthesizing the current state of research. The review includes 65 articles published in HCI-related research outlets between 1977 and 2016. It covers both SLBF and FLBF in the application domains of art, architecture, economic decision making, education, games, and well-being. This Chapter seeks to answer the following first research question:

Research Question 1: In the emerging and fragmented field of self live biofeedback and foreign live biofeedback, (i) what is the current knowledge, (ii) what are knowledge gaps in research on live biofeedback, and (iii) how could future research close the identified gaps?

By answering this first research question, four core contributions to IS research and practice are made in this Chapter. First, based on the seminal Transmission Model of Communication by Shannon and Weaver (1949), a framework for LBF research is introduced in IS that clarifies the relationship between feedback sender and receiver and provides a taxonomy for investigating LBF as a UI element. Second, current knowledge on SLBF and FLBF within Computer Science, Engineering and Technology, IS, Medical Science, and Psychology, is synthesized, outlining key theories and the constructs they affect. Third, an overview of the various measurement modalities employed to compute LBF and the different forms of feedback manifestations used to convey a feedback response to the user is provided. Fourth, knowledge gaps in research on LBF are identified and directions for future research to fill these gaps are derived.

This Chapter is based on a joint research project with Marc T. P. Adam, Verena Dorner, Sina Helming, Michael T. Knierim, and Christof Weinhardt. The remainder of this Chapter is structured as follows: Section 2.2 outlines the theoretical foundations of SLBF and FLBF and in Section 2.3 a framework and taxonomy for LBF research is proposed based on the

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[1] For a review of clinical biofeedback see e.g., Futterman and Shapiro 1986; Schoenberg and David 2014.

transmission model of communication. The structure of this framework is then used to synthesize existing research on SLBF and FLBF with regard to user perception, behavioral consequences, and application domains in Sections 2.4 and 2.5. In the subsequent Section 2.6 we identify gaps in the current body of knowledge on LBF and suggest directions for future research. Finally, Section 2.7 provides a summary of results, a discussion of practical implications and concluding remarks.

2.2. Theoretical Background of Live Biofeedback Systems

2.2.1. Fundamentals of Live Biofeedback

The Association for Applied Psychophysiology and Biofeedback (AAPB), the Biofeedback Certification International Alliance (BCIA), and the International Society for International Society for Neurofeedback and Research (ISNR) define the term biofeedback as follows:

"Biofeedback is a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. Precise instruments measure physiological activity such as brainwaves, heart function, breathing, muscle activity, and skin temperature. These instruments rapidly and accurately "feed back" information to the user. The presentation of this information – often in conjunction with changes in thinking, emotions, and behavior – supports desired physiological changes. Over time, these changes can endure without continued use of an instrument." (AAPB, 2011)

This definition and its many variations in related literature share the view that biofeedback comprises the measurement of physiological processes and the generation of a feedback response that addresses at least one of a person's five traditional senses (auditory, gustatory, olfactory, tactile, and visual) in order to trigger a change in cognitive, affective, and/or behavioral processes (Al Osman et al., 2013; Hilborn et al., 2013; Riedl and Léger, 2016). LBF aims at interacting with the body-mind loop, a psychophysiological principle first introduced by Green et al. (1970) which states that changes in the mental-emotional state affect physiological states and vice versa (Al Osman et al., 2013). Riedl and Léger (2016) conceptualize a biofeedback system as a cycle of three steps: (i) biosignal recording, (ii) feedback provision based on the recorded biosignal, and (iii) change in behavior to control the biosignal. Thus, the aim of LBF systems is to support deliberate changes in cognitive and affective processing.

2.2.2. Transmission Model for Live Biofeedback

Conceptually, a person can be provided with feedback on their own physiological state or on another person's physiological state. However, no consistent terminology for LBF in a UI context has been established in the literature so far. We propose a transmission model for LBF based on the seminal *Transmission Model of Communication* by Shannon and Weaver (1949) which describes the communication process from source to destination on a conceptual level. The model aims at integrating these concepts and their relations within the LBF research domain and at providing an intuitive illustration and shared frame of reference of the transmission processes between feedback transmitter and feedback receiver.

The adapted transmission model for LBF applications is depicted in Figure 2.1. Similar to the original model by Shannon and Weaver (1949), the transmission model for LBF comprises four main elements, namely (i) source, (ii) transmitter, (iii) receiver, and (iv) destination. The model implies three scenarios, where transmission signals (TS) are sent from one person to the same person or to another person. In scenario one, a person receives a transmission signal based on their own physiology (TS1; e.g., Buttussi et al. 2007; Feijs et al. 2013). In scenarios two and three, a person receives a transmission signal based on another person's physiology (TS2; e.g., Al Mahmud et al. 2007; Curmi et al. 2013) and the person is aware that another person receives a transmission signal based on their physiology (TS3; e.g., Tan et al. 2014; Walmink et al. 2013). Distinguishing between signal transmissions TS2 and TS3 is important – on the one hand, subjects are not necessarily aware that their physiological data is recorded and on the other hand, the cognitive processes affected by receiving LBF on another person's physiology or knowing that another person has access to one's own physiological data are not identical.

In an LBF context, the source is a person's physiological state and the biosignals obtained from this current state (e.g., electrical activity of the heart). The transmitter transforms a

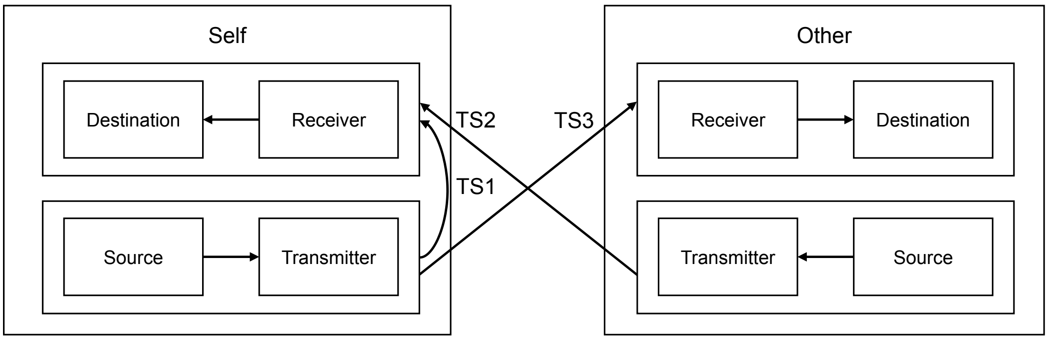

Figure 2.1.: Transmission model for live biofeedback

biosignal into an electrical signal and transmits it to the receiver (e.g., ECG for calculating heart rate) in an understandable format. Receivers represent LBF manifestations such as visual heart rate display on a screen or auditory representation of heart rate through a tone. The receiver transforms the signal into a message to the destination, which is one of the user's five sensory channels. The user can now interpret the message, with potential impact on their cognitive, affective, and behavioural processes.

Providing real-time information about the user's own physiological state (TS1 in Figure Figure 2.1) – in terms of the proposed model, feedback transmitter and feedback receiver belong to the same person – is by far the most common approach in LBF literature (Section 4). Nevertheless, no uniform terminology has emerged yet to distinguish this form of feedback provision from LBF approaches where feedback transmitter and feedback receiver belong to different persons (TS2 and TS3 in Figure Figure 2.1). The model aims at clarifying and systematizing this conceptual distinction. We propose the terms SLBF to refer to LBF where feedback transmitter and feedback receiver belong to the same person andFLBF to refer to cases where feedback transmitter and receiver belong to different persons (Section 5). A special case of FLBF is group LBF where feedback is received by each group member either individually or in an aggregate manner (e.g., a collective stress level, Fernández et al. 2013). From the perspective of a particular person, all signals TS1, TS2, and TS3 can be transmitted simultaneously.

2.2.3. Sources and Transmitters: Modalities for Live Biofeedback

Generally, the tools used for measuring physiological activity can be divided into tools for measuring biosignals emitted by the central nervous system, the peripheral nervous system, and the endocrine (hormone) system (Riedl et al., 2014; Riedl and Léger, 2016)[2]. In this review, the focus lies on tools for measuring changes in the peripheral nervous system as they are well suited for IS applications of LBF in everyday life (e.g., wearable sensors with wireless connectivity), interfere little with tasks, place few restrictions on participant behavior, and can be applied "over longer periods in natural environments" (Riedl and Léger, 2016, p. 58). Moreover, consumer-grade mobile measurement devices for the peripheral nervous system are becoming increasingly affordable and widespread.

Altogether, 39 studies with ECG-based LBF, 26 studies with LBF based on electrodermal activity (EDA), 17 studies with respiration-based LBF, and 14 studies with LBF based on

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[2] For further details on NeuroIS methodology, tools, and measurements please see the works by Dimoka et al. 2012, Riedl et al. 2014, and Riedl and Léger 2016.

photoplethysmography (PPG) are identified. Fewer studies use EMG (5), movement detection (video, step counter, and GPS; 4), temperature (4), acceleration (4), and eye tracking (2) as a source for LBF.[3] More than half of the 65 reviewed studies provide unimodal LBF (38). The remaining studies (27) combine two or more measurement modalities to a multimodal LBF. About half of these studies (14) combine ECG and EDA measurements. Chittaro and Sioni (2014) compare unimodal and multimodal LBF and suggest that "a single-sensor approach is more practical and less costly, but the use of multiple physiological sensors may improve the accuracy" (p. 664). However, their study did not bear out this thought; users perceived the unimodal LBF as more accurate than the placebo condition, whilst the multimodal LBF scored even lower than placebo feedback.

Further, it is important to distinguish between LBF modalities that measure biosignals under direct or indirect control of the user (Nacke et al., 2011). The most commonly used modalities are based on measurements of cardiovascular activity and EDA. In both cases the underlying biosignals can only be controlled indirectly as, for example, the electric activity of the heart muscle fibers, changes in blood flow, and alterations in skin conductance are triggered by autonomous reactions. Similarly, body temperature, which is used in hardy any LBF application, cannot be controlled directly by the user. Biosignals with a higher degree of control include body movements (e.g., measured through EMG or cameras), eye activity (e.g., measured through electrooculography (EOG) or eye tracking), and respiration (e.g., measured with an optical sensor or a girth sensor). Hence, depending on the specific application scenario, researchers and practitioners need to take into account the required and possible level of control when choosing an appropriate biosignal for their LBF application.

2.2.4. Receivers and Destinations: Manifestations of Live Biofeedback

LBF manifestations address at least one of the five traditional human senses – sight (visual), hearing (auditory), touch (tactile), taste (gustatory), and smell (olfactory). Based on the review, we find that the most common manifestations used in the literature are visual (58), auditory (16), and tactile (5) forms of feedback. Some studies provide a combination of these manifestation types, such as virtual or physical alterations in game mechanics (e.g., Liu et al. 2009; Oertel et al. 2007; Huang and Luk 2015; Marshall et al. 2011).

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[3] While EEG-based LBF is outside the scope of this study, it is important to note that three studies employing EDA measurements additionally included EEG measurements and are hence included in this review (see Tables 2.1 and 2.2).

One popular approach for visual biofeedback is to display human elements such as cues for heart activity and breathing (Tan et al., 2014), clip arts of groups (Fernández et al., 2013), stickmen (Tennent et al., 2011), or a Pinocchio with changing nose size (Al Mahmud et al., 2007). The use of human elements in LBF visualization is driven by the rationale that such elements help non-expert users develop an intuitive interpretation of the provided information (Tan et al., 2014). Al Mahmud et al. (2007) find that even children have no problems to interpret human elements representing physiological feedback. Another approach for visualizing LBF employs nature-inspired elements, such as trees (Al Osman et al., 2016), water ripples (Slovák et al., 2012), flowers (Feijs et al., 2013), or butterflies (MacLean et al., 2013). Nature-inspired elements often serve as an analogy, for instance using the health status of a tree (Al Osman et al., 2016) or the opening and closing of a flower (Feijs et al., 2013) to represent the user's current stress level. In some research areas, such as IS or Computer Science, more detailed feedback is provided through meters, scales, or bars (Al Osman et al., 2013; Astor et al., 2013; Curmi et al., 2013). These more complex visual representations may require specific training (Al Osman et al., 2013).

Auditory biofeedback is frequently based on nature-inspired sounds, such as the splash of a waterfall (Millings et al., 2015) or sounds that change their pitch according to the user's relaxation level (O'Neill and Findlay, 2014). Less commonly employed, tactile biofeedback can be used to provide people with information about their physiological state without distracting them from their primary task (Nishimura et al., 2007). Ueoka and Ishigaki (2015) conduct the only study in the review where LBF is provided exclusively as tactile biofeedback. Nearly all studies combine tactile feedback with visual and/or auditory feedback (Curmi et al., 2013; Schnädelbach et al., 2010, 2012). Since gustatory and olfactory biofeedback systems are difficult to implement with real-time feedback, they are correspondingly rare in literature. In fact, within the scope of this literature review, no prototype for gustatory or olfactory LBF has been found.[4]

In line with the notion that the human brain gathers information from multiple senses to accurately capture a situation (Ernst and Bülthoff, 2004), some studies use multiple LBF manifestations. All of them include visual feedback and combine it, for example, with tactile feedback (Huang and Luk, 2015), auditory feedback (Davis et al., 2005), or the combination of auditory and tactile feedback (Schnädelbach et al., 2010). However, the great majority of studies rely on one type of LBF manifestation only (e.g., visual feedback, 89 % of all reviewed studies).

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[4] The only study within the scope of this literature review that is remotely related to gustatory feedback evaluates a personalized sports drink based on heart rate data which is provided to study participants *after* they finished their workout (Khot et al., 2015).

2.3. Literature Review Research Methodology

In order to provide a comprehensive overview on existing LBF literature in non-clinical domains, a review of fragmented literature following the approach of Webster and Watson (2002) is conducted. The review only includes studies that (i) investigate LBF based on peripheral nervous system activity, (ii) are situated in non-clinical domains with healthy subjects, and (iii) include some level of qualitative and/or quantitative evaluation. The search, conducted within the Google Scholar database, focuses on keywords likely to occur in LBF studies, namely "realtime" OR "real time" OR "real-time" OR "live" AND "biofeedback". In addition, forward and backward search is applied. The time frame of the search is not restricted. For a more detailed differentiation between studies addressing SLBF and FLBF, the search results are filtered manually, which results in 47 publications on SLBF and 18 publications on FLBF. Table 2.1 in Section 2.4 and Table 2.2 in Section 2.5 summarize the studies included in the review[5]. Table 2.2 further differentiates the studies on FLBF with respect to the direction of the communication between the actors in the transmission model, that is, whether feedback is provided based on one's own physiology and/or another person's physiology and whether feedback on one's physiology is provided to another person.

As shown in Figure 2.2, the number of publications on SLBF and FLBF increased noticeably during the last 15 years. In all, 65 relevant articles in journals and conference proceedings in Computer Science (25 studies on SLBF and 17 studies on FLBF)[6], Engineering and Technology (2+0), IS (7+0), Medical Science (4+0), and Psychology (9+1) are identified.[7] The application domains of the reviewed studies are architecture (2+0), art (2+0), economic decision making (3+1), education (2+0), games (13+5), interpersonal communication (0+7), social media (0+1), sports (0+3), and well-being (25+1). The reviewed studies focus on variables related to stress management (17+4), user experience (11+5), emotion regulation (9+0), social interaction (0+8), and physiology (7+0). With regard to the directionality of the signal transmission between two users in the reviewed FLBF applications, Table 2.2 in Section 2.5 shows that most studies on FLBF use TS1 and TS3. In other words, most of these studies use SLBF in addition to bidirectional FLBF.

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[5] All publications which used FLBF in any way are listed in Table A2 as this is their primary focus, even though some of these studies also include SLBF.

[6] Abbreviated in the following (number of articles on SLBF + number of articles on FLBF).

[7] Due to the breadth of the search, a categorization solely according to the ABS ranking is insufficient. The SCImago Journal and Country Rank (www.scimagojr.com/) is additionally used for the classification of outlets into research areas. Classified outlets are then clustered into the five above-mentioned, meaningful research areas.

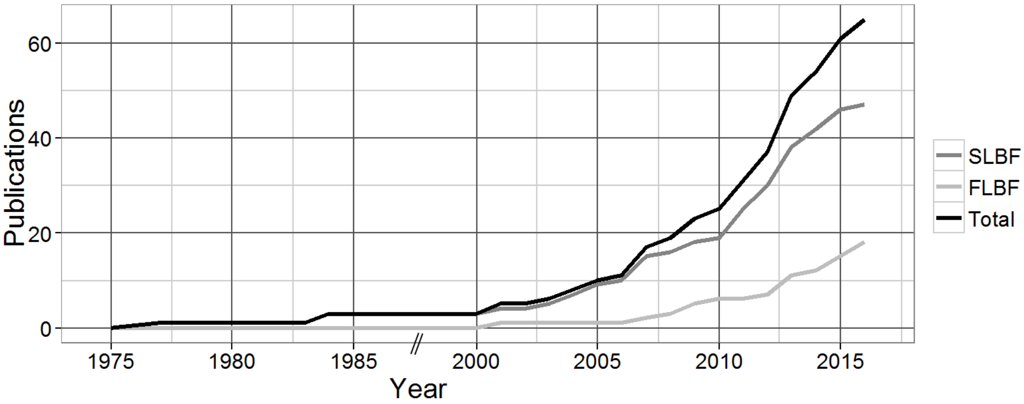

Figure 2.2.: Publications on self and foreign live biofeedback over time

2.4. Synthesizing Research on Self Live Biofeedback

2.4.1. Self Live Biofeedback in Cognitive and Affective Processing

According to the psychophysiological concept of the body-mind loop by Green et al. (1970), cognitive and affective processes interact constantly. Affective processing can influence cognitive processing and vice versa; both kinds of processes shape the resulting behavioral reaction. Al Osman et al. (2013) integrate the concept of LBF into the body-mind loop and describe how LBF can be used to alter cognitive and affective processing, resulting in changes in perception and physiology. Since consciously perceiving changes in physiology requires high interoceptive skills, that is, skills to sense the physiological condition of the body (Craig, 2003; Dunn et al., 2010), providing feedback on a person's physiological state (TS1) can increase the coherence of their physiology and their perception thereof (Bonanno and Keltner, 2004; Mauss et al., 2005), which in turn may affect behavior (Figure 2.3).

In line with the conceptualization of SLBF systems in Figure 2.3, studies commonly explore one or more pathways in which SLBF can affect user perception, physiology, and behavior. First, studies investigate the impact of SLBF on enhancing users' perception of their physiology, hence increasing the coherence of physiology and people's perception thereof. Studies focusing on this pathway often employ relatively simple visual manifestations such as light pulses for indicating the end of each inter-beat (R-R) interval obtained from a heart rate recording (Goldstein et al., 1977), a balloon that expands and contracts with the rhythm of respiratory frequency (Xiong et al., 2013), or screens that change their color and thus provide breathing instructions to support paced breathing (Pastor et al., 2008).

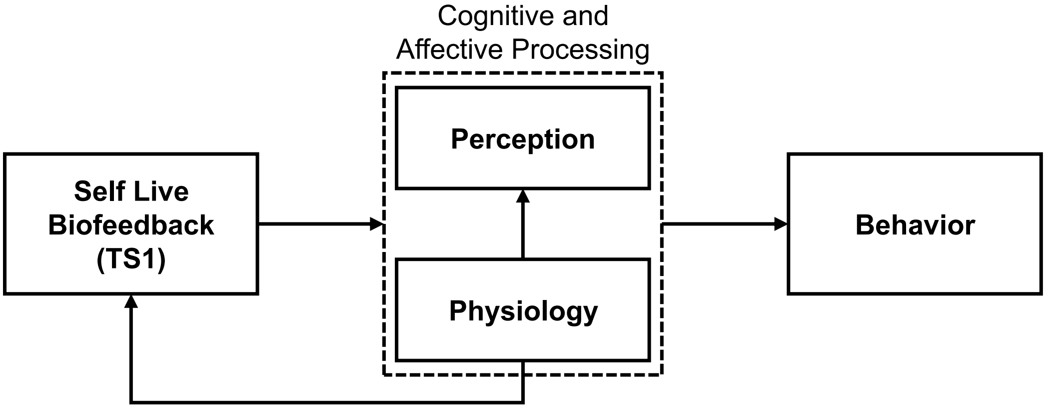

Figure 2.3.: Self live biofeedback, cognitive and affective processing, and behavior

Second, studies investigate the impact of SLBF on improving users' ability to control their physiology. These studies frequently employ cardiovascular measures such as heart rate (e.g., Goldstein et al. 1977; Höysniemi et al. 2004; Lehrer et al. 2003; Masuko and Hoshino 2006; Ueoka and Ishigaki 2015) and/or heart rate variability (e.g., Ebben et al. 2009; Lehrer et al. 2003; Sakakibara et al. 2013). Goldstein et al. (1977) find that providing SLBF during exercise results in significantly lower mean heart rate, blood pressure, and rate-pressure. Schnädelbach et al. (2010, 2012) and Lehrer et al. (2003) find that SLBF can lead to physiological changes like higher heart rate variability. Pastor et al. (2008) find that SLBF results in improved learning of how to control their physiological responses, but only if SLBF was accompanied by precise instructions.

Third, studies investigate the pathway between SLBF and the behavior that results from changes in user perception and/or physiology. Höysniemi et al. (2004) and Masuko and Hoshino (2006) evaluate SLBF in fitness games and find that SLBF improves users' sense of accomplishment and helps users to maintain an optimal heart rate for the respective exercise, resulting in an increased effectiveness of the exercise. With respect to user behavior, it is important to note that the use of indirectly controlled biosignals such as EDA, limits the usefulness of SLBF systems for certain applications, for instance for biosignal-based navigation through a virtual landscape (Friedman et al., 2007). Nacke et al. (2011) conclude that indirectly controlled biosignals are not suitable for control actions in gameplay. An example for a SLBF gaming or training system based on a directly controllable measure is developed by Chollet et al. (2015) who use gaze behavior in a training system for public speaking. Although the authors do not find significant behavior changes in terms of speaking performance, they do report that the presenters enjoy the system. Table 2.1 summarizes the reviewed studies on SLBF.

Table 2.1.: Studies on self live biofeedback

Authors (Year)	Outlet [Subject Area, Domain]	Brief Description	Focus Variable	Modality	Manifestation
Goldstein et al. (1977)	ABP Journal [Psyc, well-being]	Heart rate biofeedback during treadmill exercise	Physiology	ECG	Visual
Reynolds (1984)	AAPB Journal [Psyc, well-being]	Supporting homeostasis for coping with stress	Stress management	PPG	Auditory
Zeier (1984)	AAPB Journal [Psyc, well-being]	Arousal reduction with meditation supported by respiratory feedback	Stress management	Resp.	Auditory
Chandler et al. (2001)	AABP Journal [Psyc, well-being]	Relaxation training for counselor trainees	Stress management	Temp.	Auditory
Lehrer et al. (2003)	Psychosom Med [MS, well-being]	Biofeedback for increasing vagal baroreflex gain	Physiology	ECG	Visual
Höysniemi et al. (2004)	NordiCHI 2004 [CS, games]	Physically interactive fitness game	Physiology	Video	Visual
IJsselsteijn et al. (2004)	ICEC 2004 [CS, well-being]	Virtual coach based on heart rate	User experience	ECG	Visual
Davis et al. (2005)	MULTIMEDIA 2005 [CS, art]	Artwork with biofeedback for novel user experience	User experience	ECG, movement (GPS)	Visual, auditory
Rani et al. (2005)	HCII 2005 [CS, games]	Maintaining optimal challenge in computer games	Emotion regulation	ECG, EDA, PPG, EMG	Visual

Masuko and Hoshino (2006)	ACE 2006 [CS, games]	A fitness game reflecting heart rate	Physiology	ECG	Visual
Buttussi et al. (2007)	LECT NOTES COMPUT SC [CS, games]	Fitness game that incorporates physiological sensors	User experience	ECG, PPG, accel.	Visual, game mec.
Dekker and Champion (2007)	DiGRA 2007 [CS, games]	Horror game that incorporates physiological data to enhance gameplay	User experience	EDA, PPG	Visual, auditory, game mec.
Friedman et al. (2007)	ACII 2007 [CS, art]	Artistic exhibition with skin conductance based navigation	Navigation	EDA	Visual
Nenonen et al. (2007)	CHI 2007 [CS, games]	Real-time heart rate data for biathlon game control	User experience	ECG	Visual, game mech.
Oertel et al. (2007)	AC 2007 [CS, education]	E-learning system for emotion regulation	Emotion regulation	ECG, EDA, Temp.	Visual, game mec.
Pastor et al. (2008)	AAPB Journal [Psyc, well-being]	Skin conductance biofeedback during respiration exercise to reduce arousal	Physiology	EDA	Visual
Ebben et al. (2009)	AAPB Journal [Psyc, well-being]	Improving sleep quality with biofeedback	Stress management	PPG	Visual
Liu et al. (2009)	INT J HUM-COMPUT INT [CS, games]	Dynamic difficulty adjustment in computer games	Emotion regulation	ECG, EDA, PPG, EMG	Visual, game mec.

Schnädelbach et al. (2010)	NordiCHI 2010 [CS, architecture]	Externalizing a person's physiological data through architecture	Adaptive architecture	ECG, EDA, Resp.	Visual, auditory, tactile
Cederholm et al. (2011)	DiGRA 2011 [IS, economic decision making]	Emotion regulation training with a serious aiming game for financial investors	Emotion regulation	EDA, EEG	Visual, game mech.
Marshall et al. (2011)	CHI 2011 [CS, games]	Breath control of a bucking bronco ride	User experience	Resp.	Visual, game mech.
Moraveji et al. (2011)	UIST 2011 [CS, well-being]	Desktop respiration-pacing training	Stress management	Resp.	Visual
Morie et al. (2011)	HCII 2011 [IS, well-being]	Virtual world application for mitigating stress	Stress management	Resp.	Visual, auditory
Nacke et al. (2011)	CHI 2011 [CS, games]	Enhancing game interaction by means of direct and indirect physiological control	User experience	ECG, EDA, PPG, EMG, Resp., eye tracking, Temp.	Visual, game mech.
Tennent et al. (2011)	ACE 2011 [CS, games]	Breath control as an interaction medium for gaming	User experience	Resp.	Visual, game mech.
Bouchard et al. (2012)	PLoS ONE [Psyc, well-being]	Stress management training for soldiers	Stress management	ECG, EDA	Visual, auditory
Jercic et al. (2012)	ECIS 2012 [IS, economic decision making]	Serious game for emotion regulation training in financial decision making	Emotion regulation	ECG	Visual, auditory

Reitz et al. (2012)	MobileHCI 2012 [CS, games]	Integration of biofeedback into gameplay	User experience	ECG, EDA	Visual, game mech.
Schnädelbach et al. (2012)	TOCHI [CS, architecture]	Physiologically Driven Adaptive Architecture	Adaptive architecture	ECG, EDA, Resp.	Visual, auditory, tactile
Vidyarthi et al. (2012)	DIS 2012 [CS, well-being]	Connection of respiration ando music	Stress management	Resp.	Auditory
Al Osman et al. (2013)	MULTIMED TOOLS APPL [CS, well-being]	Stress management application for office workers	Stress management	ECG, Resp.	Visual
Astor et al. (2013)	JMIS [IS, economic decision making]	Serious game for emotion regulation training in financial decision making	Emotion regulation	ECG	Visual
Feijs et al. (2013)	HCI International [CS, well-being]	Biofeedback to enhance relaxation during milk expression	Stress management	EDA	Visual, auditory
Hilborn et al. (2013)	HCII 2013 [IS, games]	Biofeedback game for training arousal regulation during a stressful task	Emotion regulation	ECG	Visual
Horta et al. (2013)	Healthcom 2013 [MS, well-being]	Biofeedback monitoring solution for real-time falls prevention and detection	Health	ECG, EDA, PPG, EMG, Resp., accel.	Visual

MacLean et al. (2013)	PETRA 2013 [ET, well-being]	Wearable biofeedback device to mirror a user′s real-time stress state	Stress management	ECG, EDA	Visual
Sakakibara et al. (2013)	AAPB Journal [Psyc, ell-being]	Biofeedback for improving the cardiorespiratory resting function	Stress management	PPG	Visual
Xiong et al. (2013)	ICSH 2013 [MS, well-being]	Biofeedback system for mobile healthcare	Physiology	ECG, Resp.	Visual
Al Rihawi et al. (2014)	CHI PLAY 2014 [CS, well-being]	Biofeedback game for relaxation training	Stress management	ECG, EDA, Resp.	Visual
Chittaro and Sioni (2014)	INT J HUM-COMPUT ST [IS, well-being]	Biofeedback-controlled game for relaxation training	Stress management	EDA, PPG, EMG	Visual, auditory
Peira et al. (2014)	INT J PSYCHOPHYSIOL [Psyc, well-being]	Use of HR biofeedback to improve cardiac control during emotional reactions	Emotion regulation	ECG	Visual
Chollet et al. (2015)	AAMAS 2014 [CS, education]	Interactive platform for public speaking training	Speech	Movement, eye tracking	Visual
Hicks et al. (2014)	EATC 2015 [ET, well-being]	Using peripheral biofeedback to facilitate autonomic regulation	Emotion regulation	EDA, PPG, Resp., Temp.	Visual
Matthews et al. (2015)	CHI 2015 [CS, well-being]	Playful biofeedback system for stress management	Stress management	EDA	Visual

Millings et al. (2015)	INVENT [MS, well-being]	Biofeedback system for better mental health	Stress management	ECG	Visual
Ueoka and Ishigaki (2015)	HCII 2015 [IS, games]	Cross modal display system to enhance horror emotion	Physiology	PPG	Tactile
Al Osman et al. (2016)	IEEE ACCESS [CS, well-being]	Stress management though a serious game	Stress management	ECG, Resp., accel.	Visual

2.4.2. Self Live Biofeedback for Stress Management

Stress management is the most intensely studied application of SLBF (17 of 47 studies). This research stream includes SLBF studies on the perception of stress, often referred to as "stress awareness" (Al Osman et al., 2013; Chittaro and Sioni, 2014; MacLean et al., 2013), as well as studies on the ability to change stress levels and resulting behavior, commonly referred to as "stress management" (Bouchard et al., 2012; Vidyarthi et al., 2012). From a theoretical perspective, SLBF-based stress management approaches can be linked back to the seminal *Transactional Model of Stress* by Lazarus and Folkman (1987). In this model stress is conceptualized as an emotion that emerges from an emotion-generative process, comprising causal antecedents (personal and environmental variables), mediating/moderating processes (appraisal and coping), and immediate effects (affect, physiological changes, outcome quality; Lazarus and Folkman 1987). The conceptualization of "stress" varies between SLBF studies: "mental stress" (Al Osman et al., 2016), "arousal" (Snyder et al., 2015; Zeier, 1984), "tension" (Moraveji et al., 2011), "depression" (Millings et al., 2015), or "being upset" (Morie et al., 2011). A number of studies examine the opposite of stress, the "level of relaxation" (Al Rihawi et al., 2014; Chandler et al., 2001; Feijs et al., 2013; Matthews et al., 2015; Reynolds, 1984).

SLBF studies that focus on improving stress perception often use serious or playful games (Al Osman et al., 2016; Al Rihawi et al., 2014; Buttussi et al., 2007; Chittaro and Sioni, 2014; Tennent et al., 2011) with simple UI elements, like a bar moving across the screen (Moraveji et al., 2011) or ambient light (Matthews et al., 2015; Snyder et al., 2015). Visual SLBF manifestations dominate these applications; one exception is Vidyarthi et al. (2012), who provide auditory SLBF based on respiration. The results of SLBF studies on stress management, however, are mixed. MacLean et al. (2013), for example, find that drivers wearing the SLBF application MoodWings, a bracelet that reflects stress, drive more safely, but experience more stress (physiologically and self-perceived) than the drivers in a control group. By displaying the users' physiological state through colored ambient light, the SLBF application MoodLight by Matthews et al. (2015) also aims at supporting stress management. However, the authors find that "feedback that displays systematic progress towards relaxation regardless of the users' level of physiological relaxation" (Matthews et al., 2015, p.605) is more helpful for stress reduction than SLBF. Millings et al. (2015) report that integrating SLBF into a stress management program reduces its effectiveness. Moraveji et al. (2011) investigate a peripheral SLBF application that helps the user pace respiration, but find that initial decreases in breathing rate are not sustained throughout the tasks. Chittaro and Sioni (2014) test user perception of multimodal and unimodal SLBF against placebo SLBF and find that only the unimodal SLBF is significantly more accurate than the placebo SLBF application.

In contrast to the findings above, several studies find evidence that SLBF is an effective tool for stress management. In a business context, a stress management application for office workers by Al Osman et al. (2013) provides a feedback response when stress levels reach a threshold with a detection accuracy of nearly 90%. In this sense, information systems can become stress-sensitive and "trigger context-sensitive interventions" (Adam et al., 2016, p. 5). In a second study, Al Osman et al. (2016) observe that subjects maintain more control over their mental stress when SLBF is provided. Bouchard et al. (2012) report that their SLBF stress management application reduces stress and the SLBF-assisted relaxation application for counselor trainees by Chandler et al. (2001) helps users reduce their stress levels and results "in a greater sense of personal well-being" (Chandler et al., 2001, p. 1). Al Rihawi et al. (2014) investigate an SLBF game that supports the user in acquiring breathing skills and in reducing arousal during a stress-inducing task. In studies where SLBF is combined with meditation tasks or autogenic training, SLBF is identified as a useful tool for relaxation and heart rate reduction (Zeier, 1984) as well as for detecting affect (Reynolds, 1984). Morie et al. (2011) demonstrate an SLBF application that reduces user distress while running and the SLBF application for breast milk expression by Feijs et al. (2013) helps mothers to relax and thus, to produce and eject more milk in shorter time intervals. Two studies investigate the commercial stress reduction product StressEraser®[8]. Ebben et al. (2009) evaluate the StressEraser® device and find that this SLBF application significantly

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[8] The StressEraser® (http://www.stress.org/certified-product-stress-eraser) is a portable SLBF device based on heart rate variability measurements. It was developed by The American Institute of Stress.

increases sleep quality. The findings of Sakakibara et al. (2013) indicate that this device improves cardiorespiratory function during sleep.

2.4.3. Self Live Biofeedback for Emotion Regulation

Studies on stress management primarily focus on the arousal dimension of emotion. A number of SLBF studies (9) extend this focus to the valence dimension (Cederholm et al., 2011; Hilborn et al., 2013; Jercic et al., 2012; Nasoz et al., 2010; Peira et al., 2014) and the application of specific emotion regulation strategies (Astor et al., 2013; Hicks et al., 2014; Hilborn et al., 2013; Jercic et al., 2012; Peira et al., 2014). Emotion regulation theory builds on the assumption that emotions emerge in an emotion-generative process, where the extent and magnitude of an emotion as well as its behavioral consequences depends on the way it is regulated by the person experiencing this emotion (Gross and John, 2003). Hence, SLBF systems for emotion regulation are often situated in scenarios that are known to potentially trigger high levels of arousal and have detrimental effects on decision making (e.g., driving, Nasoz et al. 2010; financial decision making, Astor et al. 2013).

SLBF systems support emotion regulation in two distinct ways. In line with the conceptualization in Figure 2.3, one group of studies investigate the pathway of how SLBF may improve users' perception of their physiological states (e.g., driving, Nasoz et al. 2010; learning, Oertel et al. 2007). Peira et al. (2014), for example, report that heart rate-based changes of the background color of the screen (i.e., changes towards green for decreasing and changes towards red for increasing heart rate) supports emotion regulation when participants are confronted with negative pictures resulting in lower heart rates. A second group of studies is concerned with employing SLBF to improve the regulation of physiological (hence, emotional) states and the resulting behavior. Instead of directly interfering with the actual decision context, several studies show that using serious games with biofeedback can be helpful for training users' emotion regulation capabilities (e.g., Cederholm et al. 2011; Hilborn et al. 2013; Jercic et al. 2012).[9] In these studies typically the game mechanics are altered based on heart rate (Astor et al., 2013; Hilborn et al., 2013; Jercic et al., 2012) or skin conductance (Cederholm et al., 2011; Hicks et al., 2014) to reward the regulation of physiological states. Studies on serious games that incorporate SLBF show that specific affective states (e.g., of anxiety or engagement) can be detected in real-time

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[9] Four of these studies are conducted within the project xDelia (Astor et al., 2013; Cederholm et al., 2011; Hilborn et al., 2013; Jercic et al., 2012). xDelia (http://www.xdelia.org) is an interdisciplinary project funded by the European Commission with contributions from various European research institutions and businesses that investigate emotion-centric financial decision making and learning

and that adjustments of game difficulty based on the detected affective state can be used to support emotion regulation, increase performance, and boost perceived challenge (Liu et al., 2009; Rani et al., 2005).

2.4.4. Self Live Biofeedback for User Experience

Most SLBF studies that aim at improving user experience are set in a gaming context (7 out of 9), ranging from virtual environments such as sports and fitness games (Buttussi et al., 2007; Nenonen et al., 2007), games on mobile devices (Reitz et al., 2012), and first-person shooter games (Dekker and Champion, 2007; Tennent et al., 2011), to real-world environments such as a rodeo amusement ride (Marshall et al., 2011). As before, we find that studies build on three pathways in which SLBF can affect user experience, namely enhancing perception of physiology, controlling physiology, and facilitating changes in behavior. Importantly, however, while most studies in the context of stress management and emotion regulation employ dedicated UI elements to convey SLBF, studies in the context of gaming commonly focus on the adaptation of existing UI elements, e.g., altering game mechanisms in an effort to "make computer games more exciting and more involving" (Nenonen et al., 2007, p. 853).[10]

Nacke et al. (2011) investigate the adaption of multiple game mechanics such as the character′s speed, target size, or weapon reach, concluding that biosignal integration can result in a "more fun experience than using only a traditional control scheme for game interaction" (Nacke et al., 2011, p. 110). The authors derive two design implications for integrating LBF into games: First, action control in gameplay should be based on physiological measures that underlie direct control (e.g., respiration, Tennent et al. 2011; eye movement, Chollet et al. 2015, and second, physiological input underlying indirect control (e.g., heart rate, skin conductance level) should be used to alter the game world.

Similarly, several studies map physiological measurements directly to game difficulty or intensity (Buttussi et al., 2007; Marshall et al., 2011; Nenonen et al., 2007; Reitz et al., 2012). Nenonen et al. (2007) and Reitz et al. (2012) find that heart rate data can enrich game interaction, increasing fun and enjoyment players derive from playing the game. Dekker and Champion (2007) integrate SLBF into a horror-themed computer game, adapting various

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[10] Interestingly, one of the first consumer-grade LBF systems that was available to a broader audience also focused on the adaptation of existing UI elements. In 1998, Nintendo released a Bio Tetris extension of its Tetris 64 game in Japan, where the speed of the gameplay increases or decreases with the player′s heart rate based on an ear-mounted PPG sensor (Christy and Kuncheva, 2014; Nacke et al., 2011). For an overview of affective games see Christy and Kuncheva (2014).

game elements such as movement speed, sound volume, and number of enemies based on the player's physiological data. For users who generally enjoy the horror game genre, the authors find that SLBF results in increased levels of enjoyment. Tennent et al. (2011) and Marshall et al. (2011) find that breath flow can be a useful input mechanism for increasing players' enjoyment as it offers "an intriguing balance between voluntary and involuntary control" (Marshall et al., 2011, p. 73).

Two studies investigate SLBF for user experience outside a gaming context. Davis et al. (2005) study an artwork application that adjusts the brightness of a digital artwork installation based on the users' heart rate. Based on a focus group evaluation, the authors find that users are excited about the integration of SLBF into the artwork. IJsselsteijn et al. (2004) evaluate a virtual coach who instructs and encourages users based on their heart rate. The authors report that SLBF does not influence training intensity or enjoyment, but lowers users' perception of pressure, tension, and raises perceived control and competency.

2.5. Synthesizing Research on Foreign Live Biofeedback

2.5.1. Foreign Live Biofeedback in Cognitive and Affective Processing

While SLBF systems address the dynamic interplay of cognitive and affective processes within a person (TS1), FLBF is applied in the context of interpersonal interactions (Figure 2.4). Through FLBF a user is provided with feedback on the physiological state of another user (TS2) and/or is aware that another user is provided with such feedback (TS3). FLBF is potentially useful in easing interpersonal interactions, which are driven by the sending and receiving of social cues, and the inferences drawn from these cues. People vary in their ability to perceive and interpret such cues and, consequently, in their ability to perceive other people's emotions and manage social situations (Joseph and Newman, 2010; Mayer et al., 2008). FLBF can amplify social cues and/or increase people's sensitivity towards such cues, for instance to increase a feeling of social presence, that is, "the feeling of warmth and sociability conveyed through a medium" (Hess et al., 2009, p. 890).

