Wiimote vs. Controller: Electroencephalographic Measurement of Affective Gameplay Interaction

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ABSTRACT

Psychophysiological methods provide covert and reliable affective measurements of user experience (UX). The nature of affective UX in interactive entertainment is currently not well understood. With the dawn of new gaming consoles, scientific methodologies for studying user interaction in immersive entertainment (e.g., digital gaming) are needed. This paper reports a study on the influence of interaction modes (Playstation 2 game controller vs. Wii remote and Nunchuk) on subjective experience and brain activity measured with electroencephalography (EEG). Results indicate that EEG alpha and delta power correlate with negative affect and tension when using regular game controller input. EEG beta and gamma power seem to be related to the feeling of possible actions in spatial presence with a PS2 game controller. Delta as well as theta power correlate with self-location using a Wii remote and Nunchuk.

Categories and Subject Descriptors

K.8.0 [**General**]: Games – *Personal Computing*; J.4 [**Computer Applications**]: Sociology, Psychology – *Social and Behavioral Sciences*; J.3 [**Life and Medical Sciences**].

General Terms

Design, Human Factors, Theory.

Keywords

Psychophysiology, affective computing, entertainment, user experience (UX), digital games, electroencephalography (EEG).

1. INTRODUCTION

Digital games as a form of immersive media entertainment have matured in their content and interactive design in recent years. The global gaming market is predicted to grow at a compound annual rate of 9.1% to $48.9 billion in 2011 [27]. One of the main questions in the game industry is what exactly makes games successful at their very core. In light of this, evaluating the design and user experience (UX) of gaming interaction is an open research challenge. With the advent of the Nintendo Wii on the game market, a growing shift of investigations in game research labs and industry is happening with a focus on human computer interaction (HCI). Industry examples for this trend are Microsoft's announcement of Project Natal and Sony's planned use of the Eye Toy as an input tracking technology for novel game interaction, dubbed PlayStation Move. Hence in research, digital games are being studied from a UX perspective [24], which focuses on user-centered design implications from the affective experiences in digital games.

While gaming consoles continue to implement different forms of interactions, tangible and affective forms of interaction are becoming more popular in desktop software design as well. For software and product evaluation studies, this marks a shift from analyses that center on usability to those that are looking at UX with focus on human aspects of interaction, such as the behavioral, perceptual, emotional, and cognitive capabilities of people. This trend indicates that now is a good opportunity for HCI researchers and practitioners to evaluate new methodologies for studying game interaction. The study of interaction in digital games may inform the interface design of new controllers or the interaction design process in entertainment and desktop applications [17].

Most UX research (in games and in general) utilizes qualitative approaches such as usability evaluations, playtesting, interviews and focus groups, and surveys [24]. For entertainment systems, we are unable to define the same success metrics as for desktop systems, so that regular usability metrics (e.g., task completion time, errors) would have to be adapted to work as metrics of in-game behavior (for an example see [35]). More important than performance measures, however, is the evaluation of the emotional and cognitive experiences provided by game technology and virtual environments. One of the current research problems for game interaction evaluation is what mental processes relate to which experiential constructs and how to measure them. Establishing such a methodology and correlations for assessing cognitive underpinnings of gameplay experience will be beneficial for game researchers and developers as well as for affective computing researchers in the UX community.

In the HCI community, we have recently seen studies that use sensor technology [6, 23] to study complex human experience in the process called gameplay [19, 21], and assess UX in digital games [8, 18, 22]. More specifically, studies have evaluated the usability of user interfaces [33] and software learnability [34] with the help of electroencephalography (EEG). While other non-invasive techniques for measuring brain activation, such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and functional near-infrared spectroscopy (fNIR) exist, EEG is most common because of its relatively easy application in comparison to fMRI and PET. Major limitations of fMRI and PET are, among others, the price, apparatus size, re-

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quired shielding, digestion of a radioactive tracer (PET), and how prone PET scans are to motion artifacts. Hence, these technologies are hardly used in HCI research. More recently, the emerging fNIR technique has gained more attention in HCI research [10]. It uses near-infrared light to spot oxygenated and deoxygenated hemoglobin in the blood flow of the brain as indicators of mental activity. As the technology matures, it will be worthwhile to investigate fNIR as a future supplement to the more established EEG analysis.

