International Journal of Human-Computer Studies 120 (2018) 14–21

Contents lists available at ScienceDirect

International Journal of Human-Computer Studies

journal homepage: www.elsevier.com/locate/ijhcs

Heart-rate sonification biofeedback for poker

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ARTICLE INFO

Keywords:
Poker
Heart-rate biofeedback
Emotion regulation
EDA
EMG

ABSTRACT

In this paper we show that heart-rate based audio/sonification biofeedback (HRSB) can be used to facilitate emotion regulation during poker play. We report on a laboratory experiment ($N = 29$) where participants play No Limit Texas Hold'em poker while hearing heartbeats synchronized with their actual heart-rate (biofeedback condition) or at steady pace (control condition). The synchronized heart-rate biofeedback decreased emotional reactivity in terms of arousal (as measured by skin conductance) and valence (as measured by facial electromyography). We also observed individual differences between participants in the effectiveness of the HRSB. The participants were profiled using the behavioural inhibition/activation system (BIS/BAS) questionnaires, and there was a significant correlation between the effectiveness of the biofeedback method and BIS/BAS scores; with biofeedback being effective primarily for participants with high BIS/BAS scores.

1. Introduction

Many people probably have, at one point or another in their lives, made decisions "in the heat of the moment" and later on regretted having done so. These incidences of acting out of passion ("losing it") illustrate an overt condition where emotions have an effect on decision-making. Such emotion-laden decision-making often results in detrimental consequences, especially when the emotions guiding actions are negative in valence. A recognized example of this is road rage, which refers to the aggressive and angry behavior exhibited by a motor vehicle driver, usually induced by elements of traffic (Dula and Geller, 2003). Similar observations have also been made in various sports, such as tennis and golf (Rotella and Cullen, 1996), as well as popular games like Starcraft, Hearthstone, and poker (Wei et al., 2016). In the context of games, losing control in the heat of the moment, and the resulting reduced quality of decision-making, is commonly known as *tilting* (Browne, 1989; Palomäki et al., 2014).

Since the early 2000s, the popularity of poker, and especially the variant No Limit (Texas) Hold'Em (NLHE), has increased substantially. This has been reflected in a breakthrough of players playing the game online on a computer, on various gambling sites. Over the last decade, there has been an apparent accumulation of empirical evidence concerning diverse aspects of the game (Eil and Lien, 2014; Kallinen et al., 2009; Laakasuo et al., 2015; Leonard and Williams, 2015; Palomäki et al., 2013b). Importantly, in the last few years, poker has also been used as a model system to study decision-making, emotion regulation, and affective computing (Laakasuo et al., 2015; Palomäki et al., 2016; Slepian et al., 2013; Wei et al., 2016).

Emotion regulation (ER) refers to the ability to regulate both internal feeling states and physiological reactivity related to emotional processing. Thus, ER also relates to the ability to restrict one's emotions from having a significant (overt or subtle) and detrimental effect on one's behaviour. ER abilities can be assessed by various means, including self-report questionnaires, or directly measuring psychophysiological activity during, for example, decision-making in an emotionally salient environment (Ravaja et al., 2006). Online poker, and especially NLHE, can be viewed as such an environment: players have to constantly and rapidly make decisions of investment that often involve real money and frequently result in monetary losses. Most players end up losing money in the long run. Therefore, online poker is an environment where – due to emotionally arousing game elements – players are constantly at risk of making bad decisions and losing significant amounts of money. In other words, players are constantly at risk of losing more by "losing it" (Palomäki et al., 2014).

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https://doi.org/10.1016/j.ijhcs.2018.07.001
Received 8 January 2018; Received in revised form 9 May 2018; Accepted 1 July 2018
Available online 07 July 2018
1071-5819/

The psychophysiology of emotion processes during human decision-making can be assessed by various methods, such as brain imaging (e.g., functional magnetic resonance imaging [fMRI]), measuring heart-rate, electrodermal activity (EDA), or facial electromyography (EMG). Changes in EDA (tonic skin conductance level, SCL, or phasic skin conductance responses, SCRs) are related to changes in eccrine sweating, which in turn is related to activity in the sympathetic part of the autonomic nervous system (ANS). The ANS is significantly involved in emotional reactivity, and changes in ANS activity are often associated with ER. Increased EDA is generally an indication of psychophysiological arousal, and therefore indexes the intensity (but not the valence) of affect (although EDA is associated with non-affective processes as well; e.g., Lang et al., 1993). Consequently, EDA has become a widely used tool for assessing emotion processes and their association with decision-making (Bechara, 2003; Figner et al., 2011; Kallinen et al., 2009; Ravaja et al., 2006).