Similar to studies on SLBF, studies on FLBF build on several pathways in which providing feedback based on physiological measurements may affect user perception, physiology, and behavior. First, since the ability to (correctly) assess other peoples' mental states (i.e., mentalizing) is vital for social behavior (Decety et al., 2004; Frith and Frith, 2006; Lim and Reeves, 2010; Polosan et al., 2011), quite a few FLBF studies examine how physiological information may support users in improving their perceptions of their counterpart's mental

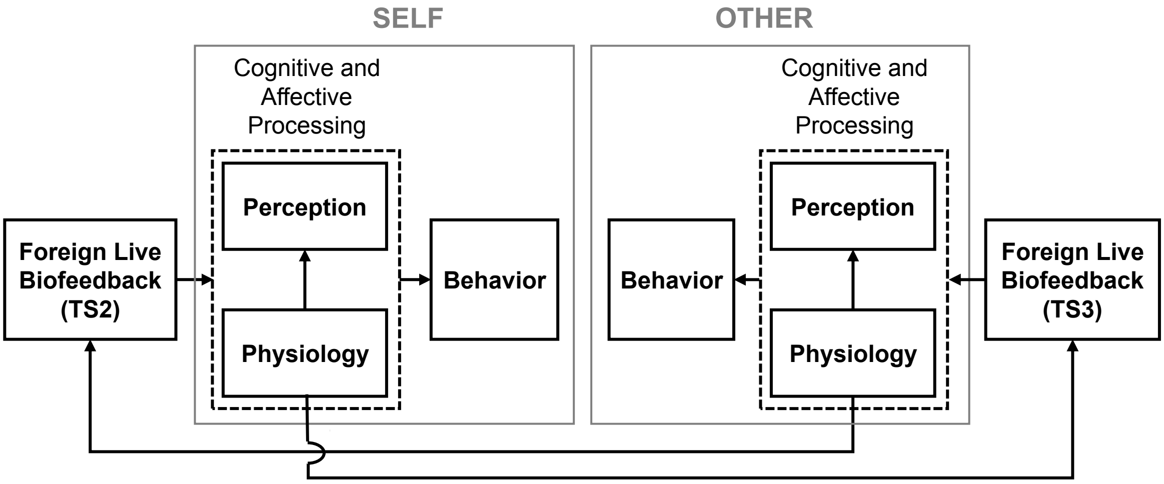

Figure 2.4.: Foreign live biofeedback, cognitive and affective processing, and behavior

state (Gervais et al., 2016; Slovák et al., 2012) – even if the other person is not physically present (Curmi et al., 2013; Fernández et al., 2013; Howell et al., 2016). Second, studies explore how FLBF can be used to facilitate social situations. Several studies investigate whether FLBF can be used to alter social situations, e.g., by increasing social presence (Järvelä et al., 2016), the enjoyment of a social activity (Stach et al., 2009), support social exertion experiences (Walmink et al., 2013), or reduce stress in a collaboration task (Tan et al., 2014). In the following the results of pathways in which FLBF is used to affect social situations are synthesized. Table 2.2 summarizes the reviewed studies on FLBF.

Table 2.2.: Studies on foreign live biofeedback

Authors (Year)	Outlet [Subject Area, Domain]	Brief Description	Focus Variable	Modality	Manifestation
Picard and Scheirer (2001)	HCI International 2001 [CS, interpersonal communication]	LED display based on skin conductivity for communication [TS1, TS2, TS3]	Social interaction	EDA	Visual
Al Mahmud et al. (2007)	IDC 2007 [CS, games]	Social gaming application for children [TS2, TS3]	User experience	ECG, EDA	Visual

De Oliveira and Oliver (2008)	MobileHCI 2008 [CS, sports]	Fitness game that increases personal awareness [TS1, TS2, TS3]	User experience	ECG, accel.	Visual
Magielse and Markopoulos (2009)	CHI 2009 [CS, games]	Outdoor game for children incorporating physiological data [TS1, TS2, TS3]	User experience	ECG, movement (step counter)	Auditory
Stach et al. (2009)	GI 2009 [CS, games]	Fitness game with heart rate [TS1, TS2, TS3]	User experience	ECG	Visual
Mueller et al. (2010)	UIST 2010 [CS, sports]	Heart rate based spatialized audio system [TS1, TS2, TS3]	Social interaction	ECG	Auditory
Slovák et al. (2012)	CHI 2012 [CS, interpersonal communication]	Heart rate communication to improve social connectedness [TS1, TS2, TS3]	Social interaction	ECG	Visual, auditory
Curmi et al. (2013)	CHI 2013 [CS, social media]	Broadcasting heart rate data to social networks [TS2]	Social interaction	ECG, movement (GPS)	Visual, tactile
Fernández et al. (2013)	J.UCS [CS, economic decision making]	Self-aware trader system for safer financial decisions [TS1, TS2, TS3]	Stress management	PPG	Visual
Mueller and Walmink (2013)	IE 2013 [CS, games]	Engaging gameplay in a sword fighting game with real-time body data [TS2, TS3]	User experience	ECG	Visual
Walmink et al. (2013)	TEI 2014 [CS, sports]	Display of heart rate data on a bicycle helmet [TS2, TS3]	Social interaction	ECG	Visual

Tan et al. (2014)	CHI 2014 [CS, interpersonal communication]	Biofeedback to reduce stress and workload during video-mediated collaboration [TS3]	Stress management	EDA, PPG, Resp.	Visual
Huang and Luk (2015)	HCI International 2015 [CS, games]	Biofeedback board game to improve emotional control [TS1, TS2, TS3]	Stress management	ECG	Visual, tactile, game mec.
Roseway et al. (2015)	IJMHCI [CS, interpersonal communication]	Colored crystal for awareness and mood sharing [TS1, TS2, TS3]	Social interaction	ECG, EDA	Visual
Snyder et al. (2015)	CSCW 2015 [CS, interpersonal communication	Exploring of ambient biosignal display [TS1, TS2, TS3]	Stress management	EDA	Visual
Gervais et al. (2016)	TEI 2016 [CS, well-being]	Toolkit for reflection of physiological and mental states [TS1, TS2, TS3]	Social interaction	ECG, EDA, EOG, EEG, Resp.	Visual
Howell et al. (2016)	DIS 2016 [CS, interpersonal communication]	T-shirt that indicates changes in skin conductance [TS1, TS2, TS3]	Social interaction	EDA	Visual
Järvelä et al. (2016)	FS 2016 [Psyc, interpersonal communication]	Display of physiological linkage based on HR synchrony [TS1, TS2, TS3]	Social interaction	ECG	Visual

2.5.2. Foreign Live Biofeedback for Social Interaction

Perception of one's counterpart is a key aspect in studies on FLBF (8 out of 18 studies). This perception is, in the first step, related to increased awareness of another person or, more precisely, to the perceived social presence conveyed through a medium, such as a smart phone application (see e.g., Mueller et al. 2010; Snyder et al. 2015). FLBF is often investigated as a driver for social interaction (Al Mahmud et al., 2007; Howell et al., 2016), social connectedness (Curmi et al., 2013; Slovák et al., 2012), social experience (Mueller et al., 2010), social engagement (Snyder et al., 2015), or social support (Walmink et al., 2013). Interestingly, the majority of studies that address constructs related to social interaction use ECG as the NeuroIS method and, more specifically, heart rate as the NeuroIS feature. The wide use of heart rate measurements as LBF modality might be explained by the notion that most users have an intuitive understanding of this parameter, enabling them to interpret it as a source of "objective *information* about one's own or someone else's international state" and a "direct *connection* to the other" (Slovák et al., 2012, p. 863, emphasis in original). In general, FLBF applications are used for social interactions are used in three ways, namely, on ambient, wearable, and mobile devices.

Ambient devices facilitate not only FLBF but also SLBF since ambient feedback can potentially be perceived by the users themselves and others. Studies that use such devices usually evaluate both FLBF-specific constructs, such as social connectedness, and constructs typically relevant for SLBF, such as self-awareness (Gervais et al., 2016; Roseway et al., 2015; Slovák et al., 2012). Gervais et al. (2016) find that ambient FLBF devices can ease social interaction, foster empathy and relaxation, and promote self-reflection. Järvelä et al. (2016) report increased heart rate synchrony for dyads at different geographical locations. The BioCrystal by Roseway et al. (2015) results in higher awareness of their physiological states and supported interpersonal communication. Slovák et al. (2012) find that heart rate sharing does not improve feelings of closeness in the workplace. However, the authors suggest that heart rate can be a useful information in more private interactions, when users are less concerned about their external perception (Slovák et al., 2012).

Wearable FLBF devices like a bicycle helmet (Walmink et al., 2013), a t-shirt (Howell et al., 2016), and a glove (Picard and Scheirer, 2001) have been shown to fuel social interaction. Walmink et al. (2013) find that the accessibility of another person's heart rate during outdoor cycling results in a social interplay which increases the cyclists' engagement, hence ultimately affecting their behavior. The authors identify temporal and spatial data accessibility and easy interpretation of the given feedback as key dimensions for designing FLBF.

With the FLBF t-shirt by Howell et al. (2016), pairs of friends are able to share emotions, such as joy or embarrassment. The application supports the enactment of social performances such as emotional engagement (Howell et al., 2016). Picard and Scheirer (2001) observe that users enjoy the glove-like FLBF device (galvactivator) and try to make each other's FLBF devices light up. Due to the ambiguity of the feedback, the authors find that the device often leads to conversations about the wearer's feelings.

FLBF applications on mobile devices have been examined in the context of physical exertion to motivate users or to increase the perceived level of social experience (Curmi et al., 2013; Mueller et al., 2010). The results reveal that FLBF can positively influence social network ties and feelings of social connectedness (Curmi et al., 2013) and facilitates a social experience of exercising together (Mueller et al., 2010).

2.5.3. Foreign Live Biofeedback for User Experience

Similar to SLBF, employing FLBF holds great potential in gaming scenarios as a UI element to increase fun and enjoyment (Al Mahmud et al., 2007; De Oliveira and Oliver, 2008) and improve game performance (Stach et al., 2009). Moreover, due to the inherent social connotation of FLBF, this type of feedback can also improve user experience by leveraging social factors such as connectedness and empathy (Al Mahmud et al., 2007; Magielse and Markopoulos, 2009; Mueller and Walmink, 2013). The games investigated in the extant literature range from fitness games (De Oliveira and Oliver, 2008; Stach et al., 2009) over party and outdoor games (Magielse and Markopoulos, 2009; Mueller and Walmink, 2013) to tabletop games (Al Mahmud et al., 2007).

Overall, the empirical results support the notion that FLBF can be an effective UI element for enhancing user experience. Al Mahmud et al. (2007) find that physiological input can be a fun game element to support social interaction among players, as the users' physiological states are reflected within the game and are thus, easier to interpret. De Oliveira and Oliver (2008) report FLBF to be a driver of competition in a running exercise experience, where runners are provided with information on each other's heart rates by means of a mobile device. Importantly, however, Mueller and Walmink (2013) find that if users have only indirect control over the physiological input (here: heart rate) and the users are not provided with a feedback on this physiological measure themselves, FLBF can increase perceived ambiguity which may eventually lead to an impaired gaming experience. Yet, the authors conclude that FLBF provides new opportunities for creating engaging play experiences (Mueller and Walmink, 2013). Stach et al. (2009) find that their FLBF mechanism did not significantly affect engagement during gameplay or average speed. Their results, however, indicate that FLBF reduces the performance gaps between people of different fitness levels. The results of the FLBF study by Magielse and Markopoulos (2009) are similar to Stach et al. (2009), as their game does not alter engagement in the physical activity.

2.5.4. Foreign Live Biofeedback for Stress Management

Several studies investigate FLBF in a stress management context, showing that this type of feedback can be an effective way to increase awareness of stress (Fernández et al., 2013; Huang and Luk, 2015; Snyder et al., 2015) and to reduce stress responses (Tan et al., 2014). Using the ambient lighting system MoodLight (see also Matthews et al. 2015) Snyder et al. (2015) explore how EDA measurements may support stress management in social contexts. The authors use variations in the physiological arousal levels of pairs (two subjects) to change the lighting color of the room they are in. Results imply that subjects are able to use the system as a tool for self-revelation in order to create a connection with their counterpart. Fernández et al. (2013) also use colors to display stress levels in a financial trading context. In order to avoid "unsafe" trading, traders are provided with a real-time indicator that reflects the stress level experienced by the market based on the traders' heart rates (i.e., a collective stress level aggregating the values of the different traders into a single feedback score). The authors find that the system is able to increase traders' awareness of their own and other trader's stress levels, supporting them in making less risky financial decisions. Based on the popular tabletop game Jenga, Huang and Luk (2015) develop a game-based system to support stress regulation training which changes its difficulty level based on the players' heart rates (ambient lighting, shakiness of the table). However, early demonstration sessions do not show a noticeably increase in the players' ability to control their heart rates. Finally, Tan et al. (2014) study how FLBF may support instructors in providing workers with remote video-mediated assistance. Based on the rationale that a worker's performance might be reduced when experiencing stress, the authors provide the instructors with information about the worker's stress levels based on skin conductance response, blood pressure, and respiration. The authors find that providing the instructor with FLBF leads to reduced levels of mental workload in the worker and improved task performance.

2.6. Knowledge Gaps and Directions for Future Research on Live Biofeedback

Research on SLBF and FLBF has evolved noticeably over the last 15 years, growing from 5 publications in 2001 to 65 publications in 2016 (see Figure 2.2). This review reveals several research gaps in the literature, suggesting five promising directions for further research. In the following, a brief summary of each of these directions is provided. Importantly, these directions each require individual research attention in terms of closing specific knowledge gaps as well as research oversight in terms of how advances in a specific research stream (e.g., feedback manifestation) affect results in another stream (e.g., technology acceptance). As LBF research progresses, further directions with dedicated foci will emerge, such as group feedback or unconscious feedback processing.

Direction 1 – Modalities and Manifestations: A key design question for LBF applications is the selection of (i) the modalities used for calculating the feedback and (ii) the manifestations used to convey the feedback to the user. The review reveals that the majority of studies employ visual (89%) and/or auditory (25%) manifestations. However, current research certainly does not cover the full range of conceivable feedback manifestations. This calls for further research on how different forms of feedback manifestations, and combinations thereof, affect user perception and behavior in the different application domains of SLBF and FLBF. Also, especially against the backdrop of wearable devices, it appears that tactile manifestations deserve further research attention as only few of the reviewed studies investigated this type of feedback (see Curmi et al. (2013), Huang and Luk (2015), Schnädelbach et al. (2012, 2010), and Ueoka and Ishigaki (2015) for exceptions). Tactile feedback may be a particularly effective way to draw user attention during tasks when other sensory channels such as vision or hearing are occupied (Damian and André, 2016; Lee and Starner, 2010). Furthermore, research on sensory substitution shows the potential to transmit large and complex amounts of information to a receiver through unconscious processing from tactile stimulation patterns (Novich and Eagleman, 2015; Shull and Damian, 2015). Building on the elements of the transmission model (source, transmitter, receiver, and destination), a systematic evaluation of feedback modalities should consider the limitations of people's perception (Baumeister et al., 1998; Miller, 1956), how they will interpret the provided feedback response (e.g., manifestations resembling human features versus nature-inspired elements), and how that will lead to changes in behavior.

Direction 2 – Construct Validity: More research is needed to better understand the relations between physiological features, feedback manifestations, and target variables. Specifically, it needs to be evaluated whether the combination of all elements of an LBF application, from the underlying biosignal (source) over the measurement modality (transmitter) to the manifestation (receiver), address the identified constructs to achieve the desired effects on the user and their environment (destination). For instance, LBF applications may affect other perceptual and behavioral variables than intended (e.g., driving safety, MacLean et al. 2013; perceived ambiguity, Mueller and Walmink 2013). Hence, similar to the original purpose of the transmission model for communication by Shannon and Weaver (1949), the effectiveness in terms of "the success with which the meaning is conveyed to the receiver" (Shannon and Weaver, 1949, p. 5) needs to be validated. Studies that systematically vary single elements of LBF or their characteristics could provide further insights into the degree to which they affect specific constructs such as stress or emotional arousal. The validation of physiological measures for LBF response generation, e.g., by applying the multi-trait multi-method matrix by Ortiz de Guinea et al. (2013) or examining the relationship between those physiological measures and psychological measures (Tams et al., 2014), is necessary in order to ensure that the LBF response bears information about the identified construct.

Direction 3 – Context Dependence: In their design guidelines for the integration of biosignals into information systems, Astor et al. (2013) emphasize that the chosen biosignals need to be "adequate for the environment of the users" and that any feedback manifestation needs to take into account the "contextual and situational circumstances of the users" (Astor et al., 2013, p.268). What is common to all studies covered in this review is that they examine one specific LBF application in one specific scenario (e.g., communication, decision making, games). This leads to findings which are difficult to compare or may even contradict each other. For example, while some studies demonstrate that LBF can be used to reduce stress levels in a specific context (Al Osman et al., 2016; Al Rihawi et al., 2014), others are unable to find a lasting effect (Moraveji et al., 2011), or find that LBF increases users' stress levels (MacLean et al., 2013). The review reveals that no structured evaluation has been conducted so far that investigates the interdependencies between biosignals, measurement modalities, transmission signal directions, LBF manifestations, and the effect on the users with respect to environmental conditions in an IS setting. In this sense, no conclusions can be drawn on whether an LBF application that increases performance in one task (e.g., gaming) also increases performance in another task (e.g., trading), or whether it may in fact be detrimental to performance in that task. Future research needs to investigate when and under which circumstances an LBF application can be transferred successfully from one context to another.

Direction 4 – Interplay of Self and Foreign Live Biofeedback: Most research on LBF addresses SLBF; comparably few studies have been conducted in the field of FLBF. Existing research on FLBF, however, shows that providing another person with one's own physiological data can be an interesting and promising approach for many different application domains such as communication (Picard and Scheirer, 2001), games (Al Mahmud et al., 2007), and economic decision making (Fernández et al., 2013). Due to increasing connectedness of individuals, the impact of social media, the need for remote collaborations, and the availability and practicability of wearable sensors, FLBF will continue to gain importance. Similarly, group feedback (i.e., feedback for interactions of more than two people) is investigated in only two studies (Fernández et al., 2013; Järvelä et al., 2016), but will likely become more relevant in the future. Most studies on FLBF are conducted in the field of Computer Science (94%). Hence, future research in other subject areas such as IS and Psychology is required to improve our understanding of how people interact with and are affected by FLBF systems. Only few studies explicitly investigate both SLBF and FLBF. The concept of the transmission signals, which specify whether the feedback response is provided to users' themselves or to other persons (see Figure 2.1), could be used to systematically evaluate the effects of SLBF and FLBF and their interplay. A systematic evaluation could provide insights whether the same combination of biosignals, NeuroIS methods, manifestations, and constructs yields similar results in SLBF and FLBF systems. Furthermore, while SLBF and FLBF applications use nearly the same biosignals, NeuroIS methods, and manifestations, the targeted constructs differ. In future research, constructs such well-being, which have mainly been addressed by SLBF studies, should be specifically examined for both SLBF and FLBF.

Direction 5 – Technology Acceptance: LBF applications raise a range of important questions of technology acceptance. First, hardly any research examines how acceptable it is for users to see feedback on their own physiological data, and how the level of perceived usefulness may be increased through appropriate design. For instance, Astor et al. (2013) find that some users report that they did not find SLBF useful in regulating their emotional state. Yet, the data shows that users who are provided with LBF in fact exhibit more effective emotion regulation, leading to the conclusion that "biofeedback is to some extent processed unconsciously" (Astor et al., 2013, p. 268). Furthermore, users might be more willing to accept LBF if they are in control of it, that is, if they are able to switch the feedback on and off or determining the format of the feedback manifestation and the level of feedback obtrusiveness. Second, technologies such as remote photoplethysmography (rPPG) (Rouast et al., 2016) enable physiological measurements and, hence, FLBF, that may be conducted without the awareness of the sender (e.g., by analyzing video data gained from cameras integrated into head-mounted devices such as Google Glass or Microsoft's HoloLens). This development raises important questions around involuntary surveillance and privacy invasion associated with physiological measurements (Fairclough, 2014) and how it affects the technology acceptance of FLBF applications, both from the sender and the receiver perspective.

2.7. Discussion of Live Biofeedback Literature

2.7.1. Summary of Results of Existing Live Biofeedback Literature

In their application strategies of NeuroIS methods in design science research, vom Brocke et al. (2013) concluded that IS research should explore the "use of neuroscience tools as built-in functions of IT artifacts" (vom Brocke et al., 2013, p. 3, Strategy 3). As one important application domain of such neuro-adaptive systems (Riedl et al., 2014), LBF systems enable users to get insight into their own or other persons' physiological processes for everyday use (Astor et al., 2013). While LBF has been studied primarily in the clinical domain, a growing number of studies employ LBF in non-clinical domains such as decision making, education, and games. As such, SLBF and FLBF offer a promising avenue for IS research and practice. Hence, in this Chapter a transmission model for LBF based on the model by Shannon and Weaver (1949) is developed and a systematic review of fragmented literature covering 65 studies published in Computer Science, Engineering and Technology, IS, Medical Science, and Psychology is conducted. The review provides insights into the elements of LBF applications and offers a comprehensive overview of LBF applications in non-clinical domains, separating the field into (i) studies on SLBF systems that address the dynamic interplay of cognitive and affective processes within a person (TS1) and (ii) studies on FLBF systems, which are applied in the context of interpersonal interactions, that is, where a user is provided with feedback on the physiological state of another user (TS2) and/or is aware that another user is provided with such feedback (TS3). Based on these studies we identified key theories and focus variables and synthesize research results for both, SLBF and FLBF.

In total, we find 47 studies on SLBF, and 18 studies on FLBF. Although, up to 2016, the majority of studies was conducted on SLBF, the concepts applied in FLBF studies show strong similarities with respect to biosignals, modalities and manifestations, building strongly on the established SLBF literature. The majority of studies on SLBF and FLBF focus on visual biofeedback (89%; 88%). Colors play a key role for both SLBF (Jercic et al., 2012) and FLBF (Fernández et al., 2013). Human elements (e.g., a heart or a pair of lungs, Hicks et al. 2014) or nature-inspired elements (e.g., a flower, Feijs et al. 2013; water ripples, Slovák et al. 2012) as well as vibrations (Huang and Luk, 2015; Schnädelbach et al., 2010) are also popular for both kinds of LBF. However, there are important differences with respect to the theoretical underpinnings of SLBF and FLBF. In terms of theory, SLBF applications primarily build on the psychophysiological principle of the body-mind loop introduced by Green et al. (1970) and related theories of stress management, emotion regulation, and individual user experience. Due to their inherent social connotation, FLBF applications extend the theoretical basis, building on theories of social presence (Hess et al., 2009) and mentalizing (Decety et al., 2004; Frith and Frith, 2006).

This review provides a comprehensive overview of the various different application domains for LBF in non-clinical settings (Tables 2.1 and 2.2). Interestingly, studies on SLBF focus on different application domains than studies on FLBF. While the majority of SLBF studies address well-being (53%, e.g., Chittaro and Sioni 2014; Kuipers et al. 2016), followed by serious and playful games (27%, e.g., Hilborn et al. 2013; Nacke et al. 2011), and economic decision making (6%, e.g., Cederholm et al. 2011; Jercic et al. 2012), studies on FLBF focus on domains such as interpersonal communication (39%, e.g., Picard and Scheirer 2001; Slovák et al. 2012; Tan et al. 2014), social interaction in games (28%, e.g., Al Mahmud et al. 2007; Huang and Luk 2015; Stach et al. 2009), and joint sport activities (17%, e.g., De Oliveira and Oliver 2008; Mueller and Walmink 2013). Hence, the latent variables of interest addressed through the UI are considerably different for SLBF and FLBF. While SLBF studies often address stress management (36%, e.g., Al Osman et al. 2016; Al Rihawi et al. 2014) or emotion regulation (19%, e.g., Astor et al. 2013; Cederholm et al. 2011), the primary focus of FLBF studies lies on social interaction (44%, e.g., Howell et al. 2016; Picard and Scheirer 2001).

This review has some limitations that need to be taken into account. Since its aim is to provide a general and comprehensive overview on existing literature on consumer LBF applications for everyday use, the search scope is limited to (i) healthy subjects, (ii) non-clinical domains, and (iii) physiological activity measures of the peripheral nervous system. The review only includes studies that provide some level of qualitative and/or quantitative evaluation (excluding work such as Djajadiningrat et al. (2009) and Hudlicka (2009) where no evaluation is presented). Since we investigate a body of highly fragmented literature on LBF applications, a fragmented literature review is conducted, including backward and forward search, and focusing on a broad range of outlets with keywords pertinent to different types of LBF systems. However, as the body of LBF literature in non-clinical domain grows, structured reviews of the literature and LBF applications in distinct research domains will become necessary.

2.7.2. Implications for Practice based on Existing Live Biofeedback Literature

In summary, SLBF as well as FLBF can be employed in various different domains, ranging from individual settings such as immersive elements in computer games, stress management tools, and emotion regulation training to systems which support remote group collaborations in social settings. The review reveals a number of design considerations for integrating LBF into information systems, each of which depends on situational factors and the characteristics of the user's primary task.

First, system designers need to consider the time frame available for (i) calculating the underlying features of the LBF (e.g., heart rate) and (ii) conveying the feedback to the user. While fast-paced decision environments may only allow time frames of several seconds (e.g., financial trading, Fernández et al. 2013; driving, Nasoz et al. 2010), other decision scenarios allow longer time frames of up to several minutes (e.g., certain aspects of stress management training). The available time frame determines the range of available biosignals and modalities that the system designer can choose from as the source for the feedback. For instance, some techniques for determining changes in skin conductance level may require several minutes or hours (Boucsein, 2012; Dawson et al., 2007) and all real-time frequency analysis of heart rate in the reviewed studies was based on a time frame of at least 30 seconds (Al Osman et al., 2013, 2016; Lehrer et al., 2003).

Second, system designers need to consider the desired level of feedback obtrusiveness in addressing one or more of the five traditional sensory channels. Some decision scenarios may require actively disrupting the user's decision making process, e.g., in order to avoid impulsive decisions in the "heat of the moment" (Loewenstein, 1996, p. 286). Importantly, however, instead of reducing stress, obtrusive feedback may be perceived as distracting and even more stressful (MacLean et al., 2013; Slovák et al., 2012), possibly leading to adverse outcomes in terms of user experience and decision outcomes. The desired level of feedback obtrusiveness can be crucial for the success of an LBF system, as evidenced by the conflicting results of SLBF applications for stress management. Another consideration in choosing the level of feedback obtrusiveness is whether the feedback could (or should) be perceived by people other than the intended feedback recipient. Certain forms of feedback (e.g., auditory feedback) may inadvertently be conveyed to third parties with detrimental effects for the original feedback receiver (e.g., increased stress from being in the social spotlight).

Third, the various forms of modalities and manifestations allow for different levels of feedback complexity. While some studies employ manifestations that convey low levels of complexity, using intuitive elements resembling human (e.g., heart and breathing activity, Tan et al., 2014) or natural features (e.g., water ripples or flowers, Feijs et al. 2013; Slovák et al. 2012), other studies employ more complex manifestations such as meters (e.g., Jercic et al. 2012). Furthermore, LBF that is employed through dedicated UI artefacts (e.g., in stress management applications, Al Osman et al. 2013) is often more complex than LBF that is provided though the adaption of existing UI elements (e.g., in playful games, Nacke et al. 2011). Therefore, the level of complexity needs to be carefully considered against the characteristics of the primary task and the skills of the user. For instance, Jercic et al. (2012) find that most participants did not pay attention to a radial arousal meter in the top-right corner of the screen due to the fast-paced nature of the decision environment and the complexity of the arousal meter. In that study, participants prefer the use of overlay elements added to the center of the screen where colors indicated their arousal levels. Hence, system designers need to set a level of feedback complexity that acknowledges the level of attention and processing of the users to understand the provided feedback in a given context. Importantly, using a combination of different feedback types is not necessarily more effective than a single feedback type, although it is generally assumed that the human brain is able to processes more information if it is transmitted to multiple sensory channels (Ernst and Bülthoff, 2004). Schnädelbach et al. (2010), for example, apply a combination of visual, auditory, and tactile biofeedback elements, but participants do not find the visual feedback elements useful.

Fourth, system designers need to consider the level of control that the user has and/or should have over the physiological activity measure used as system input. While some biosignals (e.g., EDA) are modulated by the autonomous nervous system and therefore, can only be controlled indirectly, other biosignals (e.g., body movements, respiration) are largely under the user's direct control (Riedl et al., 2014). Hence, practitioners need to define the level of control the user should have over the measured physiological activity for a given purpose (e.g., decision support, entertainment, stress management), considering both the physiological characteristics of the biosignal as well as the skill set of the target audience to control the biosignal. Nacke et al. (2011) conclude that with respect to user experience in gaming, biosignals that can be directly controlled by the user are preferred for game control, due to their visible responsiveness, while biosignals that the user can only control indirectly are considered slow and inaccurate and are rather suitable for altering game environments. For some application domains, however, such as stress management and emotion regulation training applications, gaining higher levels of control of the underlying biosignal is the actual purpose of the LBF application. Hence, such applications often focus on biosignals over which the user has only indirect physiological control (e.g., Al Osman et al. 2013, 2016; Howell et al. 2016).

Finally, and most importantly, system designers need to consider the level of meaningfulness of the feedback to the user, making sure that the relationships between the biosignal (e.g., cardiac activity) and the addressed direct (e.g., arousal, stress) and indirect constructs (e.g., excitement, social connectedness, social presence) are well understood and informed by theory. For instance, research by Mueller et al. (2010) and Slovák et al. (2012) on FLBF shows that heart rate measurements can increase feelings of co-presence and social connectedness. In other contexts, however, heart rate and heart rate variability measurements are useful to train emotion regulation and stress management capabilities (Al Osman et al., 2013, 2016; Al Rihawi et al., 2014). The meaning of a particular measurement needs to be carefully considered and evaluated against the background of the study. After all, physiological data are "only meaningful and useful when the user has the ability to understand what is being represented" (Snyder et al., 2015, p. 152).

2.7.3. Concluding Note on Existing Live Biofeedback Literature

With the advances in mobile sensor technology, researchers and practitioners have begun to explore the integration of neuro-adaptive system components for consumer applications. As a specific category of such systems, LBF systems have emerged in application domains such as gaming, communication, and stress management. Building on the transmission model of communication, structured classification of the components and transmission signals in different settings is introduced, a body of highly fragmented literature on SLBF and FLBF is synthesized, and an overview of the theories, measurement modalities, and feedback manifestations used in both areas is provided. Furthermore, a set of practical design considerations as well as important directions for future research on LBF systems for everyday use are identified. We hope that researchers and practitioners will find this review useful as a reference guide to inform the integration of LBF into information systems.

This Chapter reveals that several LBF applications have been studied for a variety of purposes. In order to analyze how LBF affects decision making in electronic markets and evaluate whether LBF can be used to support emotional processing and decision making, we first aim at identifying emotionally charged situations in which decision makers' behavior is influenced by the arousal they experience. Thus, in Chapter 3 the context dependence of the effect of arousal on decision making is examined.

Chapter 3.

The Effects of Incidental Arousal on Auction Bidding and Final Prices

> “I found myself in a bidding war that seemed to have no end. As the dollars ran up and up into the thousands, my internal stress level had reached a point where I was not thinking clearly about the ramifications about my decision to run the bids up higher. I was more concerned with *winning* and not *giving up*.
>
> ANONYMOUS BIDDER (MURNIGHAN, 2002)

3.1. Introduction to Arousal and Auction Bidding

The first reports on auctions reach back to 500 B.C. (Krishna, 2010). Since then auctions have been an important mode of economic exchange, both in practice and theory. Auction mechanisms can be used to efficiently determine prices for a wide range of goods and the allocation of resources more generally (McAfee and McMillan, 1987). A variety of auction formats exist, which often fit a specific purpose: Dutch auctions, for instance, are commonly used when large quantities of homogenous goods, such as flowers or fish, have to be sold in short time (Adam et al., 2016), while English auctions are frequently used to sell unique goods, e.g., at traditional auction houses like Sotherby’s or Christie’s. However, auctions are not only an important mode of economic exchange, but also constitute situations that can involve significant levels of social competition and, as a result, emotions involving arousal (Malhotra, 2010; Ku et al., 2005; Adam et al., 2015). Observations of auctions and individual experiences, like the one stated in the opening quote above (Murnighan, 2002), have led to the highly discussed concept of "auction fever" (Ehrhart et al., 2015; Heyman et al., 2004; Jones, 2011) or "the emotionally charged and frantic behavior of auction participants that can result in overbidding" (Ku et al., 2005, p. 90). Several studies provide empirical evidence indicating that auction fever is a real phenomenon (Adam et al., 2015; Jones, 2011; Ku et al., 2005). For instance, Jones (2011) observed that final prices for 41.1% of eBay auctions for Amazon.com gift certificates exceeded the certificates' face value. Similarly, Adam et al. (2015) found that high time pressure and social competition led to higher bidding and more arousal. Although the existence of auction fever is disputed (for alternative explanations for unexpectedly high bids in auctions, see Malmendier and Lee 2011), we find that auction fever is frequently viewed as arousal-induced bidding.

Despite the hypothesized central role of arousal, that is, the activation of the autonomic nervous system (Schachter and Singer, 1962), in auction bidding (Ku et al., 2005; Malhotra, 2010), the empirical evidence for auction fever lacks clarity. Specifically, three problems exist with the current research on arousal and auction fever. First, only few studies actually measure the effect of arousal on auction bidding, but they usually use self-report measures. Self-perception, e.g., of arousal, however, depends on a particular person and might be impaired when one actually experiences high levels of arousal (Mauss and Robinson, 2009; Dunn et al., 2010). Second, research on auction fever has focused only on the effects of *integral* arousal (i.e., arousal which is generated within the auction) on bidding behavior. When investigating the effects of *incidental* arousal in auctions, it is difficult to isolate arousal's role on bidding. Third, auction fever suggests that there is a specific characteristic inherent to auctions, which creates emotionally charged behavior, leaving unanswered which characteristic this is and whether arousal will have similar effects in other contexts such as a "normal" (i.e., non-auction) purchasing decisions.

To contribute to theory and investigate whether auction fever exists and when arousal affects decision making, a laboratory experiment is conducted that addresses the three problems stated above and aims at answering the following research question:

Research Question 2: Does arousal that is induced outside the decision making context affect purchasing behavior (i) in an auction and (ii) in a non-auction context?

In the conducted experiment, physiological arousal is measured to assess whether arousal actually impacts bidding. Therefore, heart rate measured via ECG is used as an indicator for physiological arousal. Furthermore, to provide clearer evidence of effects of arousal, it is investigated whether incidental arousal, that is, arousal generated outside of the auction context, influences bidding or purchasing behavior in general. For this purpose, a pattern matching task is used prior to the actual auction or non-auction purchasing task to create incidental arousal. In order to evaluate whether social interaction and competition, which is characteristic to auction bidding, is a necessary prerequisite for arousal to affect behavior, we explore whether incidental arousal also alters purchasing behavior in a non-auction context. In contrast to purchasing an item in an auction, in this non-auction purchasing context arousal cannot be attributed to an auction's inherent social competition. Overall, the current research addresses these three issues in the literature by offering empirical evidence for auction fever and a better understanding of its underlying driving forces. By identifying characteristics of situations, where arousal drives behavior, we thus build a foundation for further studies in this thesis that investigate how LBF can be used to support emotion regulation in these emotionally charged situations.

This Chapter is based on joint a research project with Marc T. P. Adam, Gillian Ku, Adam D. Galinsky, and J. Keith Murnighan and is structured as follows: In Section 3.2 we discuss literature on integral and incidental arousal its effects on auction bidding. In Sections 3.3 and 3.4 we present the experimental methods and effects incidental arousal has on auction bidding and purchasing behavior in a non-auction context, respectively. Section 3.5 provides a general discussion of the results.

3.2. Literature on Integral and Incidental Arousal and Decision Making

In the following, existing literature that investigates how arousal affects human behavior is discussed. The results of the reviewed studies are summarized in Table 3.1. At first we focus on integral arousal and then we turn to the effects of incidental arousal.

3.2.1. The Effects of Integral Arousal in Decision Making and Auctions

Many studies have explored the effects of integral arousal across a wide range of tasks and domains related to decision making (for reviews, see Peters et al. 2006; Rick and Loewenstein 2008). Although adequate processing of arousal is necessary for making advantageous decisions (Bechara and Damasio, 2005; Bechara et al., 1997) and arousal can improve task performance under certain circumstances (e.g., when individuals have positive attitudes towards the task; Brown and Curhan 2013; Zajonc 1965), much literature has documented how high arousal can also be detrimental for decision making e.g., by narrowing attentional capacity and reducing cognitive flexibility (Easterbrook, 1959; Staw et al., 1981). High levels of arousal are, for instance, linked to changes in risk perception (Finucane et al., 2000) and greater loss aversion (Sokol-Hessner et al., 2009). Additionally, Brown and Curhan (2013) found that although arousal boosts economic outcomes for negotiators when they have positive attitudes towards negotiations, it detrimentally affects outcomes when they have negative negotiation attitudes.

With respect to auctions, Ku et al. (2005) suggested in their *competitive arousal model* that a specific set of features that are characteristic to auctions, that is, rivalry, time pressure, the presence of an audience, and being in the spotlight, can stimulate integral arousal and increase auction bidding and overbidding past previously-set limits. Similarly, Malhotra (2010) manipulated two antecedents of integral arousal – rivalry and time pressure – and found that their combination fueled a desire to win even when winning was costly and provided no strategic advantage, which then increased participants' bidding. Finally, Adam et al. (2015) showed that higher levels of social competition and time pressure increased bidders' physiological arousal and bids.

Although consistent with the anecdotal evidence about auction fever, there are three open questions that the literature has not answered. First, it is unfortunate and noteworthy that only one research project has actually measured the physiological manifestation of arousal when investigating auction fever (Adam et al., 2015). Instead of measuring physiological arousal, Ku et al. (2005) relied on participants' self-reported arousal by asking participants to report their excitement and anxiety: although both excitement and anxiety are high-arousal emotions, excitement is positively-valenced whereas anxiety is negatively-valenced (Russell, 1980; Watson et al., 1988), resulting in an incomplete operationalization of the arousal construct. Malhotra (2010) did not include self-reported or physiological measures of arousal. Second, because research on auction fever has only examined the role of integral arousal on auction bidding, it is not possible to disentangle and isolate arousal's effects. For instance, although Adam et al. (2015) provide evidence for the role of physiological arousal in bidding, the researchers focused on integral arousal, making it difficult to disentangle correlation from causation, that is, whether bidders placed higher bids because they were more aroused, or alternatively, whether bidders were more aroused because they placed higher bids. Third, it remains unclear which contextual features, such as social competition or high interest in a good, are necessary prerequisites for creating such emotionally charged purchasing behavior.

In the experimental design of this study, these three questions are addressed: First, we measure not only perceived arousal self-reports, but also physiological arousal though heart rate measurements using ECG. Second, the effects of incidental rather than integral arousal are examined by generating arousal outside the decision context, while creating as little arousal as possible though the decision itself. Therefore, a sealed-bid auction format that does not induce time pressure is used. Additionally, the content of money jars is auctioned off, in order not to generate integral arousal through a good that each person might value differently. Third, two scenarios that are almost identical are examined: The first is used to investigate purchasing behavior in an auction context while the second scenario comprises a purchasing decision in a "normal" non-auction context. In doing so, we sought to test whether social interaction and competition that is inherent to auctions results in auction fever, i.e., whether arousal increases auction bidding.

Table 3.1.: Reviewed literature on arousal and decision making

Author	**Outlet**	**Experimental study**	**Incidental arousal**	**Integral arousal**	**Not manipulated**	**Findings**
Adam et al. (2015)	J Retailing	x		x		Social competition is a driver of auction fever.
Bechara et al. (1997)	Science	x		x		Neural systems hold knowledge related to the individual's emotional experiences.
Brown and Curhan (2013)	Psychol Sci	x	x			Positive (negative) prior attitudes towards negotiations have beneficial (detrimental) effects on their outcomes.
Cooper and Fazio (1984)	Adv Exp Soc Psychol		x			Dissonance involves arousal that can be misattributed to an external source.
Delgado et al. (2008)	Science	x		x		Social competition in auctions leads to a more pronounced blood oxygen level in the striatum, whereby the magnitude is positively correlated with overbidding.