Nevertheless, in this paper the traditional EEG approach is used to get a better understanding of UX in games. In addition to the use of psychophysiology in HCI research, we are also seeing more studies that apply neurological and affective methods for examining human experience in design practice [1, 13].

In conclusion, psychophysiological methodology provides relatively non-intrusive, covert and reliable measurements of affective states influencing UX, which makes it suitable for studying interactive entertainment [28] and possibly evaluating game and interaction design.

In this paper, we will use EEG and subjective questionnaires to establish correlations between EEG activity patterns and described gameplay experience. The paper makes the following contributions to HCI and UX research:

1. We present a methodology for affective evaluation of UX in interactive entertainment using EEG signals and subjective surveys. The innovation of this methodology is that it links cumulative brain activity on different frequencies to subjective ratings of experiential phenomena. It builds on prior work that studied relationships between frontal asymmetry and subjective experience [29].
2. The results from our experiment point to a link between EEG beta activity and spatial presence (SP) action possibilities [36] as well as gamma activity and SP action possibilities for PS2 game controller input. There was also a link between theta activity and SP self-location and delta activity and SP self-location for Wii remote and Nunchuk (from here on called *Wiimote*) input. Finally, we could find indicators that alpha activity and negative affect may be related on both Wiimote and regular controller interaction. Thus, EEG activity may be a sign of Wiimote controller input being more intuitive (decreased theta and delta is indicative of lower task load) for a point-and-shoot style game.

2. RELATED WORK

2.1 Brief Introduction to Gameplay Experience

IJsselsteijn, Poels, and de Kort theorized that *immersion*, *tension*, *competence*, *flow*, *negative affect*, *positive affect*, and *challenge* are important elements of gameplay experience and developed a game experience questionnaire (GEQ) to assess these elements [11]. The questionnaires are employed in this paper's study. Preliminary results linking these dimensions to frontal EEG asymmetry during cooperative and competitive play were presented recently [29]. In addition, we have seen investigations on spatial presence (SP) that have successfully linked psychometric presence questionnaire data [36] and EEG activity in a non-interactive virtual reality environment [2]. Spatial presence is a two-dimensional construct in which the core dimension is the sensation of physical location in a virtual environment and the second dimension entails the perceived action possibilities (i.e., individuals only perceive possible actions relevant to the virtual mediated space) [37]. Presence, in general, is often defined as a state of mind (i.e., being transferred to a virtual location) or a characteristic of people's experience, while immersion, in contrast, is often seen as a technological characteristic.

This motivated us to investigate the ties between mental activation and SP, since prior studies did not investigate tonic EEG power differences for game interaction modes and did not establish correlations of brain wave frequencies with subjective experience. From an interaction design perspective, we see designing game input modalities and interactions with a digital game as a primary driver for game design innovation. Thus, our main goal here is to establish a correlation of EEG activity measures and subjective reports as a methodology for understanding gameplay design. While we consider EEG to be complementary to many other measures of gameplay experience (e.g., electromyography (EMG) or focus group interviews), it is outside the scope of this article to explore all of these measures in detail.

Gameplay experience may consist of many factors, but the most discussed ones in related literature are immersion [14], presence [32, 37], and flow [5]. Jennett et al. [14] give an extensive conceptual overview of immersion and define it as a gradual, time-based, progressive experience that includes the suppression of all surroundings, together with focused attention and involvement in the sense of being in a virtual world. Flow is described as a holistic sensation and peak experience [5]. Hence, complete mental absorption in an activity is fundamental to this concept, which ultimately makes flow an experience mainly elicited in situations with high cognitive load likely accompanied by a feeling of pleasure. All of these three experiential concepts deal with the allocation of attention or mental processing in gameplay, which indicates the dedication of cognitive capacities for experiencing the game. The study of mental activity, such as EEG activity, is therefore a plausible approach to researching gameplay experience.