EMG is a well-established psychophysiological index of hedonic affective valence. Contractions of the facial muscles responsible for positive and negative facial expressions are reflected in specifiable increases in EMG activity. Increased activity at the zygomaticus major (cheek) and corrugator supercilii (brow) muscle areas are consistently associated with positively and negatively valenced emotions, respectively (Cacioppo et al., 1986; Lang et al., 1993). Furthermore, increased activity at the orbicularis oculi (periocular) muscle area has been shown to correlate with positively valenced emotions (Lang et al., 1993).

It is reasonable to presume that the intensity and valence of emotional reactivity during decision-making in a poker game, as measured by EDA and facial EMG, relates to ER abilities. Both empirical and anecdotal evidence suggests that the more intensively a person experiences various decision-making elements in a poker game – sometimes irrespective of their hedonic valence –, the harder it is for him or her to keep it cool and make good decisions (Palomäki et al., 2013b; Tendler and Carter, 2011). In particular, strong negative emotions (e.g., anger) experienced during playing are a prominent cause bad decisions and, by extension, superfluous losses (Palomäki et al., 2013b). However, also strong positive feelings (e.g., elation) might predispose players to make sub-optimal decisions. A strong corpus of anecdotal evidence suggests that to play optimally and rationally, decisions should be made as impassively as possible (Tendler and Carter, 2011). Previous research has also shown that poker players with proficient ER abilities are less prone to making poor emotion-driven decisions in poker, as compared with players with inept ER abilities (Bjerg, 2010; Leonard and Williams, 2015; Palomäki et al., 2014). Together, these findings underscore the importance of ER in poker.

ER can be assisted by means of *biofeedback*, which refers to using an instrument to gain a better awareness of affective processes (Valins, 1966). Usually, the goal while using a biofeedback technique is to be able to manipulate the ongoing psychophysiological emotion process at will, to some extent. For example, increased heart-rate indicates a state of increased psychophysiological arousal, and giving a person information on his or her ongoing heart-rate is a simple yet effective method of biofeedback (Fenigstein and Carver, 1978; Henriques et al., 2011; Schwartz and Andrasik, 2017). This can be accomplished by, for example, listening to heartbeat-like sounds representing one's actual heartbeats using headphones – or in other words, heart-rate sonification biofeedback (HRSB). HRSB makes it possible to rapidly become aware of a state of increased psychophysiological arousal (increased heart-rate), at which point it is easier than otherwise to actively down-regulate said aroused state. Such active down-regulation can be accomplished by, for example, concentrating on breathing more slowly to decrease one's heart-rate.

We had two aims in our current study: firstly, to assess the effects of HRSB on emotion-related psychophysiological responses (EDA and facial EMG) during playing a computer poker game. We hypothesized that applying HRSP will result in decreased emotional reactivity during poker decision-making, as indexed by both decreased EDA (indicative of decreased psychophysiological arousal) and facial EMG (indicative of decreased levels of experienced negative and positive emotions) activity.

Secondly, we aimed to explore the potential differences in biofeedback efficacy across participants. To do this, we focused on individual differences in behavioural inhibition system (BIS) and behavioural activation system (BAS) activity. The BIS and BAS constructs reflect individual differences in both approach (BAS) and withdrawal (BIS) related behavioural motivations (Carver and White, 1994). Individuals with high BAS/BIS activity are typically sensitive to signals of reward/punishment and positive/negative emotions. Given that poker typically involves encountering both wins and losses at high frequencies, we expected the BIS/BAS constructs would be implicated in the game.

Our main contributions are the following:

- We show that HRSB decreases both the arousal, as measured by EDA, and valence, as measured by facial muscle activity, during a computer poker game
- We show that individual differences in BIS/BAS activity moderate the effect of HRSB

Next, we briefly review related work on heart-rate biofeedback, and how biofeedback methods have previously been utilized in a gaming context. We then describe our experimental design and results. Finally, we discuss the results as well as their implications and limitations.

2. Related work

2.1. Heart-rate biofeedback

Several experiments have been conducted where the effect of hearing false heart-rate has been studied. Valins (1966) played false heartbeat sounds to participants while they viewed sexually-oriented stimuli; the stimuli that were presented during increasing or decreasing heart-rates were rated as significantly more attractive than those shown when the heart-rate did not change. In a similar vein, Fenigstein and Carver (1978) showed that when hearing a heartbeat believed to be their own, the participants made greater self-attributions to hypothetical outcomes compared with a control group who thought the heartbeats were extraneous noise.

Actual heart-rate has been successfully used in heart-rate variability based biofeedback (HRV; the variance in time between each heartbeat) when treating various disorders, such as depression, anxiety (Henriques et al., 2011), hypertension, and obsessive compulsive disorder (Schwartz and Andrasik, 2017). However, surprisingly little research has been done with the actual heart rate as the biofeedback signal. In one such study, Iwasaki et al. (2014) displayed the actual electrocardiographic signal, heart-rate included, to participants watching emotional movies. While the participants receiving this heart-rate biofeedback did not differ from the control group in self-reported emotion scores, they showed significantly decreased HRV.