Dunn et al. (2012)	Cogn Affect Behav Neurosci	x		x		Higher arousal is related to greater rejection of unfair offers in the ultimatum game for participants with accurate interoception.
Dutton and Aron (1974)	Journal of Personality and Social Psychology	x	x			High anxiety results in heightened sexual attraction.
Elkin and Leippe (1986)	J Pers Soc Psychol	x		x		Dissonance creates arousal which is sustained by attitude change.
Forgas (1998)	J Pers Soc Psychol	x	x			Moods affect negotiation strategies and outcomes in bargaining.
Ku et al. (2005)	Organ Behav Hum Dec	x		x		Competitive arousal due to rivalry, social facilitation, time pressure, and the uniqueness of being first can result in overbidding.
Lewinsohn and Mano (1993)	J Behav Decis Making	x	x		x	Persons who experience more naturally occurring arousal deliberate less (Study 1). Incidental arousal restricts attentional capacity (Study 2).
Malhotra (2010)	Organ Behav Hum Dec	x		x		The coincidence of rivalry and time pressure and salient desire to win increases bidding.
Mano (1992)	Organ Behav Hum Dec	x	x			Arousal results in simpler decision strategies and more polarized evaluations.
Mano (1994)	Organ Behav Hum Dec	x			x	Arousal results in higher (lower) willingness-to-pay for lotteries (insurance) due to restricted attentional capacity.

Mano (1997)	Psychol Market	x			x	In a persuasive communication situation with weak messages and high involvement arousal increases thought positivity and reduces message elaboration.
Mano (1999)	J Retailing	x			x	Arousal restricts attentional capacity and increases purchase intentions.
Mezzaceppa (1999)	Cognition Emotion	x	x			Arousal increases experienced fear during frightening films.
Murnighan (2002)	J Manag Educ			x		Anecdotal evidence for the effect arousal can have in a dollar auction.
Paulhus and Lim (1994)	Eur J Soc Psychol	x	x			Arousal reduces cognitive complexity of social information retrieval and results in more polarized judgments.
Pham (2007)	Rev Gen Psychol		x	x		Arousal affects people's evaluations and negative arousal disrupts self-control.
Rick and Loewenstein (2008)	Handbook of emotion		x	x		Arousal can be beneficial for decision making as it informs decision makers about their own values. However, it can also make people act contrary to their own material interests.
Rottenstreich and Hsee (2001)	Psychol Sci	x		x		When accounting for arousal, the prospect theory's weighting function is more s-shaped under high arousal.
Schachter and Singer (1962)	Psychol Rev	x	x			Arousal is only misattributed to the current situation, when its source remains unclear.
Schwarz (2000)	Cognition Emotion				x	Pre-existing arousal is often attributed to an external source.
Shapiro et al. (2002)	J Advertising	x	x			Arousal results in more shallow processing.
Storbeck and Clore (2008)	Soc Personal Psychol Compass				x	Arousal provides information about urgency or importance.

Teubner et al. (2015)	J Assoc Inf Syst	x		x		When bidding against humans, arousal leads to riskier decisions.
Van't Wout et al. (2006)	Exp Brain Res	x		x		Arousal increases rejection rates of unfair offers by humans in the ultimatum game.
White et al. (1981)	J Pers Soc Psychol	x	x			Misattribution of arousal facilitates romantic attraction.
Zillmann and Bryant (1974)	J Pers Soc Psychol	x	x			Arousal increases retaliatory behavior.

3.2.2. The Effects of Incidental Arousal in Decision Making and Auctions

In order to isolate the effects of arousal on auction bidding, incidental rather than integral arousal is examined. Incidental arousal refers to arousal generated outside the decision-making context. The consequences of incidental arousal are similar to those of integral arousal (Pham, 2007; Rick and Loewenstein, 2008). For instance, arousal alters negotiation outcomes regardless of whether arousal is manipulated by asking participants to walk on a treadmill (i.e., incidental arousal) or by asking participants to walk or sit during a negotiation (i.e., integral arousal, Brown and Curhan 2013). Additionally, just as integral arousal can affect loss aversion and risk perceptions (Finucane et al., 2000; Sokol-Hessner et al., 2009), incidental arousal has similar effects on the attractiveness of lotteries and insurance (Mano, 1994). Building on this research and to cleanly establish the role of arousal on bidding, we predict that incidental arousal, like integral arousal, increases auction bidding.

Research has shown that incidental arousal affects individuals through an attributional process. For instance, Schachter and Singer (1962) manipulated arousal via an epinephrine injection and found that, even though everyone experienced the same physiological stimulus, individuals' interpretations of their arousal and their subsequent actions depended on whether they interacted with a playful or angry confederate. Similarly, when people are injected with epinephrine, they express more fear during a frightening film than people who were injected with saline (Mezzaceppa, 1999). These findings have led to an important principle: to interpret their arousal, people must attribute it to a stimulus, even a non-causal stimulus. Indeed, research has found that people often misattribute their arousal to a salient and plausible environmental stimulus (e.g., Zillmann and Bryant 1974). Incidental arousal, however, is not misattributed when its actual source is known (Schachter and Singer, 1962).

In auctions, incidental arousal may affect bidding through two alternative attributional processes. First, incidental arousal may fuel bidding by being attributed to interest in the item. Consistent with this hypothesis, prior research has found that arousal from an unrelated source can be attributed to interest in and attraction towards a focal interaction partner. Dutton and Aron (1974), for example, found that male participants interpreted the arousal they experienced from crossing a shaky suspension bridge as sexual interest in an attractive female interviewer. Similarly, the incidental arousal from exercising, awaiting electric shocks, or hearing violent stories has increased sexual attraction towards others (White et al., 1981).

Second, arousal may alternatively fuel bidding by being attributed to the inherent social interaction and competition in auctions. Auctions are contexts that can involve high levels of social competition. For instance, studies on auction fever highlight the rivalry that comes with bidding and its role in overbidding (e.g., Ku et al. 2006, 2005; Malhotra 2010; Murnighan 2002). Similarly, individuals experience stronger frustration when losing an auction than a theoretically-equivalent lottery, with research attributing this finding to the "social competition inherent in an auction" (Delgado et al., 2008, p. 1849). Social competition in auctions is believed to create a "thrill of bidding" and "stimulation of beating competitors" (Lee et al., 2009). Thus, rather than attributing their arousal to interest in the item, bidders may attribute their arousal to the social competition inherent in auctions and bid more to win this competition.

These two alternative attributional mechanisms have implications for whether emotionally charged purchasing behavior is unique to auctions. If arousal is attributed to an item, arousal should increase purchasing behavior regardless of the purchasing context, i.e., whether the item is sold in an auction or non-auction context. However, if arousal is attributed to social competition, then we should only observe arousal-induced purchasing behavior in auctions.

3.2.3. Experimental Design

Based on the literature discussed above, we argue that auctions are unique and that the social competition inherent in auctions may be necessary for creating emotionally charged purchasing behavior. Thus, we formulate the following hypothesis:

Hypothesis 3.1 (H3.1): Incidental arousal is attributed to the social competition that is inherent to auctions and thus affects auction bidding.

Research that manipulates human vs. computer opponents offers evidence to support this view. For instance, Adam et al. (2015) found that social competition increased bidders' integral arousal and bids, but only when bidding against a human opponent. Arousal is lower and the relationship between integral arousal and bidding behavior no longer observable when bidders compete with computer rather than human opponents (Teubner et al., 2015). These findings are consistent with research on ultimatum bargaining, where decision makers behave less impulsively when facing computer counterparts (Sanfey et al., 2003; Van't Wout et al., 2006). Thus, in the absence of social competition, the influence of incidental arousal on purchasing behavior may disappear.

A laboratory experiment was conducted to test H3.1 and thus, to fill the gaps in the literature and provide clear evidence that auction fever is a real phenomenon. In this Chapter evidence for auction fever is offered by establishing the critical role of physiological arousal and by showing that incidental arousal only affects purchasing behavior when social competition is present. In total, we examine eight treatment conditions by varying three two-staged treatment variables: (i) the decision context, (ii) the level of induced incidental arousal, and (iii) the monetary stakes. With respect to the first treatment variable, either an auction or a non-auction purchasing context is used, where the participants submit either bids or their willingness-to-pay (WTP). Regarding the second treatment variable, the level of incidental arousal (i.e., high and low arousal) that is induced through a symbol-matching game prior to the purchase is manipulated. For varying the third treatment variable, the amount of money (i.e., €2.37 and €11.85) in the offered money jars varies in order to alter monetary stakes. While each participant participated in only *one* of the two conditions with respect to the purchasing context (either auction or non-auction context) and induced arousal (either high or low), *all* participants were offered two money jars, one inducing high and another inducing low monetary stakes, in random order. Taken together, we test whether physiological measures of incidental arousal mediate the effects of incidental arousal on purchases with or without social competition while being offered a money jar inducing high or low monetary stakes.

The experiment was conducted at Karlsruhe Institute of Technology. We used the Online Recruitment System for Economic Experiments (ORSEE) software environment, in order to recruit participants for all treatments of the experiment. Altogether, we recruited 288 participants (224 men, 64 women, 6 per session; Greiner 2004).[1] Participants were compensated €10 plus their individual earnings from the arousal and auction or randomly generated price (RGP) tasks. Measurements failed (e.g., electrodes detached) or noise in the signal was too strong to accurately identify the intervals between subsequent heart beats for 32 participants, who were equally distributed across the treatment conditions. These common measurement problems reduced the final sample to 256 participants (194 men; 62 women). The experiment had a 2 (purchasing context: auction, non-auction) x 2 (arousal: low, high) x 2 (stakes: low, high) mixed design with repeated measures on the third factor. Participants of all eight treatment conditions were placed at isolated PC terminals. The experimental procedures were implemented using z-Tree software (Fischbacher, 2007) and the arousal induction task was implemented in Java. In the following we first discuss the four treatments comprising live auctions (see Section 3.3). Subsequently, we analyze the remaining four treatments in a "normal" non-auction purchasing context (see Section 3.4).

3.3. Investigating the Effects of Incidental Arousal in Auctions

In the following, the four out of eight treatment conditions that investigate the effects of high and low levels of incidental arousal with high and low monetary stakes in an auction context are examined. In other words, we investigate whether monetary stakes or incidental arousal manipulated outside the auction context is attributed to auction bidding and thus affect final prices. Therefore, the level of induced arousal before an auction task was manipulated. All participants subsequently engaged in two live auctions, one with high and another with low monetary stakes. We measured participants' heart rates throughout the experiment.

3.3.1. Experimental Method

Participants were informed that they would engage in several different tasks (see Appendix A for participant instructions). After attaching the electrodes, participants received instructions about the auctions and bid in two trial auctions with hypothetical payoffs and computerized opponents to ensure that they understood the rules and procedures. They then proceeded to the arousal induction task and, finally, to the two real auctions.

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[1] For each experiment, we determined the sample size in advance based on participant availability and no additional participants were run after initial analysis.

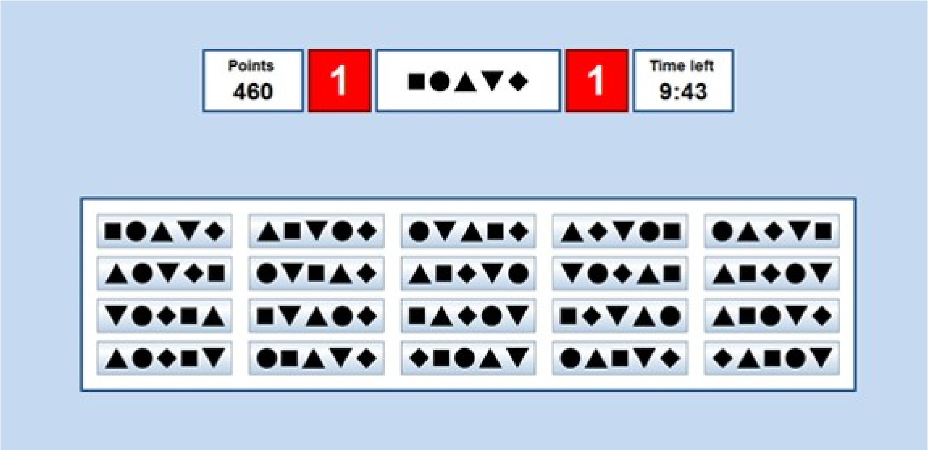


Figure 3.1.: Pattern matching game in high arousal condition

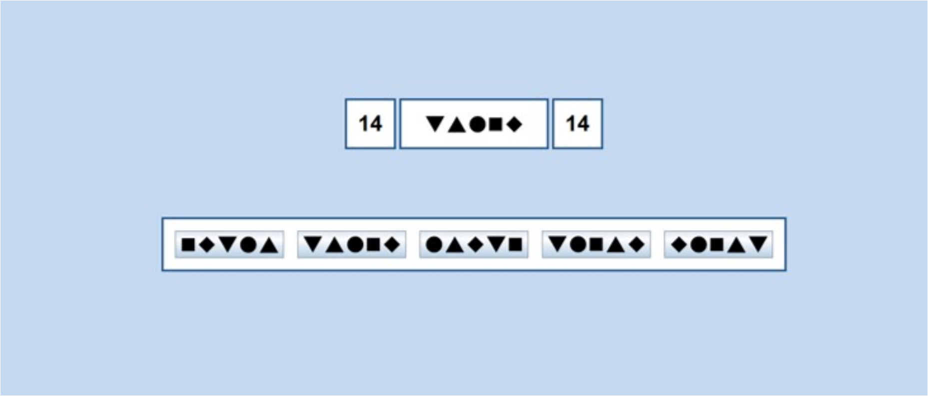


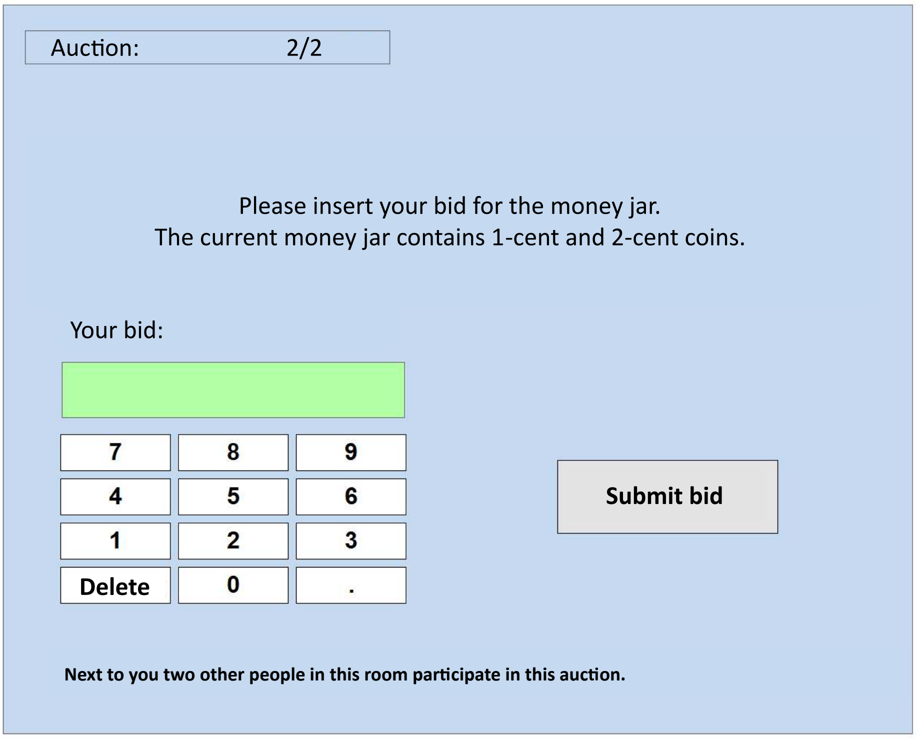
Figure 3.2.: Pattern matching game in low arousal condition

To manipulate arousal, all participants engaged in a 10-minute symbol-matching task: a five-symbol sequence appeared in the middle of the screen and participants had to choose the correct (i.e., identical match) sequence from a list.

The high-arousal condition (see Figure 3.1) involved energizing music (Bernardi et al., 2006), time pressure (Ku et al., 2005), and competition (Ku et al., 2005). Specifically, fast-paced music was played throughout. Participants chose from 20 symbol sequences and had 7 seconds to make each decision. They received 20 points for every correct choice, lost 10 points for every incorrect choice, and lost 30 points if they took more than 7 seconds to make a choice. Participants' final payoffs depended on their relative performance, which was not revealed until the end of the experiment. Thus, after the auctions, the participant with the most points received €15; the second best participant received €12; the third best received €9, etc. Although participants competed against one another for these final payoffs, the instructions pushed them to focus on the symbol-matching task. Additionally, participants did not interact with each other and received no information that would allow them to make social comparisons.

In the low-arousal condition (see Figure 3.2), participants listened to slow, soothing "spa" music. They chose from only 5 symbol sequences and had twice as much time (14 seconds) to make each decision. Their task performance did not affect their payoffs. Instead, to match their expected payoffs with those in the high-arousal condition, participants were told that they would roll a die at the end of the experiment for an additional payoff (from €0 to €15).

Participants next engaged in two auctions, each with two other bidders. The auction interface is depicted in Figure 3.3. Because we were interested in the impact of incidental arousal from the arousal induction task on bidding, we minimized any integral arousal that the auction might stimulate. Thus, participants bid on jars of money (i.e., items that have an objective value, which is unknown to bidders at the time of bidding) in two first-price sealed-bid auctions, in which each bidder made a single secret bid and the highest bidder won the item for the amount bid (Kagel and Levin, 2000; McAfee and McMillan, 1987). This format eliminated the integral arousal that can result from a bidding-rebidding process.



Auction: 2/2

Please insert your bid for the money jar.
The current money jar contains 1-cent and 2-cent coins.

Your bid:

Next to you two other people in this room participate in this auction.

Figure 3.3.: User interface of the auction task

Figure 3.4.: Money jars with high and low monetary stakes

We auctioned off jars that included low and high monetary totals, in random order for each participant (see Figure 3.4 with low stakes jars on the left and high stakes jars on the right). Low-stakes jars contained 1-cent and 2-cent coins, totaling €2.37; high-stakes jars contained 5-cent and 10-cent coins, totaling €11.85. Before bidding, participants could examine the relevant jar. Then they made their bid and proceeded to their second, final auction. The values of the money jars and the auction results were only revealed after the second auction.

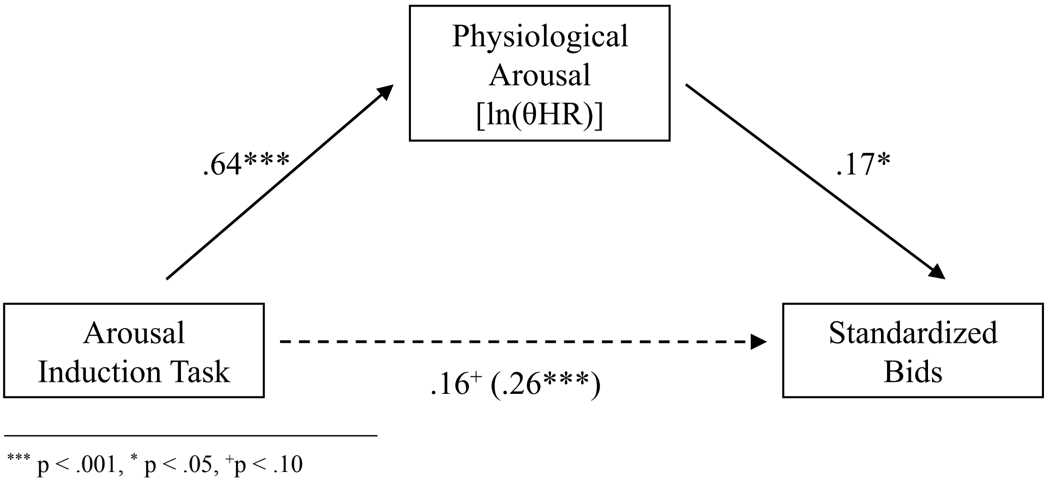
To assess physiological arousal, participants wore chest straps with dry-electrodes to acquire information on their heart's electrical activity using ECG. We measured participants' basic arousal level for seven minutes before the experiment (Sütterlin et al., 2010). To track incidental arousal, we assessed participants' average heart rate during the last minute of the arousal induction task. Due to between-participants variance, we divided these values by each bidder's basic arousal level and log-normalized the results (Adam et al., 2012; Smith and Dickhaut, 2005).

We also recorded participants' two bids, one for each auction. We standardized these bids within the high- and low-stakes conditions. Finally, because participants bid within three-person groups, we also calculated the final price for each auction and standardized these within the stakes conditions.

3.3.2. Results and Discussion

Participants in the high-arousal condition (*M* = .24, *SD* = .16) exhibited more physiological arousal than participants in the low-arousal condition (*M* = .04, *SD* = .07, $t(116) = 8.82$, $p < .001$, $d = 1.62$). Participants in the high-arousal condition also bid more than those in the low-arousal condition. A 2 (arousal: low, high) x 2 (stakes: low, high) repeated measures analysis of covariance (ANCOVA) on participants' standardized bids with auction order (i.e., low- or high-stakes auction first) as a covariate, led to a significant main effect for arousal ($F(1, 116) = 10.90$, $p = .001$, $\eta_p^2 = .25$, $d = .54$). Participants in the high-arousal condition bid significantly higher (*M* = .26, *SD* = 1.04) than those in the low-arousal condition (*M* = -.26, *SD* = .88). The arousal x stakes interaction ($F(1, 116) = .78$, $p = .38$, $\eta_p^2 = .007$) and the auction order covariate ($F(1, 116) = .00$, $p = .952$, $\eta_p^2 < .001$) were not significant.

A simultaneous regression analysis to examine whether incidental physiological arousal affected the auction bidding (see Table 3.2) showed that participants' physiological arousal significantly predicted their bids (B = 1.04, SE = .50, $\beta = .17$, $p = .04$) and that the effect for the arousal induction task was reduced to marginal significance (B = .31, SE = .16, $\beta = .16$, $p = .06$). Figure 3.5 includes the results of a mediation analysis showing standardized beta coefficients for the relations between the arousal induction task, physiological arousal, and standardized bids, whereby the regression analysis included auction order as a covariate. Using a bootstrap analysis with a sample of 5,000, zero fell outside the 95% bias-corrected CI (.005 to .412), providing evidence of a significant indirect effect. Compared to participants in the low-arousal condition, those in the high-arousal condition exhibited greater incidental physiological arousal, which led them to bid more for the money jar auctions.



*** p < .001, * p < .05, $^{+}$p < .10

Figure 3.5.: Mediation analysis of arousal induction, physiological arousal, and bids

Table 3.2.: Results of regression analysis for physiological arousal and bidding

	Dependent Variable														
	(I) Physiological Arousal (ln(θHR))					**(II) Standardized Bids**					**(III) Standardized Bids**				
Variable	β	**B**	**SE**	**t-stat**	**Sig.**	β	**B**	**SE**	**t-stat**	**Sig.**	β	**B**	**SE**	**t-stat**	**Sig.**
Arousal Induction Task (Dummy)	.635	.204	.016	12.548	<.001***	.263	.523	.126	4.155	<.001***	.156	.310	.162	1.917	.056+
Auction Order (Dummy Covariate)	.051	.016	.016	1.006	.316	-.005	-.010	.126	-.076	.940	-.013	-.027	.125	-.212	.832
Physiological Arousal (ln(θHR))											.168	1.045	.505	2.070	.040*
Constant		.030	.014	2.140	.033*		-.257	.110	-2.342	.020*		-.288	.110	-2.623	.009**
	N=236 R^2=.404					N=236 R^2=.069					N=236 R^2=.086				

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$

Finally, we assessed whether incidental arousal affected the overall financial outcome of the auctions. A 2 (arousal: low, high) x 2 (stakes: low, high) repeated measures ANCOVA on standardized final prices with auction order (i.e., low- or high-stakes auction first) as a covariate found that high arousal (M = .21, SD = 1.11) led to marginally higher standardized final prices than the low arousal did (M = -.21, SD = .82, F(1,45) = 3.44, p = .070, η_p^2 = .13). Neither the arousal x stakes interaction (F(1, 45) = .01, p = .931, $\eta_p^2 < .001$) nor the auction order covariate (F(1, 45) = .61, p = .438, η_p^2 = .025) were significant.[2] On average, the difference between the high- and low-arousal conditions was € .46 and € .96 in the low and high stakes conditions, 19.4% and 8.1% of the value of the jar, respectively.

We find that incidental arousal from a non-auction source increases individuals' arousal, which in turn increases auction bids, providing clean and clear empirical evidence for the role of arousal-induced bidding. Importantly, we observe this effect physiologically in a context with actual bids that had real monetary consequences. Thus, we find that the incidental arousal manipulation tends to increase the auction's final prices.

3.4. Investigating the Effects of Incidental Arousal in Non-Auction Contexts

Although the four treatment conditions discussed above demonstrated that incidental arousal increases physiological arousal, which increases auction bidding, the question remains as to whether incidental arousal will increase purchasing behavior in "normal" non-auction contexts. Using the same arousal induction task and jars of coins, we conducted four further treatments to investigate the effects of high and low levels of incidental arousal with high and low monetary stakes in a non-auction context. In these treatments, we manipulated the level of induced incidental arousal (i.e., low and high) and the induced monetary stakes (i.e., low and high) in the same manner and measured participants' heart rates, after which they reported their maximum WTP in two RGP tasks that had financial consequences.

Because research has found that arousal is misattributed as interest in non-causal stimuli (Dutton and Aron, 1974; White et al., 1981), it is possible that arousal will be attributed as

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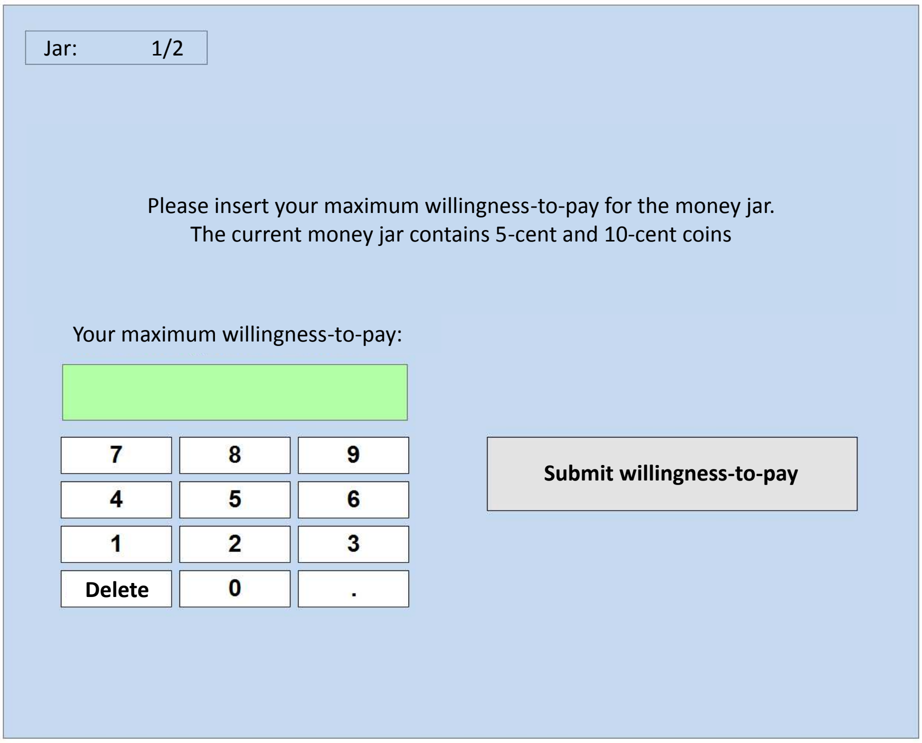
[2] Separately, we wanted to analyze whether the induction task affected physiological arousal, which then increased standardized final prices. These analyses required us to aggregate individual-level physiological data to the auction-level, which resulted in complexities of how to aggregate the data (e.g., mean, max, etc.) and how to deal with missing data. Together with the resulting small sample size, we were not able to properly examine this hypothesis.

interest in the item, which will then increase participants' WTP in the non-auction, RGP task. However, arousal could also be misattributed to auctions' social competition. If so, arousal should not increase participants' WTP in the RGP task, indicating that auctions' social competition is necessary for emotionally charged purchasing behavior.

3.4.1. Experimental Method

The arousal induction task was identical to that of the first four treatment conditions, and participants received instructions about the RGP task and submitted their WTP in two trial RGP tasks with hypothetical payoffs.

The UI in the RGP task is depicted in Figrue 3.6. Participants stated their maximum WTP for the same jars of coins depicted in Figure 3.4, after which a random price was drawn from a distribution that was based on the final auction prices derived from the treatments described above, but was unknown to participants. If the WTP was equal to or higher than the RGP, the participant purchased the good at their stated price. If the WTP was lower than the RGP, the good was not purchased. This type of value elicitation is a frequently used variant of the seminal *Becker-DeGroot-Marschak technique* (Becker et al., 1964).



Jar: 1/2

Please insert your maximum willingness-to-pay for the money jar.
The current money jar contains 5-cent and 10-cent coins

Your maximum willingness-to-pay:

Figure 3.6.: User interface of non-auction purchasing task

As described before, the low-stakes (€ 2.37) and high-stakes (€ 11.85) jars were presented to participants in random order, and participants could examine the relevant jar before submitting their WTP. The values of the jars and the RGP results were revealed after the second RGP task. If a participant purchased a jar, they received a payoff of the true value of the jar minus the purchase price.

Furthermore, we followed the procedure described above (see Subsection 3.3.1), to track participants' incidental physiological arousal: we divided participants' heart rate values during the last minute of the arousal induction task by their basic arousal level and log-normalized the results. We also recorded participants' WTP, one for each RGP task. We standardized these two WTPs within the high- and low-stakes conditions.[3]

3.4.2. Results and Discussion

Participants in the high-arousal condition (M = .23, SD = .14) exhibited more physiological arousal than did participants in the low-arousal condition (M = .06, SD = .10, $t(136) = 8.47$, $p < .001$, $d = 1.44$).

Participants in the high-arousal condition (M = .03, SD = .99) did not express higher WTPs than those in the low-arousal condition (M = -.03, SD = 1.00). A 2 (arousal: low, high) x 2 (stakes: low, high) repeated measures analysis of covariance (ANCOVA) on participants' standardized WTPs with task order (i.e., low- or high-stakes jar first) as a covariate did not reveal a significant arousal main effect ($F(1, 136) = .13$, $p = .720$, $\eta_p^2 = .004$, $p = .06$). The arousal x stakes interaction ($F(1, 136) = .07$, $p = .796$, $\eta_p^2 = .058$) and the task order covariate ($F(1, 136) = 1.20$, $p = .276$, $\eta_p^2 < .001$) were not significant. There was no correlation between physiological arousal and participants' standardized WTP ($r(274) = .02$, $p = .70$).

Contrary to the findings in an auction context, where incidental arousal increased auction bidding, we found that incidental arousal did not increase WTP in a non-auction purchasing context for the same items. These results suggest that social competition must be present for arousal to affect purchasing behavior. To examine these cross-experimental differences in participants' purchasing behaviors, we conducted a 2 (context: auction, RGP) x 2 (arousal: low, high) x 2 (stakes: low, high) repeated measures analysis of covariance (ANCOVA) on participants' purchasing behavior (auction bids in an auction context and WTPs in a non-auction purchasing context) with task order (i.e., low- or high-stakes jar first) as a covariate.

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[3] Participants also completed a post-task questionnaire (see Appendix A) about their perceptions of and reactions to the RGP tasks as well as various scales (e.g., risk preferences and competitiveness).

Overall, the predicted context x arousal interaction was significant, ($F(1, 252) = 4.46$, $p = .04$, $\eta_p^2 = .07$). Participants bid more in the high-arousal ($M = .26$, $SD = 1.04$) than low-arousal ($M = -.26$, $SD = .88$, $F(1, 252) = 16.12$, $p < .001$) condition but there was no effect of arousal on WTP ($M_{high\ arousal} = .03$, $SD = .99$; $M_{low\ arousal} = -.03$, $SD = 1.00$, $F(1, 252) = .05$, $p = .821$). Overall, the auction context and its inherent social competition play a critical role in explaining the impact of incidental arousal on individuals' purchasing behaviors.

3.5. General Discussion of Effects of Incidental Arousal

3.5.1. Summary of Results

The two experiments above establish that arousal increases auction bidding and that physiological arousal and social interaction and competition are critical ingredients in auction fever. Experimental findings in an auction context (see Subsection 3.3.2) demonstrate that an auction-irrelevant game increases participants' heart rates, which leads to significantly higher bidding and marginally higher final prices in real auctions. Experimental findings in a non-auction purchasing context (see Subsection 3.4.2) show that incidental arousal does not affect purchasing behavior when people reported their WTP in a non-auction context; thus, the social competition of auctions appears to be critical for arousal to affect purchasing behavior, implying that the effect of arousal on purchasing behavior is context-dependent.

To further understand the economic impact of incidental arousal's effects in our auctions, we re-examine the final auction prices to see if incidental arousal may have even fueled overbidding at the auction level, i.e., does incidental arousal raise the final price above the value of the coins? Although the data are not completely conclusive, we see some evidence that incidental arousal can cause overbidding. Table 3.3 presents unstandardized final price data for ease of interpretation.

In auctions, high arousal leads to final prices that ware directionally higher than the true value of the low-stakes jar of coins. In contrast, final auction prices are no different than the true value of the coins when participants experience low arousal. The final prices for the high-stakes auctions were below the true value of the coins. The reason for this is unclear, potentially representing participants' disbelief that we would auction off something worth more than € 10, a general risk aversion towards high-stakes items, or a boundary effect for the findings. However, the final price data for the low-stakes auctions show that incidental arousal can cause overbidding at the auction level. This overbidding stands in contrast to

Table 3.3.: Auction final prices and willingness-to-pay

	Final Auction Prices		**Willingness-to-Pay**	
	Low Arousal	**High Arousal**	**Low Arousal**	**High Arousal**
Low Stakes (€ 2.37)				
Final Price/ Willingness-to-Pay	€ 2.25 (SD = € .75)	€ 2.71 (SD = € 1.24)	€ 2.44 (SD = € 2.53)	€ 2.59 (SD = € 1.57)
Comparison to True Value	$t(23) = -.77$ $p = .45$ $d = .31$	$t(23) = 1.37$ $p = .19$ $d = .55$	$t(68) = .25$ $p = .40$ $d = .06$	$t(68) = 1.17$ $p = .12$ $d = .28$
High Stakes (€ 11.85)				
Final Price/ Willingness-to-Pay	€ 8.28 (SD = € 2.12)	€ 9.24 (SD = € 2.43)	€ 8.05 (SD = € 4.16)	€ 8.20 (SD = € 3.68)
Comparison to True Value	$t(23) = -8.27$ $p < .001$ $d > 1.51$	$t(23) = -5.27$ $p < .001$ $d > 1.51$	t(68) = -7.58 $p < .001$ $d > 1.51$	$t(68) = -8.22$ $p < .001$ $d > 1.51$

participants' maximum WTPs in the RGP task in a non-auction purchasing context – WTPs were not significantly different from the true value of the low-stakes jars and significantly lower than the true value of the high-stakes jars.

These results raise the important question of whether and under what circumstances the impact of arousal-induced bidding is beneficial or detrimental and for whom. Clearly, from the auctioneer's perspective, the positive impact of arousal on bids is desirable as it generates higher revenues. However, the picture is more complicated for bidders who must balance capitalizing on the auction opportunity with potentially overpaying for the item. On the one hand, higher bids increase the probability that a bidder will win the auction. As such, auction fever can be beneficial as it might actually help an individual avoid "missing an opportunity" (Engelbrecht-Wiggans and Katok, 2008). This would be the case in the high-stakes auctions where bidding higher was desirable since doing so allowed an individual to not lose the auction and to actually make a profit. On the other hand, arousal-induced bidding means decreased expected surplus for the average bidder (as is the case of the high-stakes auctions) as well as increased risk of overpaying for the winner (as in the case of the low-stakes auctions). Thus, auction fever can also be detrimental. It is noteworthy that these conclusions come in the context of bidding for jars of coins where it is possible to precisely calculate the true value of the good. Such precise objective values are usually hard or impossible to obtain, particularly when goods have at least some private-value component and when consumers can derive hedonic value from the product.

3.5.2. Theoretical Contributions and Future Research

The study presented in this Chapter contributes to the theoretical understanding of the role of arousal in auctions. First, we provide empirical evidence that physiological arousal affects bidding. Despite anecdotal evidence that auction fever is an emotionally charged, high-arousal state, research that has actually examined the role of physiological arousal in auctions is scant. Even research that has measured physiological arousal in auctions has only focused on integral arousal, making it difficult to disentangle correlation from causation (Adam et al., 2015). In the current research, we sought to find clear evidence of the role of physiological arousal in auction bidding. Thus, by manipulating arousal and measuring participants' heart rates before bidding, the current research introduces a methodological innovation to advance the theoretical understanding of auction fever.

Second, to further clarify and isolate the role of arousal in auction bidding, the discussed experiment examines incidental rather than integral arousal. Together, by measuring physiological arousal and manipulating incidental arousal, this experiment provides clear and consistent evidence that arousal affects bidding and final prices. Importantly, although auction fever has been anecdotally discussed and theoretically examined in terms of integral arousal, we demonstrate that even arousal outside the auction context (i.e., incidental arousal) can impact bidding and final prices. Thus, the current research forces us to broaden our conception of what auction fever involves. Ku et al. (2005) defined auction fever as "the emotionally charged and frantic behavior of auction participants that can result in overbidding" (p. 90). This research clarifies that this arousal can also result from non-auction sources such as a pattern matching game.

It is also noteworthy that consistent with the definition by Ku et al. (2005), the findings of this study show that auction fever involves arousal-induced bidding that can, but does not necessarily, result in overbidding. There has been some ambiguity with how prior research has used the term auction fever, often using it interchangeably with unexpected overbidding (e.g., Hou 2007; Jones 2011). Defining auction fever in terms of arousal-induced overbidding is problematic for two reasons. First, higher bids do not necessarily mean that bidders are bidding too much (i.e., more than the item is worth objectively or subjectively to them). Similarly, as discussed above, auction fever is not definitively detrimental; in fact, it may help bidders to secure a good opportunity. Second, unexpectedly high bids may be caused by arousal or alternative factors (Lee and Starner, 2010). Thus, using the term auction fever to explain every case of overbidding is misleading and may lead to a vague conceptualization of what auction fever really is. Overall, the results of this study help to clarify that auction fever is arousal-induced bidding that causes bidders to bid more and can, but does not necessarily, result in overbidding.

Finally, this research clarifies the important role that social competition has in generating auction fever. When participants expressed their maximum WTP in RGP tasks without any social competition, arousal did not affect purchasing behavior and participants did not overpay in comparison to the true value of the jars of coins. These findings are consistent with recent research pointing to the role of social interaction and competition in auction bidding (Adam et al., 2015; Teubner et al., 2015) and ultimatum games (Sanfey et al., 2003; Van't Wout et al., 2006) where arousal did not impact bidding against computer-based opponents. Additionally, the findings of this study clarify to what arousal is attributed: we show that social competition is a necessary ingredient for arousal-driven bidding: incidental arousal gets attributed not to interest in the item but to the auction's social competition.

Combining findings from the competitive arousal model (Ku et al., 2005) on integral arousal and the current results on incidental arousal highlights arousal's potent effects on auction bidding. In this Chapter, however, incidental and integral arousal has been separated: while the integral arousal within the auction has been reduced as much as possible (e.g., participants experience no time pressure and money jars are used in order to control the interest the participants have in the good that is auctioned off), incidental arousal is specifically generated though the pattern matching task prior to the purchase in the high arousal conditions. Thus, future research might explore possible interactions between integral and incidental arousal during the auction process. Incidentally-aroused bidders, for instance, may be more affected by the drivers of integral arousal, resulting in much higher bids.

3.5.3. Practical Implications for Auctioneers and Bidders

Practically, this study has clear implications for how auctioneers can raise their revenues. First, the treatments that comprise an auction context show that even incidental arousal can cause individuals to bid more and to create higher final prices at the auction level. It is noteworthy that auction organizers may already understand that they should do all that they can to stimulate arousal. *Thoroughbred auctions*, for instance, hype the event via glamour (people wear tuxedos and formal gowns), and they employ bid spotters who roam the crowd and use social pressure and audience attention to encourage additional bidding. Arousal may also play a key role in bidding wars, be they individual-level battles for highly sought-after MBA recruits or organizational-level company-acquisition battles. Second, the findings in the non-auction purchasing context suggest that it is equally important for auctioneers to emphasize the social competition of auctions.

Finally, highlighting the importance of arousal's attributional process (see also Savitsky et al. 1998), the results form a non-auction context suggest that bidders might not be at the mercy of integrally- or incidentally-induced arousal: by understanding their reactions and attributing their arousal to other sources, bidders may be able to avoid auction fever. For instance, "thinking like a trader" can help decision makers to experience less integral arousal and reduce loss aversion in financial decision making (Sokol-Hessner et al., 2009). Similarly, biofeedback may help individuals and managers make better decisions. For instance, to aid in investment decisions, retail investors at the Dutch bank ABN AMRO use a biofeedback device called the "rationalizer" to receive feedback on their current arousal levels (Djajadiningrat et al., 2009). Thus, biofeedback may help bidders become aware of their arousal, re-evaluate their decisions, and avoid decisions with undesired outcomes (Astor et al., 2013).

