Correlation between Heart Rate, Electrodermal Activity and Player Experience in First-Person Shooter Games

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Abstract

Psychophysiological methods are becoming more popular in game research as covert and reliable measures of affective player experience, emotions, and cognition. Since player experience is not well understood, correlations between self-reports from players and psychophysiological data may provide a quantitative understanding of this experience. Measurements of electrodermal activity (EDA) and heart rate (HR) allow making inferences about player arousal (i.e., excitement) and are easy to deploy. This paper reports a case study on HR and EDA correlations with subjective gameplay experience, testing the feasibility of these measures in commercial game development contexts. Results indicate a significant correlation ($p < 0.01$) between psychophysiological arousal (i.e., HR, EDA) and self-reported gameplay experience. However, the covariance between psychophysiological measures and self-reports varies between the two measures. The results are consistent across three different contemporary major commercial first-person shooter (FPS) games (*Prey*, *Doom 3*, and *Bioshock*).

CR categories: K.8.0 [Games]; H.1.2 [User/Machine Systems]: Human Factors; H.5.2 [User Interfaces]: Evaluation/methodology.

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1 Measuring Player Experience

Emotions form a vital component of our experiences with interactive entertainment, motivating the cognitive decisions made during gameplay [Nacke 2009]. Since emotions are important in determining player behavior and the quality of user experience (UX) in interactive entertainment applications, such as digital games (e.g., player experience, PX), the amount of research dedicated to assessing emotional responses has grown [Ravaja 2004; Mandryk et al. 2006; Nacke 2009].

Emotions can be expressed via several channels, such as voice, speech, facial responses, and physiological responses [Brave and Nass 2002]. Various characteristic features can be analyzed to assess the emotional state of a participant; using subjective and objective measurement techniques [Nacke 2009]. Many approaches for evaluating UX exist already [Law et al. 2007], which can generally be divided into qualitative/semi-quantitative approaches, such as questionnaires [Pagulayan et al. 2003; Ijsselsteijn et al. 2008], and quantitative approaches, notably psychophysiological measures [Cacioppo et al. 2007] and user-behavior analysis [Pagulayan et al. 2003; Drachen and Canossa 2009]. Each approach carries different strengths and weaknesses. Quantitative approaches provide objective and detailed information whereas qualitative approaches permit context-awareness and in-depth information about UX.

Psychophysiology per definition investigates the relationships between psychological manipulations and resulting physiological activity (measured in living organisms to understand mental and bodily processes and their relation to each other) [Cacioppo et al. 2007]. Heart rate (HR) and ElectroDermal Activity (EDA) are measures of psychophysiological signals originating from the peripheral nervous system (PNS) and have been successfully used as measures of arousal and emotion, generally in a laboratory environment [Nacke 2009; Mandryk 2008].

Different psychophysiological measures are not independently reliable indicators of feelings alone [Ravaja 2004]. Therefore, psychophysiological methods are usually applied together with questionnaires to contextualize the measurements [Nacke 2009]. This process is important to identify which patterns in the physiological responses of users reflect which emotional responses. Importantly, the many-to-one relationship between psychological processing and physiological responses [Cacioppo et al. 2007] allow linearly linking physiological measures with psychological constructs, such as cognition or emotion. Therefore, the correlation of patterns of physiological measurement with subjective characterizations of emotions and UX is receiving more attention in game research [Nacke, 2009; Nacke et al. 2009].