2.2. Biofeedback and games

Adapting games to players' physiological signals has been explored in several studies. A classic example is dynamic difficulty adjustment (DDA), in which players' physiological signals are used in adjusting the game difficulty to provide an optimal challenge for them. Liu et al. (2009) used EDA, facial EMG (corrugator supercilii) and ECG to measure players' anxiety levels; the difficulty of the game was adjusted accordingly, which resulted in small improvement in performance and self-reported game experience. Similar dynamic difficulty adjustment schemes have been implemented using a wide variety of physiological signals such as respiration, body temperature and blood pressure (Chanel et al., 2011; Tijs et al., 2008).

Games allow for exploring many different feedback modalities. Biofeedback has been used to enhance game elements like the camera viewpoints: By combining several physiological signals (heart-rate, EDA and blood volume pulse) Yannakakis et al. (2010) detected players' affective states (boredom, excitement, and anxiety) to predict their preferences for different camera settings. The authors argued that such a system could be used for real-time adaptive camera control based on biofeedback. In horror games affective biofeedback has been used to control the horror affordances, that is, to make the game scarier (Dekker and Champion, 2007; Vachiratamporn et al., 2014).

Games have also been used to study the differences between explicit and implicit biofeedback methods. In the former, the players are aware of the feedback mechanism, and in the latter, the game is adapted to the players' biosignals without their explicit knowledge. Kuikkaniemi et al. (2010) used a first-person shooter game to explore how the gaming experience differed between explicit and implicit biofeedback conditions and found that the players preferred the added control granted by the explicit feedback.

3. Research questions and hypotheses

We conducted a user study to evaluate the following research questions.

Research Question 1: How does HRSB affect emotion regulation in poker?

Based on previous work we expected HRSB to improve ER in both valence and arousal dimensions. Note that decreased EMG activity across both negatively and positively valenced affectivity can be viewed as improved ER in the context of poker. We, therefore, formulated the following two hypotheses:

- **Hypothesis 1:** HRSB will decrease EDA.
- **Hypothesis 2:** HRSB will decrease facial muscle activity associated with valence, namely corrugator supercilii, orbicularis oculi and zygomatic major.

It is worth emphasizing that we did not expect HRSB also to affect decision outcomes or overall success in the game (e.g., increased profit or "chips won" at the end of the experiment). The beneficial effects of ER (staying cool under pressure) in poker typically become evident only "in the long run", and not during a relatively short period of playing in a laboratory setting. We return to this point in more detail in the "Discussion" -section.

Research Question 2: Are there individual differences in the effectiveness of HRSB?

We expected that participants' BIS/BAS scores would moderate the effectiveness of the biofeedback method. However, to our best knowledge, there are no existing studies on how BIS/BAS might interact with biofeedback. Thus, we formulated a two-sided hypothesis:

- **Hypothesis 3:** The effectiveness of HRSB will differ between participants according to their BIS/BAS scores.

4. Method

4.1. Participants

Twenty-nine adults ($N = 29$, 14 male) participated in the experiment (mean age = 25.1, SD = 5.1, range = 20–47). They were recruited by sending email invitations to various university student mailing lists in Helsinki. The subjects had to be familiar with the rules of NLHE. The poker game used in the experiment was modified, and players with too much poker playing experience could have too easily noticed these modifications. Thus, the participants were also required to have played less than an hour a week on average and not to have ever played poker actively for more than a year. Participant compensation is explained in below Section 4.3.

4.2. Apparatus

EDA and EMG were recorded using a mobile physiological data acquisition system (Varioport-B, Becker Meditec, Karlsruhe, Germany) using a constant 0.5 V voltage across Ag/AgCl electrodes that had a contact area of 4 mm in diameter (Becker Meditec). The EDA signal was sampled at 32 Hz. The electrodes were attached to the medial phalanges of the participants left hand's ring and little finger using self-adhesive electrode collars and electrolyte gel. According to common practice, the electrodes were taped to secure their attachment, which also prevents the fingers from touching. Participants were instructed not to move their hand or fingers. EMG data were recorded at 1024 Hz over sites overlying the left zygomaticus major, orbicularis oculi, and corrugator supercilii muscle regions. Heart-rate was measured using Polar fitness band, and the data were sonified with PureData. Matlab (version 1.6 0.17) was used to preprocess the physiological signals. The poker game application was ran on an Intel Pentium Core 2 Duo desktop computer. The experiment used a modified version of the PokerTH (www.pokerth.net) open source software. The same electrodes and equipment were used throughout the experiment for each individual participant.