3.5.4. Concluding Note on Incidenal Arousal

In this Chapter, the first causal evidence that arousal increases bidding in auctions, and that this effect depends on auctions' social interaction component resulting in competition is established. As such, the current research provides proof that the effects of arousal are context-dependent and that auction fever is a real phenomenon, allowing empirical evidence to catch up with auction fever's anecdotal notoriety.

On this basis, Chapter 4 and 5 examine the use of LBF applications in decision situations that involve social interaction. In Chapter 4 an auction scenario is used to evaluate the effects of LBF on emotional processing. The auction design differs from the auctions used in this Chapter targets the induction of high integral arousal instead of incidental arousal. Therefore, the contextual factors identified by Ku et al. (2005), namely rivalry, time pressure, the uniqueness of being first, and social facilitation are used to generate arousal. Similar to the study in this Chapter, the content of money jars are auctioned off in, as they represent items that have an objective value, which is unknown to bidders at the time of bidding. In Chapter 5 LBF is examined in a beauty contest game. The concept of beauty contest game has been linked to financial markets (Keynes, 1936), which have also been modeled through continuous double auctions (Smith et al., 1988). Thus, we use the beauty contest game as an supplementary scenario to evaluate the use of LBF in electronic markets.

By using the experimental design by Kocher and Sutter (2006), we limit the participants answer time in the beauty contest and induce time pressure, which generates arousal.

Chapter 4.

Impact of Live Biofeedback in Electronic Auctions

> “I am not saying that the mind is in the body. I am saying that the body contributes more than life support and modulatory effects to the brain. It contributes a content that is part and parcel of the workings of the normal mind.
>
> ANTÓNIO ROSA DAMÁSIO (1994)

4.1. Introduction to Live Biofeedback in Electronic Auctions

Emotions are an integral part of human decision making. In a dynamic interplay between cognitive and affective processes, emotions facilitate our interactions with the socioeconomic environment and support human decision making by preparing behavioral responses with desirable outcomes (Bechara et al., 1997; Bechara and Damasio, 2005). From the neuroscience perspective, the interplay between cognition and affect is channeled in the so-called body-mind loop (Damasio, 1994; Green et al., 1970), where raw affective processing of the socioeconomic environment leads to changes in perception (Walla and Panksepp, 2013) and where changes in cognition can interact with the emotion-generative process (Gross and Thompson, 2007). In recent years, NeuroIS research has provided new insights into how this interplay affects the perceptions and behaviors of users interacting with information technology (Riedl et al., 2014). Previous research found that adequate emotion processing is a necessary prerequisite for taking advantageous decisions (Bechara and Damasio, 2005), manifesting in a pronounced relationship between affective processes and behavior (Adam et al., 2012; Teubner et al., 2015). When emotions get "out of control" (Loewenstein, 1996, p. 272), users are overwhelmed by them and make impulsive rather than well thought-out decisions (Adam et al., 2015). One approach for helping users make better decisions in such situations proposes to adapt elements of the user interface based on changes in neurophysiological processes, that is, LBF (Adam et al., 2015; Riedl and Léger, 2016). One application area of "neuro-adaptive information systems" (Riedl et al., 2014, p. 1) is LBF which provides users with real-time feedback on their physiological processes (Astor et al., 2013; Riedl and Léger, 2016). An overview of existing LBF applications in research is provided in Chapter 2.

In this Chapter, we study whether and how LBF can affect the body-mind loop in an electronic auction setting. We investigate how LBF affects decision-making processes in an emotionally charged decision environment and whether LBF interacts with the emotion-generative process. As shown in Chapter 3, electronic auctions create a competitive decision environment that is characterized by high levels of emotional arousal (Ku et al., 2005; Malhotra, 2010). On this basis, we conduct a controlled laboratory experiment, where participants bid against each other in four consecutive English auctions. In particular, we study the influence of LBF on the interplay of emotion regulation strategies, on physiological and perceived arousal, and on final prices. We review LBF as an IS artifact by analyzing users' perceptions of the LBF interface element. Thus, this Chapter seeks to answer the following research question:

Research Question 3: Does live biofeedback influence (i) physiological arousal, (ii) perceived arousal, and (iii) bidding prices in an electronic English auction?

We derive a theoretical model and make four core contributions to IS theory and practice. First, we find that LBF reduces the physiological cost of employing the emotion regulation strategy suppression. Second, the results support the theoretical model regarding the effect of LBF on the body-mind loop: LBF increases the coherence of perceived arousal and physiological arousal. Third, we find that LBF impacts the relationship between arousal and decision making predominantly by way of cognitive processing. Fourth, we evaluate LBF as an IS artifact and find that without training on how to use LBF, users do not rate LBF as being useful for emotion regulation even though LBF does affect the emotion-generative process. This study is the first to investigate how LBF affects the interplay of the body-mind loop in electronic auctions, revealing that LBF reduces the physiological cost of suppression, supports interoception, and enhances the coherence of perceived arousal and auction decision making.

This Chapter is based on joint research projects with Marc T. P. Adam, Fabian Both, Verena Dorner, Anuja Hariharan, Jella Pfeiffer, and Christof Weinhardt. Early works of these studies were published as research in progress in ECIS 2015 Proceedings (see Lux et al. 2015) and in Economics Letters (see Both et al. 2016). The remainder of this Chapter is structured as follows. Section 4.2 presents the theoretical foundations. Section 4.3 describes the research model and Section 4.4 the experimental design. Section 4.5 presents the experimental results. In Section 4.6, the results and their theoretical and managerial implications are discussed.

4.2. Theoretical Background on Live Biofeedback in Auctions

4.2.1. Cognitive and Affective Processing of Arousal

The interplay of cognitive and affective processing of arousal is described in the concept of the body-mind loop. Green et al. (1970) defined the body-mind loop as a psychophysiological concept, which refers to the relationship between physiological and cognitive state, where (i) every change in physiology can lead to a change in perception and (ii) changes in cognition can change physiological processes. This theory is also an integral part of the seminal work of Damasio (1994), who postulated that the interplay between cognition and affect manifests in cycles of interaction between body and mind. Damasio (1994) argued that "[the body] contributes a content that is part and parcel of the workings of a normal mind" (p. 223). As we will outline in the following, this body-mind loop is essential for the human experience and regulation of emotion. Building on this concept, the following Subsections discuss theories and findings of the extant literature and build the ground work for the proposed research model.

From the psychophysiological perspective, emotions are "defined as a collection of changes in body and brain states" (Bechara, 2004, p. 8) induced by stimuli (Clore and Schnall, 2005; Russell, 2003) and represent reactions to changes in the individual's environment that relate to the individual's needs or goals (Zhang, 2013). In this sense, "the individual is never without being in some emotional state" (Zajonc, 1984, p. 21). Affect is defined as a neurophysiological state (Russell, 2003) and affective states are commonly categorized in the two dimensions valence and arousal (de Guinea et al., 2014; Russell, 1980). Valence reflects different states of pleasure while arousal describes the overall intensity of an individual's affective state (Posner et al., 2005). The arousal dimension plays a critical role in human decision making, as it attributes salience and preparation for action to stimuli of the environment (Jennings et al., 1990).

Due to the physiological underpinnings of emotion, the emotional displays in the human mind are "always caused by implicit affective information processing" (Walla and Panksepp, 2013, p. 112). However, humans are limited in their ability to accurately perceive their physiological arousal, a skill referred to as interoception (Bonanno and Keltner, 2004). As interoceptive skills vary across individuals, so does coherence of physiological arousal and perceived arousal (Bonanno and Keltner, 2004; Füstös et al., 2012; Mauss et al., 2005). Coherence of perceived and physiological arousal can be improved through specialized training that promotes greater body awareness (i.e., Vipassana meditation or dance, Sze et al. 2010). In summary, subject to an individual's interoceptive skills, physiological arousal (body) directly affects an individual's perception thereof (mind).

The reverse direction from mind to body is more complex. In order to change the physiological processing of the environment, an individual needs to influence the emotion-generative process which governs emotions and their physiological emergence, that is, arousal, by applying emotion regulation techniques (Gross and Thompson, 2007). The application of emotion regulation techniques is possible at various stages of the emotion-generative process. Antecedent-focused strategies are used when the emotion is still unfolding while response-focused strategies are applied after the emotion has evolved (Gross, 1998b). Antecedent- and response-focused emotion regulation strategies can be applied during a decision-making process. They require specific skills, such as interoception, and have different effects on behavior and physiology (Gross and John, 2003; Gross and Levenson, 1993, 1997). Response-focused strategies such as suppression, where emotional expressions are restrained, are often associated with negative effects on decision-making (Adam et al., 2016) and come at the cost of increased physiological activity (Gross and Levenson, 1997; Hariharan et al., 2015). Antecedent-focused strategies such as cognitive reappraisal can have beneficial effects on decision making (Heilman et al., 2010; Miu and Crişan, 2011). To apply emotion regulation strategies like cognitive reappraisal effectively, interoception is a necessary prerequisite (Füstös et al., 2012). This bidirectional relation between body and mind is demonstrated in the body-mind-loop (Damasio, 1994).

4.2.2. Arousal Perception and Live Biofeedback

Arousal perception based on effective interoception has been identified as a necessary prerequisite for the application of emotion regulation techniques (Bechara and Damasio, 2005;

Damasio, 1994; Füstös et al., 2012). However, interoception can be impaired when individuals experience high levels of physiological arousal (Barrett et al., 2001).

Recent literature (Adam et al., 2015; Al Osman et al., 2013; Riedl and Léger, 2016) proposed the application of LBF in emotionally charged decision environments in order to improve arousal perception (see Chapter 2 for a review). LBF comprises measuring neurophysiological processes and subsequently generating an appropriate feedback response (Al Osman et al., 2013). Bodily changes are captured utilizing a variety of sensor technologies, such as EMG, electroencephalography (EEG), ECG, as well as the measurement of EDA, respiration, or body movements. Feedback responses are mostly visual, haptic, or auditory. Feedback based on physiological states has been applied in various domains, e.g., in order to reduce stress (Chittaro and Sioni, 2014; Matthews et al., 2015; Al Rihawi et al., 2014; Tan et al., 2014), improve cognitive performance (Cochran, 2011; Jirayucharoensak et al., 2014), support emotion regulation (Antle et al., 2015), enhance HCI and gaming experience (Kuikkaniemi et al., 2010; Nacke et al., 2011), facilitate the learning process in sports training (Umek et al., 2015), and to reduce impairments due to health disorders such as asthma (Lehrer and Gevirtz, 2014; Murray et al., 2013). Theoretically, LBF could be applied to influence the interplay of the body-mind loop by supporting interoceptive skills and providing the foundation for the effective application of emotion regulation strategies.

4.2.3. Arousal in Auction Bidding

According to the somatic marker hypothesis, accurate emotional processing is a vital part of sound and rational decision making (Bechara and Damasio, 2005). Studies with healthy participants and neuropsychiatric patients showed that impaired affective processing results in less advantageous decisions (Bechara, 2000; Bechara et al., 2001; von Borries et al., 2010). If integral to a task, physiological arousal can contain valuable information for fast and beneficial decision making (Bechara et al., 1997; Bechara and Damasio, 2005). Incidental arousal, on the other hand, which is due to events unrelated to the decision, is often disruptive (Bechara and Damasio, 2005; Grey, 1999). A more detailed discussion on the effects of integral and incidental arousal is provided in Chapter 3.

The extent to which decision makers benefit from their emotions also depends on their individual abilities to access the information contained in physiological arousal (Sütterlin et al., 2013). Studies in economics (Fenton-O'Creevy et al., 2011; Seo and Barrett, 2007), psychology (Dunn et al., 2010; White et al., 1981), and neuroscience (Dunn et al., 2012; Füstös et al., 2012) provide evidence for a positive influence of interoception on decision making.

With respect to arousal, Dunn et al. (2010) found that interoception moderates the relation between physiological responses and intuitive decision making. In particular, the authors found that physiological generation of arousal and arousal perception are crucial aspects for explaining emotional experience and intuition and hence, support bodily feedback theories.

Arousal plays an important role in competitive socio-economic environments such as auctions (Teubner, Adam, and Riordan 2015). Auction environments comprise several factors that are known to elicit arousal, such as rivalry, social facilitation, time pressure, and the uniqueness of being first (Ku et al., 2005). Rivalry comprises consciousness of the desire to win (Kilduff et al., 2010), focuses on beating other human beings (Kilduff et al., 2010), and is strongest in competition with few individuals (Ku et al., 2005). According to Ku et al. (2005), rivalry induces competitive arousal. Social facilitation occurs when participants know that their actions are observable by other participants (Zajonc, 1965; Zajonc and Sales, 1966). Zajonc (1965) noted that social facilitation can increase arousal and Ku and colleagues concluded that social facilitation can also fuel overbidding (Ku et al., 2005). Time pressure in auctions requires bidders to make quick decisions whether to place a bid or not and also increases arousal (Maule et al., 2000). Ku et al. (2005) also show that the uniqueness of being first fuels arousal.

Bidding behavior is influenced by arousal. For instance, auction fever may occur in an emotionally charged auction setting, where bidders deviate from their initially chosen bidding strategy due to high arousal (Adam et al., 2011). As shown in Chapter 3 social competition, an inherent characteristic of auctions (Adam et al., 2015; Ku et al., 2005), is one of the main drivers for emotionally charged bidding. When it comes to the effect of arousal on auction bidding, it is important to understand how bidders experience and regulate their emotions. A bidder always experiences an emotional state (Zajonc, 1984) and always has to manage its influence on behavior by applying emotion regulation strategies. Suppression in particular has been shown to have a negative effect on bidding behavior, and bidders who suppress their emotions are more influenced by affective images (Adam et al., 2016).

4.3. Research Model for Live Biofeedback in Auctions

Based on the psychophysiological concept of the body-mind loop and empirical findings of the extant auction literature, we develop a research model that describes the pathways in which LBF affects the emotion-generative process in the context of auctions (Figure

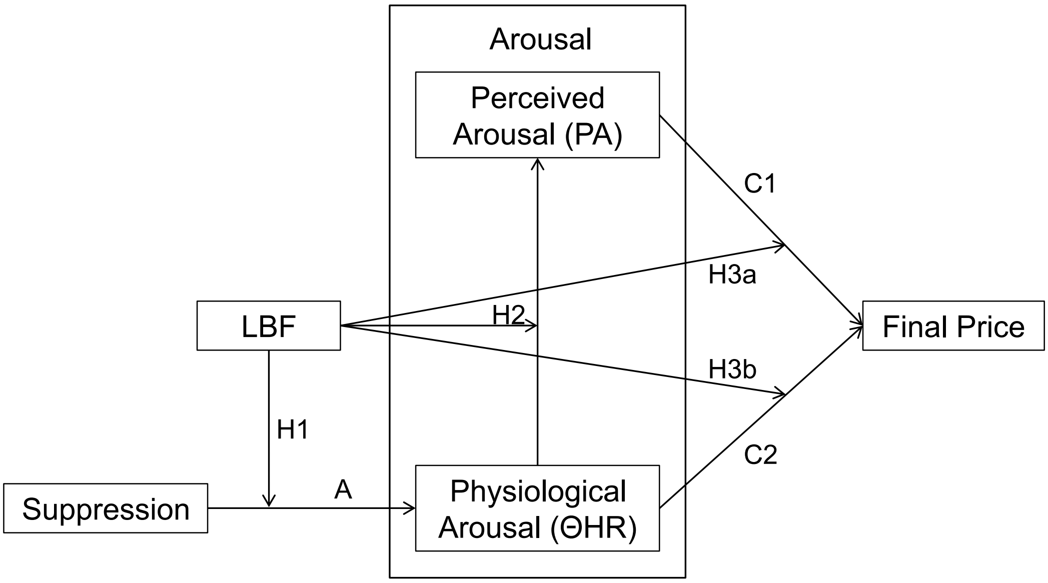


Figure 4.1.: Research model for live biofeedback in auction bidding

4.1). The relationships between the emotion regulation strategy suppression, physiological arousal, perceived arousal, and auction bidding (A-C in Figure 4.1) are derived from the extant literature. These relations as well as the research hypotheses (H4.1-H4.3) are discussed in detail in the following three Subsections.

4.3.1. Influence of Live Biofeedback on Physiological Arousal

According to the body-mind loop, individuals can apply emotion regulation techniques to change the emotional responses of their body to external stimuli. Such emotion regulation techniques incur different consequences, depending on the particular technique and the time at which this technique is applied in the emotion-generative process (Gross, 1998b, 2002; Gross and Levenson, 1993, 1997). When applying suppression while arousal is experienced, individuals inhibit emotionally expressive behavior and avoid the conscious reflection of emotional experiences (Gross and Levenson, 1993). Suppressive behavior comes at a physiological cost: suppression of positive or negative emotions causes sympathetic activation of the cardiovascular and electrodermal system and thus increases physiological arousal (Gross and Levenson, 1997). Reappraisal shows no such effects (Gross, 2002; Gross and Levenson, 1997). The relationship between suppression and physiological is reflected in relation A (Figure 4.1).

LBF visualizes physiological arousal based on physiological measures such as heart rate. Hence, LBF could make users who suppress their emotions and are unable or unwilling to reflect their emotional experiences more aware of their physiological activity. Consequently, by visualizing physiological arousal, we expect LBF to reduce the physiological costs of suppression, resulting in lower physiological arousal. Therefore, we hypothesize that:

Hypothesis 4.1 (H4.1): LBF moderates the influence of suppression on physiological arousal, resulting in lower physiological arousal.

4.3.2. Influences of Live Biofeedback on Perceived Arousal

The somatic marker hypothesis emphasizes the importance of physiological activities that are processed unconsciously (Bechara and Damasio, 2005). Even though perceived arousal is influenced by physiological arousal, emotional experiences and interoceptive skills vary considerably across individuals (Barrett et al., 2001; Ekman, 1992; Mauss et al., 2005; Sze et al., 2010). The well-established influence of physiological arousal on perceived arousal is included in the research model in relation B (Figure 4.1).

Considering that a greater body awareness improves coherence of perceived and physiological arousal (Sze et al., 2010), it is likely that individuals will be able to improve their interoceptive skills when provided with information about their current physiological state. Interoception is often defined in terms of cardioceptive skills (Astor et al., 2013; Critchley et al., 2004; Sütterlin et al., 2013). Since LBF is used to visualize the physiological arousal of a user, it may support arousal perception and thus result in higher coherence. By using an underlying parameter that almost instantly reflects sympathetic and parasympathetic activation, such as heart rate (Berntson et al., 2007), and provides an intuitive visualization of physiological arousal, LBF may increase coherence without specific LBF training or instruction for emotion regulation. We therefore hypothesize:

Hypothesis 4.2 (H4.2): LBF moderates the influence of physiological arousal on perceived arousal, resulting in higher coherence.

4.3.3. Influences of Live Biofeedback on Auction Bidding

As outlined above, previous research found a marked relationship between arousal and auction bidding, where increased arousal results in higher bids and final prices. Conceptually, the relationship between arousal and bidding prices can occur at the level of perceived arousal (C1 in Figure 4.1, Ku et al. 2005; Malhotra 2010) as well as at the level of physiological arousal (C2 in Figure 4.3, Adam et al. 2015; Teubner et al. 2015). However, evidence for the relationship between perceived arousal and bidding prices is mixed (Adam et al., 2015, 2012; Ku et al., 2005; Malhotra, 2010; Teubner et al., 2015). Theoretically, this can be explained by limited interoceptive skills of the decision maker. Although their physiological arousal affects their bids, bidders are limited in their perception of it. In such cases, the relationship between perceived arousal and bidding prices would appear tenuous or even inverted. Since LBF helps users to perceive their physiological state more accurately, we expect that LBF moderates the relationship between perceived arousal and bidding prices:

Hypothesis 4.3a (H4.3a): LBF moderates the relationship between perceived arousal and bidding prices.

Importantly, if bidders' perceptions of their physiological arousal are improved with LBF (H4.2), they may aim to regulate their behavioral response to increased arousal levels (response-focused emotion regulation), which would weaken the relationship between physiological arousal and bids. Moreover, even though LBF is provided as a UI element, there is evidence that the influence of LBF on arousal, hence on bidding prices, can partially occur at an unconscious level (Astor et al., 2013). We therefore hypothesize:

Hypothesis 4.3b (H4.3b): LBF moderates the relationship between physiological arousal and bidding prices.

4.4. Experiment for Analyzing Live Biofeedback in Auctions

A laboratory experiment is designed to test the proposed research model. In the experiment, we investigate the effects of LBF on the decision making process, i.e., its influence on (i) the effect of suppression on physiological arousal (H4.1), (ii) the perception of arousal based on the physiological arousal (H4.2), and (iii) the relationships between perceived arousal and final prices, and physiological arousal and final prices, respectively (H4.3a and H4.3b). This Section presents the auction design, the treatment structure, the experimental procedure, and the measures that are used in this study.

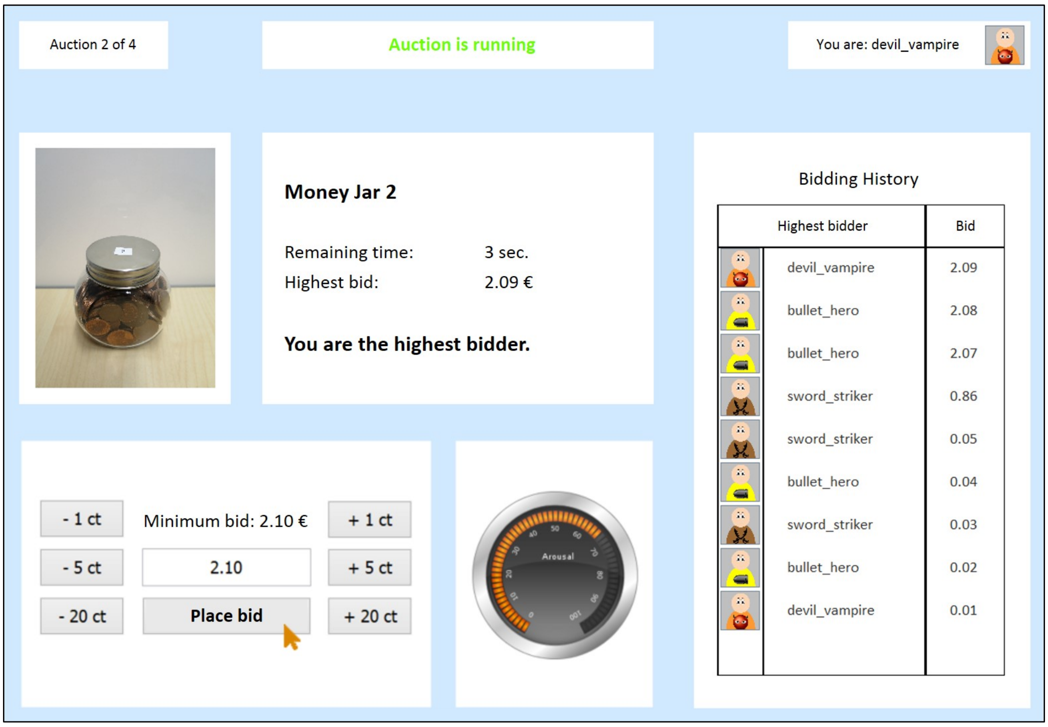
4.4.1. Auction Design

The experiment consists of four ascending open-outcry auctions with a soft-close end, also referred to as English auctions (Ku et al., 2005). We chose this auction format because bidders in English auctions tend to experience high levels of arousal (Adam et al., 2015; Ku et al., 2005). This is due to the fact that English auctions implement four aspects which fuel arousal, namely rivalry, social facilitation, time pressure, and the uniqueness of being first (Ku et al., 2005). We briefly describe how we operationalized each factor (see Figure 4.2):

(i) Rivalry. Bidders are informed during the entire auction whether they are currently the highest bidder (i.e., the current winner). As rivalry is higher when on encounters only few opponents, we set the number of participants per auction to three in order to enhance rivalry. Furthermore, each participant chooses an individual bidder name and avatar in the beginning of the experiment (Adam et al., 2015; Ku et al., 2005).

(ii) Social facilitation. Participants are provided with a bidding history that contains bidder information (i.e., avatar and bidder name which are identical to the ones used by Adam et al. (2015)) and placed bids. Hence, all bids are visible to all three bidders and are assigned to an individual bidder (Adam et al., 2015; Ku et al., 2005).

(iii) Time pressure. Time pressure is an effective way to induce arousal in an electronic auction setting (Adam et al., 2015; Ku et al., 2005). During an auction the remaining auction time is displayed on the auction interface. The clock starts at 20 seconds and the remaining time is set back to at least 8 seconds whenever a new bid is placed. Once the auction time



Auction 2 of 4

Auction is running

You are: devil_vampire

Money Jar 2

Remaining time: 3 sec.
Highest bid: 2.09 €

You are the highest bidder.

Bidding History

Highest bidder	Bid
devil_vampire	2.09
bullet_hero	2.08
bullet_hero	2.07
sword_striker	0.86
sword_striker	0.05
bullet_hero	0.04
sword_striker	0.03
bullet_hero	0.02
devil_vampire	0.01

Minimum bid: 2.10 €

2.10

Figure 4.2.: User interface with live biofeedback for auction bidding

has ticked down to below 8 seconds, each new bid gives the other bidders 8 seconds to react.

(iv) Uniqueness of being first. Before the auction ends, the uniqueness of being first is indicated to an individual on the auction interface by the information whether they are currently the highest bidder or not. The highest bidder is displayed to all bidders of an auction by the topmost entry of the bidding history (Ehrhart et al., 2015; Malhotra, 2010).

In each auction three bidders who have not met in a previous auction (i.e., perfect stranger matching, see Subsection 4.4.5, Both et al. 2016) bid on a common value good. The common value good has the same actual value for all bidders but this true value is unknown and bidders need to estimate it. Similar to Chapter 3, money jars filled with four different combinations of 2, 5, or 10 Euro-cent coins totaling € 4.9 each are used as common values in the four payoff relevant auctions. Throughout the auction, bidders bid on the content of the jar. Each bidder receives the respective money jar 45 seconds prior to the auction (all bidders receive the same jar). The soft-close prevents bid-shading and ensures that each bidder has the chance to react to new bids. When the auction time is over, the bidder who placed the last (i.e. highest) bid wins the auction and buys the content of the money jar at the price of their last bid.

The auction starts with a price of € 0. To keep the physiological measurements as accurate as possible, the participants are asked to move as little as possible. They are instructed not to make keyboard entries but to use a mouse device and buttons on the screen to place their bid. The minimum increment is € .01 and the smallest possible bid (i.e. current price + € .01) is used as default. Bidders are able to change their bids in increments of € .01, € .05, and € .2 using buttons on the auction interface. Bids are placed by clicking on the place bid button (participant instructions are provided in Appendix B.1).

4.4.2. Treatment Structure for Analyzing Live Biofeedback in Auctions

The experiment is a between-subjects design with two treatments (i.e., subjects participated in only one of the two treatments but not both). In the first treatment, we show LBF to the participants (LBF treatment). The participants of the second treatment receive no LBF (NBF treatment). The LBF is based on heart rate measurements, since this physiological measure almost instantly reflects sympathetic as well as parasympathetic activity (Berntson et al., 2007). Before the experiment, we conduct a 5 minute rest period to allow participants to calm down. The average heart rate of minutes 2 to 5 of this rest period serves as the individual baseline for each participant. We compute the level of physiological arousal (θHR) during the experiment as follows:

$$\theta\text{HR}=\frac{HR}{HR_{baseline}}$$

A physiological arousal value greater than 1 implies that participant's current heart rate is higher than their baseline. Likewise, a value smaller than 1 indicates a heart rate below their baseline. LBF is displayed in two ways. The first type is a gauge meter, containing bars that are colored with respect to the participant's current level of physiological arousal (see Figgure 4.2). In line with guidelines for designing LBF systems by Astor et al. (2013), we used five colors to indicate different levels of physiological arousal. Level 1 corresponds to physiological arousal values up to 1.0 (i.e., an increase in heart rate up to 0%) and is displayed with up to 20 dark blue colored bars. Level 2 corresponds to physiological arousal values between 1 and 1.0375 (i.e., between 0% and 3.75% increase in heart rate) and is associated with up to 40 light blue bars. Levels 3 and 4 are calculated in the same manner and displayed by up to 60 yellow and 80 orange bars, respectively. Level 5 corresponds to physiological arousal values above 1.15 (i.e., more than 15% increase in heart rate) and is represented by up to 100 red bars.

The second type of LBF display is implemented by the mouse cursor, which changes color depending on physiological arousal similar to the gauge meter (i.e., from dark blue to red). We show the mouse cursor in addition to the gauge meter since prior research indicates that the participants do not watch the gauge meter all the time (Astor et al., 2013). The cursor, however, moves as the participant uses the user interface and is in the participant's field of vision most of the time.

The instructions in the LBF treatment include an additional Section for the LBF features. The participants were informed that the gauge meter and the colors of the cursor represent their current level of physiological arousal based on their heart rates measured during the rest period and throughout the experiment. In all other respects, LBF and NBF treatments are identical.

4.4.3. Experimental Procedure for Analyzing Live Biofeedback in Auctions

The experiment was conducted at Karlsruhe Institute of Technology complying with the university's ethics guidelines and no-deception policy. For the experiment 72 participants were invited to the lab (mean age = 23.35, 47 males, 25 females) with ORSEE (Greiner,

2015) and assigned randomly to a treatment. The majority of participants were of European origin. All participants declared their consent to having their heart rate measured, their actions tracked throughout the experiment, and their anonymized data stored and analyzed. One complete experimental session took 1.5 hours on average. In total 8 sessions with 9 participants each were conducted. The participants received a € 6 show-up fee and earned on average € 13.06 (min=4.85, max=31.6). The experiment was conducted using the NeuroIS platform Brownie (Hariharan et al., 2017). The temperature in the air-conditioned lab was 23°C (73.4°F). Due to technical issues, heart rate measurement failed for three subjects.

The experiment can be divided in three phases, namely, (i) a preparation phase including an initial perception phase, (ii) a decision-making phase, and (iii) a final perception phase as depicted in Figure 4.3. In the preparation phase, ECG electrodes were attached on the participants' chests. Then the participants completed an initial five minute rest period. This initial rest period is necessary for assessing participants' heart rates at rest. This initial rest period was followed by Questionnaire 1 (see Appendix B.2), where the participants stated their initial valence and arousal levels. Subsequently, participants listened to an audio recording of the instructions and chose unique avatars and bidder names. The decision-making phase comprised five auctions, each preceded by a 1 minute rest period and a 45-second observation period in which participants inspected the auction item. The first auction was a practice round in which each participant competed against two computer bidders for a pen. This practice round was not payoff-relevant and intended to ensure that all participants understood the rules, the auction interface, and the experimental procedure. The practice round was followed by four iterations of a rest period followed by an observation period and an auction. In each of these four auctions, participants competed against two other participants. Perfect stranger matching ensured that any two participants

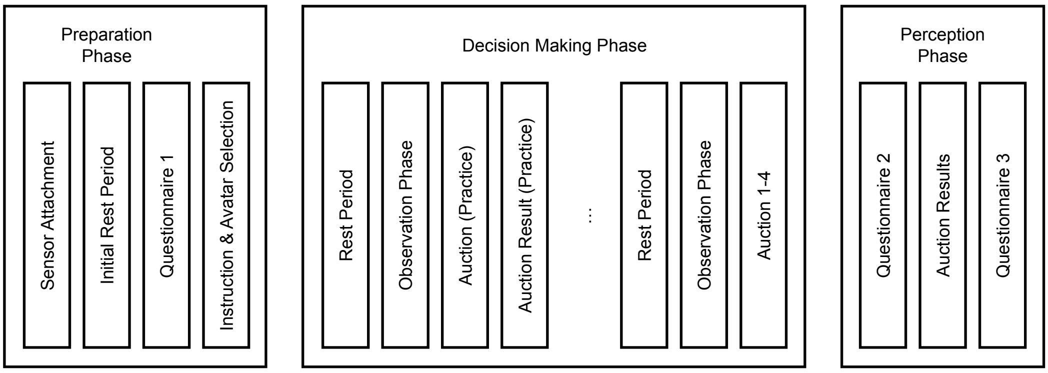


Figure 4.3.: Session structure for analyzing the effects of live biofeedback in auctions

did not meet more than once. The true values of the auction items were revealed after the last auction.

In the final perception phase, participants completed Questionnaire 2 (see Appendix B.2) on their perceptions during the auction task and, subsequently, participants learned about their individual gains and losses in each auction as well as their overall payoffs. After the results were shown, participants completed the demographic questions of Questionnaire 3 (see Appendix B.2).

4.4.4. Measures for Analyzing Live Biofeedback in Auctions

This study used three types of measures: (i) behavioral measures (i.e. participants' actions during the auctions), (ii) self-report measures (i.e. questionnaires), and (iii) physiological measures (i.e. heart rate measurements). Participants' actions manifested in the final price of the auction. Aggregated final prices (over the four auctions) were used in the analysis.

Three questionnaires were used within the experimental procedure to assess participants' perceptions. Questionnaire 1 used the Self-Assessment Manikin (SAM) technique (Bradley and Lang, 1994) to measure how participants perceive their affective state, in terms of valence and arousal (Russell et al., 1989), before auction bidding. Questionnaire 2 assessed participants' perceptions of their affective state after auction bidding, again using SAM (Bradley and Lang, 1994), the emotion regulation strategies applied by participants during the auctions (Gross and John, 2003), and perceived physiological activation (heart rate). Since arousal perception comes with high inter-personal differences, perceived arousal (PA) was measured as the difference between perceived arousal before and after auction bidding. Questionnaire 3 assessed demographic information (gender, age) and risk aversion (Holt and Laury, 2002), to be used as control variables in the subsequent analysis.

We used heart rate to analyze participants' average physiological arousal during auction bidding. Heart rate was derived from interbeat intervals, which were accessed by ECG placing three electrodes on the participants' chests. For determining the interbeat interval, R-waves were detected and the interval (in milliseconds) between two successive R-waves is calculated (Jennings et al., 1981). To eliminate inter-personal differences across participants and make it comparable to other measures (e.g. perceived arousal), heart rate was first normalized by dividing current heart rate through baseline heart rate (measured during the initial rest period) and then z-standardized across all participants. The normalized and z-standardized heart rate is referred to as physiological arousal (i.e. θHR, see Adam et al. 2015; Teubner et al. 2015) for a similar approach.

Prior to analyzing the relations, e.g., between variables on a 7-point Likert scale and variables on other scales, such as bidding prices or heart rate measurements, all variables were aggregated at an participant level and z-standardized. Table 4.1 summarizes used constructs and measures.

Table 4.1.: Measures used to examine live biofeedback in auctions

Construct	**Definition**	**Scale**	**Source**
Final Price	Average final price of the four auctions at a participant level.	€	Auction bidding
Perceived arousal (PA)	Perceived arousal is the increase of arousal the participant declares to experience during auction bidding. Perceived arousal is calculated as the difference of arousal perceptions during auction bidding and within the initial rest period. Arousal perception is assessed with Self-Assessment Manikins.	7-point Likert scale	Bradley and Lang (1994)
Physiological arousal (θHR)	Physiological arousal is the normalized level of arousal a participant experiences in terms of physiological (i.e., bodily) activation. Perceived arousal is calculated by dividing a participant's current heart rate through their respective baseline heart rate measured in the initial rest period. Hence, if a participant's heart rate equals their respective baseline heart rate, perceived arousal equals 1.	Numerical	Astor et al. (2013)
Suppression (S)	Suppression measures how strongly a participant avoids to show emotional reactions. The suppression score is assessed with the emotion regulation questionnaire.	7-point Likert scale	Adapted from Gross and John (2003)
Reappraisal (R)	Reappraisal measures whether a participant reflects the current situation with respect to their emotional state. The reappraisal score is assessed with the emotion regulation questionnaire.	7-point Likert scale	Adapted from Gross and John (2003)

Perceived LBF (PB)	Perceived LBF describes to which degree a participant sees and hence, perceives the LBF artifact on their computer screen.	7-point Likert scale	New construct
Perceived intrusiveness of LBF (IB)	Perceived intrusiveness of LBF measures to which extent the LBF artifact impeded the participant in performing the bidding task.	7-point Likert scale	Derived from Riedl et al. (2014)
Use of LBF (UB)	Use of LBF indicates to which extent a participant stated to use the provided LBF artifact during auction bidding.	7-point Likert scale	New construct
Perceived usefulness of LBF for emotion regulation (PUBER)	Perceived usefulness of the LBF for emotion regulation describes whether a participants finds the LBF artifact useful for regulating their emotional state.	7-point Likert scale	Adapted from Davis (1989)
Perceived usefulness of LBF for performance (PUBP)	Perceived usefulness of the LBF for emotion performance describes whether a participants finds the LBF artifact useful for archiving a higher payoff in the bidding task.	7-point Likert scale	Adapted from Davis (1989)
Desire to win	Assessment of the participant's desire to win the auctions.	7-point Likert scale	Adam et al. (2015)
Fear of losing	Assessment of the participant's fear of losing the auctions.	7-point Likert scale	Adam et al. (2015)

4.4.5. Perfect Stranger Matching

This Subsection is based on a joint research project with Marc T. P. Adam, Fabian Both, Verena Dorner, Anuja Hariharan, and Christof Weinhardt and has been published in Economics Letters (see Both et al. 2016). In order to keep the multiple observations from the four auctions each subject played as independent as possible, we used perfect stranger matching (PSM). Thus, we assured that all participants knew that they will not meet another participant in an auction more then once. Other experimenters tried to achieve the same result by matching participants randomly to groups while preserving anonymity between group members (Andreoni and Croson, 2008; Fehr and Gächter, 2000). However, such a simplified stranger matching does not rule out the possibility that repeated interactions between the same participants systematically alter experimental outcomes (Fehr and Gächter, 2000; Fudenberg and Pathak, 2010). Existing solutions to the PSM problem for up to 28 participants and varying group sizes are part of frameworks for economic experiments, such as BoXS (Seithe, 2012) or z-Tree (Fischbacher, 2007). The PSM problem, however, has not been analyzed in terms of algorithmic and computational efficiency, and existing solutions were mostly computed using a brute-force approach or a brute-force approach with backtracking.

When PSM is applied, p participants are repeatedly assigned to groups of size g, constituting a PSM *configuration (p,g)*, under the condition that no two participants meet more than once. A feasible assignment of all participants to groups is called *group allocation*. A series of group allocations over several periods is a *sequence*, and a sequence is considered *complete* if no further feasible group allocation can be added. Numerous complete sequences of different lengths may be found for a single configuration (*p,g*). The length of a complete sequence depends on both, the respective configuration and the combination of group allocations within this sequence. The core difficulty of PSM is thus twofold: (i) finding feasible group allocations that result in a complete sequence, and (ii) maximizing the length of a complete sequence for a given configuration (*p,g*).

The first difficulty, finding feasible group allocations that result in a complete sequence for a given configuration (*p,g*), is, in its essence, a permutation problem. The PSM problem represents a special case due to the constraints imposed by the matching histories of all participants, which render it a highly constrained permutation problem. Treating a problem as a constrained problem improves generalizability of the representation and reduces the required domain-specific expertise (Russell and Norvig, 1995). The second difficulty, finding a complete sequence with maximum length, requires an analytic approach, which, to the best of our knowledge, does not exist in the extant literature. By definition, each participant can meet the other $p-1$ participants only once and encounters $g-1$ group members per period. Hence, $limit_{upper} = \left\lfloor \frac{p-1}{g-1} \right\rfloor$ expresses the trivial upper limit for the maximum sequence length (Mathon and Rosa, 1996). But for many problem configurations, the longest known sequences are shorter than this trivial upper limit. For matching 24 participants in groups of 4 (i.e. configuration (*24,4*)) a maximum sequence length of 6 has been claimed by

Fehr and Gächter (2000), while $limit_{upper}$ suggests 7 to be the maximum sequence length. Since no schema exists for evaluating sequences, the effect of adding a group allocation to a sequence can only be tested ex-post. Figure 4.4 illustrates the problem of finding complete sequences of maximum length. A shifting pattern is used to determine a sequence for the configuration (*6,2*), resulting in a complete sequence of length 3. By using a different matching pattern, however, a complete sequence of length 5 – corresponding to the trivial upper limit – can be found.