2.2 EEG Basics

Typically, an EEG represents the voltage recorded between two electrodes on the scalp.

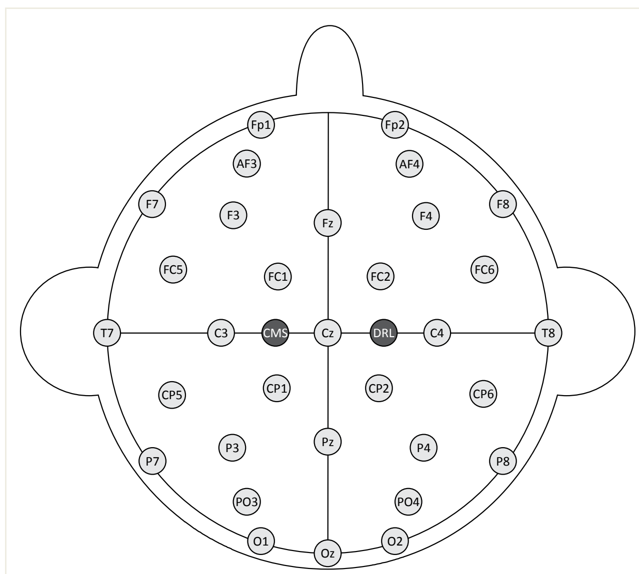

Figure 1. Locations of 32 EEG electrodes of the Biosemi ActiveTwo system. The two ground-equivalent electrodes are active common mode sense (CMS) and passive driven right leg (DRL) electrodes.

Electrodes are placed in standard positions on the scalp via a cap adhering to the international standard 10-20 system [12] or its extended version [4] known as the 10% system, illustrated for our specific example in Figure 1. Each electrode is color-, letter- and number-coded to indicate its positioning (frontal (*F*), parietal (*P*), temporal (*T*), occipital (*O*), central (*C*); even numbers denote the right hemisphere and odd numbers the left, z indicates a central position). The neural signals recorded with an EEG are just a rudimentary representation of neural activity, since the electrodes only register the attenuated signal of neuronal activity near the brain's surface. Thus, signals need to be appropriately filtered before analysis to be distinguishable from for example muscular scalp activity.

We recorded brain activity using 32 BioSemi pin-type active electrodes and did not use a ground or reference electrode, because the BioSemi Common Mode Sense (CMS) active electrode and Driven Right Leg (DRL) passive electrode replace the ground electrodes used in conventional systems. The signal is then typically average referenced before any further analysis. This analysis generally includes the calculation of spectral power averages in several frequency bands, such as alpha (e.g., 8-14 Hz), beta (14-30 Hz), theta (4-8 Hz), delta (1-4 Hz), and sometimes gamma (30-50 Hz); for more details see [3]. Alpha power increases have been associated with cortical inactivity and mental idleness. Beta activity is most evident in the frontal cortex and has been connected to cognitive processes, decision making, problem solving and information processing. Theta activity seems to be related to daydreaming, creativity, intuition, memory recall, emotions and sensations. Delta activity is most prominent during deep sleep and could be associated with unconscious processes, such as fatigue or trance, while gamma is used rarely because of frequency overlap with muscle activities on the scalp.

2.3 Evaluative use of EEG in Game Research

HCI researchers have made use of EEG for classifying cognitive and memory work load [7], for task classification [16], for monitoring task loading to improve the usability of interfaces [33], and in assessing learnability by discriminating EEG activity averages of top and weak performers [34]. In addition, we have seen much research effort in the area of brain-computer interfaces (BCI) in recent years [38], especially as an input device for game interaction [15, 20, 23], while only a few studies have used EEG as an analytical tool for validating and improving game designs.