There is relatively limited knowledge available about how qualitative and quantitative measures of PX in digital games correlate. For example Ravaja et al. [2006], Nacke and Lindley. [2009], Mandryk et al. [2006], Yannakakis et al. [2008] and Ravaja et al. [2008] utilized both psychophysiological and subjective measures in the study of emotional components of PX, however, of these, only the Yannakakis et al. [2008] study statistically correlated these measures. For example, Mandryk et al. [2006] asked their participants to rate emotional aspects of PX (i.e., fun, excitement, frustration, challenge, and boredom) on scales from 1-5, but did not statistically correlate these measures with psychophysiological measures. Ravaja et al. [2008] compared self-reported measures of user personality – not PX - with phasic measures of EMG. Ravaja et al. [2006] used EKG (i.e., interbeat intervals) and a survey on spatial presence. Nacke

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and Lindley [2009] used EMG and EDA in conjunction with self-reported measures of PX, however a statistical correlation analysis was not done in that study. Martinez et al. [2009] – while investigating affective camera control – presented correlations between basic psychophysiological measures (i.e., heart rate, blood volume pulse, and electrodermal activity) that indicated correlations between heart rate and self-reported values of fun, frustration, and boredom. The digital game used as stimulus was a simple predator-prey simulation game, and it is uncertain if the results can be transferred to major commercial game titles. Finally, Mandryk et al. [2006] reported correlates between psychophysiological measures and specific self-reported measures of boredom, challenge, frustration and fun (based on single-item measures), when playing a hockey computer game, with however, substantial variation between the experiment participants. In this paper, experimental results are reported that address the question of whether self-reported measures of player experience correlate with easy-to-deploy psychophysiological measures in several major commercial games: heart rate (HR) and electrodermal activity (EDA). From the perspective of game development, the main setback of psychophysiological methods is that they are relatively difficult to learn and to deploy compared to qualitative approaches, which rely for example on user feedback and experimenter expertise [Pagulayan et al. 2003]. HR and EDA were selected because they are easier to field than psychophysiological measures, such as EMG, EEG, and fMRI, and therefore more likely to be utilized in an industrial context.

Rather than focusing on a single game, three major commercial First Person Shooter (FPS) games were used: *Doom 3* (Id Software, Inc., 2004), *Prey* (Human Head Studios, Inc., 2006) and *BioShock* (2K games, 2007). FPS was chosen as the game genre because: a) It is the most popular contemporary genre of digital games; b) Action gameplay forms a key part of the player experience. Therefore, measures of arousal would be expected to be ideally suited for this game genre.

Our motivation for the current study is twofold. Firstly, there is little research available about how qualitative and quantitative approaches toward measuring the emotional component of UX correlate. Secondly, empirical research addressing this issue is vital to ensure development of mixed-methods approaches carrying the advantages of quantitative as well as qualitative methods. Given the resource constraints of game-industry-based UX research, exploring the potential of easy-to-deploy psychophysiological measures is relevant.

2 Method

The purpose of the experiment was to address the question of whether there is a correlation between self-reported measures of gameplay experience (i.e., a questionnaire: GEQ) [IJsselsteijn et al. 2008] and physiological measures of arousal. The research study presented here is exploratory research and not hypothesis-driven.

2.1 Measures

Self-report data: The *In-Game Experience Questionnaire* (iGEQ) is a short self-report scale for exploration of player experience during playing a digital game [IJsselsteijn et al. 2008]. The iGEQ has been tested multiple times under various experimental conditions together with psychophysiological measures, such as EMG, [e.g., Nacke and Lindley 2009; Nacke 2009]. It contains 14-items, all rated on a Likert-type scale scored from 0-4, distributed in pairs between seven dimensions of player experience: 1) Immersion (sensory and imaginative), 2) Flow, 3) Competence, 4) Tension, 5) Challenge, 6) Negative affect and 7) Positive affect.

Heart Rate: The heart forms part of the cardiovascular system and includes the organs regulating blood flow in the body. The cardiovascular system offers a variety of measuring options to determine valence or arousal, including Heart Rate (HR), which has been correlated with player arousal before [e.g., Mandryk et al. 2007; Mandryk 2008].