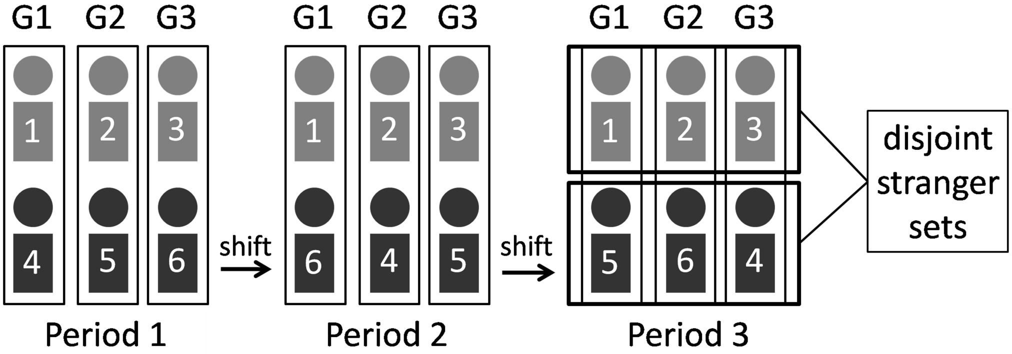


Figure 4.4.: Illustration of a perfect stranger matching pattern

The PSM can be viewed as a generalization of the social golfer problem (SGP), formulated by Harvey (1998) as a test problem for constraint solvers. The SGP describes the combinatorial problem of allocating 32 golfers who play once a week in groups of four for as many weeks as possible, without two golfers playing in the same group more than once. This formulation of the SGP can be represented as the PSM configuration (*32,4*). The SGP is unsolved (Pegg, 2007) and, based on results by Colbourn (1984), shown to be NP-hard. Even small problem instances of the SGP and, hence of PSM, are computationally expensive, due to the inability to determine if the maximum number of matches have been found.

The proposed algorithm[1] addresses the two difficulties of (i) finding feasible group allocations that result in a complete sequence, and (ii) maximizing the length of a complete sequence for a given configuration (*p,g*). To find a complete sequence of maximum length, the algorithm searches for several complete sequences until all possibilities are tested or a user-defined time limit is reached. A single sequence is computed by recursively adding groups to a group allocation. If a feasible group allocation is found, groups for a further group allocation are computed until the sequence is complete. In order to increase search efficiency (i.e. exclude infeasible solutions) and reduce run time, the proposed algorithm

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[1] The peudocode of this algorithm is provided in Appendix B.3. The Java Code of this algorithm is available at `https://github.com/PerfectStrangerMatching/PSM` or from the author on request.

comprises two main components – tabu search and random shuffling. The first component, tabu search, has been used to solve less constrained permutation problems (Misevicius, 2004; Fiechter, 1994). The idea of tabu search is to utilize knowledge gained during the search process to shrink the search space by either temporarily or permanently excluding visited regions of the search space from further searches. Similar to tabu search procedures by Misevicius (2004), the proposed algorithm excludes infeasible solutions from its search space ex-ante, using the matching history of all participants. The search space of the algorithm is thus recursively reduced to the size of the problem space of the PSM problem. As a consequence, ex-post validation of constructed group allocations and sequences is not required. The second component, random shuffling of list elements, is used to generate further group allocations within a sequence. Complete sequences can only be constructed by conducting a heuristic search for feasible solutions, either systematically or randomly. Neither have attempts to define a neighbourhood or fitness function for finding complete sequences or determining their optimality in terms of sequence length been successful so far, nor has the PSM problem been solved analytically (Seithe, 2012; Fischbacher, 2007). To compute complete sequences no pattern for generating subsequent group allocations has been identified that exploits the structure of the search space better than randomness. Hence, the developed algorithm employs random shuffling of list elements. However, if the length of the heuristically derived sequence does not meet the trivial upper limit, it cannot be evaluated whether maximum sequence length is achieved.

We used the proposed algorithm to generate sequences with potentially maximum length for configurations up to $n = 40$ participants. Configurations for more participants can be calculated, however, run time increases exponentially. Table 4.2 summarizes the results computed on a high-performance cluster. The number of participants equals the number of groups (n) multiplied by the group size (g). For each entry, a matching table is generated, which allows for reconstruction of the longest sequence found. We compare sequence length and run time of the proposed algorithm with commonly used brute-force methods [2], which iterate over all possible participant assignments to groups, until a group allocation is found that does not violate PSM constraints. Run times required to generate a single complete sequence for a specific configuration (p,g) are provided in Table 4.3. Run time tests were conducted on an i5 2500k without parallel computing (only a single core was used). Computation time per configuration was measured over two hours for each configuration, resulting in at least 4000 computations per configuration for the algorithm. For large prob-

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[2] According to the authors, the PSM solutions provided in BoXS and z-Tree are based on a brute-force algorithm (Seithe, 2012), and brute-force algorithm combined with backtracking (Fischbacher, 2007), respectively.

Number of Groups (n)	Group Size (g)				
	2	3	4	5	6
1	1	1	1	1	1
2	3	1	1	1	1
3	5	4	1	1	1
4	7	4	5	1	1
5	9	7	5	6	1
6	11	8	6	6	3
7	13	9	7	5	
8	15	10	8	6	
9	17	11	9		
10	19	13	10		
11	21	14			
12	23	15			
13	25	17			
14	27				
15	29				
16	31				
17	33				
18	35				
19	37				
20	39				

Table 4.2.: Sequence length for configurations up to 40 participants

lem instances, it was not possible to measure the brute-force run time due to its substantial increase in computation time. Computations were stopped after five hours. Configurations, were no complete sequence could be calculated within five hours are marked with an x. For configurations with a group size of 2, the obtained longest sequences always reach the trivial upper limit. That this does not hold for larger group sizes could be a consequence of dependencies among participants in larger groups. For a specific group size g equal or even larger sequence lengths can be expected as the number of participants p increases. Hence, the obtained results indicate that for some configurations (e.g., (*30,5*) with a maximum sequence length of 6 and (*35,5*) with a maximum sequence length of 5) the the proposed algorithm does not yield maximum sequence length. However, the obtained sequences are at least as long and for several configurations even longer than those found with existing PSM approaches (Seithe, 2012; Fischbacher, 2007).

The run time for finding a group allocation depends on the configuration. For small groups, an increase in the number of participants leads to an increase in run time, since participants have to be exchanged between groups more often. For large groups, run time is high for constructing even a single group that does not violate PSM constraints. Run time analysis

	Proposed Algorithm					**Brute-Force**				
P	G=2	G=3	G=4	G=5	G=6	G=2	G=3	G=4	G=5	G=6
4	~0ms	-	-	-	-	~0ms	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-
6	~0ms	-	-	-	-	~0ms	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-
8	~0ms	-	-	-	-	~0ms	-	-	-	-
9	-	~0ms	-	-	-	-	0.3ms	-	-	-
10	~0ms	-	-	-	-	3.1ms	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-
12	0.1ms	~0ms	-	-	-	23ms	4.3ms	-	-	-
13	-	-	-	-	-	-	-	-	-	-
14	0.1ms	-	-	-	-	30ms	-	-	-	-
15	-	0.1ms	-	-	-	-	70ms	-	-	-
16	0.2ms	-	~0ms	-	-	61ms	-	~0ms	-	-
17	-	-	-	-	-	-	-	-	-	-
18	0.2ms	0.1ms	-	-	-	6.4s	1.2s	-	-	-
19	-	-	-	-	-	-	-	-	-	-
20	0.3ms	-	0.4ms	-	-	88s	-	0.7s	-	-
21	-	0.2ms	-	-	-	-	0.6s	-	-	-
22	0.4ms	-	-	-	-	1096s	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-
24	0.5ms	0.5ms	0.9ms	-	-	x	5.1s	3.8s	-	-
25	-	-	-	0.1ms	-	-	-	-	0.3s	-
26	0.7ms	-	-	-	-	x	-	-	-	-
27	-	1ms	-	-	-	-	54s	-	-	-
28	0.9ms	-	2.6ms	-	-	x	-	3.7s	-	-
29	-	-	-	-	-	-	-	-	-	-
30	1.2ms	2ms	-	1.1s	-	x	x	-	x	-
31	-	-	-	-	-	-	-	-	-	-
32	1.8ms	-	8.6ms	-	-	x	-	0.5s	-	-
33	-	5.5ms	-	-	-	-	x	-	-	-
34	2.3ms	-	-	-	-	x	-	-	-	-
35	-	-	-	1.2s	-	-	-	-	x	-
36	3ms	8.8ms	25ms	-	0.2ms	x	x	102s	-	215s
37	-	-	-	-	-	-	-	-	-	-
38	4.3ms	-	-	-	-	x	-	-	-	-
39	-	19ms	-	-	-	-	x	-	-	-
40	7.2ms	-	72ms	1.7s	-	x	-	x	x	-

Table 4.3.: Average computation times required to generate complete sequences

reveals two opposing effects. First, each additional group allocation increases search space complexity, due to added constraints, leading to an increase in run time. Second, when tabu search is applied, each group allocation reduces the size of the search space due to the history of each participant, reducing run time necessary to find feasible group allocations. This means that while run time initially increases with every group allocation found due to increasing number of constraints, it eventually starts to decrease again, as the effect of complexity reduction due to reduced search space size becomes prevalent.

Figure 4.5 provides a qualitative illustration of run time effects. It illustrates two contrary effects which influence the run time for finding subsequent group allocations. Initially, a low run time is achieved when searching for a feasible group allocation since the search space is not constrained through matching histories. The longer the sequence of group allocations under the perfect stranger criterion, the more constraints have to be satisfied for further group allocations. While this increases the complexity of the search space, it simultaneously shrinks the size of the search space since many solutions can be excluded a-priori. Overall, this leads to an increase in run time for subsequent group allocations up to a certain point after which the run time decreases again.

Generating group allocations within a sequence based on a pattern (e.g. replacement of elements by their successors) shows that some group allocations require significantly longer

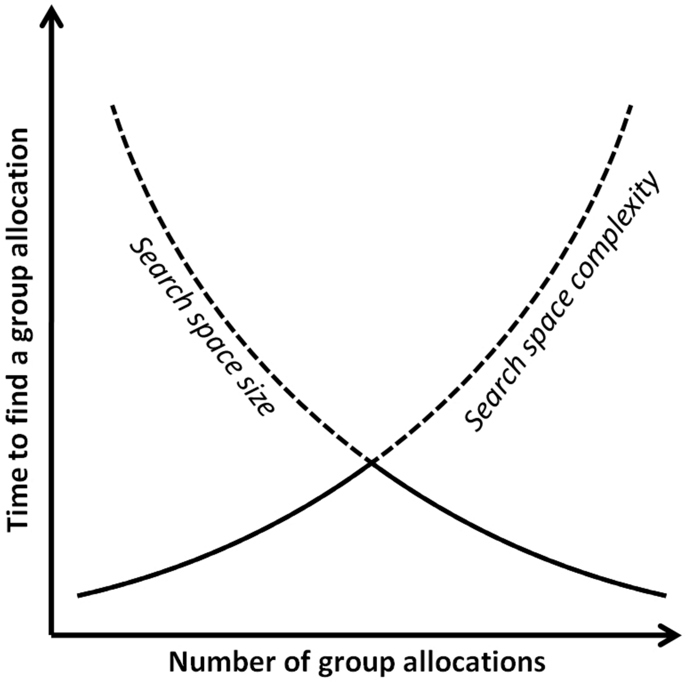

Figure 4.5.: Qualitative illustration of run time effects in perfect stranger matching

run time. Using random shuffling of element lists rather than specified patterns results in shorter run times for finding complete sequences.Figure 4.6 illustrates a run time comparison. In order to generate Figure 4.6, group allocations for the configuration (p,g) = (36,2) have been computed 1 million times. Thereby, the average time for finding the next group allocation within a sequence was measured. Run time measurements where conducted on an i5 2500k. The top graph displays the computation time for the proposed algorithm without random shuffling. For the graph in the middle, the first 17 group allocations have been generated with a systematic pattern before applying the proposed algorithm. The bottom graph displays average results of the proposed algorithm, combined with random shuffling. We find that tabu search reduces the magnitude of necessary operations and random shuffling of the search space exploits structures within the search space generated by the searching method. Hence, both, tabu search and random shuffling, help to reduce run time compared to brute-force methods, however, the latter shows greater leverage. For large problem instances tabu search reduces computation time by a factor of about ten, whereas random shuffling in conjunction with tabu search is up to several thousand times faster. Taking the configuration (27,3) as an example, the brute-force algorithm takes 54 seconds to find a complete sequence. Tabu search without random shuffling is nearly 10 times faster than brute-force approaches, with a completion time of 5.7 seconds. Combining tabu search with random shuffling reduces run time to 1ms, thus making the algorithm additionally 5700 times faster.[3]

Although PSM is sufficient to avoid direct learning effects caused by two subjects interacting with each other more than once, it is important to emphasize that PSM is limited with respect to contagion and thus does not preserve a best-reply-structure (Kamecke, 1997). Best-reply-structure-preserving matching schemes prevent repercussion effects caused when two partners of a subject meet. Since such matching schemes are more constrained than PSM, the resulting sequence lengths are even smaller (i.e. maximum sequence length is shorter or equal to p/g, Kamecke 1997). Future research needs to explore alternative PSM approaches, e.g., by addressing neighbourhood and fitness functions to find and evaluate complete sequences. One promising alternative approach is the usage of predefined sequence lengths, which allows the application of several optimization methods to find even longer sequences. To improve the proposed algorithm, we suggest to further investigate effects on run time.

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[3] These computations were performed on an i5 2500k CPU without parallel processing.

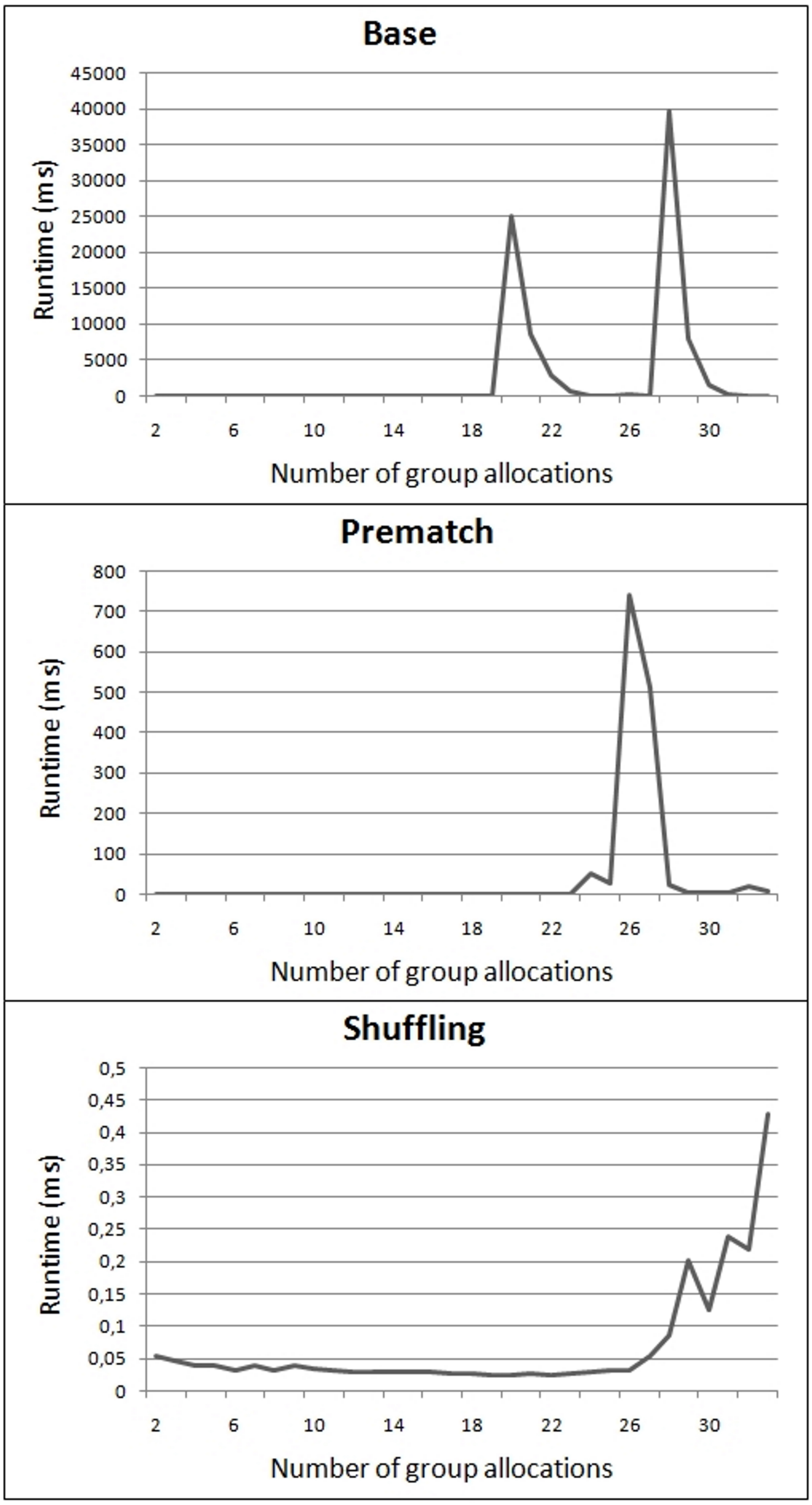

Figure 4.6.: Run time comparison of perfect stranger matching algorithms

4.5. Effects of Live Biofeedback in Auctions: Experimental Results

In the analysis, we first focus on manipulation checks and the evaluation of LBF as an IS artifact. We then analyze how LBF moderates the influence of suppression on physiological arousal (H4.1). Subsequently, we investigate the moderating influence of LBF on arousal perception based on physiological arousal (H4.2). Finally, we investigate how LBF influences the effect of perceived arousal (H4.3a) and physiological arousal (H4.3b) on the final price. To be consistent in the analysis, we focus only on those 69 out of 72 participants whose heart rate values were successfully obtained.

4.5.1. Manipulation Checks

To test whether we successfully induced arousal in the experiment, we compare perceived arousal and physiological arousal before and during the auctions. One-sample t-tests show that PA (i.e., the difference between perceived arousal during auction bidding and the initial rest period; see Table 4.1) deviates positively and significantly from zero in both treatments (LBF: mean=2.314, $t(34)=7.628$, $p<.001$; NBF: mean=1.735, $t(33)=6.106$, $p<.001$). Heart rate during the auctions significantly differs from heart rate during the rest period, i.e., θHR is significantly higher than 1 (LBF: mean=1.052, $t(34)=3.246$, $p=.001$; NBF: mean=1.077, $t(33)=4.313$, $p<.001$). We conclude that the induction of integral arousal through the auction bidding was successful.

The valence of emotional experience is comparable across treatments (LBF: mean=.076, NBF: mean=-.044, $t(62.232)=-.501$, $p=.618$). This is also reflected in similar values for participants' desire to win (LBF: mean=.020, NBF: mean=-.028, t(63.17)=-.195, p=.846) and fear of losing (LBF: mean=.089 vs NBF: mean=-.078, $t(60.729)=-.69$, $p=.493$). Hence, the treatment manipulation did not affect the valence dimension of the emotional experience.

The extent to which the participants applied the two emotion regulation strategies reappraisal and suppression (Gross and John, 2003) is comparable across treatments. Independent sample t-tests show that LBF neither particularly promotes reappraisal (mean=-.032 in the LBF treatment vs. mean=.009 in the NBF treatment, b= -.023 se=.241, t=-.096, p=.924) nor suppression (mean=-.105 in the LBF treatment vs. mean=.064 in the NBF treatment, b=-.169, se=.240, t=-.707, p=.482). In other words, LBF had no impact on the extent to which the two emotion regulation strategies were applied.

4.5.2. Live Biofeedback as an Information Systems Artifact

This study integrates and investigates LBF as a novel IS artifact in electronic auctions. In order to evaluate the LBF artifact, we assess perceived intrusiveness and perceived usefulness of LBF with respect to emotion regulation and performance. LBF is consciously perceived as an element of the user interface without being disturbing, but with no further effects upon use or perceived usefulness of this artifact for emotion regulation or performance. One sample t-tests show that participants in the LBF treatment perceived LBF during auction bidding (mean=4.524, $t(34)=2.1$, $p=.022$) and did not find it intrusive (mean=2.543, $t(34)=-6.207$, $p<.001$). However, perceived usefulness is unexpectedly low, with medium levels for emotion regulation (mean=3.19, $t(34)=-3.108$, $p=.998$) and slight disagreement regarding usefulness for performance (mean=2.836, $t(34)=-4.491$, $p=.999$). We will come back to this result in the discussion.

4.5.3. Effect of Live Biofeedback on Physiological Arousal

Given that LBF does not directly relate to emotion regulation strategies, we now test the influence of suppression on physiological arousal, in the LBF condition. To evaluate whether LBF reduces the influence of suppression on physiological arousal (H4.1), we use an ordinary least squares (OLS) regression to regress suppression scores and the corresponding interaction term (suppression x LBF) on participants' physiological arousal (Regression I in Table 4.4). In line with H4.1, we found that the influence of suppression on physiological arousal is indeed moderated by the treatment condition of LBF ($b=-.472$, se=.215, $t=-2.197$, $p=.032$).[4]

A floodlight analysis (Spiller et al., 2013) in Figure 4.7 and 4.8 reveals a significant negative effect of the LBF treatment condition on physiological arousal (i.e., θHR) for any value of the standardized suppression score greater than .507 ($b=-.474$, se=.238, $t=-1.997$, $p=.05$), but not for standardized scores smaller than .507.

Taken together, the results show that participants with high suppression scores in the LBF treatment are less physiologically aroused than participants with similar suppression scores in the NBF treatment. Thus, we reject the null hypothesis in favor of H4.1. The effect of suppression on physiological arousal is mitigated by LBF.

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[4] Including risk aversion in the model does not change effect sizes or directions. This also applies for all following models.

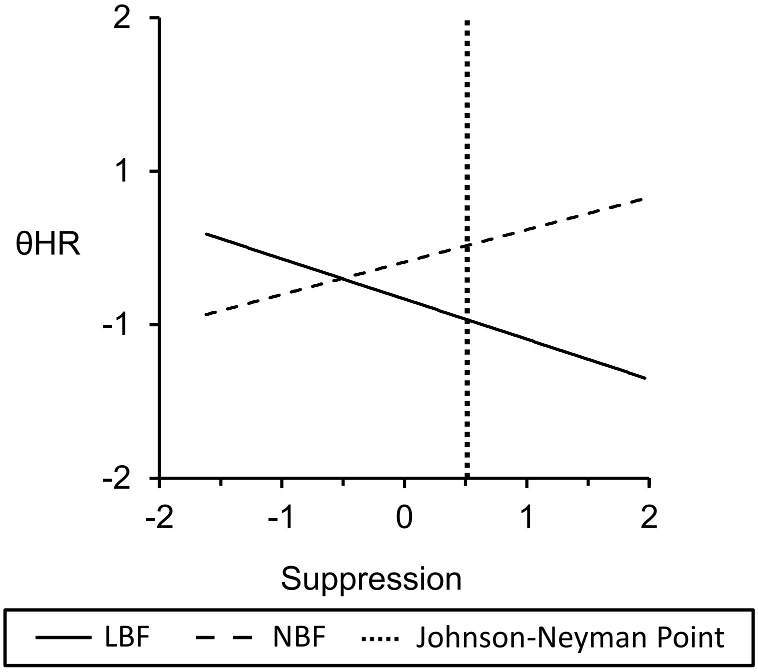

Figure 4.7.: Effect of suppression on physiological arousal in auctions

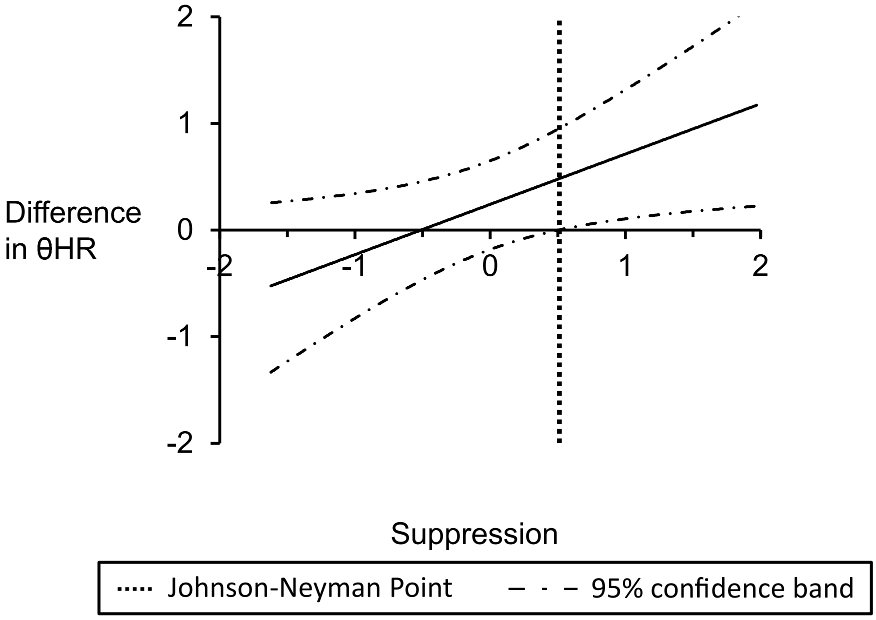

Figure 4.8.: Differences in physiological arousal at different levels of suppression

Table 4.4.: Effects on physiological arousal and perceived arousal in auctions

	Dependent Variables	
	Regression I	**Regression II**
Independent Variables	**θHR**	**PA**
dummy_LBF	-.241	.467*
	(.211)	(.231)
θHR		-.144
		(.183)
θHR x LBF		.767**
		(.271)
suppression	.211	.091
	(.148)	(.165)
suppression x LBF	-.472*	.137
	(.215)	(.241)
gender	0.083	-.199
	(0.229)	(.248)
constant	-.093	.182
	(.397)	(.430)
R^2	8.8%	17.4%
Num. obs.	69	69
AIC	183.04	195.631

Note: OLS regression. Regression coefficients with standard errors in parenthesis. Significance levels are based on two-tailed tests.
***p <.001, **p <.01, *p <.05

4.5.4. Effect of Live Biofeedback on Perceived Arousal and Coherence

Next, we focus on the effect of LBF on coherence between arousal perceptions and physiological arousal (H4.2). We use an OLS regression to regress physiological arousal and the corresponding interaction term (θHR x LBF) on perceived arousal at the participant level (Regression II in Table 4.4). Supporting H4.2, LBF is associated with higher coherence between physiological arousal and perceived arousal (b=.767, se=.271, t=2.83, p=.006), i.e. a higher level of physiological arousal leads to higher perceived arousal. We conclude that LBF increases the coherence between physiology (body) and perception (mind).

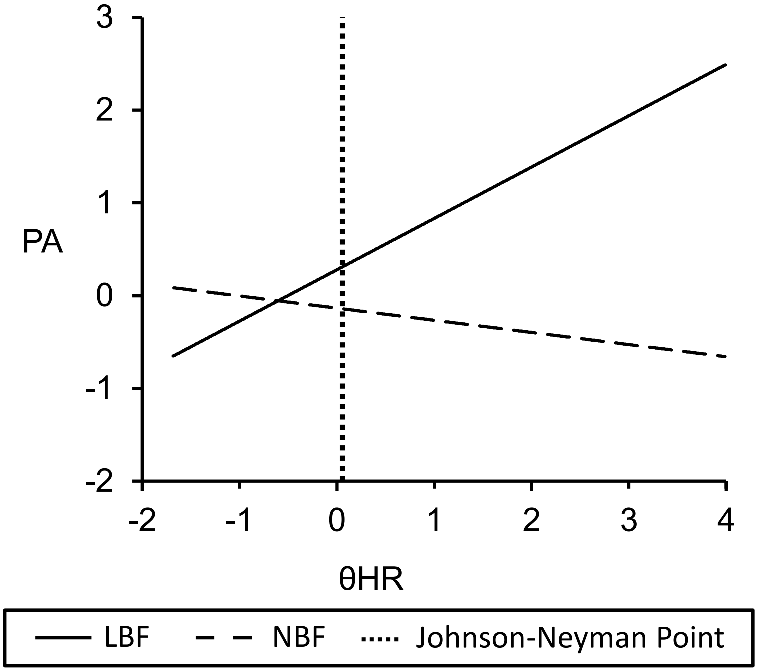

Figure 4.9.: Effect of physiological arousal on perceived arousal in auctions

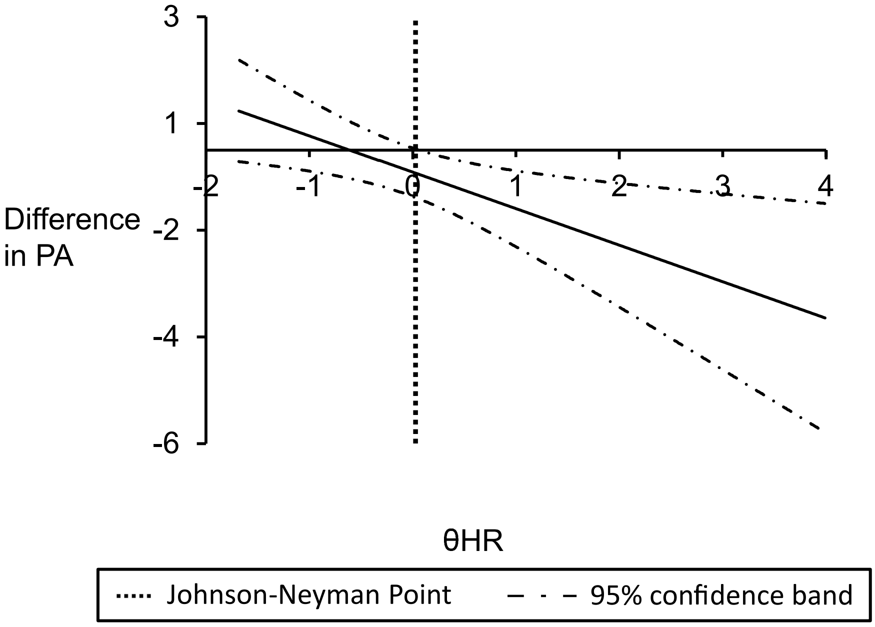

Figure 4.10.: Differences in perceived arousal at different levels of physiological arousal

The floodlight analysis (Spiller et al., 2013) in Figure 4.9 and 4.10 reveals a significant positive effect of physiological arousal (i.e., θHR) on perceived arousal (i.e., PA) in the LBF condition for levels of physiological arousal at least .063 standard deviations above average (*b*=.456, se=.229, *t*=1.997, *p*=.05). For any θHR value greater than .063, perceived arousal is significantly higher in the LBF treatment than it is in the NBF treatment. Conversely, for any θHR smaller than .063, difference in perceived arousal between the treatments is not significant. For no level of physiological arousal LBF reduces coherence between physiological arousal and perceived arousal. Taken together, we reject the null hypothesis in favor of H4.2.

Additionally, we tested whether the correlation coefficients between perceived arousal and physiological arousal are different from zero. In line with H4.2, there is a significant positive correlation (i.e., coherence) between physiological arousal and perceived arousal in the LBF treatment (Pearson's *r*(35)=.457, *t*=2.952, *p*=.003), while in the NBF treatment the correlation coefficient is slightly negative and not significantly different from zero (Pearson's *r*(34)=-.128, *t*=-.73, *p*=.235).

4.5.5. Effect of Live Biofeedback on Auction Bidding

We now turn to the relationship between LBF, arousal, and auction bidding. We analyze the effect of perceived arousal (H4.3a) and physiological arousal (H4.3b) on final prices separately (Regressions III and IV in Table 4.5) and together (Regression V in Table 4.5). We regress LBF and the corresponding interaction term (PA x LBF and θHR x LBF, respectively) on final auction prices.[5] Model fit, as indicated by the Akaike information criterion (Table 4.5), is best for Regression V, which comprises both perceived arousal and physiological arousal.

In line with H4.3a, we observe that the effect of perceived arousal on final prices is conditional on treatment (Regression V: *b*=.305, se=.120, *t*=2.534, *p*=.014). Contrary to H4.3b, the effect of physiological arousal on final prices is not conditional on treatment (Regression V: *b*=.038, se=.135, *t*=.280, *p*=.780). In other words, the results show that LBF affects the relationship between arousal and auction bidding, but only on a cognitive level. We reject the null hypothesis in favor of H4.3a and reject H4.3b.

The floodlight analysis (Spiller et al., 2013) in Figure 4.11 and 4.12 reveals a significant positive effect of perceived arousal (i.e., PA) on final prices in the LBF treatment for lev-

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[5] Suppression has no significant effect on final prices and including suppression in the model does not result in significant changes.

Table 4.5.: Effects of physiological arousal and perceived arousal on auction prices

	Dependent Variables		
	Regression III	**Regression IV**	**Regression V**
Independent Variables	**Final Price**	**Final Price**	**Final Price**
dummy_LBF	.001	.034	.049
	(.114)	(.116)	(.114)
θHR		.168	.137
		(.090)	(.086)
θHR x LBF		.045	.038
		(.132)	(.135)
PA	-.255**		-.239**
	(.086)		(.085)
PA x LBF	.388**		.305*
	(.116)		(.120)
dummy_gender_male	.199	.196	.182
	(.118)	(.121)	(.115)
constant	3.488***	3.519***	3.510***
	(.206)	(.211)	(.201)
R^2	19.0%	15.1%	25.4%
Num. obs.	69	69	69
AIC	96.588	99.777	94.860

Note: OLS regression. Regression coefficients with standard errors in parenthesis. Significance levels are based on two-tailed tests.
***p <.001, **p <.01, *p <.05

els of perceived arousal at least .661 standard deviations above average (*b*=.456, se=.229, *t*=1.997, *p*=.05). For levels of perceived arousal greater than .661, final prices are significantly higher in the LBF treatment than in the NBF treatment. Conversely, for any value of perceived arousal smaller than .661 but greater than -.803, difference in final prices between treatments were not significant. We find a significant negative influence of LBF on the effect perceived arousal has on final prices for levels of physiological arousal smaller than -.803.

In addition to hypothesis testing, we also took a closer look at possible differences in bidding behavior across treatments. Independent sample t-tests show that neither the number of bids (LBF: mean=14.15 vs NBF: mean=14.368, *t*(64.269)=.107, *p*=.915), the increments by which a bidder increases the current bid (LBF: mean=.181 vs NBF: mean=.176, *t*(64.022)=-.092, *p*=.927), nor final prices (LBF: mean=3.849 vs NBF: mean=3.846, *t*(65.42)=-.027, *p*=.979) differ between the two treatments. Hence, while we observe that LBF moderates the relationship between perceived arousal and auction prices, presumably due to an enhanced coherence between physiological arousal and perceived arousal, we cannot observe differ-

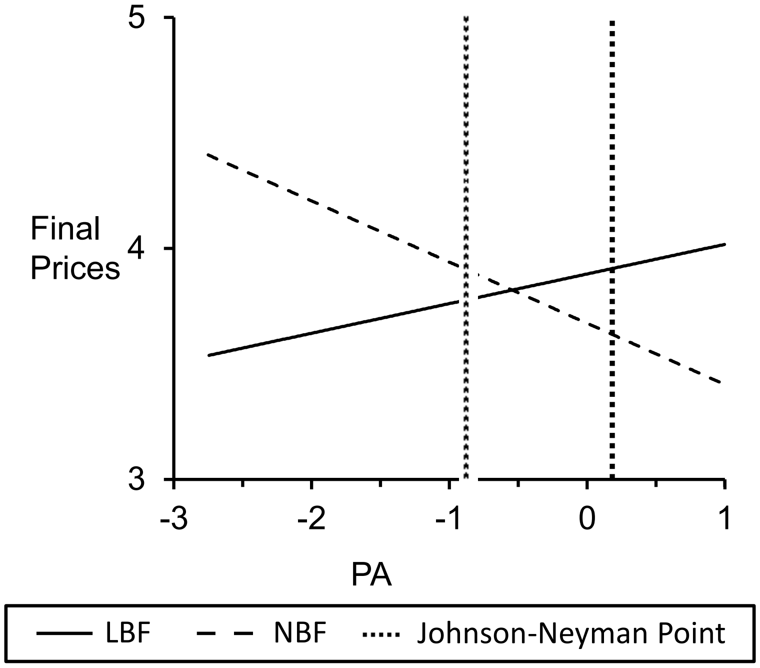

Figure 4.11.: Effect on perceived arousal on final prices in auctions

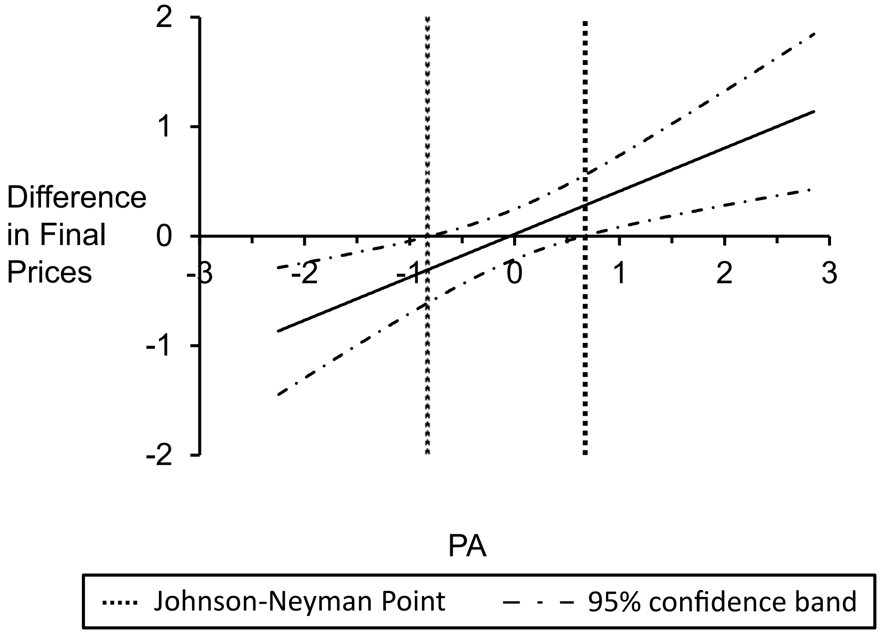

Figure 4.12.: Differences in final prices at different levels of perceived arousal

ences in actual behavior. As we will outline in more detail in the discussion, we presume that a change in behavior would require a training of how to use LBF for effective application of emotional regulation strategies.

4.6. Discussion of the Effects of Live Biofeedback in Auctions

4.6.1. Summary of Results and Theoretical Implications

Based on the body-mind loop, we developed a theoretical model of how providing users with LBF affects the interplay of cognitive and affective processing in electronic auctions. We tested the model in a laboratory experiment where subjects participated in emotionally charged auctions and were either provided with LBF (LBF treatment) or not (NBF treatment). LBF provided the participants with real-time information about their affective states, based on real-time measurements of their heart rates (Riedl et al., 2014).

Previous research on emotion regulation strategies showed that applying suppression comes at the cost of increased physiological arousal (Gross and Levenson, 1997). The results of this study are in line with this finding and extend them by an important aspect: If participants suppress their emotions, they experience higher physiological arousal, but providing users with LBF results in lower physiological costs of suppression (H4.1 supported). This implies that for avoiding physiological costs it is not necessary to alter the emotion regulation strategy, for instance by applying cognitive reappraisal. Instead, LBF can be offered.

Interoception and emotion regulation are reflected in the relations between mind and body in the body-mind loop. As interoception is an important prerequisite for emotion regulation, we examined LBF as an IS artifact that provides visual information, facilitating access to affective processes that are difficult to access otherwise. We find that LBF increases interoception, as evidenced by a significant positive relationship between physiological and perceived arousal (H4.2 supported). This finding is in line with results on body awareness training, where higher body awareness is associated with better interoceptive skills (Sze et al., 2010). Participants without LBF exhibit no significant relationship between physiological and perceived arousal, indicating low interoception, which is consistent with previous research (Barrett et al., 2001; Ekman, 1992; Mauss et al., 2005). We conclude that, when decision makers experience high levels of emotional arousal, LBF can establish a foundation for sound decision making and has similar positive effects as body awareness training.

As for the relationship between arousal and behavior, we find that LBF leads to a positive relation between perceived arousal and final prices (H4.3a supported). This implies that bidders who are provided with LBF and who place high bids are aware of their high arousal levels, as reflected in the positive relationship between physiological arousal and perceived arousal. Interestingly, we observe the opposite for bidders without LBF: higher bids are associated with lower perceived arousal levels. Yet, coherence of perceived and physiological arousal is low, which implies that participants without LBF place high bids without being aware of their high level of physiological arousal.