EEG studies on game players have shown increased frontal and parietal alpha activity during a racing game [31], increasing theta activity during long gaming tasks as an indicator of mental load [9]. Another study has investigated EEG modulation of children during digital gameplay activity [25]. The study found frontal midline theta activity to increase and alpha activity to attenuate as mental load in games increased. Event-related EEG data was reported for wounding and killing events in a digital console game [30]. Both events evoked increased occipital theta activity, while wounding showed an increase in occipital high theta activity and killing showed a central low alpha asymmetry.

In summary, EEG has been used to study activity during gameplay, but most common is the study of mental load or alpha differences. Only a few current baseline findings of differences in EEG spectral power estimates have been reported. No direct correlation between cumulative EEG activity and subjective gameplay experience constructs exists, although we have recently seen research approaching this area [29]. In our work, we aim at providing a more complex investigation of relationships between subjective experience and EEG activity using two different forms of gaming input. One of the driving questions for this research was to assess whether a gaming input device will result in measurable experience differences.

3. USER STUDY

The overarching objective of this experimental study was to help us understand how we can use EEG to measure affective gameplay interaction during an immersive gaming task. Thus, we picked a highly atmospheric horror video game to encourage an affective interaction experience. We chose the console horror video game "Resident Evil 4" (Capcom, 2005). The main task in the game is to survive in a gruesome environment by killing Zombie-style enemies with a point-and-shoot interaction from a third-person perspective. Participants were asked to play the game on a Sony PlayStation 2 (PS2) console using a regular DualShock 2 analog controller and on a Nintendo Wii using a Wiimote (see Figure 2).

Figure 2. Measuring EEG activity during playing games with different interaction devices. Shot taken from experiment during Wiimote condition.

The first village level in the game was used for this study, because it is almost identical on both consoles, except for the point-and-shoot game interaction mechanic, which I will describe in detail later in this section.

3.1 Participants

Thirty-six (7 female) Swedish undergraduate university students and employees participated in this experiment. Their age ranged between 18 and 41, having an average (M) age of 24 (Standard Deviation [SD] = 4.9). Twenty-six participants indicated playing digital games at least once a week. When asked to self-estimate their skill in digital games, 17 participants rated themselves as casual gamers, 14 as hardcore gamers, with five abstentions. Twelve participants preferred playing single-player games, while 24 participants preferred multi-player games (12 of which liked to play co-located via system link on a console). Ten participants had played the game "Resident Evil 4" before, while 26 had never played it. Three participants were left-handed. Thirty-four participants had full hearing capacity. Inclusion criteria for the frequency analysis were right-handedness and correctly recorded raw data from all electrodes. This lead to including 27 participants (6 female), aged between 19 and 41 years (M = 23.9, SD = 5.1) in the analysis after screening the raw data.

3.2 Design

We employed a repeated-measures, within-subjects design, with game interaction mode as an independent variable in two conditions: *classic gamepad input on a PS2* and *point-and-shoot remote input on a Wii*. We were especially interested in differences in EEG spectral power activity for the alpha, beta, theta, delta, and gamma frequency bands in the two game interaction modes (IM: PS2 × Wii). We employed survey measures to see whether we could correlate spectral power in bands to the questionnaire results. Participants played under each condition in a shifting order (AB, BA) to eliminate repeated-measures effects (using a counter-balanced Latin Squares design). Physiological EEG responses were recorded for each session, as well as questionnaire answers.

3.3 Procedure

The experimental sessions were conducted in a European game interaction laboratory during weekdays. The approximate time of each experimental session was one hour. Before the experiment began, participants confirmed that they had filled out a demographic and psychographic screening questionnaire on the web. After a brief description of the experimental procedure, each participant filled out two forms. The first one was a compulsory "informed consent" form (with a request not to take part in the experiment when suffering from epileptic seizures or game addiction). The second one was an optional photographic release form. Participants were then seated in a comfortable office chair, which was adjusted according to their individual height. The electrodes were attached and participants were asked to relax. During this resting period of approximately 5 minutes, baseline recordings were taken. The laboratory room was normally illuminated during the resting period and game session.