Due to activation of the central nervous system when people experience physical arousal, sweat is produced in the *eccrine* glands, which measurably changes the conductivity of the skin. The sweat glands used for measurement are typically those in the palms of the hand or the soles of the feet [Boucsein 1992]. Research using picture stimuli have shown EDA to be highly correlated with self-reported emotional arousal (e.g., [Cacioppo et al. 2007], also in a digital game context [Ravaja 2004]), reflecting emotional responses and cognitive activity [Boucsein 1992]. Finally, EDA is one of the most straight-forward and low-cost psycho-physiological measures [Mandryk et al. 2007; Nacke 2009].

Electrodermal activity (EDA): Measures of EDA are also known as skin conductance levels (SCL) or galvanic skin response (GSR) when analyzing phasic physiological reactions to game events [Ravaja et al. 2008]. EDA measures the electrical conductivity of the skin (see Figure 1 for an example of EDA sensors).

For the two physiological measures, the *Garmin Forerunner 50* sport watch with HR monitor and the *Thought Technologies ProComp Infiniti* bio sensor system were utilized. The Garmin device measures HR by means of a wireless heart-rate monitor strapped around the chest of the test subject, while the *ProComp* device measures EDA through two sensors attached to the ring and little finger on the mouse-using hand (these fingers are not used during mouse operation and therefore the least intrusive). In addition to the physiological measurements, the test participants and the computer screen were video-recorded for later analysis of facial expressions.

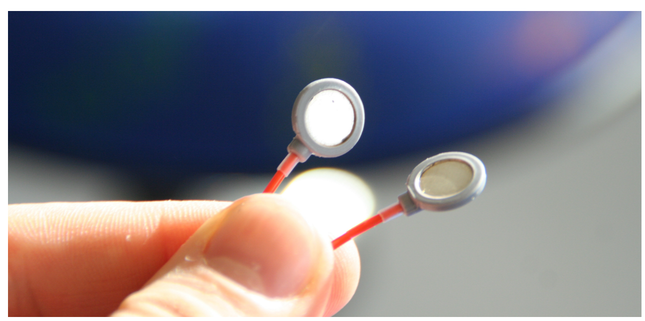

Figure 1: *EDA sensors, used in a variety of psychophysiological experiments, where they are usually taped to the participants palm, fingers or toes.*

Three digital games selected for the experiment (*Doom 3, Prey* and *BioShock* (see Figure 2)). All three games are in the FPS genre, with the player controlling a single character in first-person view, set on a medium/default difficulty, and played in single player mode. For each game, a level/map was selected, which occured after the introduction of the characters and the introductory storyline, albeit early in the game storyline.

2.2 Test procedure

A repeated-measures experimental design was used, with 3 levels of 1 independent variable (*Prey*, *Doom 3* and *Bioshock*) and 3 dependent variables (EDA, HR, iGEQ). Measures were ratio scale (HR, EDA) or interval scale (iGEQ). All datasets were found to conform to the requirements for parametric statistical evaluation: Normal distribution using the Kolmogorov-Smirnov test; and homogeneity of variance using Levene's test, run using SPSS.

Each participant (N = 16) was given a consent form, and introduced to the experiment. Basic demographic data and previous game experiences were noted. Sensors were fitted and tested, with baselines one minute in duration being run prior to the participant starting to play each game. The participants played each game for 20 minutes, following an introduction to the game controls if needed. Players were also given as much time as needed to familiarize themselves with the game. Every five minutes, the game was paused and the participant completed the 14-item iGEQ. The five-minute interval was chosen following consultation with experts in psychophysiological experimentation and games. Given the relative novelty of research area, the optimal baselines remain unknown for a compromise between obtaining as many measures as possible during one play segment and allowing players to play the game reasonably uninterrupted. In the current case, shorter intervals were tried during pilot testing, but it was found that testers would express frustration if self-report surveys were too frequent and if they took too long to complete. This emphasized the benefit of using the quick-to-complete iGEQ: Participants would usually complete the survey in less than one minute. After 20 minutes, the players were briefly interviewed about their playing experience. Participants played the games in random order. Seating was adjusted to the height of the participant. Sixteen participants were included in the experiments, resulting in 192 completed iGEQs, 64 per game. 4 participants were novice gamers, 6 intermediate and 6 hardcore gamers, scored via a short survey.