4.3. Experimental procedures and poker game modifications

Previous results pertaining to the current data have been published by Palomäki et al. (2013a), where the focus was on EDA differences across various poker decisions. The experimental procedures in Palomäki et al. (2013a) and the current paper are identical. In this paper we provide a brief description of our modified poker game, but will not go into full detail about the specific modifications; these details are not pertinent with respect to the biofeedback manipulation, which is the focus of the current paper. For full details about the procedure and poker game modifications see (Palomäki et al., 2013a).

The poker game had the standard rules of NLHE for five players. Each hand started with the small and big blinds (forced bets placed into the pot before play begins) set at 10 and 20, respectively, and with 2000 chips (play money) for each player to play with. Here, poker "hand" refers to a single round of game play; the period beginning when cards are dealt and ending with revealing of players cards and deciding the winner of a given hand. The number of chips was reset to 2000 after each played hand to enable comparability between hands across subjects. During each hand, the participants could choose to "check", "call", "bet", "raise" or "fold" according to the standard rules of NLHE. The other four players on the table were computer opponents who were dealt the same hands in the same order across both conditions (biofeedback and control) and all participants. The number of chips won or lost was recorded in a leaderboard visible at the bottom right corner of the screen (see Fig. 1).

The leaderboard displayed the current score of the participant and the fictitious scores of four other human players. These players had supposedly (but not actually) previously participated in the same experiment. Participants were also told truthfully that their reward for the experiment would depend on their leaderboard ranking as follows: four movie tickets for first place (valued at 48€), three for second place (valued at 36€), two for third place (valued at 24€) and one for both fourth and fifth place (valued at 12€). Thus, participants had an incentive to perform well in the poker game.

The participants played two sets of 64 hands for a total of 128 hands. The two sets of 64 cards were fully identical in terms of card distribution. There was a short 5 min break between the two sets during which the participants filled in questionnaires on game experience. After both sets were played (approximately 30 min in total), Likert- and verbal open-ended questions were used to determine if the participants had noticed that the two sets of 64 cards were identical, and if they had

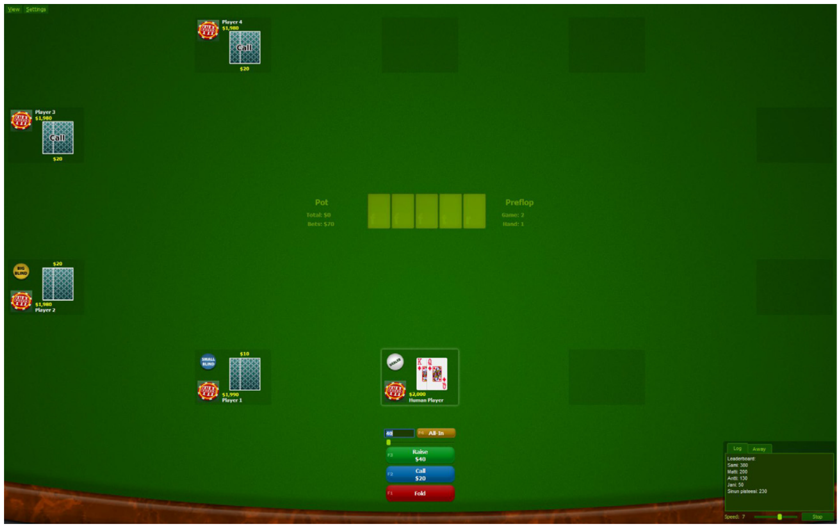

Fig. 1. Screenshot of the poker game window. The leaderboard is on the bottom right.

felt the poker game was "rigged". The participants also filled the BIS/BAS questionnaire. Afterwards, the participants were debriefed and rewarded.

Participants had headphones on during the experiment and were instructed not to remove them before the experiment was over. During one of the two sets of 64 hands, participants heard sound beats that were synchronized with their own heartbeats (biofeedback condition), and during the other set, they heard the same sound beats at a non-synchronized steady pace (control condition). Listening to steady beats (66 bpm) has previously been shown to reduce anxiety (Gadberry, 2011). Thus, our control condition could have made it more difficult to observe an effect for biofeedback, essentially making it a rigorous control condition. The order of the sets was counterbalanced across participants. In other words, half of the participants received the biofeedback condition first, and the other half received the control condition first. During the biofeedback condition, participants were verbally instructed to be mindful of their sonified heartbeats, and attempt to calm down (e.g., by breathing calmly or deeply) and relax if they noticed their heart-rate increasing; during the control condition, they were instructed to attempt to remain calm and relaxed until the game ends. Thus, the instructions between the conditions were kept as similar as possible, with the exception of informing participants how to actually make use of the sonified biofeedback signal. This is generally how biofeedback technologies are supposed to be used – that is, with knowledge of what the biofeedback signal represents. We made these decisions regarding the instructions to assure the ecological validity of our experimental design (given that our results can potentially be applied "in the wild")