Next, participants were seated in front of a 32-inch cathode-ray tube television monitor, which was connected with a PS2 and a Wii via a 21-pin SCART connector. Participants played a game session of Resident Evil 4 on each console in a counter-balanced order. A saved game was loaded, so that each participant played 2 × 10 minutes (maximum time) of the same game segment, once on a Wii and once on a PS2. After completion of the experiment, all electrodes were removed; the participants were debriefed, thanked, and paid a small compensation (100 SEK) for partaking.

3.4 Game and Player Interaction Materials

The game used in this study was the survival horror third-person shooter game "Resident Evil 4" (Capcom, 2005) known in Japan as "Biohazard 4." In this game, the player takes the role of Leon Kennedy, a U.S. secret service agent, set out to investigate the disappearance of the President's daughter in a rural European village. The game segment played in this experiment was the first combat encounter in the Chapter 1 village, where the player has to battle through slow moving enemy throngs called "Los Ganados." Part of the challenge for eliminating these enemies comes from the slow positioning of the gun to correctly shoot at enemies, who approach players in a speed alternating between slow skulking and rapid dashing.

The content in this part of the game is similar in both console versions; however, of particular interest for our study was the different shooting game mechanic employed by controller interaction on PS2 and the Wiimote. The (PS2) controller interaction mode (IM) allows players to enter shooting mode with a shoulder button and move a virtual laser pointer with the right control stick on the controller to find and eliminate targets. This is a standard IM for many console shooter games. For the Wii version, the shooter mechanic employs a more direct IM, since the Wiimote is used to point at the monitor on which a crosshair appears, allowing for a direct point-and-shoot IM known from laser gun arcade shooter games. For the Wii, the targeting mechanism is a direct mapping of pointing motor action to game interaction and effect, but for the PS2, the targeting mechanism is an indirect mapping of stick-control motor action to game interaction. This study investigates effects of these IMs on brain activity, subjective game experience and spatial presence.

3.4 Equipment and Measures

The equipment used for this study includes electrooculography (EOG) and EEG psychophysiological measurement apparatus. EOG was used for artifact scoring.

3.4.1 Electroencephalographic Measures

We recorded brain activity using 32 BioSemi scalp Ag/AgCl (silver/silver chloride), pin-type active electrodes, with Common Mode Sense (CMS) active electrode and Driven Right Leg (DRL) passive electrode, allowing for interference-free, extremely low-noise recordings. The 32 electrodes were placed on the scalp via a cap adhering to the extended 10-20 system [4, 12], known as the 10% system.

EOG was recorded to correct artifacts from eye movements by placing flat-type active Ag/AgCl electrodes above and below the right eye. Additionally, electromyography (EMG) and electrodermal activity (EDA) were recorded and will form the basis of a future analysis. For EEG electrodes low impedance highly conductive Signa electrode gel was used as a conducting medium. The raw EEG signal was recorded with the ActiveTwo AD-box at a sample rate of 2 kHz, using ActiView acquisition software.

3.4.2 Survey Measures

We used the short version (14 items) of a game experience questionnaire (GEQ) [11] for this study, which combines several game-related experiential measures. The questionnaire was developed on the basis of focus group research [26] and following investigations among frequent players. It consists of the seven dimensions *flow*, *challenge*, *competence*, *tension*, *negative affect*, *positive affect* and *sensory and imaginative immersion* that are measured using 2 questionnaire items (in the short GEQ). Each item consists of a statement on a five-point scale ranging from 0 (no agreement with the statement) to 4 (complete agreement with the statement). In addition, we employed the MEC Spatial Presence Questionnaire (SPQ) [36]. More precisely, we used the spatial presence self location (SPSL) and spatial presence possible actions (SPPA) subscales, each measured with four items. Each item consisted of a statement on a five-point scale ranging from 1 ("I do not agree at all") to 5 ("I fully agree").