Figure 2: *Screenshots from the three FPS games used in the experiment. (top) Prey – developed and published by Human Head Studios, Inc. (2006). (middle) Doom 3 – developed by Id Software, Inc., and published by Activision Publishing, Inc. (2004). (bottom) Bioshock – developed and published by 2K games (2007). All images © the respective publishing companies.*

2.3 Data Processing

The MATLAB program developed by Yannakakis et al. [2008] was modified to be used to denoise the data (via discrete Fourier transformation and moving-averages) in preparation for feature extraction and analysis. In is worth noting that the *ProComp Inifiniti* outputs a blood volume pulse (BVP) signal which allows HR to be induced through linear extrapolation of the beats detected within BVP (as a backup to the *Garmin Forerunner 50*). The denoising and feature extraction process is a multi-stage process, consisting of an initial noise reduction process using discrete Fourier transformation and a moving average. The resulting noise-reduced signal is used directly for feature extraction (e.g., *EDAmin*; *EDAmax* and *EDAavg*). For a full description of the process, please see Yannakakis et al. [2008]. Ninety-five percent of the HR-data were of sufficient quality to be used for further analysis. For the *EDA* data, a faulty sensor unfortunately corrupted 31% of the samples, leaving 69% of the data following the denoising and feature extraction process.

A variety of measures were extracted from the psychophysiological measures. However, the focus of this analysis will be on the tonic average values for each 5-minute segment. The psychophysiological measurements were subsequently denoised and adjusted after the average of the three recorded baselines. Different algorithms exist for normalizing physiological features to baselines. In the current experiment, a simple normalization was used (where the average value for the feature for each 5-minute segment was divided with the average value from all three baselines recorded per participant). Each segment came with a completed iGEQ per participant. By normalizing HR and EDA data with the average HR/EDA, the game-related effects are isolated. Pearson's correlation coefficient was calculated between iGEQ values and normalized physiological data across the three games (single-feature analysis).

3 Results & Discussion

The focus of the analysis was to investigate the correlation between the average five-minute physiological measurements for EDA and HR (baseline-adjusted) values and the seven dimensions of the iGEQ questionnaire. The results indicate that there is covariance between the psychophysiological measures of HR and EDA. However, different strengths and patterns emerge in the covariance (see Table 1). HR correlations with the iGEQ dimension result in Pearson's correlation coefficients that are statistically significant across the seven components, with a p <

Physiological measures	Competence	Immersion	Flow	Tension	Challenge	Negative affect	Positive affect
HR	-0.36	-0.43	-0.25	0.37	-0.31	0.24	-0.42
EDA	-0.08	-0.23	-0.24	0.02	-0.18	0.38	-0.20

Table 1. *Pearson's correlation coefficient between GEQ dimensions and physiological measures (N = 27). For heart rate, significance was at least p < 0.01 for all GEQ dimensions, while EDA only was significant with the GEQ negative affect dimension (difference in dataset size means difference in r-critical values). HR was recorded as beats per minute (measured every five seconds), EDA was measured in µS.*

0.01, at medium-scale effect sizes ($0.3 < r < 0.5$), with only Tension and Negative Affect providing positive *r*-values. EDA provided a significant positive correlation with the Negative Affect dimension, and no significant correlation with any other components.

3.1 iGEQ survey

The iGEQ survey data do not indicate a statistically significant difference among the participants for any of the three games (see Figure 3). Comparing the experience level of players with iGEQ data, indicates that the positive dimensions of the survey are rated highest by the hardcore gamers, whereas the negative dimensions are rated the lowest. In comparison, novice gamers rate the negative dimensions of the iGEQ survey higher, and positive dimensions lower (see Figure 4). Given that hardcore gamers play games more often, it could be assumed that they derive enjoyment from the interaction, possibly to a higher degree than novice gamers. Going into more detail, the hardcore gamers generally rated Prey higher than novice and intermediate gamers in all seven iGEQ-dimensions (lower rating for Tension and Negative Affect).