We do not find that LBF alters the overall emotional experience with respect to the joy or frustration that bidders experience as they win or lose an auction. However, we show that LBF moderates the relationship between arousal and auction bidding on the cognitive level, i.e., the cognitive perception of emotion (H4.3a supported) but not on the physiological level (H4.3b not supported). This implies that LBF, which affects emotional processing at a cognitive level, can be used as a foundation for applying emotion regulation strategies to alter overall emotional processing (Füstös et al., 2012).

Despite the described effects of LBF, the participants state low usage of the LBF artifact. This might be due to two reasons. First, similar to the results of previous studies (Adam et al., 2015), the auction task was very engaging and induced a high level of emotional arousal, both perceptional and physiological. Due to time pressure and the high level of arousal participants might not have had enough time to focus on the LBF artifact and to learn how to interpret it. This first reason is supported by findings from Astor and colleagues, who reported that increasing task complexity resulted in decreasing attention the participant paid to LBF (Astor et al., 2013). The second reason might be the limited experience of the users with LBF. No explicit LBF training was provided, and participants were not primed on how to use the information given by the LBF artifact to improve their performance. We will return to this aspect in the discussion of limitations and future research.

4.6.2. Managerial Implications

From a practical perspective, this study has several implications. Accurate perception of arousal is a foundation for sound emotion processing and hence, for beneficial decision making (Bechara and Damasio, 2005). Interoceptive skills vary across people (Bonanno and Keltner, 2004; Füstös et al., 2012; Mauss et al., 2005), however, the results of this study show that they can be supported through LBF. Therefore, the first implication is that by increasing interoception through LBF, new opportunities arise for emotion regulation and emotional processing in emotionally charged decision scenarios. Füstös et al. (2012) found that interoceptive awareness facilitates reappraisal. Hence, with training LBF could support people to apply cognitive reappraisal – an emotion regulation strategy that is known for its positive effect on decision making (Gross and John, 2003; Heilman et al., 2010; Miu and Crişan, 2011). Importantly, the LBF artifact improved interoception even though no training on using it was provided, and it was not perceived as intrusive in an electronic auction setting. Hence, the integration of LBF in IS requires only little time and effort on part of the users even in a complex task such as an electronic auction, which involves strategic interaction with other bidders.

Furthermore, the "heat of the moment" – in a situation in which people experience high levels of physiological arousal – can cause people to decide differently than they would in a calm situation (Ariely and Loewenstein, 2006; Loewenstein, 2000; Peters et al., 2006). Moreover, people are unable to predict how arousal affects their decision making (Ariely and Loewenstein, 2006; Ariely, 2009). The results show that when users have no LBF perceived arousal and physiological arousal are not correlated in an emotionally charged auction task. With LBF, however, higher bids are associated with higher levels of perceived arousal, hence enabling bidders to be aware of their affective states. Hence, the results also imply that with LBF those users who place higher bids are aware of their high arousal. This awareness is an important prerequisite for altering decision-making processes in emotionally charged situations.

People have different ways to cope with their emotions. One frequently applied emotion regulation strategy is suppression (Gross and John, 2003). However, suppressing emotional reactions comes at the cost of increased physiological arousal (Gross and Levenson, 1997; Hariharan et al., 2015). We observe this consequence of suppression in the treatment without LBF, however, we find that LBF helps to overcome this physiological cost of suppression. While increasing interoceptive skills alone has no impact on physiological arousal, we find that by visualizing physiological arousal LBF reduces sympathetic activity caused though suppressive behavior. Hence, the third implication of the results is that providing people with LBF ion practice reduces their physiological costs of suppressive.

4.6.3. Limitations and Future Research

This study has several limitations. One limitation lies in the LBF artifact itself. Currently, it is based on ECG measurements of heart rate, which of course limits its practical applicability outside laboratory settings. However, heart rate measurements are becoming less expensive and recent research has shown that heart rates can be obtained without body-contact (Rouast et al., 2016). We chose ECG measurements with Ag/AgCl electrodes because they yield higher accuracy. Other than heart rate, different ECG-based features, such as heart rate variability, or other physiological modalities (e.g., electrodermal activity or facial muscle movements), or even multimodal biofeedback parameters that comprise information from a variety of biosignals could be used for LBF (e.g., Antle et al. 2015; Jirayucharoensak et al. 2014; Kuikkaniemi et al. 2010).

With respect to the feedback modality, we chose to provide visual feedback, which was displayed on the user's screens. Recent literature has developed further modalities, such as acoustic (Chittaro and Sioni, 2014) or tactile feedback (Schnädelbach et al., 2012; Ueoka and Ishigaki, 2015). In this study, we displayed an arousal meter with colored bars and a colored mouse cursor. We decided to display both LBF visualizations because the arousal meter provides detailed information about the current arousal level but is stationary and therefore often outside of the user's field of vision when concentrating on auction bidding, while the mouse courser is within the user's field of vision more frequently but is less informative. Many other manifestations, ranging from plain numbers to images, are conceivable and some of them might be perceived as being more useful than the chosen design. Which feedback modality is appropriate in different IS usage scenarios and for different user cohorts is an important question for future research.

Furthermore, we provided LBF to participants without any instructions or specific LBF training. Participants in the LBF treatment were merely informed that LBF visualizes the relation between their current heart rate and their heart rate during the initial rest period. While LBF did increase interoception, participants did not perceive it to be useful for emotion regulation or auction bidding. However, physiological arousal affects decision making, even when it is below awareness (Lerner et al., 2004; Sokol-Hessner et al., 2009). A promising path for future research may be to investigate whether the impact of LBF on interoception and behavior increases when training is provided (Astor et al., 2013). This may increase users' perceived usefulness of the LBF artifact, influencing arousal levels and decision making.

Finally, when investigating the influence of arousal it is important to consider the valence dimension of emotional experience (Gregor et al., 2014). This study shows that this valence dimension does not change when introducing LBF in an auction context. However, the role of LBF may be different in other IS settings with a different emotional experience, such as knowledge management (Gregor et al., 2014) or technostress interventions (Adam et al., 2016; Riedl, 2012). Hence, further research is needed to understand whether and how LBF can be applied in different IS contexts and with varying levels of valence.

4.6.4. Concluding Note on Live Biofeedback in Auctions

Decision making in electronic auctions often involves high levels of arousal with definite influences on human decision making. Integrating LBF into IS offers new opportunities in terms of decision support as it can help betters to improve their ability to assess their affective states and apply emotion regulation. This experimental study supports the proposed theoretical model of how the IS artifact LBF impacts cognitive and affective processing of stimuli in an emotionally charged scenario. We conclude that LBF is an appropriate IS artifact for giving individuals better access to the physiological processes underlying their affective processing of stimuli and thus improves peoples' interoceptive skills. While interoception is reflected in the body-mind pathway of the body-mind loop model, LBF supports also the mind-body pathway by decreasing the physiological costs of suppression.

In the next Chapter the investigation of LBF in electronic markets is extended by an alternative scenario. As behavior of market participants has often been examined in the beauty contest game (Keynes, 1936; Nagel, 1995), we use this game to broaden our knowledge of the effects that LBF can have. Furthermore, as the results of this Chapter revealed that without having the chance to familiarize with the novel UI element participants do not find it useful, the experiment that is discussed in Chapter 5 comprises a training period, where the participants have the chance to try out how their LBF reacts with respect to changes in their physiological processes.

Chapter 5.

Live Biofeedback for Decision Support under Time Pressure

> “We usually think of ourselves as sitting in the driver’s seat, with ultimate control over the decisions we made and the direction our life takes; but, alas, this perception has more to do with our desires – with how we want to view ourselves – than with reality.
>
> DAN ARIELY (2009)

5.1. Introduction to Live Biofeedback and Decisions under Time Pressure

Economic decisions are often influenced by the principle of time is money, causing feelings of severe time pressure in decision makers due to explicit or implicit time constraints. Previous research has shown that making decisions under time pressure can negatively affect outcomes as it can result in the application of more simplistic decision strategies where the consequences of other peoples’ actions are more likely to be ignored transforming a strategic decision effectively into a non-strategic decision (Spiliopoulos et al., 2017; Rieskamp and Hoffrage, 2008). Furthermore, time pressure can increase manipulability (Reutskaja et al., 2011), reduce information acquisition (Weenig and Maarleveld, 2002), and overall detrimentally affect decision quality (Kocher and Sutter, 2006). There is reason to believe that the detrimental effects of time pressure on decision quality can to some extent be explained by changes in the decision maker’s emotional state and the regulation thereof (Loewenstein, 1996; Maule et al., 2000). More specifically, time pressure has been shown to increase decision makers' overall arousal levels (Ku et al., 2005; Adam et al., 2015), which in turn restricts attentional capacity and promotes risk seeking behaviors (Mano, 1994; Shapiro et al., 2002). While emotion regulation may alleviate these potentially detrimental effects of arousal (Gross et al., 2006), decision makers are limited in their ability to accurately assess and regulate their current emotional state (Craig, 2002; Dunn et al., 2010; Sütterlin et al., 2013).

Recent literature has proposed the use of LBF to support perception and regulation of emotional states (Astor et al., 2013; Fernández et al., 2013; Al Osman et al., 2013, 2016). At this stage, however, only little research has investigated the use of LBF for supporting decision making in economic contexts. In a systematic review of existing LBF literature in Chapter 2, we identified 47 studies that evaluate applications that provide users with feedback based on their own physiological processes in real-time. Only four of these studies investigate the use of LBF for emotion regulation in the context of economic decision making: Cederholm et al. (2011), Jercic et al. (2012), and Astor et al. (2013) designed and investigated serious games with LBF to support emotion regulation for financial investors and Fernández et al. (2013) concluded that LBF raises traders' emotional awareness and "is helpful and welcomed within that profession" (p. 2316). However, the effect of LBF on emotionally charged strategic interactions has not been investigated in economic literature so far. Thus, we seek to answer the following research question in this Chapter:

Research Question 4: Does live biofeedback improve the quality of decision making under time pressure?

More specifically, we conduct a laboratory experiment to answer the question whether LBF improves the quality of decision making under time pressure in a beauty contest game. We build on the concept of emotional intelligence and investigate how LBF alters participants' arousal perceptions, emotion regulation strategies, and their physiological states. The experimental design is based on the beauty contest experiment by Kocher and Sutter (2006) and comprises thee treatments: (i) a control treatment, (ii) a treatment where participants are instructed to regulate their emotions, and (iii) a treatment, where participants are instructed to regulate their emotions and are additionally provided with LBF. We find that LBF increases decision making quality, while the mere instruction to regulate one's emotions has no such effect. Furthermore, we find that LBF results in lower physiological arousal, higher perceived arousal, and lower engagement in suppression than the control group.

This Chapter is based on joint a research project with Marc T. P. Adam, Verena Dorner, and Christof Weinhardt. The remainder of this Chapter is organized as follows: In Section 5.2 we discuss related work on time pressure and the role of arousal on decision making and provide a theoretical background on how LBF may support decision making under time pressure. The experimental design is presented in Section 5.3 and in Section 5.4 the results are discussed.

5.2. Theoretical Background and Related Work

5.2.1. Arousal and the Quality of Decision Making

Decisions in economic contexts such as bargaining (Roth et al., 1988; Sutter et al., 2003), auction bidding (Adam et al., 2015; Roth and Ockenfels, 2002), and stock trading are frequently made under severe time pressure (Busse and Green, 2002). Several studies that investigate the relation between decision making and time pressure acknowledge the detrimental effects that time pressure can have. Carnevale and Lawler (1986) show that time pressure increases competitiveness and reduces information exchange in negotiations. Similarly, Cates and Shontz (1996) observe that time pressure results in the generation of more aggressive solutions for social problems. Ibanez et al. (2009) apply a mild form of time pressure in a search task and report that participants stop searching earlier than theoretically optimal. Kocher et al. (2013) study the effect of time pressure on risky decisions and find that time pressure does not affect risk attitudes for gains, but increases risk aversion for losses. Sutter et al. (2003) report that in the ultimatum game time pressure can cause the rejection of mutually advantageous deals and Spiliopoulos et al. (2017) conclude that under time pressure decision makers tend to reduce decision complexity by ignoring the consequences of other players' actions.

Furthermore, and fundamental for the present study, Kocher and Sutter (2006) examine the influence of time pressure on decision making quality in a beauty contest game. The authors chose this game to examine the effect of time pressure on strategic decision making for three main reasons. First, the beauty contest game can be used to investigate strategic interaction and multiple levels of reasoning and is linked to professional investment activity Keynes (1936), where decisions must frequently be made under time pressure. Second, the participants' payoffs, which reflect the distance between their estimates and the respective target numbers, provide a clear ex-post evaluation criterion for performance and thus, quality of decision making. Third, the participants' behavior in the beauty contest game is not affected by other motives such as risk attitudes or fairness considerations, but by the incentive to maximize their payoffs. Kocher and Sutter (2006) find that the decision quality in terms of payoff is reduced under high time pressure. Despite time pressure, however, the authors find that a time-dependent payoff scheme results in quicker decision making without reducing decision making quality.

Ku et al. (2005) identify time pressure as a major environmental factor that fuels arousal, which might be one of the reasons for the detrimental effects of time pressure on decision making. As an important dimension of the emotional state of a decision maker (Russell, 1980), arousal can result in the selection of simpler decision strategies (Mano, 1992), restricted attentional capacity (Paulhus and Lim, 1994; Shapiro et al., 2002), increased risk-seeking (Mano, 1994), more polarized judgements (Mano, 1992), and stronger reliance on heuristics and emotional processes (Rubinstein, 2007). Arousal can result in decision making that is "out of control" (Loewenstein, 1996). Thus, a person's abilities to perceive their level of arousal, evaluate reasons and consequences, and regulate their arousal – abilities to which Joseph and Newman (2010) refer to as *emotional intelligence* – are essential for advantageous decision making in emotionally charged situations.

5.2.2. Live Biofeedback and Emotional Intelligence

Emotional intelligence has gained increasing research attention over the last few years, especially in psychology, but also in other research domains such as economics, finance, and management (Caldarola, 2014; Grandey, 2003; Law et al., 2004; Tomer, 2003). Salovey and Mayer (1990) define emotional intelligence "as the subset of social intelligence that involves the ability to monitor one's own and others feelings and emotions, to discriminate among them and to use this information to guide one's thinking and actions" (p. 189). Joseph and Newman (2010) build on this ability-based definition of emotional intelligence and conceptualize the sequential relations of emotion perception, emotion understanding, and emotion regulation as well as their effect on performance (measured through ratings of their supervisors at work) in the *cascading model of emotional intelligence*. Even though there are a variety of definitions for performance in literature on emotional intelligence, they generally include task performance as a key dimension of overall performance (Borman and Motowidlo, 1997; Côté et al., 2006; Hogan and Holland, 2003; Hurtz and Donovan, 2000). Subsequently, if the task is to make a decision, for instance, to decide whether to buy or to sell stocks, task performance is reflected in decision quality.

In their cascading model of emotional intelligence, Joseph and Newman (2010) identify a direct relationship between emotion regulation and performance. Emotion regulation describes the "attempts individuals make to influence which emotions they have, when they have them, and how these emotions are experienced and expressed" (Gross et al., 2006, p. 14). In fact, the emotional state of a decision maker is continuous, that is, a person "is never *without* being in some emotional state" (Zajonc, 1984, p. 121, emphasis in original) and always – automatically or controlled, consciously or unconsciously – pursues some kind of emotion regulation (Gross et al., 2006). Gross (1998a) identifies reappraisal (i.e., the interpretation of potentially emotion-relevant stimuli in unemotional terms) and suppression (i.e., the inhibition of emotion-expressive behaviour) as the two main emotion regulation strategies. Literature on emotion regulation often attributes neutral or positive properties to reappraisal, which is applied early in the emotion generative process (Miu and Crişan, 2011; Wallace et al., 2009), while suppression emotion regulation strategies that is applied after an emotion unfolds is generally linked with negative consequences (Butler et al., 2003; Gross, 1998a, 2002; Gross and John, 2003).

The aim of suppression is the inhibition of any emotional expressions, e.g., in a situation where one wants to conceal one's emotions in order to save face. Suppression is associated with cognitive and affective costs, for instance, increased physiological activity (Gross, 1998a, 2002; Gross and Levenson, 1997; Richards and Gross, 1999), impairment of explicit memory (Richards and Gross, 1999, 2000), and increased cognitive load (Gross, 2002; Heilman et al., 2010), which, in turn, may have behavioural consequences such as impulsive decision making (Leith and Baumeister, 1996), inhibited relationship formation (Butler et al., 2003), and increased manipulability through affective images (Adam et al., 2016). According to Butler et al. (2003) people with high emotion regulation skills are less likely to engage in suppression and Joseph and Newman (2010) report a positive relation between emotion regulation skills and job performance for high emotional labour jobs. Accordingly, we are interested to which extent the participants of this study engage in suppression and how suppression is linked with performance in terms of decision making quality.

Importantly, emotion regulation is preceded by emotion perception and understanding. While the latter refers to the ability to evaluate the reasons and consequences of emotions (Mayer et al., 1999), emotion perception refers to the ability to identify an emotion and to differentiate them from one another (Brackett et al., 2006). Emotions involve changes in physiological states (Bechara and Damasio, 2005; Damasio, 1994) that carry information: Bechara et al. (1997) found that healthy participants, in contrast to participants with impaired emotional processing due to prefrontal damage, exhibited physiological responses whenever they were about to make a risky decision. Furthermore, the authors reported that "[healthy participants] began to choose advantageously before they realized which strategy worked best, whereas prefrontal patients continued to choose disadvantageously even after they knew the correct strategy" (Bechara et al., 1997, p. 1293). On this basis, Bechara and Damasio (2005) postulated the somatic marker hypothesis and concluded that emotions carry implicit or explicit knowledge that can be valuable for decision making. The authors argue that conscious and accurate perception of physiological processes, also described as interoception (Critchley et al., 2004), is a necessary prerequisite for sound decision making. In this sense, accurate emotion perception is the first step to gain control over the effects these processes have on our behaviour.

Building on emotion perception, emotions can be regulated and utilized to guide one's behaviour, which in turn can result in higher decision quality (Bechara and Damasio, 2005; Füstös et al., 2012). However, interoceptive awareness varies from person to person and, especially under high levels of arousal (e.g., increased heart rates), people are often not able to accurately perceive their bodies' physiological processes (Craig, 2002, 2003; Dunn et al., 2010; Sütterlin et al., 2013; Sze et al., 2010). LBF comprises the measurement of a person's physiological processes (e.g., cardiac activity, electrodermal activity) and the generation of a feedback response that addresses at least one of a person's five traditional senses (e.g., sight, hearing) in order to trigger a change in cognitive, affective, and behavioural processes (Hilborn et al., 2013; Al Osman et al., 2013; Riedl and Léger, 2016). Previous research has proposed LBF as a technology to support human decision makers in effective emotion perception and regulation (Astor et al., 2013; Al Osman et al., 2013, 2016; Peira et al., 2014). Based on the reviewed LBF literature (see Chapter 2), we found that most LBF applications employ visual feedback and apply ECG to acquire information on the users' physiological processes. Heart rate or related cardiac measures are frequently-used measures for LBF applications as they are established physiological indicators for arousal (Cacioppo et al., 2000; Järvelä et al., 2016). LBF has been used to support emotion regulation in the context of (serious) games (Astor et al., 2013; Cederholm et al., 2011; Hilborn et al., 2013; Jercic et al., 2012; Liu et al., 2009; Rani et al., 2005) and e-learning applications (Oertel et al., 2007). The results of these studies indicate that LBF can be used to boost the user's perception of their emotional state and thus improve their skills for effective emotion regulation (Astor et al., 2013; Peira et al., 2014).

Based on the findings from LBF literature and the cascading model of emotional intelligence, we hypothesize that LBF can improve emotion perception and consequently emotional intelligence resulting in higher decision quality. In summary, we derive the following hypothesis:

Hypothesis 5.1 (H5.1): Live biofeedback results in higher decision quality under time pressure.

5.3. Experiment for Analyzing Live Biofeedback in Decision Making

5.3.1. Experimental Design: Live Biofeedback in the Beauty Contest

To examine whether LBF increases decision quality under time pressure, we conduct a beauty contest game. We chose this game because it has frequently been used to examine strategic decision making on financial markets, where market participants are often exposed to time pressure (Keynes, 1936; Leder et al., 2013; Nagel, 1995, 2004). Furthermore, the participants' decisions in this game are not affected by other factors such as risk attitudes, but only by the incentive to increase their payoff by submitting an estimate as close as possible to the target number. Thus, payoffs can be used as a measure for decision quality. Kocher and Sutter (2006) showed that reducing the response time to 15 seconds (respectively 20 seconds in the first round of a phase) induces sufficient time pressure to detrimentally affect decision making quality. We decided to employ an experiment building on the design of Kocher and Sutter (2006), because their design alterations from the standard game provides an experimental setup that allows us to examine the effects of LBF on decision making under time pressure.

In the standard beauty contest game by Nagel (1995) n players simultaneously estimate a real number in the closed interval [0, 100] that ideally meets the target numberx_r^*, which is defined as $p \cdot \bar{x}_r$, the mean $\bar{x}_r$ of all estimates x in round r multiplied by a commonly known factor $p \in (0,1)$. Kocher and Sutter (2006) alter the standard game design in two ways: (i) the target number additionally depends on a constant C, while both factor p and constant C are altered across phases, and (ii) a continuous payoff scheme is applied so that the payoff decreases as the distance to the target number increases. The authors made these adaptations to (i) change the equilibrium and examine the participants' adaptability to a changing environment and (ii) because a continuous payoff scheme resembles financial decision making more than the basic winner-takes-all scheme and provides each participant with the incentive to make effort.

Table 5.1.: Experimental parameters used in the conducted beauty contest game

Phase	p	C	Nash Equilibrium
Phase 1 (round 1-8)	2/3	0	0
Phase 2 (round 9-16)	2/5	90	60
Phase 3 (round 17-24)	1/5	100	25

We use a fixed group size of n=4 participants. Once matched, a group of four participants, in the following referred to as cohort, will remain matched throughout the entire experimental session. Each session consists of three phases with eight rounds each. Factor p and constant C change between phases but are consistent over the eight rounds within a phase. Analogous to the experiment by Kocher and Sutter (2006), we use p=2/3 and C=0 in the first phase (round 1-8), p=2/5 and C=90 in the second phase (round 9-16), and p=1/5 and C=100 in the third phase (round 17-24) with 0, 60, and 25 being the respective Nash equilibria. Table Table 5.1 summarizes the parameters used throughout the three phases.[1] As Kocher and Sutter (2006) observed round effects, we will control for potential round effects in the analysis.

As the average payoff of €20.4 per person in the experiment by Kocher and Sutter (2006) was "exceptionally high" (p. 381), we adjust the continuous payoff function in a way that the payoff decreases by 8ct instead of 4ct with every increment distance from the target number. Thus, the calculation of the target number x_r^* in Eq. (1) and the Nash equilibrium strategy x^N in Eq. (2) are identical to the ones used by Kocher and Sutter (2006). Only player i's payoff $\pi_{i,r}$ given the estimation $x_{i,r}$ in Eq. (3) is modified (8ct instead of 4ct as described above). The original payoff function is given in Eq. (4).

(1) $x_r^* = p \cdot (\frac{\sum_{i=1}^{n} x_{i,r}}{n} + C)$

(2) $x^N = \frac{p \cdot C}{1-p}$

(3) $\pi_{i,r} = 1.00 - 0.08 \cdot |x_{i,r} - x_r^*|$

(4) $\pi_{i,r} = 1.00 - 0.04 \cdot |x_{i,r} - x_r^*|$

5.3.2. Treatment Structure: Emotion Regulation and Live Biofeedback

In order to test the hypothesis on the effect of LBF on decision quality, we employ three treatments (see Table 5.2). The first treatment serves as control treatment (CTL treatment),

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[1] In the following analysis the rounds of each phase are coded from 0 to 7.

Table 5.2.: Applied treatment structure in the beauty contest game

	Treatment		
	CTL	ER	LBF
Emotion regulation training and instruction	No	Yes	Yes
Live biofeedback	No	No	Yes
Time for decision making (s)	15	15	15
Cohort size (n)	4	4	4
Number of participants/cohorts	56/14	48/12	56/14

replicating the 15s treatment by Kocher and Sutter (2006). In the CTL treatment, participants experience time pressure, which has been shown to result in lower decision quality than without time pressure (Kocher and Sutter (2006). As the induced time pressure is likely to increase arousal, we introduce a 1-minute resting period prior to each phase of the beauty contest (see Adam et al. 2012; Järvelä et al. 2016; Sütterlin et al. 2010). In this resting period, participants have time to calm down, and thus allow their arousal to return to an individual baseline level.

In the second treatment (ER treatment), the CTL treatment is extended by an emotion regulation training prior to the beauty contest task. In this training, participants are asked to become emotionally aroused for one minute and subsequently to calm themselves down for one minute. Up and down regulation was supported by stressful and calm music, which has been applied in other studies to induce or reduce arousal (cf. Astor et al. 2013). During the 1-minute resting period prior to the three phases of the beauty contest, the participants are reminded to regulate their emotions during the beauty contest game.

Finally, in the third treatment (LBF treatment), the ER treatment is extended by the display of the user's LBF on their screens. This means that the participants of the LBF treatment also participate in the two times 1-minute emotion regulation training and are also reminded in the 1-minute resting period prior to each phase to regulate their emotions during the beauty contest game. However, during emotion regulation training, resting periods and the actual beauty contest game, participants in the LBF treatment are additionally provided with LBF.

5.3.3. Measures Used to Analyze Live Biofeedback for Decision Support

In this study we use three types of measures: (i) behavioral measures, (ii) self-report measures, and (iii) physiological measures. The participant's behavior is measured in terms of their estimates in each round of the experiment. Following Kocher and Sutter (2006) we use the difference between a participant's estimate $x_{i,r}$ and the respective target number x_r^* as an indicator for the quality of decision making. Smaller differences result in higher payoffs $\pi_{i,r}$, therefore, we interpret high payoffs as high decision making quality. In order to increase the robustness of the results, the difference between the ex-ante expected average and the ex-post actual average of the other players' number $\Delta x_{i,r}$ is used as an additional indicator for decision quality Kocher and Sutter (2006).

Table 5.3.: Measures used to examine live biofeedback in the beauty contest game

Measure	**Description**	**Scale**	**Source**
Decision quality ($\pi_{i,r}$)	The participants' payoffs in each round are used as an indicator for decision quality.	€	Kocher and Sutter (2006)
Decision quality ($\Delta x_{i,r}$)	Under the assumption that each player is playing best response, the difference between the ex-ante expected average and the ex-post actual average of the other players' numbers can be used as an alternative indicator for decision quality.	€	Kocher and Sutter (2006)
Suppression	Suppression score indicates how strongly a participant avoids to express emotional reactions.	7-point scale	Adapted from Gross and John (2003)
Perceived arousal	Perceived arousal is the level of arousal from low to high that a participant declares to experience during the beauty contest game.	9-point scale	Bradley and Lang (1994)
Perceived valence	Perceived valence is the level of valence from negative to positive that a participant declares to experience during the beauty contest game.	9-point scale	Bradley and Lang (1994)
Physiological arousal (HR)	The participant's average HR in each round is used as an indicator for physiological arousal.	Beats per minute [bpm]	Adam et al. (2016)

Participants' perceptions are assessed within questionnaires. We adapt the emotion regulation questionnaire by Gross and John (2003) that assesses a character trait by altering the questions so that they specifically refer to the beauty contest game and, hence, acquire the participant's self-reported suppression score referring to their current state. Furthermore, we use the self-assessment manikins (SAM) by Bradley and Lang (1994) to assess the participants' perceived arousal. With respect to physiological measures, we use ECG to record the participants' HR and generate the LBF throughout the experiment for all three treatments. We calculate the participants' average HR within each round (20 seconds in the first, 15 seconds for all consecutive rounds within a phase) as an indicator for physiological arousal. Table 5.3 provides an overview of the described measures.

5.3.4. Experimental Protocol

The experiment was conducted in fall 2016 at the Karlsruhe Decision & Design Lab. We conducted 14 sessions with 4 to 16 participants per session. In total 160 participants, that is, 40 cohorts (see Table 5.2), were recruited with hroot (Bock et al. 2014). The participants were randomly assigned to treatment conditions and groups of four within each session. The group composition remained constant throughout a session. The average payoff over

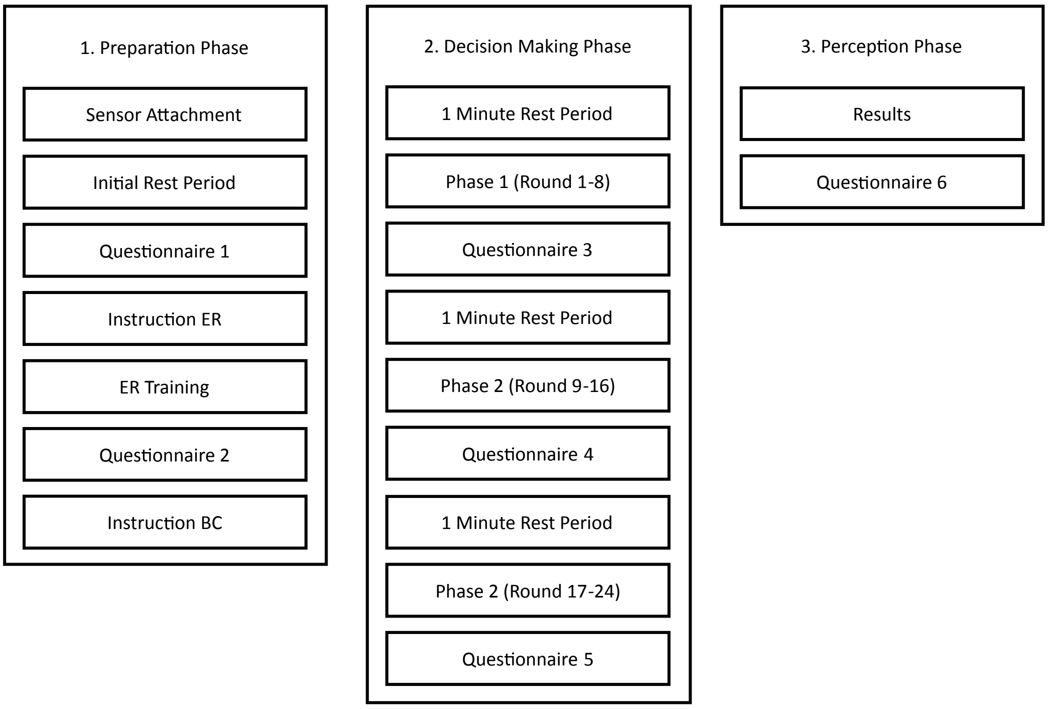

Figure 5.1.: Session structure for analyzing live biofeedback in the beauty contest game

all treatments was € 12.66 for an average session duration of one hour. Each session started with an initial 5-minute resting period (see Adam et al. 2012; Järvelä et al. 2016; Sütterlin et al. 2010). The stucture of a session from sensor attachment to the final questionnaire is depicted in Figure 5.1. The sessions were conducted with an average room temperature of 22°C (71.6°F), which is in line with the recommendation of the Society for Psychophysiological Research (Fowles et al., 1981). The ECG recordings of 9 participants failed completely. Moreover, as the duration of a single round was only 15 seconds (respectively 20 seconds in the first round of a phase) and the calculation of the average HR was prone to movement artifacts, we had to remove 2 further observations due to too much noise in the signal. We removed all observations with defect HR measurements from the data set. Thus, the data set contains 3622 ($151 \cdot 3 \cdot 8 - 2$) observations from 151 participants.

The experiment was fully computerized using the experimental platform Brownie by Hariharan et al. (2017). Instructions were based on the original instructions by Kocher and Sutter (2006) extended by instructions for the emotion regulation training and the LBF user interface element (see Appendix C.1). Prior to the experiment, we conducted an initial 5-minute resting period to measure the participants' baseline heart rate at rest. A print copy of the instruction was provided to all participants and a recording of the instructions was played out loud in the beginning of each experimental session. With a quiz prior to the experiment, we assured that all participants understood rules and the information displayed on the user interface.

Before playing the beauty contest game, participants in the LBF and ER treatments completed a 2-minute emotion regulation training. Participants in the LBF treatment were additionally provided with LBF. All participants knew that they would play three phases consisting of 8 rounds each (24 rounds in total) and that parameters p and C change between phases but remain constant within a phase. The user interface was aligned to the one employed by Kocher and Sutter (2006) and displayed parameters p and C, remaining time (20s in the first round of each phase, 15s in all subsequent rounds), phase, round, their last own estimate, last group average, last target number, and their payoff of the previous round. LBF was displayed in form of an arousal meter, which displayed the participant's current level of arousal based on the ratio of their current HR and average HR at rest. The arousal meter was designed following the design guidelines for LBF integration by Astor et al. (2013) and similar to the arousal meter used in Chapter 4. We chose ECG measurements in order to provide LBF with minimal disruption to the participant's primary task, used a graduation of five colors in order to provide intuitive and meaningful feedback (cp. Astor et al. 2013; Cederholm et al. 2011; Al Osman et al. 2013), implemented a mouse cursor in the same color as the arousal meter to ensure that the LBF is within the user's vision, and employed a training phase prior to the experiment, where the user could familiarize with the provided LBF. At the end of the experimental sessions all participants were paid privately in cash.

5.4. Live Biofeedback for Decision Support: Experimental Results

5.4.1. Effects on Decision Quality

First, we investigate participants' payoffs as an indicator for decision quality. Average payoff in euro [€] of phase 1-3 at the cohort level is depicted in Figure 5.2[2]. At the cohort level, we analyze average payoff per round in a mixed-effect linear regression with random intercepts for cohorts (Regression I in Table 5.4) as described by Laird and Ware (1983). We use a mixed-effects model as it allows us to control for the interdependencies of the 24 observations (i.e., 3 phases with 8 rounds) of each cohort *c*. We use two binary dummy variables for representing the two treatments (ER and LBF) as compared to the control treatment (CTL) and two binary dummy variables for the two phases (*p2* and *p3*) that follow the first phase (p1). Furthermore, we include rounds (*r*: 0-7) and the interaction between phases and rounds into the model. Hence, the model can be described as:

$$\pi_{c,r} = \beta_0 + \xi_c + \beta_{ER} \cdot ER + \beta_{LBF} \cdot LBF + \beta_{p2} \cdot p2 + \beta_{p3} \cdot p3 + \beta_{p2:} \cdot (p2 \times r) + \beta_{p3:r} \cdot (p3 \times r) + \epsilon_{c,r}$$

With respect to the hypothesis (H5.1), we find that LBF significantly increases payoffs relative to the control treatment (*b*=.109, SE=.055, *p*=.037, *one-tailed*[3]). Hence, LBF increases decision making quality in the beauty contest game under time pressure. This result remains stable, when we analyze the same relations considering the payoffs of each participant *i* (*b*=.092, SE=.047, *p*=.026, one-tailed, Regression II in Table 5.4[4]) applying a random intercept for participants. This second model can be described as:

$$\pi_{i,r} = \beta_0 + \xi_c + \beta_{ER} \cdot ER + \beta_{LBF} \cdot LBF + \beta_{p2} \cdot p2 + \beta_{p3} \cdot p3 + \beta_{p2:} \cdot (p2 \times r) + \beta_{p3:r} \cdot (p3 \times r) + \epsilon_{i,r}$$

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[2] The error bars indicate the 90% confidence interval.

[3] As we formulated a directional research hypothesis concerning decision quality (i.e., LBF increases decision quality under time pressure), we employ one-tailed tests for the analyses of decision quality. All other analysis are conducted with two-tailed testing.

[4] ECG recordings failed for 9 participants and two observations were removed due to too much noise on the signal, resulting in 3622 ($151 \cdot 3 \cdot 8 - 2$) observations from 151 participants.

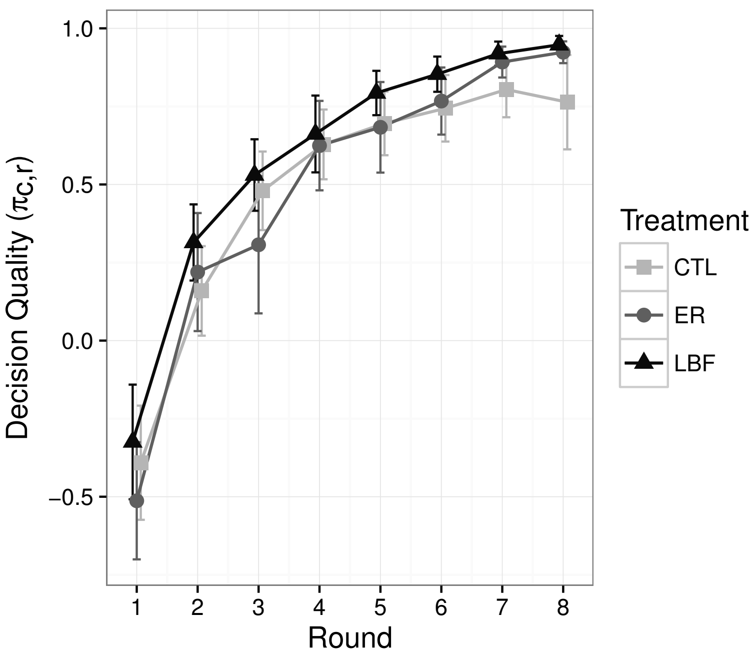

Figure 5.2.: Decision quality based on average payoff in euro

Importantly, however, emotion regulation instruction and training without LBF (ER treatment) has no observable effect on payoffs (*b*=.003, SE=.057, *p*=.483, *one-tailed*). In other words, emotion regulation training alone is not sufficient to increase decision making quality, while its supplementation by LBF results in significantly higher payoffs.

As expected, we find that even tough factors *p* and *C* change between the three phases, participant's decision quality in terms of payoffs increases over the phases, which eventually results in significantly higher payoffs in phase 3 compared to phase 1 (*b*=.644, SE=.054, *p*<.001, *two-tailed*). This observation is in line with the results of the original study by Kocher and Sutter (2006), who found that average payoff increased over phases in all three treatments. Furthermore, we observe that the participant's decision quality significantly increases over rounds within a phase (*b*=.178, SE=.009, *p*<.001, *two-tailed*). However, this improvement over rounds is particularly strong in the first two phases and significantly smaller in the third phase (*b*=-.066, SE=.013, *p*<.001, *two-tailed*).

Kocher and Sutter (2006) pointed out that "[a]ssuming that each subject is playing best response to the expected behavior of the others, one can infer from a subject's chosen number the expected average number chosen by the other group members" (p.382). Under this assumption, the difference between the ex-ante expected average and the ex-post actual average of the other players' numbers can be calculated as a measure for how well a subject

Table 5.4.: Effects of emotion regulation and live biofeedback on decision quality

	Dependent Variable			
Independent Variables	**(I) Decision Quality** ($\pi_{c,r}$)	**(II) Decision Quality** ($\pi_{i,r}$)	**(III) Decision Quality** ($\Delta x_{c,r}$)	**(IV) Decision Quality** ($\Delta x_{i,r}$)
Dummy: ER	.003	-.005	-.319	-.228
	(.057)	(.049)	(2.372)	(2.179)
Dummy: LBF	$.101^{+}$	$.092^{+}$	-4.439^{+}	-4.097^{*}
	(.055)	(.047)	(2.279)	(2.074)
Dummy: Phase 2	.067	$.118^{*}$	18.781^{***}	16.615^{***}
	(.054)	(.046)	(2.713)	(2.429)
Dummy: Phase 3	$.644^{***}$	$.663^{***}$	103.759^{***}	103.030^{***}
	(.054)	(.046)	(2.713)	(2.424)
Round (#0-7)	$.178^{***}$	$.181^{***}$	-4.603^{***}	-4.663^{***}
	(.009)	(.008)	(.459)	(.408)
Phase 2 x Round	.007	.000	-3.307^{***}	-3.052^{***}
	(.013)	(.011)	(.649)	(.574)
Phase 3 x Round	$-.066^{***}$	$-.069^{***}$	-2.281^{***}	-2.170^{***}
	(.013)	(.011)	(.649)	(.573)
Intercept	$-.305^{***}$	$-.319^{***}$	33.967^{***}	34.217^{***}
	(.053)	(.045)	(2.431)	(2.205)
AIC	888.782	7016.462	8405.287	34577.453
Num. obs.	960	3622	960	3531
Num. groups	40 cohorts	151 participants	40 cohorts	151 participants

$^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$, $^{+}p < .10$, two-tailed

Note: Due to the inclusion of interaction terms, the eight rounds within a phase are coded from 0 to 7.

was able to predict the estimates of the other players. As strategic thinking is an essential element of the beauty contest game and smaller differences indicate better abilities to predict the behavior of the other group members, the authors used this difference $\Delta x_{i,r}$ as an alternative indicator for decision making quality. Thus, we additionally analyze the difference $\Delta x_{i,r}$ ($\Delta x_{c,r}$ at the cohort level) to test the robustness of the findings.[5] Decision quality based on average absolute difference of actual and assumed estimates of other players of phase 1-3 at the cohort level is depicted in Figure 5.3[6]. In Regressions III and IV in Table 5.4[7], we applied the same models as in Regression I and II, but used the difference at

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[5] We do not use the distance to equilibrium (no significant difference between LBF and CTL treatment, b= -1.086, SE=1.115, p=.017, one-tailed) as an indicator for decision quality, as the participants were not incentivized to reduce the distance to the equilibrium, but to the target number.