4.4. BIS/BAS measure

We measured BIS/BAS activity using a 20-item scale developed by Carver and White (1994). In this scale, BAS is divided into three subcategories: Fun seeking (4 items), Reward responsiveness (5 items), and Drive (4 items). BIS (7 items) is a uniform measure. All items are coded as "1 = very true for me"; "2 = somewhat true for me"; "3 = somewhat false for me"; "4 = very false for me". Example items are "When I want something I usually go all-out to get it" (BAS Drive), "I'm always willing to try something new if I think it will be fun" (BAS Fun seeking), "When I see an opportunity for something I like I get excited right away." (BAS Reward responsiveness), "I worry about making mistakes." (BIS). All sub-category Cronbach's alpha values were between 0.68 and 0.79, suggesting satisfactory internal scale consistency. Higher scores on BIS reflect higher sensitivity to punishments and negative emotions; higher scores on BAS reflect higher sensitivity to rewards and positive emotions.

4.5. Data analysis

Mean values for each of the four physiological signals (EDA, corrugator supercilii, orbicularis oculi and zygomaticus major) were derived for a 6 s window around each action (fold, check, call, bet and raise), that is, from 3 s before to 3 s after an event (previous research has shown that EDA reaches its peak amplitude in 3 s after event onset in digital games; see Ravaja et al., 2008). A logarithmic transformation was conducted for EDA data to normalize the distribution. The data were analyzed using the Linear Mixed Models procedure in SPSS with restricted maximum likelihood estimation and a first-order autoregressive covariance structure for the residuals. Subject ID was specified as the subject variable, and an aggregate variable, "hand sequence", that indexed each action within a single hand was selected as the repeated variable: Correlation was assumed between the residuals within a given hand, and the correlation was modeled with the first-order autoregressive covariance. Our statistical procedure effectively used the mean EDA value as a baseline. Thus, if there were a drift in the EDA signal it would cause a non-systematic error, making it more difficult for us to observe significant effects (decreasing the chance of observing false positives).

5. Results

5.1. Research question 1

The first research question was divided into two hypotheses: 1) HRSB will decrease EDA activity, and 2) HSRB will decrease valence as measured with facial EMG activity.

Hypothesis 1: HRSB will decrease the EDA activity.

The results supported the first hypothesis: there was significantly less EDA during the biofeedback condition ($p < .05$; see Table 1).

Hypothesis 2: HRSB will decrease facial muscle activity associated with valence, namely corrugator supercilii, orbicularis oculi and zygomaticus major

The results partly support the hypothesis that HSRB decreases facial EMG activity during biofeedback. Specifically, the EMG associated with orbicularis oculi and zygomaticus major was significantly decreased during the biofeedback condition ($p < .001$). However, no decrease in corrugator supercilii (brow) muscle activity was detected (see Table 1).

Table 1
The effect of HRSB on physiological signals. Bold entries indicate statistical significance at the level of $\alpha = 0.05$ (*) and $\alpha = 0.001$ (***). "Signal" refers to the dependent variable in the analysis, and "Estimate" is analogous to the slope of the linear model (the B-value), that is, the difference between the biofeedback and control conditions.

Signal (Dependent variable)	Estimate	SE	Df	t
EDA	−0.01583	0.00720	2914.07	**−2.20** *
Corrugator supercilii	0.01806	0.01752	2939.24	1.03
Orbicularis oculi	−0.16381	0.01988	2897.20	**−8.24** ***
Zygomaticus major	−0.14518	0.02381	2929.53	**−6.10** ***

5.2. Research question 2: are there individual differences in the efficacy of HRSB?

The second research question was concerned with the potential differences in the efficacy of the biofeedback procedure between participants. The BIS/BAS scale was used to evaluate the behavioral inhibition and behavioral activation profiles for each participant.

Hypothesis 3: The efficacy of HRSB will differ between participants according to their BIS/BAS profiles.

As can be seen in Table 2 and Fig. 2, all the five BIS/BAS scales had a statistically significant interaction ($p < .001$) with the effect of the HRSB. The results show that the effect of HRSB is stronger for participants with higher BIS/BAS scores.

After visually observing the data we noticed that there were large differences in the amount of EDA activity, or EDA responsiveness, between participants. As an exploratory analysis, we tested whether also EDA responsiveness moderated the effect of our biofeedback method. To do so, we calculated the standard deviation of EDA activation for each participant; this variable effectively indexes the "volatility" of each participant's EDA activity. As can be seen in Table 2 and Fig. 2, biofeedback was more effective for the EDA responsive participants.

5.3. Awareness of game modifications

Five subjects (out of 29) reported having suspected that some of the hands dealt in the second set of 64 hands might have been similar to ones dealt in the first set. However, excluding these five participants did not significantly change the observed pattern of results.