In the post-game interviews, the hardcore gamers generally note that they found *Prey* to be the most interesting game due to the added element of puzzle solving, which added a new dimension to the gameplay (it does not exist in *Bioshock* and *Doom 3*). In comparison, most novice and intermediate gamers in the experiment noted that they had problems solving the puzzles in the segment of the game chosen for the experiment.

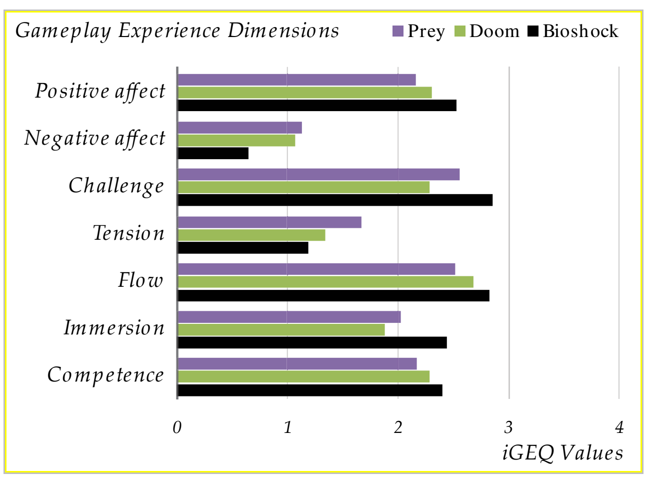

Figure 3. *iGEQ scores across the seven dimensions of Gameplay Experience, for the three FPS games used in the experiments.*

3.2 Heart Rate

HR correlates negatively with the iGEQ dimensions of Competence, Immersion, Flow, Challenge, and Positive Affect, but positively with Tension and Negative Affect. These results indicate that, in FPS games, a high HR is indicative of players feeling tense and frustrated. Similarly, a low HR is indicative of Positive Affect, achieving the Flow-state, feelings of competence and immersion and low levels of challenge. To supplement Pearson´s correlation, a series of scatterplots were produced for the different features derived from the Garmin-HR data and the different iGEQ-dimensions. These indicated a strong negative correlation between minimum *HR*, average *HR* and maximum *HR* and the Immersion dimension. In essence, the lower the minimal HR of the participant during a 5-minute measurement interval, the higher the reported feeling of Immersion, Competence, Flow, Challenge and Positive Affect – the positive dimensions in the iGEQ survey. Conversely, higher minimum, average, and maximum *HR* scores correlate with high scores in the negative dimensions in the iGEQ survey: Tension and Negative Affect. These results indicate that a high average *HR* value is indicative of player frustration, which can explain the covariation with the Tension and Negative Affect dimensions of the iGEQ. In contract, Mandryk et al. [2006] reported no correlation between HR and subjective measures of e.g. frustration and boredom in one of two experiments, with a single case of correlation in the other experiment presented.

An interesting contrast to prior studies exists. In an experiment of Mandryk et al. [2007], an ice hockey game was used, where two participants played against each other. While the FPS games used in the current experiment are similarly fast-paced games, they were played in single-player mode. This means that the player could directly control the pace of the game, possibly causing a difference in the experimental results. If this explanation is correct, it indicates that different games may have different relationships between psychophysiological signals and self-reported UX. Since the results provided here are consistent across three different FPS, it might be the case that correlates between HR and self-reported UX-dimensions are consistent in game genres/types.