3.5 Data Reduction and Analysis

3.5.1 Processing of EEG Data

Raw EEG signals were recorded using ActiView software. The raw data was processed in brain-electrical source analysis software (BESA). A low cutoff filter of 1 Hz (type: forward, slope: 6dB/oct), a high cutoff filter of 40 Hz (type: zero phase, slope: 48 dB/oct), and a notch filter of 50 Hz (with 2 Hz width) were applied. Since the BioSemi system uses no ground electrodes, the signal was average referenced in BESA and first filtered using a semi-automatic artifact correction with +/- 85 µV EOG thresholds. Ten-minute epochs were selected and visually inspected for artifact contamination. Those subjectively interpreted to contain artifacts were rejected for all channels. Average power estimates (μV^2) were calculated using Fast-Fourier Transformation (FFT), which was conducted on artifact-free epochs using two-second blocks (4096 points per block) for averaging and including individual baseline values. The power estimates were calculated for the following frequency bands: Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-14 Hz), Beta (10-30 Hz), and Gamma (30-50 Hz). Spectral power estimates were then averaged over all 32 electrodes for each frequency band and finally transformed using a natural logarithm (ln) to normalize the data distribution (reported as 5 + ln to adjust for positive values).

3.5.2 Statistical Analysis

The band power averages were analyzed in SPSS using repeated-measures analyses of variance (ANOVAs) with IM (PS2 × Wii) as the within-subjects factor and accounting for moderating effects of *gender* (G), *skill level* (SL: hardcore, casual, abstention), *multi vs. single player preference* (PP), and *prior playing experience* (PX) of the "Resident Evil 4" game (on the PS2) as between-subjects factors.

4. EXPERIMENTAL RESULTS

4.1 Results of EEG

Multivariate analysis of variance (MANOVA) showed general effects of IM on band power averages. Specifically, there was a main effect of IM ($F_{5,13}$ = 6.52, p < .01, η_p^2 = .72) on spectral power, showing a general increase of brain activity in the Wii condition. This effect seems to be moderated by SL and PP, since we also found an interaction effect of IM with SL ($F_{10,28}$ = 3.12, p < .01, η_p^2 = .53), and an interaction effect of IM with PP ($F_{5,13}$ = 5.90, p < .01, η_p^2 = .69), as well as a complex three way interaction between SL, IM, and PP ($F_{5,13}$ = 9.28, p < .01, η_p^2 = .78).

4.1.1 EEG Delta Activity Results

There were a number of interesting effects on delta power. A main effect of IM on delta power (1-4 Hz, $F_{1,17}$ = 7.31, p < .05, η_p^2 = .30). This means that regardless of other factors, the delta power (5 + ln[μV^2]) was significantly higher in the Wii IM (*M* = 6.80, *SE* = .08) than in the PS2 IM (*M* = 6.72, *SE* = .07). This main effect seems to be moderated by a number of interaction effects, first an interaction effect of IM and SL on delta waves ($F_{1,17}$ = 4.38, p < .05, η_p^2 = .34).

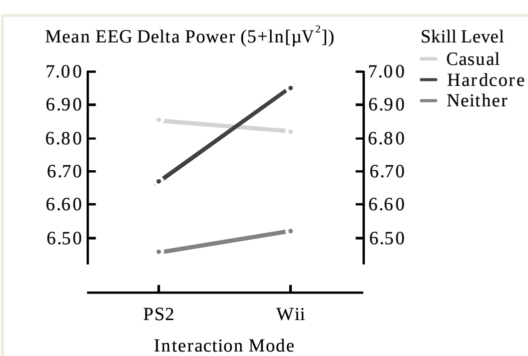

Figure 3. Mean EEG power for delta band, showing greater delta activity during Wiimote interaction

This means that participants, who rated themselves as hardcore players, had higher delta activity with Wiimote interaction than with PS2 interaction (see Figure 3).