6. Discussion

We evaluated the effects of sonified heartbeat biofeedback on participants' emotional arousal (as measured by EDA) and valence (as measured by EMG) while they played a computer poker game in a laboratory setting. We also evaluated how individual differences in emotional reactivity (as measured by the BIS/BAS scales) moderate the effectiveness of the biofeedback procedure.

Our results showed that biofeedback significantly reduced emotional arousal and the strength of both positively and negatively valenced emotion expressions. Previous research has found strong links between poker success and proficient emotion regulation, and avoiding negative emotions in particular. Only players who can remain calm under pressure are likely to succeed in the game (Palomäki et al., 2014). Although the effects of positive emotions on poker success have not, to our knowledge, been studied, little evidence suggests that positive emotions are beneficial in the long run in poker. Thus, it seems that the key to poker success is remaining impassive, or "cool and composed"–in terms of regulating both positive and negative emotions (Laakasuo et al., 2015; Palomäki et al., 2013b).

We found that biofeedback reduced muscle activity in zygomaticus major and orbicularis oculi, the facial muscles that are usually associated with positive valence, but not in corrugator supercilii, the facial muscle associated with negative emotions. However, corrugator supercilii activation also reflects other psychological processes, such as concentration. Our poker task arguably required participants to concentrate during both the biofeedback and control conditions, and as such the lack of reduced activation in corrugator supercilii during biofeedback is reasonable.

We also found that individual differences in BIS and BAS activity interacted with the biofeedback condition: Biofeedback was effective in reducing EDA primarily for those participants who also had high scores on the BIS or BAS measures. Both BIS and BAS measure a specific subset of behavioural responses, such as sensitivity to punishment (BIS) or reward (BAS). As our poker game entailed punishments and rewards, participants with high scores on either BIS or BAS (or both) were arguably susceptible to increased emotional reactions throughout the game. The results thus suggest that the biofeedback method works specifically for those participants who are prone to react strongly to the various game events, such as wins and losses. This result is also supported by the interaction we observed between the standard deviation of EDA responsiveness (i.e., the standard deviation of EDA activity) and the biofeedback condition: Biofeedback reduced EDA only for the participants with high EDA responsiveness or "volatility".

While we found that biofeedback reduces emotional reactivity in a modified poker game, we could not show that receiving biofeedback also predicted success (i.e., chips won) in the game. However, this is unsurprising: The positive effect of reduced emotionality in poker is typically observed only over the long run, that is, over thousands or even hundreds of thousands of hands played (Palomäki et al., 2013b). Probably the biggest benefit of remaining calm while playing poker is in avoiding tilting, as tilting can result in losing one's entire bankroll in a single session (Palomäki et al., 2014). Nonetheless, inducing or otherwise studying tilting in a laboratory environment is extremely difficult. One possibility would be to construct simplified poker scenarios where the expected value of various decisions can be calculated (as done by, for example, Laakasuo et al., 2015), and then compare decision-making quality between conditions with and without biofeedback. Unfortunately, such an experiment with simplified poker tasks would entail a serious lack of ecological validity, because most simplified versions of poker have to forgo many key elements in the game; such as the affective nature of losses and wins, or the true complexity of choice options during a single decision. On the other hand, the expected value of poker decision-making in a realistic environment – or the expected value of individual poker decisions in an actual game – is notoriously difficult to estimate (Palomäki et al., 2016). Thus, probably the best way to observe the actual effects of biofeedback on poker success would be to implement the biofeedback procedure "in the wild" and follow poker players' performance over the long run. This being said, our current laboratory study provides an excellent starting point and a proof-of-principle for future research.

Like most laboratory studies, our study using a modified poker game faces some ecological validity concerns. However, these concerns were mitigated by recruiting novice players who by and large did not notice the game modifications. One way to increase ecological validity would be using more recognizable poker interfaces, such as those employed by

Table 2
The Interaction BIS/BAS profiling scores with the Condition factor (biofeedback/control) when predicting EDA activity. The interaction between EDA responsiveness and Condition is also reported. Bold entries indicate statistical significance at the level of $\alpha = 0.001$ (***).

Signal (Independent variable)	Estimate	SE	Df	t
BAS Fun seeking*Condition	0.02314	0.00367	2923.87	**6.32** ***
BAS Drive*Condition	0.04803	0.00445	2910.86	**10.78** ***
BAS Reward responsiveness*Condition	0.03253	0.00443	2926.46	**7.34** ***
BIS*Condition	0.00889	0.00207	2922.45	**4.30** ***
EDA responsiveness*Condition	1.66972	0.09498	3044.38	**17.58** ***