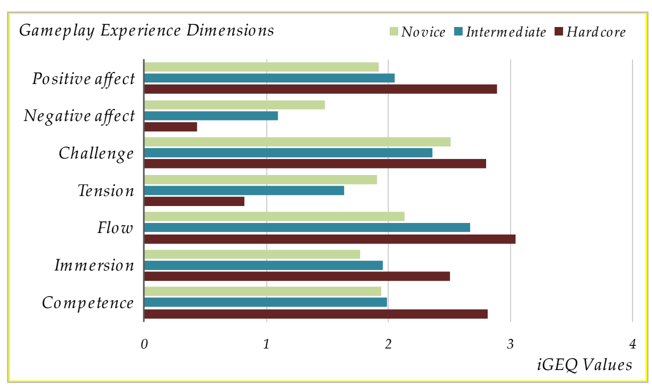

Figure 4. *iGEQ scores across the seven dimensions of user experience, for the three FPS games used in the experiments, as a function of participant experience level.*

3.3 Electrodermal Activity

Mandryk et al. [2007] noted that high EDA values correlate with high arousal and that a high level of arousal can be indicative of a high level of challenge, frustration, and/or excitement. Mandryk et al. [2007] were supported by Frijda [1986], who stated that there is a correlation between EDA and task difficulty, with EDA being elevated during the execution of difficult tasks. In the current experiment, it was similarly found that EDA correlates with Negative Affect (frustration). However, there is no significant correlation with the Challenge dimension of the iGEQ-survey. The explanation for the disparity in the results may be related to the phrasing of the two questions in the iGEQ-survey which comprise the items measuring the Challenge dimension [IJsselsteijn et al. 2008]:

1. I felt challenged
2. I felt stimulated

The first of these questions is clear in its reference to the feeling of challenge while playing. However, the second refers to a positive feeling of stimulation, without making this more precise. This question also does not correlate with the definition of challenge utilized by Frijda [1986] and Mandryk et al. [2007]. This indicates that the Challenge dimension, as defined by the iGEQ survey, has the opposite relation to EDA as compared to Challenge as defined by Mandryk et al. [2007] and task difficulty as defined by Frijda [1986]. This shows the complexity of the challenge construct within gameplay experience, since challenge may come from multiple sources and may also be of dissimilar types using the same general type of gameplay. It might indicate that the feeling of challenge while playing a digital game is a multi-dimensional experiential construct and that the iGEQ survey taps into different aspects of this construct compared to EDA measures or the physiological measures used by Mandryk et al. [2007] or Nacke [2009]. It may also, in general, be possible that there is a more complex non-linear relationship between the physiological measures and iGEQ items that cannot be captured with linear correlation methods.

4 Conclusion

There is an increasing body of evidence supporting the application of psychophysiological measures to user interaction with games [e.g., Ravaja et al. 2008; Nacke 2009]. The results of the experiments presented above indicate that physiological measures correlate with gameplay experience components, even in relatively simple measurement scenarios as the one presented here.

Additional empirical work is needed, in order to establish whether “quick & dirty” approaches toward comparing user-feedback with physiological measures are feasible within a game development context. Finally, the interpretation of psychophysiological measures and data is dependent on the context and research approach, and thus, the interpretation of these measures in the context of digital interactive entertainment requires more study and validation before consistent results can be ensured [Nacke 2009]. Future work will address these gaps in our current knowledge, with increased sample sizes and testing scenarios across different game genres. Moreover, the iGEQ (being Likert-scale based) may provide noisy interpretations of subjective player experience. Further analysis and tests will be needed to investigate the level of noise existent in the data. On that basis, other statistical measures need to be evaluated and a non-linear analysis of the relationship between physiology and player experience will be required. One approach in this direction could be the application of artificial neural networks to the analysis process [Yannakakis et al. 2008]. Despite the novelty of this research area, and the limited empirical results available, psychophysiological UX testing is emerging as a research area concentrating on the collection, analysis, and cross-correlation of physiological data. New input sources provide extensive information about users’ mental and emotional states. This is important in a digital gaming context where a pleasant UX is vital to the success of the game [Pagulayan et al. 2003].

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