For casual gamers and abstentions, there was no significant difference in delta activity between the two conditions, although casual gamers showed a slight attenuation of delta activity in the Wiimote condition. Another interaction effect of IM and PP was found on delta power estimates ($F_{1,17}$ = 4.54, p < .05, η_p^2 = .21). There was a significant increase of delta activity in the Wiimote condition for participants that prefer single player games (M_{PS2} = 6.64, SE_{PS2} = .12, M_{Wii} = 6.77, SE_{Wii} = .12), while this increase was not as prominent for participants with multiplayer preference (M_{PS2} = 6.77, SE_{PS2} = .09, M_{Wii} = 6.82, SE_{Wii} = .97). Finally, an interaction effect of IM and PX on delta activity ($F_{1,17}$ = 5.93, p < .05, η_p^2 = .26) was significant. Similar to the interaction effect of IM and PP on delta, we found that participants that had played RE4 before had a more prominent increase in delta activity (M_{PS2} = 6.59, SE_{PS2} = .13, M_{Wii} = 6.75, SE_{Wii} = .13) than those who had not played it before the experiment (M_{PS2} = 6.75, SE_{PS2} = .09, M_{Wii} = 6.81, SE_{Wii} = .09).

4.1.2 EEG Alpha Activity Results

Another interesting interaction effect was found on alpha power estimates, IM and PX had a significant effect on alpha power ($F_{1,17}$ = 8.34, p < .05, η_p^2 = .33). For participants, who had played RE4 before, we found a noteworthy increase in alpha activity in the Wiimote condition (M_{PS2} = 6.22, SE_{PS2} = .19, M_{Wii} = 6.40, SE_{Wii} = .17), while those who had not played it before the experiment showed attenuated alpha power in the Wiimote condition (M_{PS2} = 6.14, SE_{PS2} = .13, M_{Wii} = 6.08, SE_{Wii} = .11) compared to PS2. In general, people who had played RE4 before elicited higher alpha power.

4.1.3 EEG Beta Activity Results

The same interaction effect (IM × PX) was found on beta power ($F_{1,17}$ = 9.52, p < .01, η_p^2 = .36), but here people who had played RE4 before elicited generally lower beta power. Participants, who had played RE4 before had increased beta activity in the Wiimote condition (M_{PS2} = 6.73, SE_{PS2} = .17, M_{Wii} = 6.93, SE_{Wii} = .16), while those who had not played it before the experiment showed attenuated beta power in the Wiimote condition (M_{PS2} = 7.08, SE_{PS2} = .11, M_{Wii} = 6.99, SE_{Wii} = .11).

Finally, a complex interaction effect of IM × SL × PP on beta power was found ($F_{1,17}$ = 6.72, p < .05, η_p^2 = .28). Hardcore players, who preferred to play in single player mode, showed attenuated beta power in the Wiimote condition (M_{PS2} = 6.73, SE_{PS2} = .40, M_{Wii} = 6.48, SE_{Wii} = .38), while generally having a lower power average than casual gamers or abstentions, for which beta power did not change notably between Wii and PS2. Hardcore players, who preferred to play in multiplayer mode, showed increased beta power in the Wiimote condition (M_{PS2} = 6.83, SE_{PS2} = .13, M_{Wii} = 6.95, SE_{Wii} = .12). The same was true for abstentions that preferred multiplayer (M_{PS2} = 6.40, SE_{PS2} = .40, M_{Wii} = 6.59, SE_{Wii} = .38), while casual players with multiplayer preference showed attenuated beta power in this condition (M_{PS2} = 7.03, SE_{PS2} = .19, M_{Wii} = 6.85, SE_{Wii} = .18).