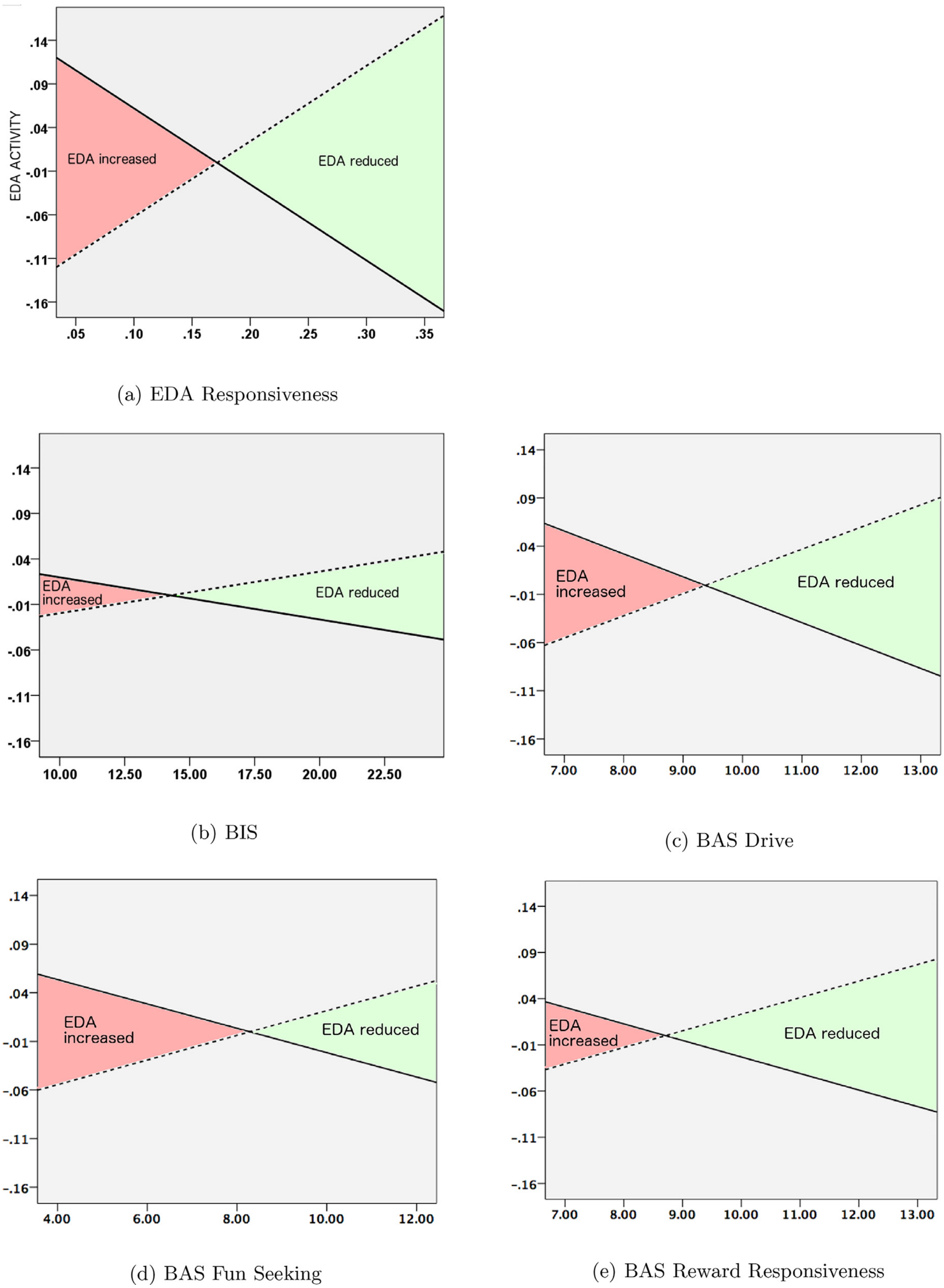

Fig. 2. Interactions of EDA with EDA responsiveness (a) as well as the BIS/BAS Measures (b-e). Dependent variable on the Y-axis is the amount of EDA activity during biofeedback (solid line) and non-feedback (dashed line) condition. The X-axis represents the independent variables (EDA responsiveness, BIS, BAS Drive, BAS Fun seeking, and BAS Reward responsiveness), and the steepness between the two lines crossing represents the strength of the statistical interaction.

popular online sites (e.g., pokerstars.com), or including actual monetary rewards instead of movie tickets. Having recruited only novice players also precluded us from evaluating how poker experience and skill would affect the observed pattern of results. Many recent studies have shown that poker skill and experience are strongly associated with emotion regulation abilities in the context of poker: experienced players, compared with inexperienced ones, seem to have a more mature and composed predisposition towards the emotion-inducing elements of the game. Thus, inexperienced players with detrimental emotion regulation skills (and "bad poker faces") might benefit more from biofeedback than experienced ones who are already calm to begin with (Laakasuo et al., 2014). This contention is in line with our current findings, where the biofeedback method worked primarily for those participants with high EDA volatility or high BIS/BAS activity (see also Martinez et al., 2014 for an alternative way of analyzing Likert scale ratings, such as the BIS/BAS scales, based on comparative analysis).