[6] The error bars indicate the 90% confidence interval.

[7] The difference between ex-ante expected average and ex-post actual average of the other players' numbers can only be calculated, if an estimate has been submitted. In 91 cases, participants did not submit an estimate, resulting in 3531 (3622-91) observations.

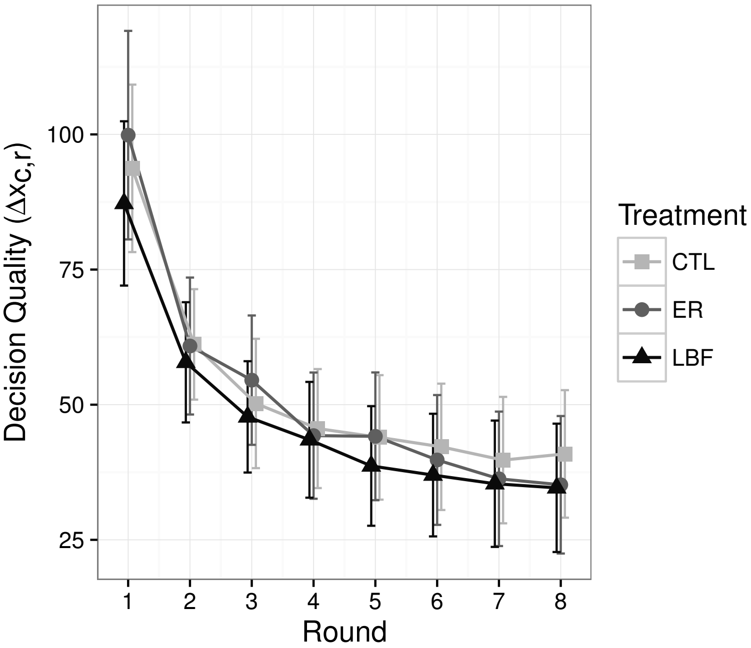

Figure 5.3.: Average difference of actual and assumed estimates of other players

the cohort level ($\Delta x_{c,r}$) and the participant level ($\Delta x_{i,r}$) as the dependent variables, respectively. Supporting the previous findings on decision quality, Regression III and IV show that LBF results in significantly lower differences between ex-ante expected average and the ex-post actual average of the other players' number at the cohort (*b*=-4.439, SE=2.279, p=.030, *one-tailed*) and participant level (*b*=-4.097, SE=2.074, *p*=.025, *one-tailed*) and thus, increases decision quality.

Result: Providing decision makers with live biofeedback increases decision quality under time pressure.

5.4.2. Effects on Emotional Processing

In the following analysis, we aim at gaining a deeper understanding of the affective and cognitive processes involved in improving decision quality with LBF. We are interested in changes of the participants' emotional intelligence, specifically, in their abilities to perceive and regulate their emotions. Therefore, we examine the arousal participants experience on a physiology and perception level. In particular, we consider the participant's perception of their emotional state, that is, their perceived arousal as indicated in the SAM scale, as well as their actual physiology, that is, physiological arousal, based on their HR. With respect to emotion regulation, we evaluate to which extent the participants engage in suppression, as this emotion regulation strategy is linked to a variety of negative consequences (Gross and Levenson, 1997; Heilman et al., 2010; Richards and Gross, 2000) and people with high emotional intelligence are less likely to engage in suppression (Butler et al., 2003).

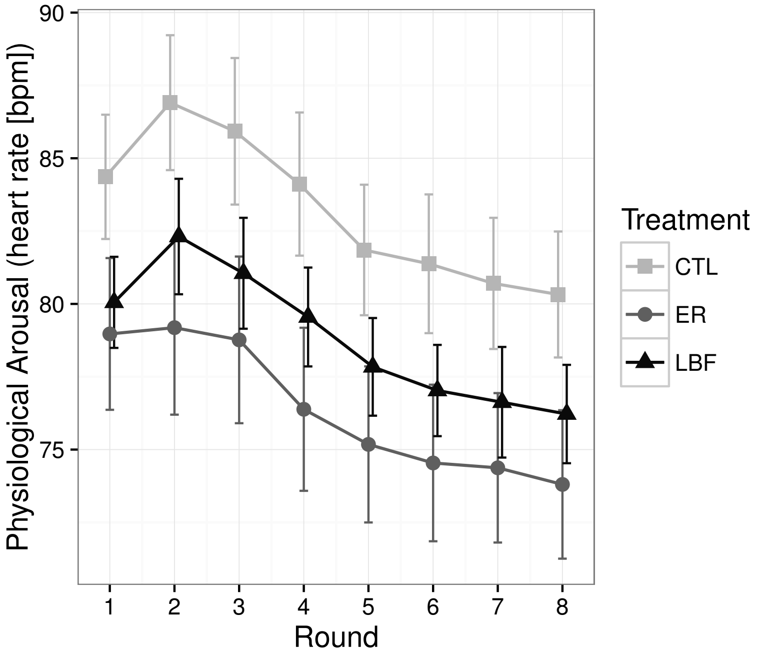

Figure 5.4.: Average physiological arousal in the beauty contest game

Subjects' average physiological arousal based on average heart rate in beats per minute [bpm] across rounds at the cohort level is depicted in Figure 5.4[8], indicating that expectedly physiological arousal is highest in the control treatment. To further investigate the impact of the treatment conditions on participants' physiological arousal, we employ mixed-effect linear regressions with random intercepts for cohorts (Regression V in Table 5.5) and participants (Regression VI in Table 5.5[9]), respectively. At both levels of observation, cohort and participant level, we find that in contrast to the CTL treatment, participants in the ER and LBF treatments exhibit lower physiological arousal. Participants in the ER treatment show the lowest levels of physiological arousal (b=-6.797, SE=2.469, p=.009, t*wo-tailed*), while physiological arousal of participants provided with LBF, which falls between the levels of physiological arousal observed in CTL and ER treatments, is marginally lower than the physiological arousal of the control group (b=-4. 361, SE=2.372, p=.074, *two-tailed*). Expectedly, and in line with previous studies on heart rate, physiological arousal mitigates

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[8] The error bars in Figure 5.4-5.4.2 indicate the 95% confidence interval

[9] ECG recordings failed for 9 participants and two observations were removed due to too much noise on the signal, resulting in 3622 $(151 * 3 * 8 - 2)$ observations from 151 participants.

Table 5.5.: Effects of emotion regulation and live biofeedback on physiological arousal

	Dependent Variable	
Independent Variables	**(V) Physiological Arousal** $(HR_{c,r})$	**(VI) Physiological Arousal** $(HR_{i,r})$
Dummy: ER	-6.797**	-6.268*
	(2.469)	(2.509)
Dummy: LBF	-4.361^{+}	-4.121^{+}
	(2.372)	(2.389)
Dummy: Phase 2	-1.342**	-1.556***
	(.426)	(.416)
Dummy: Phase 3	-2.285***	-2.496***
	(.426)	(.416)
Round (#0-7)	-.700***	-.729***
	(.072)	(.070)
Phase 2 x Round	-.200*	-.166^{+}
	(.102)	(.099)
Phase 3 x Round	-.297**	-.266**
	(.102)	(.099)
Intercept	87.435***	87.424***
	(1.701)	(1.704)
AIC	5000.609	23482.570
Num. obs.	960	3622
Num. groups	40 cohorts	151 participants

$^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$, $^{+}p < .10$, two-tailed
Note: Due to the inclusion of interaction terms, the eight rounds within a phase are coded from 0 to 7.

over the course of the experiment (Adam et al., 2015; Bradley et al., 1993) as can be seen in the negative coefficients for phases and rounds.

Turning to participants' perception, Figure 5.5 depicts the average level of perceived arousal. When analyzing perceived arousal using a linear regression (Regression VIII in Table 5.6), we observe that participants in the LBF treatment perceive significantly more arousal than in the CTL treatment at the participant level (*b*=.560, SE=.251, *p*=.027, *two-tailed*), while the perceived arousal of participants that are asked to regulate their emotions without LBF shows no significant difference to the control group (*b*=-.059, SE=.264, *p*=.823, *two-tailed*). At the cohort level (Regression VII in Table 5.6), the effect of LBF on perceived arousal is marginally significant (*b*=.502, SE=.254, *p*=.055, *two-tailed*). Perceived valence at the cohort level is depicted in Figure 5.6. We analyze the effects of the treatment conditions on perceived valence using a linear regression (Regression IX and X in Table 5.6). As expected, we do not find a significant difference in perceived valence between the LBF and the CTL treatment at the cohort (*b*=.135, SE=.260, *p*=.606, *two-tailed*) and participant

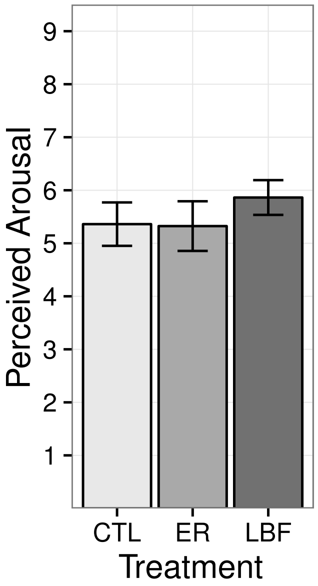


Figure 5.5.: Average perceived arousal in the beauty contest game

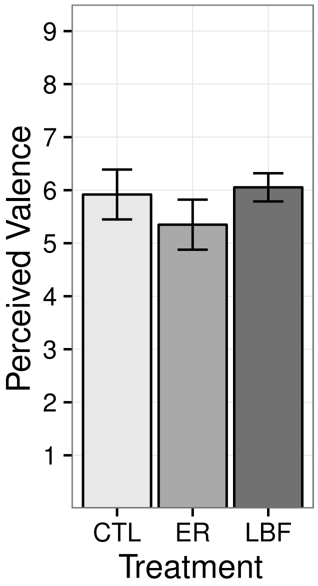


Figure 5.6.: Average perceived valence in the beauty contest game

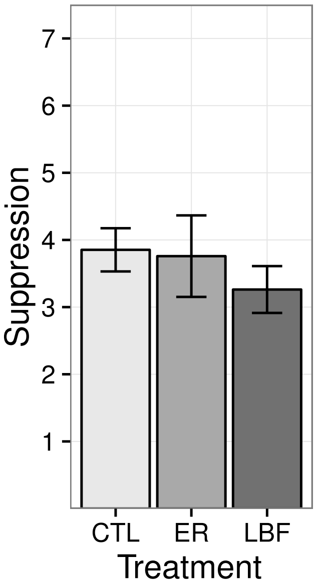


Figure 5.7.: Average suppression in the beauty contest game

(*b*=.143, SE=.231, *p*=.538, *two-tailed*) level. Interestingly, we observe that participants in the ER treatment report more negative levels of perceived valence than in the CTL treatment at the cohort (*b*=-.569, SE=.270, *p*=.042, *two-tailed*) and participant level (*b*=-.518, SE=.243, *p*=.035, *two-tailed*). The reported suppression scores are depicted in Figure 5.4.2. In a linear regression of the treatment conditions on suppression (Regression XII in Table 5.6), we find that participants in the LBF treatment engage significantly less in suppression of arousal (*b*=-.564, SE=.266, *p*=.035, *two-tailed*), while we observe no significant difference between the ER and the CTL treatment (*b*=.015, SE=.279, *p*=.956, two-tailed). The effect of LBF on suppression (Regression XI in Table 5.6) remains significant at the cohort level (*b*=-.591, SE=.270, *p*=.035, *two-tailed*).

Table 5.6.: Effects on perceived arousal, perceived valence, and suppression

	Dependent Variable					
Independent Variable	**(VII) Perceived Arousal**	**(VIII) Perceived Arousal**	**(IX) Perceived Valence**	**(X) Perceived Valence**	**(XI) Suppression**	**(XII) Suppression**
Dummy: ER	-.037	-.059	-.569*	-.518*	-.094	.015
	(.264)	(.264)	(.270)	(.243)	(.281)	(.279)
Dummy: LBF	.502^{+}	.560*	.135	.143	-.591*	-.564*
	(.254)	(.251)	(.260)	(.232)	(.270)	(.266)
Intercept	5.361***	5.340***	5.919***	5.920***	3.853***	3.843***
	(.180)	(.177)	(.184)	(.163)	(.191)	(.187)
R2	.128	.045	0.168	0.051	.129	.039
Adj. R2	.081	.033	0.123	0.038	.082	.026
Num. obs.	40 cohorts	151 participants	40 cohorts	151 participants	40 cohorts	151 participants

$^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$, $^{+}p < .10$, two-tailed

Taken as a whole, we can observe that participants who receive the instructions to regulate their emotions – with and without LBF – exhibit lower levels of physiological arousal in terms of heart rate than the participants in the control group. Arousal perception and the use of suppression for emotion regulation, however, are not altered by the instruction to regulate one's emotions alone, presumably due to limited interoceptive awareness. Only with LBF participants perceive higher levels of arousal and engage less in suppression of their emotional processes. Furthermore, those participants that received only the instruction to regulate their emotions (i.e., ER treatment) report significantly more negative levels of valence. This means that emotion regulation instruction alone results in more negative valence and is not sufficient to improve decision quality under time pressure. As people with higher emotional intelligence engage less in suppression (Butler et al., 2003), the results suggest that LBF supports participants' ability to regulate their emotions.

5.5. Concluding Note on Live Biofeedback for Decision Support

Economic decision making is often influenced by the principle *time is money*. While quick decision making can be financially beneficial as profits may depend on the decision maker's reaction time (Kocher and Sutter, 2006), time pressure is also known for inducing higher levels of arousal (Ku et al., 2005) that can lead to adverse consequences such as reduced information exchange (Carnevale and Lawler, 1986), increased aggression (Cates and Shontz, 1996), and reduced strategic thinking (Spiliopoulos et al., 2017). Thus, time pressure can result in decision making that is "out of control" (Loewenstein, 1996), e.g., due to restricted attentional capacity (Paulhus and Lim, 1994; Shapiro et al., 2002), simplified decision strategies (Mano, 1992), and reliance on heuristics (Rubinstein, 2007).

In order to retain control in an emotionally charged situation, it is important that decision makers have abilities to perceive, understand, and regulate their emotions. Over the last 20 years, LBF applications have emerged as a concept to support this set of abilities, also referred to as emotional intelligence (Joseph and Newman, 2010). Astor et al. (2013) evaluated a serious game with LBF and suggested that LBF can boost users' perceptions of their emotional state and thus, improve interoception and their skills for effective emotion regulation. Peira et al. (2014) concluded that physiological reactions can efficiently be regulated with the user of LBF and Al Osman et al. (2013, 2016) found that LBF supports office workers to control their stress levels. Even though LBF has been discussed in Psychology and IS literature, the effect of LBF on decision making has not been investigated from an economic perspective so far. In this vein, we investigate the support emotional intelligence through

LBF in order to increase decision making quality in an emotionally charged decision environment due to time pressure.

In this experimental study on the beauty contest, we find that LBF significantly improves decision quality under time pressure, while mere emotion regulation instruction alone has no effect on decision making. In the analysis of the cognitive and affective processes that underlie decision making, we find that even without LBF participants are able to reduce their physiological arousal when instructed to do so, but report more negative valence. With LBF participants reduce their physiological arousal. It falls between the levels of physiological arousal observed in CTL and ER treatments. Furthermore, LBF increases the level of perceived arousal, does not affect valence, and results in less engagement in suppression. These findings suggest that without LBF participants concentrate on the reduction of their physiological arousal, when they are instructed to regulate their emotions, while participants with LBF additionally alter their emotional processing on a cognitive level. These results are in line with existing literature that suggests the use of LBF to facilitate emotion perception (Hicks et al., 2014; Sas and Chopra, 2015; Snyder et al., 2015) and support emotion regulation (Bouchard et al., 2012; Jercic et al., 2012; Al Rihawi et al., 2014). Thus, we conclude that LBF can support participants' emotional intelligence, resulting in a reduced use of suppression as an emotion regulation strategy. This finding is strengthened by the observation that participants, who receive the mere instruction to regulate their emotions can reduce their physiological arousal. Their emotional processing, however, is not altered on a cognitive level, meaning that they do not perceive higher levels of arousal and do not engage less in suppression than the control group.

Overall, we conclude that the increased level of arousal perception and the mitigated level of suppression is the reason why participants are less affected by the negative consequences of suppression and make decisions of higher quality than participants who are not provided with LBF. These observations are in line with the theoretical conceptualization of LBF systems by Riedl and Léger (2016), who argue that since LBF improves awareness of physiological processes it may improve conscious control of arousal and thus, may have a significant influence on performance. Hence, the results suggest that LBF can be used to support essential abilities of emotional intelligence and increase decision making quality in emotionally charged decision environments, where these abilities are crucial for sound decision making.

Chapter 6.

Conclusions and Future Research

In line with the opening quote of this thesis by Keynes (1936), who claimed that – despite all attempts to act rational – we are "often falling back for our motive on whim or sentiment or chance" (pp. 162-163), recent literature recognized the limitations of traditional behavioral models and acknowledged the role of both, cognitive and emotional processes, in economic decision making (Sanfey et al., 2003; López, 2016; Van't Wout et al., 2006). In fact, theories from psychology that describe the interplay of internal processes and abilities, such as the body-mind loop (Green et al., 1970) or the concept of emotional intelligence (Mayer et al., 1999, 2008), have been introduced to economic and IS research (see Al Osman et al. 2013, 2016; Tomer 2003; Caldarola 2014). The main goal of this thesis is to provide a deeper understanding of when and how emotional states affect decision making and whether the support of emotional processing through LBF can increase decision making quality.

6.1. Summary of Results and General Discussion

The results of this thesis provide further evidence that emotions are an integral part of human decision making and that LBF can be used to support emotional processing and increase decision making quality. In this work, we investigated decision making in social interactions under high levels of arousal induced through, e.g., time pressure or competition, and found that arousal can alter one's behavior. On the premise that emotional intelligence has a positive effect on behavior in emotionally charged situations (Joseph and Newman, 2010), we investigated the effects of LBF on the abilities that are considered as emotional intelligence, namely the abilities to perceive, understand, and regulate emotions. Since beneficial emotion regulation requires an accurate perception of one's state including physiological processes (Dunn et al., 2012; Füstös et al., 2012), we aimed at using LBF to improve emotion perception, support emotion regulation and thus, increase decision making quality. Therefore, this thesis contributes to designing information systems that support decision making in emotionally charged situations due to contextual factors such as time pressure or social interaction and competition.

In four studies we investigated the effect of emotions on decision making and the use of LBF for emotion regulation and decision support in electronic markets. As LBF facilitates deeper insight into one's or another person's emotional state, LBF has been proposed for a variety of applications such as supporting stress management, enhancing user experience, and facilitating social interaction (see Chittaro and Sioni 2014; Nacke et al. 2011; Slovák et al. 2012). LBF applications acquire information about a person's physiological state by measuring biosignals that result from physiological processes like heart rate, skin conductance, or respiration. On this basis, LBF applications generate, e.g., visual, acoustic, or tactile feedback responses. Several studies evaluated LBF applications that combine multiple physiological measurements and feedback manifestations to provide even more detailed information about a person's current physiological state in real-time (Schnädelbach et al., 2010, 2012). Thus, LBF applications make information available that users may have limited access to otherwise. We found that over the past 20 years, a growing number of studies explore LBF applications for architecture, art, economic decision making, education, games, interpersonal communication, social media, sports, and well-being.

In Chapter 2 we conducted a systematic review of fragmented literature to establish the state-of-the-art of LBF research in non-clinical domains. Thereby, we reviewed studies on both, LBF applications that provide a feedback based on one's own physiological state (i.e. SLBF) and based on another person's physiological state (i.e., FLBF). In particular, we addressed the following research question:

RQ1: In the emerging and fragmented field of self live biofeedback and foreign live biofeedback, (i) what is the current knowledge, (ii) what are knowledge gaps in research on live biofeedback, and (iii) how could future research close the identified gaps?

To this end we systematically reviewed a body of fragmented literature on LBF and synthesized the results from studies that investigated feedback based on one's own (i.e., SLBF) or another person's (i.e., FLBF) peripheral nervous system activity. The reviewed studies were situated in non-clinical domains and included some level of qualitative or quantitative evaluation. We identified a total of 65 LBF studies from Computer Science, Engineering and Technology, IS, Medical Science, and Psychology. Most studies on LBF focus on SLBF (about 70%), but both, SLBF and FLBF systems, offer a promising avenue for IS research and practice. Furthermore, we provided an intuitive illustration and shared frame of reference of the transmission processes between feedback sender and feedback receiver by developing a transmission model for LBF based on the transmission model by Shannon and Weaver (1949). We identified the source of the processed information (e.g, ECG signal), the transmitter that extracts the relevant features (e.g., heart rate), the receiver that manifests the feedback response (e.g., a visual arousal meter as implemented in Chapter 3 and 4), and the destination (e.g., another user) as the four main elements of biofeedback applications. Furthermore, we found that SLBF and FLBF applications employ similar measurement modalities and feedback manifestations, but differ with respect to their theoretical underpinnings. SLBF applications primarily build on the psychophysiological principle of the body-mind loop (Green et al., 1970) and related theories of stress management and emotion regulation. FLBF applications, however, build on theories of social presence (Hess et al., 2009) and mentalizing (Decety et al., 2004; Frith and Frith, 2006). Based on the reviewed literature, we identified five directions for further research in order to close existing knowledge gaps, namely, research on (i) modalities and manifestation, (ii) construct validity, (iii) context dependence, (iv) the interplay of SLBF and FLBF, and (v) technology acceptance.

In Chapter 3 we investigated whether arousal affects purchasing behavior, and whether this effect is context-dependent. The aim of the study was to provide a better understanding of how arousal can influence decision making in order to identify economic decision scenarios in which LBF applications could be particularly useful. We found that existing literature cannot explain whether decision makers are more aroused due to their actions (e.g., higher bids) or if their actions are altered when they experience high levels of arousal. Therefore, we examined arousal in two purchasing contexts, one was an auction context where social interaction was a key characteristic and the second was a non-auction purchasing context without social interaction. We conducted a laboratory experiment to address the following research question:

RQ2: Does arousal that is induced outside the decision making context affect purchasing behavior (i) in an auction and (ii) in a non-auction context?

The results revealed that arousal affects decision making, but only when the participant is exposed to social interaction and competition. Specifically, we found that arousal only affected auction bidding, which implied that physiological arousal and social interactions in terms of competition are critical ingredients in auction fever. We observed that an auction-irrelevant game increased participants' heart rates, which led to significantly higher bidding and marginally higher final prices in real auctions, but did not affect purchasing behavior when people state their willingness-to-pay in a purchasing context without social interaction. Thus, we concluded that social interaction and competition which are characteristic to auctions are critical factors for arousal to affect purchasing behavior. These findings revealed the context dependence of arousal and broadened our conception of what auction fever involves. Ku et al. (2005) defined auction fever as "the emotionally charged and frantic behavior of auction participants that can result in overbidding" (p. 90). The conducted research showed that this arousal can even evolve from a source outside the decision making context. Furthermore, these findings are in line with recent literature, which provides evidence that the influence of arousal on behavior is particularly strong in interpersonal contexts, such as the ultimatum game (Sanfey et al., 2003; Van't Wout et al., 2006; Bosman et al., 2005), negotiations (Brown and Curhan, 2013), trading (Hariharan et al., 2015), and auctions (Adam et al., 2015; Teubner et al., 2015). Hence, in Chapters 4 and 5 we investigated market contexts that comprise social interaction. As we found evidence that in situations which involve social interaction arousal alters decision making behavior and is potentially detrimental, we suggest the use of LBF in order to support emotion regulation and subsequently decision making.

In Chapter 4 we investigated how LBF affects decision making in an emotionally charged auction scenario. We conducted a laboratory experiment to examine the effects between bodily and mental processes during decision making and tested two treatment conditions, one with and one without LBF. Based on the theoretical concept of the body-mind loop by Green et al. (1970), we derived a research model that describes how LBF can affect the interplay of cognitive and affective processing. Specifically, we raised the following research question:

RQ3: Does live biofeedback influence (i) physiological arousal, (ii) perceived arousal, and (iii) bidding prices in an electronic English auction?

We conducted a laboratory experiment and found that without LBF expressive suppression of emotions resulted in an increased perception of physiological arousal. Providing users with LBF, however, resulted in lower physiological costs of suppression. This implied that in order to reduce physiological arousal it is not necessary to alter the used emotion regulation strategy, for instance by applying cognitive reappraisal, but LBF can be offered instead. Furthermore, we observed that LBF increased interoceptive skills, as evidenced by a significant positive relationship between physiological and perceived arousal. This finding is in line with results on body awareness training, where higher body awareness is associated with higher interoception (Sze et al., 2010). Participants without LBF exhibited no significant relationship between physiological and perceived arousal, indicating low interoception. We concluded that when decision makers experience high levels of emotional arousal, LBF can establish a foundation for sound decision making and has similar positive effects as body awareness training. The experimental results showed that LBF moderates the relationship between arousal and auction bidding on the cognitive level, but not on the physiological level. This implies that LBF, which affects emotional processing at a cognitive level, can be used as a foundation for applying emotion regulation strategies in order to alter overall emotional processing.

In Chapter 5 we investigated the effects of LBF in the beauty contest game, a game that comprises social interaction and has been linked to professional trading activity (Keynes, 1936). Existing literature provided evidence that time pressure can have detrimental effects on decision making (Rieskamp and Hoffrage, 2008; Weenig and Maarleveld, 2002) – also in the beauty contest game (Kocher and Sutter, 2006) – and there is also reason to believe that this can be linked to emotional states and the regulation of these emotional states in emotionally charged situations where decisions get out of control (Maule et al., 2000). As economic decisions are frequently shaped by time pressure, which induce high levels of emotional arousal, we examined emotion regulation and LBF in a beauty contest game under time pressure to answer the following research question:

RQ4: Does live biofeedback improve decision making quality under time pressure?

We conducted three treatments, a control treatment, a treatment where participants received a 2-minute emotion regulation training, and a treatment where participants received the 2-minute emotion regulation training and were additionally provided with LBF. Based on the experimental results, we found that LBF in combination with the 2-minute training improved decision making under time pressure. We observed that decision making quality in terms of higher payoffs improved for those participants that were provided with LBF and the emotion regulation training. Those participants, who received merely the instruction to regulate their emotions, on the contrary, did not receive significantly higher payoffs than participants in the control group. To gain a deeper understanding of the effects LBF has on decision making under time pressure, we examined participants' arousal on a physiological and perceptive level. We found that the instruction to regulate one's emotions resulted in lower heart rates while making a decision, but only when participants were additionally provided with LBF, they actually perceived less arousal and engaged less in expressive suppression of emotional responses.

Altogether, the findings of this thesis emphasized the potential of LBF for decision making in electronic markets. LBF applications are endorsed by novel developments in psychology, economics, and IS research that provide new insights with respect to emotional and cognitive processing and the effects of these processes on (economic) behavior (cf. the somatic-marker hypothesis by Bechara and Damasio 2005). We found that as consumer-grade sensor technology became more accessible over the last few years, research on LBF has emerged in a wide variety of research domains. Furthermore, the results of this thesis showed that LBF applications bear high potential for decision support in an economic context, especially in market situations with social interaction where the decision maker is exposed to high levels of arousal, e.g., through competition or time pressure.

6.2. Outlook and Future Research

This thesis contributes to identifying situations in which decision making is influenced by high levels of arousal, as in such situations decision makers can potentially benefit from LBF applications. Specifically, we study social competition and time pressure in markets as contextual characteristics that elicit arousal. We use auctions and the beauty contest game to examine specific market situations. So far, it is known that whether a certain level of arousal is beneficial or detrimental for task performance depends on the respective characteristics of the task such as difficulty (i.e., Yerkes-Dodson law, Yerkes and Dodson 1908). This means that arousal due to time pressure or social competition might be detrimental for decision making quality in one task, while it might be beneficial in another task. The context dependence of emotional consequences as shown in Chapter 3 implies that for the successful use of emotion regulation strategies and LBF systems contextual characteristics must be considered. Future research, therefore, needs to identify further features that characterize economic situations and examine when they create arousal that is detrimental for performance in order to examine adequate arousal management.

Within the last 15 years more than 60 studies, mainly in the domains of computer science, IS, and psychology, developed and tested LBF applications for different purposes, for example to support social interaction or to increase user experience. Based on the LBF studies, which were reviewed in Chapter 2 and the results of the two experimental LBF studies in Chapter 4 and Chapter 5, we conclude that LBF can be used to facilitate accurate perception of emotions. Building on increased interoception through accurate perception LBF can alter cognitive and affective processing resulting in reduced arousal and less engagement in suppression – a response-focused emotion regulation strategy that is known to have detrimental effects. Thus, LBF could be integrated in a variety of applications, ranging from decision support systems for traders, over playful and serious games, to participation platforms, and peer-to-peer platforms. In order to promote the integration of LBF in such systems, we suggest five directions for future research on LBF applications with respect to feedback modalities and manifestations, construct validity, context dependence, SLBF and FLBF, and technology acceptance.

First, we did not find any two studies from two different research teams that investigated the same LBF application with the same feedback modalities and manifestation. Therefore, in order to classify, compare, and evaluate the elements of different LBF applications, we developed a transmission model for LBF based on the transmission model of communication by Shannon and Weaver (1949). As many other LBF studies (Astor et al., 2013; Masuko and Hoshino, 2006; Nenonen et al., 2007), we used heart rate based on ECG measurements as an input signal for the LBF applications in the two experimental LBF studies within this thesis (Chapter 4 and 5). However, in future research, we need to investigate whether a similar LBF application based on other biosignals such as EDA or brain activity, e.g., measured though functional near-infrared spectroscopy (fNIRS) or EEG, affects decision making processes in the same way. With respect to the feedback manifestation, we used an arousal meter in both LBF studies to display the arousal levels on participants' screens. Similar to the studies within this thesis, most LBF studies use visual LBF manifestations (cf. Al Mahmud et al. 2007; Al Osman et al. 2016; Järvelä et al. 2016). It remains unclear, how different types of feedback manifestations such as acoustic feedback or haptic feedback differ in their effects on cognitive and affective processing. Therefore, based on the findings of this thesis, we suggest a systematic evaluation of LBF modalities and manifestations.

Second, future research needs to examine the relations between physiological features, feedback manifestations, and target variables. We conducted two studies that investigated the effects of LBF on decision making. In both cases we used an LBF application that measures heart rate as an underlying physiological parameter. Based on a person's current heart rate and their individual heart rate at rest, we calculated an arousal level that indicated a person's stress level. Cardiac features such as heart rate are frequently used in LBF systems as they reflect both, the sympathetic and the parasympathetic nervous system, and therefore, are common indicators for emotional arousal and sympathovagal balance (Pumprla et al., 2002). Additionally, the wide use of heart rate for LBF applications might be explained by the notion that most users have an intuitive understanding of cardiac parameters such as heart rate, enabling them to interpret it as a source of information about one's own or another person's internal state and as a direct connection to another person (Slovák et al., 2012). It would be interesting to study how the effects of LBF applications change when other features of cardiac activity such as the standard deviation of NN-intervals (SDNN) or the ratio of high and low frequency components of the ECG-recording are used for arousal calculation. We suggest that future research should explore construct validity in LBF applications and examine the relations between measurements, manifestations, and users' interpretation of the provided information.

Third, we find that most studies on LBF (including the studies in Chapters 4 and 5) examine one specific LBF application in one specific context. In Chapter 4, for example, we examined a LBF application that displays arousal values in an arousal meter based on heart rate for emotion regulation in an auction context. In Chapter 5, we used a different LBF application (i.e., different arousal calculation and different manifestation) in a beauty contest game. Therefore, we find the results of LBF studies difficult to compare. As outlined in Chapter 2, we find that some results of LBF studies even contradict each other. We therefore propose that future research should cross-validate LBF systems in several situations to examine whether its effects alter depending on the context.

Fourth, like most LBF studies, the studies in Chapters 4 and 5 focus on SLBF, that is the provision of information on someone's *own* physiological state. However, especially in the field of Computer Science, more and more studies investigate FLBF, that is the provision of information of *other* person's physiological state. As sensor technology becomes less obtrusive and physiological measurements become possible – even without one's knowledge (e.g., heart rate measurements with standard camera devices based on rPPG, Rouast et al. 2016) – research on FLBF that examines, for instance, its effects on trust (Lux et al., 2015; Hawlitschek et al., 2015) or group behavior (Lux et al., 2015), becomes increasingly important. Thus, future research should investigate under which circumstances a specific combination of biosignals, measurement methods, and feedback manifestations for SLBF and FLBF applications has different effects on cognitive and emotional processing.

Finally, LBF applications raise several important questions with respect to technology acceptance. Hardly any study investigated whether the users would find LBF applications acceptable outside of laboratory conditions. Roseway et al. (2015) observed that some users felt uncomfortable sharing such private information as their physiological state with colleagues at work and thus preferred the private mode of the LBF application. Hence, even though LBF yields high potential for novel features of information systems, future research must evaluate under which conditions, users would be willing to allow the measurement of their biological data and accept recommendations, such as relaxation tasks, through LBF applications.

6.3. Concluding Note

In this thesis, we reported and discussed the results of four studies that examined the effect of emotion on decision making and investigated the use of LBF for emotion regulation and decision support. First, we synthesized existing research on SLBF and FLBF applications for healthy participants in computer science, engineering and technology, IS, medical science, and psychology, identified research gaps, and derived implications for practice. Furthermore, we developed a transmission model for LBF systems that classifies the main components of LBF applications and provides a shared frame of reference of the transmission processes between feedback sender and receiver. Second, we found that the effect of arousal on purchasing behavior is context-dependent. Arousal pushes up final prices in auctions but does not affect decision making in purchasing contexts that do not involve social interaction. Based on this finding, we decided to evaluate the use of LBF in contexts that involve high levels of emotional arousal and are characterized by social interaction. Third, we observed that LBF affects cognitive and affective processing in an emotionally charged auction setting. The analysis revealed that LBF reduced suppressive behavior of emotional expression and improved persons' interoceptive skills. Fourth, we examined the use of LBF in the beauty contest game which is linked to financial markets and where decision quality is reduced under time pressure. We found that LBF can be used to reduce physiological arousal. Furthermore, LBF increases arousal perception and decision making quality under high time pressure. In summary, this research will contribute to a theoretical understanding of how LBF affects emotional processing and decision making and to the practical application of LBF for decision support in electronic markets.

Appendix A.

Supplementary Material for Chapter 3

A.1. Participant Instructions for the Study in Chapter 3

In this appendix we report the participant instructions and questionnaires of the experiment conducted in Chapter 3. We only report the instructions of the RGP treatment with high arousal. The instructions for the other treatments were identical with the exception of instructions that are specific to the other treatment conditions, that is, purchasing context (auction/willingness-to-pay) and the arousal elicited in the pattern matching game(high/low). The instructions that were used in the experiments were originally in German. Print copies and audio recordings of the instructions were used to ensure that all subjects receive identical information and that all subjects know that all other subjects receive the same information.

A.1.1. Instruction 1 of 3

Welcome to the experiment and thank you for your participation. You participate in an experiment where your decision behavior in auctions will be examined. During the experiment, your pulse, skin conductance response and heart rate will be measured and processed in later analysis. All measured data will be processed anonymously. A connection between you and the acquired data is only possible with the personal identification code that only you have. All participants make their decisions isolated from the other participants at an computer terminal. Communication between the participants is not allowed. Please use the PC only for inserting your decisions and answering the questions that you will see on your screen. Please do not execute or cancel any programs and do not change any settings.

After this instruction you will participate in a 7-minute rest phase. The rest phase is necessary for the analysis and calibration of the physiological data. Please stay calm during the rest phase, relax, and avoid any unnecessary movements. After the rest phase you will receive the next part of the participant instruction.

Please use only your free hand for the interaction with the experimental system and try not to move the other hand, which is connected to the measurement devices. Please avoid any unnecessary movements as they can interfere with our measurements. Please stay seated after the experiment ended and wait until an experimenter removed the measurement electrodes from your skin. Please leave this participant instruction at your seat when you finished the experiment.

If you have any questions about the experimental procedure, please stay calm and seated. Give the experimenter a signal with your hand. Please wait until the experimenter is at your seat and ask your question as quietly as possible.

A.1.2. Instruction 2 of 3

In the following you will make two decisions.

1.) Description of the decisions

With each decision, you have the chance to hypothetically buy exactly one good. Therefore, you have to state the maximum price that you would be willing to pay in order to buy the good. In the following this price will be referred to as **"willingness-to-pay"**. Whether you actually buy the good, depends on a randomly generated selling price. Is the randomly generated selling price lower or equal to your willingness-to-pay, you will buy the good and pay the randomly generated selling price. Is the randomly generated selling price higher than your willingness-to-pay, you will not buy the good.

2.) Submit your willingness to pay

In the beginning of each round you will receive a picture of the good. Subsequently, you can insert your willingness-to-pay. Therefore, you will see a numeric keypad on your screen (see Figure A.1), where you can insert a number by using the mouse device. If you inserted your willingness-to-pay, confirm and submit your input by clicking on the button that says **"Submit willingness-to-pay"**. You can use a maximum of two decimal places before and after the decimal point. By clicking on the **"Delete"** button, you can delete your input.

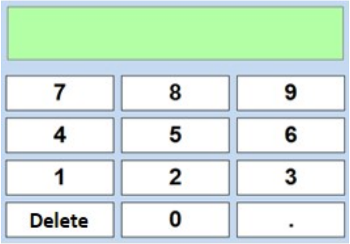


Figure A.1.: Numeric keypad

3.) Result

After you submitted your willingness-to-pay for the good, the experimental software will automatically generate a random selling price. Is the randomly generated selling price higher than your willingness-to-pay then you will not buy the good. Is the randomly generated selling price lower than your willingness-to-pay or equal then you will buy the good and receive the following hypothetical payoff:

Hypothetical payoff = real value of the good - randomly generated selling price

Example 1: You submitted a willingness-to-pay of € 67.00. The randomly generated selling price is € 65.00. Since your willingness-to-pay is higher than the randomly generated selling price, you will buy the good for € 65.00. The real value of the good is € 70.00. Therefore, you make a hypothetical profit of € 70.00-€ 65.00=€ 5.00.

Example 2: You submitted a willingness-to-pay of € 48.00. The randomly generated selling price is € 50.00. Since your willingness-to-pay is lower than the randomly generated selling price, you will not buy the good. Therefore, you have a hypothetical payoff of € 0.00.

Example 3: You submitted a willingness-to-pay of € 55.00. The randomly generated selling price is € 55.00. Since your willingness-to-pay is equal to the randomly generated selling price, you will buy the good for € 55.00. The real value of the good is € 50.00. Therefore, you make a hypothetical profit of € 50.00-€ 55.00=€ -5.00.

Please remember that all payoffs in this part of the experiment are hypothetical. This implies that you will not receive the hypothetical payoff from this part of the experiment for real. Therefore, the results from this part of the experiment have no effect on your payoff in this experiment.

A.1.3. Instruction 3 of 3

In this part of the experiment you can earn money. How much you earn depends on your decisions and the decisions of the other participants. This instruction tells you how you can earn money that you will receive in cash after the experiment. Therefore, red the instructions carefully.

1. Task

1.1. Task description

In the following 10 minutes we will ask you to solve a task that is depicted in Figure A.2. In the beginning of the task you receive 500 points that will be credited to your point account. It is your goal within this task, to find the wanted combination of five symbols that is depicted in the middle of your screen and therefore, to earn as many points as possible.

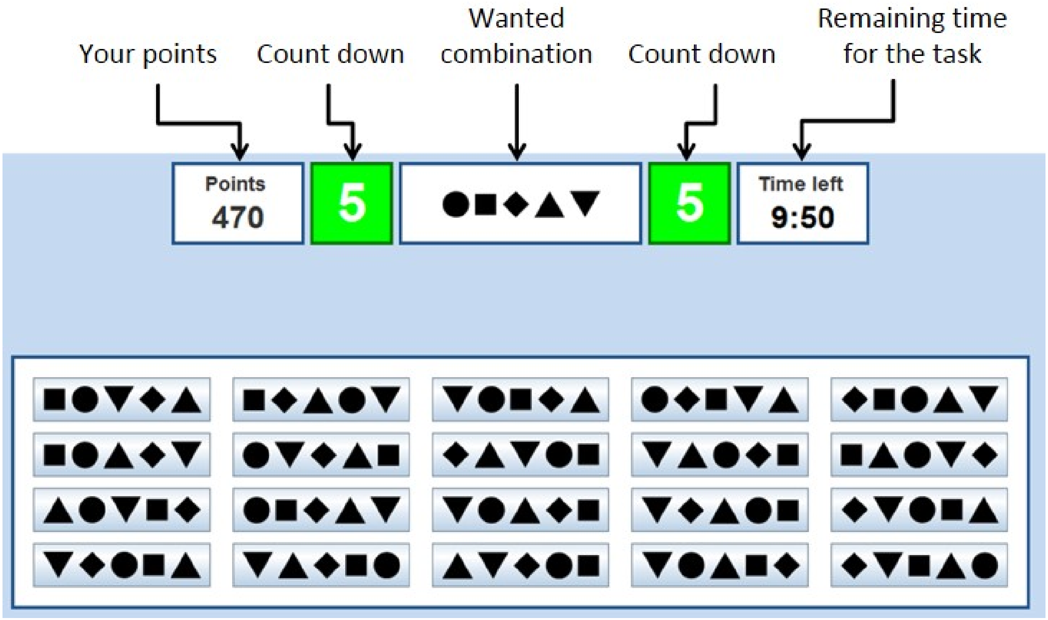


Figure A.2.: Matching task

In the lower part of the screen you will see a total of 20 combinations. Click on the correct combination. Now, there are the following possibilities:

- If you click on the right combination, that is, the wanted combination, you earn 20 points, which will be credited to your account.
- If you click on the wrong combination, that is, any other than the wanted combination, you lose 10 points, which will be subtracted from your account.

- If you click do not click on any combination within 7 seconds, you lose 30 points, which will be subtracted form your account. For this purpose a timer, which is displayed left and right from the wanted combination, counts down.

The task ends automatically after 10 minutes. You can see the remaining time on your screen.

1.2 Payoff from the task

In the following, the payoff scheme from this task is described. The other five participants in this experiment will solve this task at the same time. After you finished the task, you and the other participants will be ranked according to your points. You will receive a payoff according to your rank. The payoffs for the 6 possible ranks are depicted in Table A.1.

Table A.1.: Payoff scheme of the matching task

Rank	**Payoff**
1	€ 15.00
2	€ 12.00
3	€ 9.00
4	€ 6.00
5	€ 3.00
6	€ 0.00

Example 1: If you earned more points than all other participants, you are on rank 1 and receive a payoff of € 15.00. However, if all other participants earned more points than you, you are on rank 6 and receive a payoff of € 0.00.

If two or more participants earned the same number of points, the payoffs of the respective ranks will be divided equally.

Example 2: Two participants earned 620 points, while all other participants earned more points. In this case rank 5 and 6 cannot be assigned. The sum of the payoffs of these ranks is € 3.00 (€ 3.00+€ 0.00). Therefore, these two participants receive € 1.50 each.

2. Willingness-to-pay submission

Directly after you finished the task described above, you will be asked again to make **two decisions**. These decisions again comprise the submission of your willingness-to-pay. These two decisions are in two ways different to the two decision you made before:

1. The payoffs are **real**. This implies that you will **actually receive** the earned profits and losses.

2. The goods will be the **content** of a money jar. You will see the respective money jar in the beginning of each round.

After you submitted your willingness-to-pay for the content of the respective money jar, the experimental software will automatically generate a random selling price. If the randomly generated selling price is higher than your willingness-to-pay, you will not buy the content of the money jar and receive a payoff of € 0.00. If the randomly generated selling price is lower or equal to your willingness-to-pay, you will buy the content of the money jar and receive the following payoff:

Payoff = content of the money jar - randomly generated selling price

Please remember that the payoffs from this part of the experiment will be offset against your other payoffs from this experiment.

3. Overall payoff

At the end of the experiment the experimental software will automatically calculate your overall payoff. Additionally to your payoff from the task described in "1. Task" and "2. Willingness-to-pay submission", you will receive € 10.00 for your participation.

Your overall payoff will be calculated as follows:

1. Fixed payoff of € 10.00 for your participation.
2. Payoff from the task described in "1. Task" (minimum payoff: € 0.00, maximum payoff: € 15.00).
3. Profits and losses from the purchase of money jars described in "2. Willingness-to-pay submission".

If you have any questions regarding the experiment, please stay seated and give the experimenter a signal with your hand. Wait until the experimenter is at your seat and ask your question as quietly as possible.

A.2. Questionnaire for the Study in Chapter 3

Table A.2 summarizes all constructs that were assessed with the questionnaires in the study discussed in Chapter 3. Part 1 was assessed right at the beginning of the experiment. Part 2 was assessed after the arousal induction. Part 3 was assessed during the bidding/WTP task. Part 4 was assessed directly after the bidding/WTP task. Part 5 was assessed at the end of the experiment after the participants received information about their payoffs from the pattern matching task and the bidding/WTP task. The original questions were asked in German. For those questions that are based on existing constructs, the reference is provided in the source column.

Table A.2.: Summarized constructs of the study discussed in Chapter 3

Part	Construct	Item	Answer type	Source
1	Valence	SAM	9-point scale	Bradley and Lang (1994)
	Arousal	SAM		
2	Valence	SAM	9-point scale	Bradley and Lang (1994)
	Arousal	SAM		
3	Interest 1	How interested are you in the money jar? [Decision 1]	7-point scale	
		How appealing is the money jar? [Decision 1]		
	Value 1	What do you think is the value of the money jar? [Decision 1]	Euro	
	Price 1	What do you thing will be the selling price? [Decision 1]	Euro	
	Interest 2	How interested are you in the money jar? [Decision 2]	7-point scale	
		How appealing is the money jar? [Decision 2]		
	Value 2	What do you think is the value of the money jar? [Decision 2]	Euro	
	Price 2	What do you thing will be the selling price? [Decision 2]	Euro	

4	Valence	SAM	9-point scale	Bradley and Lang (1994)
	Arousal	SAM		
5	Satisfaction 1	How satisfied are you with the purchase? [Decision 1]	7-point scale	
		Do you feel good? [Decision 1]		
		How much do your regret your decision? [Decision 1]		
	Satisfaction 2	How satisfied are you with the purchase? [Decision 2]	7-point scale	
		Do you feel good? [Decision 2]		
		How much do your regret your decision? [Decision 2]		
	Demographics	How old are you?	Years	
		Are you male or female	m/f	
	Control	Do you study economics?	yes/no	
		Have you participated in an experiment with physiological measures before?		
		Have you participated in an experiment similar purchases before?		
	Competitiveness	I would want to get an A because that is the best grade a person can get.	5-point scale	Griffin-Pierson (1990)
		I perform better when I am competing against someone rather than when I am the only one striving for a goal.		
		I do not care to be the best that I can be.		

		When applying for an award I focus on my qualifications for the award and why I deserve it, not on how the other applicants compare to me.		
		I do not feel that winning is important in both work and games.		
		When I win an award or game it means that I am the best compared to everyone else that was playing. It is only fair that the best person win the game.		
		In school, I always liked to be the first one finished with a test.		
		I am not disappointed if I do not reach a goal that I have set for myself.		
		I have always wanted to be better than others.		
		Achieving excellence is not important to me.		
		When nominated for an award, I focus on how much better or worse the other candidates' qualifications are as compared to mine.		
		I would want an A because that means that I did better than other people.		
		I wish to excel in all that I do.		
		Because it is important that a winner is decided, I do not like to leave a game unfinished.		

		I would rather work in an area in which I can excel, even if there are other areas that would be easier or would pay more money.		
	Reappraisal	I control my emotions by changing the way I think about the situation I'm in.	7-point scale	Gross and John (2003)
		When I want to feel less negative emotion, I change the way I'm thinking about the situation.		
		When I want to feel more positive emotion, I change the way I'm thinking about the situation.		
		When I want to feel more positive emotion (such as joy or amusement), I change what I'm thinking about.		
		When I want to feel less negative emotion (such as sadness or anger), I change what I'm thinking about.		
		When I'm faced with a stressful situation, I make myself think about it in a way that helps me stay calm.		
	Suppression	I control my emotions by not expressing them.	7-point scale	Gross and John (2003)
		When I am feeling negative emotions, I make sure not to express them.		
		I keep my emotions to myself.		

		When I am feeling positive emotions, I am careful not to express them.		
	Risk aversion	Ten paired lottery-choice decisions	A or B	Holt and Laury (2002)

Appendix B.

Supplementary Material for Chapter 4

B.1. Participant Instructions for the Study in Chapter 4

In this appendix we report the participant instructions and questionnaires of the experiment conducted in Chapter 4. We only report the instructions of the LBF treatment. The instruction for the other treatment was identical with the exception of instruction that are specific to the LBF. The instructions that were used in the experiments were originally in German. Print copies and audio recordings of the instructions were used to ensure that all subjects receive identical information and know that all other subjects receive the same information.

B.1.1. Instruction 1 of 2

Welcome to the experiment and thank you for your participation. You participate in an experiment where your decision behavior in auctions will be examined. During the experiment, your pulse, skin conductance response and heart rate will be measured and processed in later analysis. Please switch off your phones and avoid any unnecessary body movements, since they can interfere with our measurements. Please place your hand with the measurement devices with its back on the table so that the electrodes do not touch the table. Please give the experimenter a signal, if you feel uncomfortable or the measurement devices cause you any problems during the experiment.

After this instruction you will participate in a 5-minute rest period. The rest period is necessary for normalizing the physiological measurements. Please stay calm during the rest period and relax. After the rest period you will be asked to answer the first of three questionnaires at your PC. Subsequently you will receive the second part of the instruction, which will be read out loud. Please push the button saying "I understood the rules of this experiment" only if you understood the rules and are instructed to do so by the experimenter.

B.1.2. Instruction 2 of 2

The main part of this experiment consists out of 4 subsequent auctions. In this experiment you can earn money. How much you earn depends your decisions and the decisions of the other players in this experiment. Communication with other players is not allowed.

This instruction explains how you can earn money that you will receive in cash after the experiment. Therefore, read the following passages carefully. If you have any questions, give the experimenter a signal with your free hand after you read the entire instructions.

1. Auction procedure

In each of the 4 auctions you and two further participants can bid on the coins in a jar, further referred to as **money jar**. The coins within the money jar are **identical for all bidders in an auction**, but its exact value is unknown during the auction. Prior to the auctions you will receive a bag with the money jar you can bid on. Please open the bag and take out the money jar, when you are instructed to do so by the experimenter. You can touch the money jar in order to observe it. **Please do not open the money jar.** Each auction has a starting price of **€ 0.00**. During the auction, all bidders can place bids. Every new bid must be at least € 0.01 higher than the highest bid at that time (or the starting price of € 0.00).

During the auction you see a **timer** on your screen. At the beginning of each auction the timer starts at 20 seconds. An auction ends, when the timer reaches 0 seconds. If you or another player places a bid when the remaining time on the timer is less than 8 seconds, the timer will be set back to 8 seconds. This means that after each bid the auction runs for at least 8 further seconds. The bidder, who holds the highest bid at the end of an auction, wins the auction and gets the coins within the money jar for the price of this bid. If you win the auction, your earnings are calculated according to the following formula:

payoff = value of the coins within the money jar - price of your bid

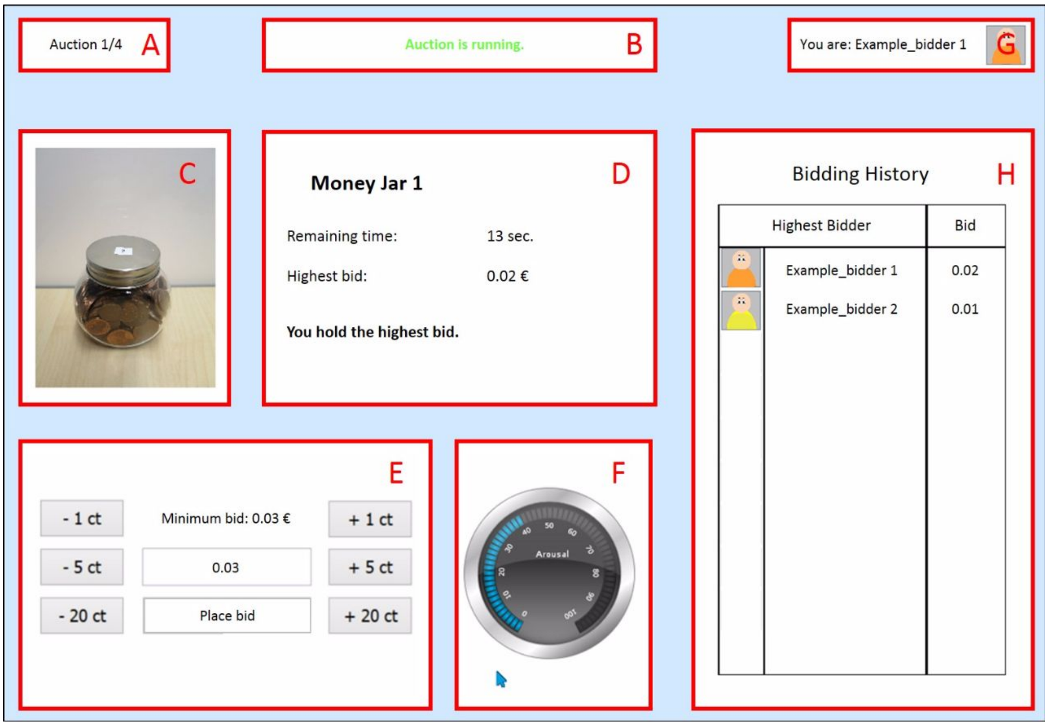
This means that the winner of the auction gets the value of the coins within the money jar minus the price of their bid. The payoff of the two other players that lose the auction is € 0.00. The following example demonstrates this payoff scheme.

Example: You win the auction with a highest bid of €10. The value of the coins within the money jar is €20. Your payoff from this auction is €20 - €10, which is €10. The other two players lose the auction. Therefore, their payoff is €0.00.

You will see your payoff from all 4 auctions and your overall payoff from this experiment at the end of the experiment.

2. Auction interface

Figure B.1 contains an example of the auction interface. In the following you will learn more about the different areas of the auction interface.



Auction 1/4

Auction is running.

You are: Example_bidder 1

Money Jar 1

Remaining time: 13 sec.

Highest bid: 0.02 €

You hold the highest bid.

Minimum bid: 0.03 €

0.03

Bidding History

Highest Bidder	Bid
Example_bidder 1	0.02
Example_bidder 2	0.01

Figure B.1.: Auction interface

A) Auction number: In area A) you can see in which of the four auctions you are right now. During the practice auction "Practice Auction" will be displayed in this area.

B) Auction status: In area B) you can see whether the auction will start in a few seconds or if the auction has already started. Prior to the auction this the auction status says "Please wait until the auction starts". During an auction the auction status says "Auction is running".

C) Display of the good: In area C) you can see a picture of the good that is auctioned off. In the 4 auctions that are relevant for your payoff, you will see a picture of the respective money jar that is auctioned off.

D) Information about the auction: In area D) you can see the name of the good that is auctioned off, the remaining time of the auction (if no new bid is placed), the currently highest bid, and information on whether you are the bidder with the highest bid or not.

E) Input window: In area E) you find information on the minimum bid. The minimum bid is €0.01 above the highest bid (or the starting price of €0.00). Below this information you find the input window where the minimum bid is inserted by default. With the button "Place Bid" you place a bid according to the value in the input window. With the buttons to the right (left) of the input window, you can increase (decrease) the value of the bid in the input window by €0.01, €0.05, and €0.20. Changing the value of the bid does not automatically place the bid. Only by pushing the button "Place Bid" you can place a bid. Please use the mouse device and the respective buttons on the screen for selecting and placing your bid. Keyboard entries are not possible.

F) Biofeedback: Area F) contains an arousal meter, which visualizes your level of physiological arousal based on your heart rate at rest and your current heart rate (arousal meter biofeedback). Additionally to the arousal meter, the cursor of your mouse will change its color according to your level of physiological arousal (cursor biofeedback). Both, arousal meter biofeedback and cursor biofeedback, visualize low levels with blue color and high levels with red color.

G) Personal information: In area G) you find your bidder name and your avatar, which you will select at the beginning of the experiment. Every bid of you will also be shown to the other two bidders of the auction in connection with your personal bidder name and avatar.

H) Bidding history: Area H) lists the last ten bids and the personal information of those bidders, who placed the bids. The bids are arranged in chronological order. The highest bid together with the personal information of the bidder who placed this bid stands at the top of the list.

3. Auction Procedure

After this instruction, you will be asked to select your personal **bidder name** and **avatar**. Your personal bidder name and avatar will remain the same throughout the entire experiment. The bids you place will be shown to the other bidders in connection with your bidder name and avatar.

After this instruction, you will participate in a **practice round** to ensure that you understood the rules. The gains and losses of this practice round are **not** relevant for your payoff from this experiment. In this practice round you bid against two computerized bidders. You will not encounter other participants of this experiment in the practice round. The purpose of this practice round is to get to know the auction procedure and auction interface.

The **main part** of this experiment consists out of 4 auctions. In each auction you will bid against two other participants of this experiment. Thereby you will meet any other participant **not more than in one auction**. Prior to each auction, you receive a new money jar covered in a paper bag. Then you will participate in a **1-minute rest period**. After this rest period you will be asked to open the paper bag and to take out the money jar. You have **1 minute to inspect** the money jar before the auction starts. Please do not open the money jar.

4. Payoff

For your participation in this experiment you receive an initial endowment of € 6.00, which will be credited to your experimental account. Gains and losses that you make in the 4 auctions will be **multiplied with 5** and are offset against your experimental account. In the unlikely case of a negative balance, you will receive an experimental payoff of € 0.00. You will receive your overall payoff after the experiment in CASH.

5. ... and a few additional remarks

Please use your free hand for any interaction with the experimental system and the keyboard entries during the questionnaire. Please do not move the hand that is connected with the sensors throughout the experiment. Avoid any unnecessary movements, as they interfere with our measurements. Please stay seated at the end of the experiment and wait until the experimenter removed the measurement electrodes from your skin.

If you have any questions, please stay calm and seated and give the experimenter a signal with your hand. Wait until the experimenter is at your seat and ask your question as quietly as possible. If you do not have any further questions, please click on the button that says "I understood the rules".

B.2. Questionnaire for the Study in Chapter 4

Table B.1 summarizes all constructs that were assessed with the questionnaires in the study discussed in Chapter 4. Part 1 was assessed right after the initial rest period. Part 2 was assessed after the auctions before the participants received information about their performance. Part 3 was assessed at the end of the experiment after the participants received information about their payoffs. The original questions were asked in German. For those questions that are based on existing constructs, the reference is provided in the source column. Constructs that are labeled with * were only assessed in the LBF treatment.

Table B.1.: Summarized constructs of the study discussed in Chapter 4

Part	**Construct**	**Item**	**Answer type**	**Source**
1	Arousal (Rest Period)	I was excited during the rest period.	7-Point Scale	
		I was tstressed during the rest period.		
		I felt arousal during the rest period.		
		I felt tense during the rest period		
	Valence	SAM	9-Point Scale	Bradley and Lang (1994)
	Arousal	SAM		
2	Arousal (Decision Phase)	I was excited during the auction.	7-Point Scale	
		I was tstressed during the auction.		
		I felt arousal during the auction.		
		I felt tense during the auction.		
	Valence	SAM	9-Point Scale	Bradley and Lang (1994)
	Arousal	SAM		

	Reappraisal	I control my emotions by changing the way I think about the situation I'm in.	7-point scale	Gross and John (2003)
		When I want to feel less negative emotion, I change the way I'm thinking about the situation.		
		When I want to feel more positive emotion, I change the way I'm thinking about the situation.		
		When I want to feel more positive emotion (such as joy or amusement), I change what I'm thinking about.		
		When I want to feel less negative emotion (such as sadness or anger), I change what I'm thinking about.		
		When I'm faced with a stressful situation, I make myself think about it in a way that helps me stay calm.		
	Suppression	I control my emotions by not expressing them.	7-point scale	Gross and John (2003)
		When I am feeling negative emotions, I make sure not to express them.		
		I keep my emotions to myself.		
		When I am feeling positive emotions, I am careful not to express them.		
	Perceived Physiology	I had the impression that my heart was beating faster during the auctions than during the rest period.	7-Point Scale	

		I had the feeling that my heart beat increased during the auctions compared to the rest period.		
	Control	I oerceived the other participants as opponents.	7-Point Scale	
		I felt time pressure during the auctions.		
		I had the impression that my behavior was observed by the other players.		
		I think that my emotions altered my bidding behavior.		
	Perceived Biofeedback*	I perceived the biofeedback on the user interface while I was bidding.	7-Point Scale	
		I noticed the colored mouse cursor during the auctions.		
		I perceived the arousal meter on my screen during the auctions		
	Intrusion of Biofeedback*	I felt disrupted by the biofeedback.	7-Point Scale	Adapted from Riedl et al. (2014)
		The biofeedback disturbed me while I was bidding		
		My attention to the auctions was reduced through the biofeedback.		
	Perceived Biofeedback for Emotion Regulation*	The biofeedback increased my abilities to regulate my emotions.	7-Point Scale	Adapted from Davis (1989)
		The biofeedback helped me to regulate my emotions.		

		I find the biofeedback useful for regulating emotions.		
	Perceived Usefulness of Biofeedback for Performance*	The biofeedback improved my decisions.	7-Point Scale	Adapted from Davis (1989)
		The biofeedback helped me to make better decisions.		
		I think that biofeedback is useful for bidding.		
		The biofeedback improved my bidding performance.		
	Desire to Win	I really wanted to win the auctions.	7-Point Scale	Adapted from Adam et al. (2015)
		It was important to me, to win against the other bidders.		
		It was important to me, to win the auctions.		
	Fear of losing	It was important to me, not to lose the auctions.	7-Point Scale	Adapted from Adam et al. (2015)
		I did not want to lose the auctions.		
		It was important to me, not to lose against the other bidders.		
	Perceived Social Presence	I had the impression that I was interacting with other humans.	7-point scale	Adapted from Gefen and Straub (2004)
		I had the impression that the other participants and I had a personal connection.		
		I had the impression of conviviality.		

		I had the impression of interpersonal closeness.		
		I had the impression that are also human.		
	Use of Biofeedback*	I used the biofeedback to regulate my emotions.	7-Point Scale	
		I used the colored mouse cursor to regulate my arousal.		
		I used the arousal meter to control my arousal.		
	Estimated Money Jar Value	What do you think is the average value of the money jars?	Number	
3	Perceived Usefulness of Biofeedback for Performance*	The biofeedback improved my decisions.	7-Point Scale	Adapted from Davis (1989)
		The biofeedback helped me to make better decisions.		
		I think that biofeedback is useful for bidding.		
		The biofeedback improved my bidding performance.		
	Intrusiveness	The sensors restricted my freedom of movement.	7-Point Scale	Adapted from Riedl et al. (2014)
		I was able to use the computer as always.		
		The sensors did not impede the usage of the computer		
	Demographics	What is your gender?	male/ female	
		How old are you?	Number	
		Did you consume a drink containing caffeine within one hour before the experiment?	yes/no	

		Did you smoke within one hour before the experiment?	yes/no	
		Are you left or right handed?	left/right	
	Risk aversion	Ten paired lottery-choice decisions	A or B	Holt and Laury (2002)

B.3. Pseudocode for Perfect Stranger Matching Algorithm

Algorithm 1 This algorithm generates a complete sequence under the perfect stranger criterion. Input parameters are the number of participants *p* and the group size *g*. Each of the *p* participants has a listing of participants, which they did not meet in previous group allocations, that is updated after each successful group allocation. Executing the function *AllocationSequence* returns a complete PSM sequence.

```
//possiblePartners[i,] symbolizes participants which are unknown to i
possiblePartners ← $p \times p$ matrix of ones with zeros on its diagonal

function ALLOCATIONSEQUENCE (p, g)
    sequence ← list of group allocations
    participantList ← list of p participants

    //Searching for a complete sequence
    while True do
        //Find new group allocation
        groupList ← empty list of groups
        groupList ← FINDALLOCATION (participantList, groupList,p, g)

        //allocate groups, if a match has been found
        if groupList != Null then
            add groupList to sequence
            $\forall r, c \in [1, p]$: $possiblePartners[r, c] = 0$ if c and r are grouped
            //optionally, shuffling of all lists can be inserted here
        else
            Break
        end if
    end while

    return sequence
end function
```

```
function FindAllocation (unusedElem, groupList, p, g)
    if number of groups in groupList == (p/g) then
        return groupList
    end if
    memory ← empty group
    pivotElement ← first element of unusedElem
    posMatches ← unusedElem ∩ (participants at possiblePartners[pivotElement,])
    if size of posMatches >= (g-1) then
        return Null
    end if

    //iterate over possible groups to add to groupList
    while True do
        //find group for given pivotElement
        curGroup ← new group with only pivotElement included
        curGroup ← FindGroup (posMatches, curGroup,g,memory)

        //stop if no group building was possible, else next recursion
        if curGroup == Null then
            return Null
        else
            add curGroup to groupList
            newUnusedElem ← unusedElem \ curGroup
            newGroupList ← FindAllocation (newUnusedElem, groupList, p, g)
        end if

        //Store latest group in memory when group allocation failed
        if newGroupList == Null then
            memory ← curGroup
            remove curGroup from groupList
        else
            return newGroupList
        end if
    end while

    return Null
end function
```

```
function FINDGROUP (availElem, group, g, memory)
    size ← number of elements in group

    //end condition
    if memory is not empty then
        recursively build the group from memory
        clear memory and skip the rebuilt group in recursion
    end if

    if $g == size$ then
        return group
    end if

    if number of elements in availElem $<$ (g-size) then
        return Null
    end if

    //fetch new partner for group
    while number of elements in availElem $> 0$ do
        newPartner ← first element of availElem
        add newPartner to group
        posPartners ← participants at $possiblePartners[newPartner,]$
        newAvailElem ← availElem ∩ posPartners
        newGroup ← FINDGROUP (newAvailElem,group,g,memory)

        if newGroup == Null then
            remove newPartner from availElem
            remove newPartner from group
        else
            return newGroup
        end if
    end while

    return Null
end function
```

Appendix C.

Supplementary Material for Chapter 5

C.1. Participant Instructions for the Study in Chapter 5

In this appendix we report the participant instructions and questionnaires of the experiment conducted in Chapter 5. We only report the instructions of the LBF treatment. The instructions for the two other treatments are identical with the exception of instructions that are specific to the treatments, that is, the emotion regulation training and the LBF instructions. The instructions that were used in the experiments were originally in German. In order to keep the study comparable with the study by Kocher and Sutter (2006) large parts of the he participant instruction are identical with the instruction of the '15s' treatment of this study. The authors provided us with the their instructions that were originally in German. Print copies and audio recordings of the instructions were used to insure that all subjects receive identical information and to assure that all subjects know that all other subjects receive the same information.

C.1.1. Instruction 1 of 3

Welcome to the experiment and thank you for your participation. You participate in an experiment, where your decision behavior is examined. Throughout the experiment your physiological data will be recorded and processed in later analysis.

Please switch off your phones and avoid unnecessary body movements, since they can interfere with our measurements. Please place your hand with the measurement devices with its back on the table so that the electrodes do not touch the table. Please give the experimenter a signal, if you feel uncomfortable or the measurement devices cause any problems during the experiment.

After this instruction you will participate in a 5-minute rest period. The rest period is necessary for normalizing the physiological measurements. Please stay calm during the rest period and relax. After the rest period you will be asked to answer the first out of 6 questionnaires at your PC terminal. Then you receive a print copy of the participant instruction for the training phase. The instruction will be read out loud. After the training period you will be asked to answer the second questionnaire. Subsequently the actual experiment begins.

C.1.2. Instruction 2 of 3

After this instruction you will participate in a training phase. During this phase you have time to familiarize with the arousal meter and the colored mouse cursor. The arousal meter and the colored mouse cursor indicate your level of emotional arousal. If you regulate your emotions and stay calm, the meter shows low values and the displayed bar is colored in green. If you are aroused or stressed, the arousal meter will show higher values. As your level of arousal increases, the color of the arousal meter will change from green over yellow and orange to red. The mouse cursor changes its color according to the arousal meter. The training phase is divided in two parts that last one minute each.

Your task in the first part: please let your emotions happen and try to amplify them. Concentrate on the music and increase your level of emotional arousal. Your aim in the first part of this training phase is to increase your heart rate and thus, to let the arousal meter rise into the red area.

Your task in the second part: please regulate your emotions and try to stay calm. Relax and breathe deeply. Your aim in the second part of this training phase is to decrease your heart rate and thus, to let the arousal meter fall into the green area.

C.1.3. Instruction 3 of 3

In this experiment you can earn money. How much you earn depends your decisions and the decisions of the other players in this experiment. Communication with other players is not allowed. If you have any questions, give the experimenter a signal with your hand after you read the entire instructions.

Three phases with eight rounds each

This part of the experiment consists of three phases with eight rounds in each phase. Therefore, we have 24 rounds in total. Prior to each phase there will be a 1-minute rest period. Within a phase, your task remains unchanged. Between phases you will be asked to answer a short questionnaire and two parameters that will be explained in the following will change.

Your decision

You are member of a group of four people, and you remain anonymous within your group throughout and after the experiment. At the beginning of each round, each group member has to choose a number x_i from the interval 0 to 100. Zero and 100 can also be chosen. Your number does not have to be an integer number, but it cannot have more than two digits after the comma. Your payoff in the experiment is dependent on the distance between your number and the target number in each round. The closer your number is to the target number, the higher is your payoff.

Calculation of target number

In order to arrive at the target number, the average of the four numbers x_i within your group will be calculated. Then, a constant C is added to the average. The sum of the average and the constant is, then, multiplied by a factor p. The resulting number is the target number. The target number can be expressed mathematically:

Target number $= p \cdot (\frac{\sum_{i=1}^{4} x_i}{4} + C)$.

Changes between phases

At the beginning of each phase, you will be informed on the values of the parameters p and C (see screen for round 1 in Figure C.1). These values remain constant over all eight rounds of a phase! After each phase, the parameters p and C change.

Payoff

Your payoff in each round is dependent on the absolute distance between the number you chose and the target number in your group. If you hit the target number exactly, you earn €1.00. Each absolute unit of distance results in a deduction of €0.08. If the distance from the target number is about 14 or more, you make a loss in this round. The loss can, of course, be balanced with earnings in other rounds. Formally, your payoff is

Payoff per round (in €) $= 1.00 - 0.08 \cdot |x_i - p \cdot (\frac{\sum_{i=1}^{4} x_i}{4} + C)|$

Time limits

First round: in the first round of each phase you have 20 s to decide.

Second-eighth round: for the decisions in these rounds you have 15 s each to decide.

If you exceed the time limit of a single round, you are not able to enter a number. In this round, you will earn nothing (€ 0). The average within your group will then be calculated from the remaining decisions within the group. Of course, you can then participate in the next round without any restrictions.

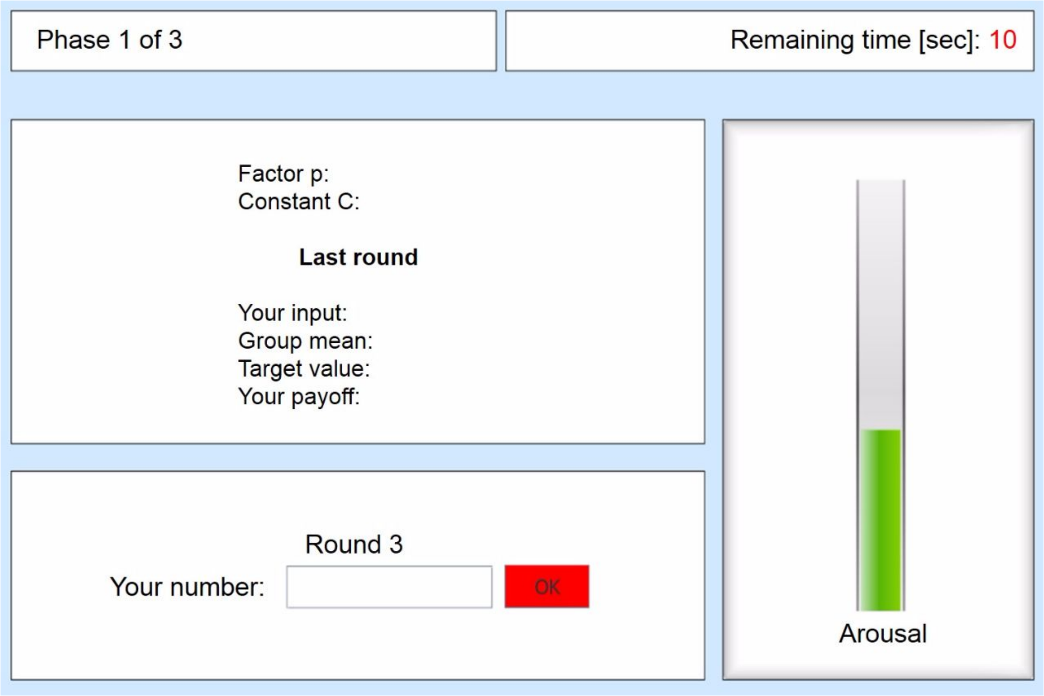
Summary

You have to choose a number which is as near as possible to the target number. The closer you are to the target number, the higher is your payoff. We ask you not to talk and to remain concentrated during the experiment.

Means of help

At your place, you find paper, a pen, and a calculator. Please do not take them with you after the experiment.

Computer screens



Phase 1 of 3

Remaining time [sec]: 10

Factor p:
Constant C:

Last round

Your input:
Group mean:
Target value:
Your payoff:

Round 3

Your number:

Figure C.1.: User interface for enter your decision

In the first round of each phase, you get the necessary information on p and C on the screen. Then you have to enter your decision. The cursor is already in the field, in which you have to type in your number. Then, you have to confirm your decision with a mouse click on the OK-field. On the upper right-hand part of the screen you can see the remaining time (counting down to zero).

From the second round on you see the values for p and C in the upper part of your screen in order to remind you of the valid parameters. Below you find the results for the previous round: your chosen number, the average of all numbers in your group, the target number and your payoff from the previous round. Directly below that you have to type in your decision for the current round. Do not forget to confirm with OK.

Additionally, you will see the arousal meter and a mouse cursor in the same color on your screen that you used in the training phase to regulate your emotions. The arousal meter shows your level of emotional arousal. If you regulate your emotions and stay calm, the arousal meter is green and shows low values. If you are aroused or stressed, the arousal meter will display higher values. As your level of arousal increases, the color of the arousal meter will change from green over yellow and orange to red. The mouse cursor changes its color according to the arousal meter.

C.2. Questionnaire for the Study in Chapter 5

Table C.1 summarizes all constructs that were assessed with the questionnaires in the study discussed in Chapter 5. Part 1 was assessed right after the initial rest period. Part 2 was assessed only in the ER and LBF treatments right after the emotion regulation training. Part 3 was asseses after the first, part 4 after the second, and part 5 after the third phase of the beauty contest game. Part 6 was assessed after the participants received information about their payoff from the experiment. The original questions were asked in German. For those questions that are based on existing constructs, the reference is provided in the source column. Constructs that are labeled with * were only assessed in the LBF treatment.

Table C.1.: Summarized constructs of the study discussed in Chapter 5

Part	**Construct**	**Item**	**Answer type**	**Source**
1	Valence	SAM	9-Point Scale	Bradley and Lang (1994)
	Arousal	SAM		
2	Valence	SAM	9-Point Scale	Bradley and Lang (1994)
	Arousal	SAM		
	Perceived Ability to Increase Arousal	I found it easy to increase my arousal in the first part of the training.	7-Point Scale	
		I was able to increase my arousal in the first part of the training.		
		In the first part of the training I increased the intensity of my emotions.		
	Perceived Ability to Reduce Arousal	I found it easy to reduce my arousal in the second part of the training.	7-Point Scale	
		I was able to reduce my arousal in the second part of the training.		

		In the second part of the training I reduced the intensity of my emotions.		
	Perceived Biofeedback*	I perceived the biofeedback on the user interface during the training phase.	7-Point Scale	
		I noticed the colored mouse cursor during the training.		
		I perceived the arousal meter on my screen during the training.		
	Use of Biofeedback*	I used the biofeedback to regulate my emotions according to the instructions.	7-Point Scale	
		I used the colored mouse cursor to regulate my arousal.		
		I used the arousal meter to control my arousal.		
	Perceived Usefulness of Biofeedback for Emotion Regulation*	The biofeedback increased my abilities to regulate my emotions.	7-Point Scale	Adapted from Davis (1989)
		The biofeedback helped me to regulate my emotions		
		I find the biofeedback useful for regulating emotions		
3	Valence	SAM	9-Point Scale	Bradley and Lang (1994)
	Arousal	SAM		
4	Valence	SAM	9-Point Scale	Bradley and Lang (1994)
	Arousal	SAM		
5	Valence	SAM	9-Point Scale	Bradley and Lang (1994)
	Arousal	SAM		

Perceived Physiology	I had the impression that my heart was beating faster during the decision making period than during the rest period.	7-Point Scale	
	I had the feeling that my heart beat increased during decision making compared to the rest period.		
	In the rest period my heart beat was slower than during decision making.		
Reappraisal	I control my emotions by changing the way I think about the situation I'm in.	7-point scale	Gross and John (2003)
	When I want to feel less negative emotion, I change the way I'm thinking about the situation.		
	When I want to feel more positive emotion, I change the way I'm thinking about the situation.		
	When I want to feel more positive emotion (such as joy or amusement), I change what I'm thinking about.		
	When I want to feel less negative emotion (such as sadness or anger), I change what I'm thinking about.		
	When I'm faced with a stressful situation, I make myself think about it in a way that helps me stay calm.		

	Suppression	I control my emotions by not expressing them.	7-point scale	Gross and John (2003)
		When I am feeling negative emotions, I make sure not to express them.		
		I keep my emotions to myself.		
		When I am feeling positive emotions, I am careful not to express them.		
	Control	I did not have much time to make my decision.		
		I felt time pressure during the decision making phase.		
		I had the impression that I had to make my decisions quickly.		
	Perceived Usefulness of Biofeedback for Performance*	The biofeedback improved my estimates.	7-Point Scale	Adapted from Davis (1989)
		The biofeedback helped me to make better estimations.		
		I think that biofeedback is useful for estimating a number close to the target value.		
		The biofeedback improved my decision making quality.		
	Perceived Biofeedback*	I perceived the biofeedback on the user interface while I was making my decision.	7-Point Scale	Adapted from Davis (1989)
		I noticed the colored mouse cursor during the decision making phase.		
		I perceived the arousal meter on my screen during decision making.		

	Perceived Biofeedback for Emotion Regulation*	The biofeedback increased my abilities to regulate my emotions.	7-Point Scale	
		The biofeedback helped me to regulate my emotions		
		I find the biofeedback useful for regulating emotions		
	Use of Biofeedback*	I used the biofeedback to regulate my emotions.	7-Point Scale	
		I used the colored mouse cursor to regulate my arousal.		
		I used the arousal meter to control my arousal.		
6	Intrusiveness	The sensors restricted my freedom of movement.	7-Point Scale	Adapted from Riedl et al. (2014)
		I was able to use the computer as always.		
		The sensors did not impede the usage of the computer		
	Perceived Usefulness of Biofeedback for Performance*	The biofeedback improved my estimates.	7-Point Scale	
		The biofeedback helped me to make better estimations.		
		I think that biofeedback is useful for estimating a number close to the target value.		
		The biofeedback improved my decision making quality.		
	NASA TLX	Mental effort	21-Point Scale	Hart and Staveland (1988)
		Time pressure		

		Performance		
		Overall workload		
		Frustration level		
	NASA TLX	Comparison of dimensions (10x)	2-Point Scale	Hart and Staveland (1988)
	Demographics	What is your gender?	male/ female	
		How old are you?	Number	

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List of Abbreviations

AAPB	Applied Psychophysiology and Biofeedback
BCIA	Biofeedback Certification International Alliance
ECG	electrocardiography
EDA	electrodermal activity
EEG	electroencephalography
EMG	electromyography
EOG	electrooculography
FLBF	foreign live biofeedback
HCI	human-computer interaction
ICT	Information and Communication Technology
IS	Information Systems
IT	Information Technology
ISNR	International Society for Neurofeedback and Research
LBF	live biofeedback
fNIRS	functional near-infrared spectroscopy
NeuroIS	Neuro-Information Systems
ORSEE	Online Recruitment System for Economic Experiments
PPG	photoplethysmography
PSM	perfect stranger matching
SDNN	standard deviation of NN-intervals
SGP	social golfer problem

SLBF self live biofeedback

RGP randomly generated price

rPPG remote photoplethysmography

TS transmission signals

UI user interface

WTP willingness-to-pay

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