We analysed our data using linear mixed models (LMMs), for which there are no straightforward ways of evaluating effect sizes. This is because definitions and interpretations of effect size measures in models with multiple error terms can be highly complicated. However, based on the relation of our parameter estimates, degrees of freedom and standard errors (see Tables 1 and 2), we can extrapolate that our effects are likely in the "low to medium" range: the relation of the linear slope estimate to the standard error corresponds to Cohen's D values of about 0.2 to 0.35; but this is only a rough estimate and needs to be interpreted with caution. We also note that medium and even low effect sizes can be highly meaningful in games involving repeated decisions (such as poker or other virtual games like Hearthstone), where small effects accumulate over time. In a similar vein, casinos systematically exclude from their premises any player who is able to obtain even a 0.5 percent edge over the house in games like blackjack.

In the biofeedback condition, participants were instructed to be mindful of their sonified heart-rate, and to calm down (e.g., by breathing calmly or deeply) if their heart-rate increased. However, during the control condition participants were merely told to attempt to remain calm and relaxed; that is, they were not specifically instructed to monitor their own affective state. Therefore, we cannot conclusively rule out the possibility that "mere instructions" to be mindful of one's affective state are enough to help participants down-regulate said affective state by breathing calmly and attempting to relax. Conversely, it is not clear whether the participants would self-regulate their affective states during the biofeedback -condition if they were not specifically instructed to do so. Future research could shed light on this by introducing two additional experimental conditions: one with participants receiving only instructions to monitor their affective state and to remain calm and relaxed, and one with participants receiving sonified biofeedback without any instructions on how to use it. Such an experiment would be costly, however, requiring a between-subjects design and four times as many participants as we currently had. Considering our limited resources, we think our design was reasonably the best and ecologically valid alternative. Moreover, the above limitation is mitigated by our participants' responses to verbal open ended questions asked during debriefing, where they clearly stated that the biofeedback procedure (and not merely the instructions) had indeed helped them gain awareness of their affective arousal and consequently down-regulate it. Finally, for future research, we suggest testing whether or not the biofeedback procedure works with a different type of audio signal (e.g., music whose tempo increases with increasing heart-rate).

Our results have implications outside the context of poker as well. Negative (or positive) emotions have been shown to detrimentally influence decision-making across a number of contexts, such as driving motor vehicles, playing golf, or stock trading, to name a few (Dula and Geller, 2003; Rotella and Cullen, 1996; Wei et al., 2016). The current biofeedback method could potentially be applied in many other contexts; the procedure requires only a Polarband-type heart-rate measure and headphones with Bluetooth. Our findings also indicate that EDA responsiveness might have a significant effect on the efficacy of HRSB, and potentially on any other feedback method designed to control arousal. For example, previous studies have linked EDA responsiveness to topics such as political involvement (Gruszczynski et al., 2013). However, our results for EDA responsiveness were derived from exploratory post hoc analyses and should be considered preliminary; future research should more thoroughly look into the interaction of EDA responsiveness and biofeedback efficacy.

While poker can be played with high stakes, most poker players play with low stakes or for fun with play money. Our poker game involved relatively low stakes (compensation was 1–4 movie tickets) and lasted for a relatively short time (30 min); this connects it more closely to other games involving friendly competition, low monetary incentives, and short rounds. A specific example is the increasingly popular digital card game Hearthstone, which, like poker, is based on both skill and chance, and where players could potentially benefit from biofeedback.

Moreover, using biofeedback in poker could be applied as a tool to teach people emotion regulation skills, as well as augmenting the gaming experience by having players hear their opponents' heartbeats (for similar ideas in different contexts, see Frey, 2016; and van Rooij et al., 2016). These two ideas can even be combined to create a game (with low stakes, or play money) where players can learn to interpret concealed social signals (e.g., bluffing), and conversely, how to better conceal their own physical signals or "tells" (i.e., how to put on a good poker face). This connects poker and our biofeedback design more clearly with existing HCI research on both social game experience and affective computing (see also Wei et al., 2016 where poker is used as a testbed for affective computing techniques, such as facial emotion recognition).

To conclude, we argue that a simple biofeedback procedure using sonified heartbeats can help poker players to remain calm and composed while playing (non face-to-face) poker, which is a game of rapid and affective decision-making. Future research should look into applying a similar procedure in other environments with emotion-inducing elements – with many such environments available.

Acknowledgments

Funding: This work was supported by the Finnish Funding Agency for Technology and Innovation (grant project "Emokeitai"). Jussi Palomäki and Michael Laakasuo were also funded by Jane and Aatos Erkko Foundation (grant project "Moralities of Intelligent Machines").

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