As an aside, gender seemed to have moderating effects on alpha ($F_{1,17}$ = 8.39, p < .05, η_p^2 = .33), beta ($F_{1,17}$ = 17.93, p < .01, η_p^2 = .51) and gamma ($F_{1,17}$ = 8.88, p < .01, η_p^2 = .34) power, which is likely due to females generally eliciting stronger psychophysiological signals [3].

4.2 Results of SP Questionnaire

Spatial presence self-location was rated significantly different between Wii and PS2 ($F_{1,35} = 4.44$, $p < .05$, $\eta_p^2 = .11$). The feeling of self-location spatial presence in the game world was experience significantly higher using the Wiimote controller compared to the PS2 controller (see Figure 4). Interaction with the Wiimote seems to have facilitated the experience of spatial presence through self-location.

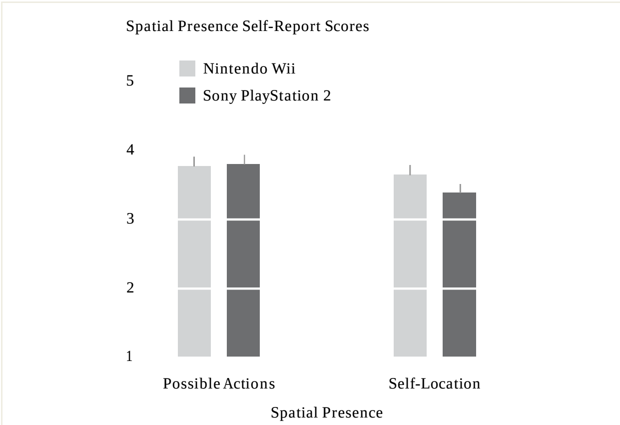

Figure 4. Results of MEC spatial presence questionnaire [36] for our experimental game interaction conditions.

4.3 Results of the GEQ

No significant main effect of IM or other significant interaction effects were found on GEQ results. Thus, although we found significantly different physiological results, subjectively playing with Wiimote and PS2 Controller was experienced equally.

4.4 Correlations of EEG Power and SP Ratings

We ran a correlation analysis (using Pearson's *r*) within the two IM conditions between normalized EEG power averages and SPQ subjective ratings. The correlation results are presented in Table 1.

EEG Band	Interaction Mode	SP Possible Actions	SP Self-Location
Alpha	PS2	.124	-.096
	Wii	-.231	-.275
Beta	PS2	.396*	.311
	Wii	-.166	.058
Theta	PS2	-.097	-.240
	Wii	-.307	-,450*
Delta	PS2	-.122	-.179
	Wii	-.357	-,448*
Gamma	PS2	.413*	.370
	Wii	-.123	.089

Table 1. Correlations (Pearson's *r*) in the two interaction mode (IM) conditions between mean EEG power bands (5+ln[μV^2]) and MEC spatial presence self-report survey answers [36] (N=27). *p < .05.

The pattern that emerges from the correlations of EEG power and SPQ lets us assume that with increasing beta power and increasing gamma power, ratings for SPPA increase when playing with a PS2 controller. On the other hand, attenuated delta and theta power is related to an increase in SPSL ratings when playing with a Wiimote.

4.5 Correlations between EEG and GEQ

We ran another correlation analysis (using Pearson's *r*) for EEG power averages and GEQ ratings, which showed a significant positive correlation between alpha power and negative affect ratings in both IM conditions (see Table 2). Therefore, an increase of alpha power during gameplay with either controller might be related to an increase in subjective negative affect ratings.

For the IM with PS2 controller, there is also a significant positive correlation between tension ratings and alpha power. Thus, the more tension is felt, when playing with a PS2 controller, the more alpha activity is elicited. In addition, delta power positively correlates with negative affect when a PS2 controller is used. Thus, both, delta power and alpha power correlated with negative affect ratings in this experiment. None of the other correlations were significant.

Interestingly, although not significant, is the negative correlation between immersion, as well as flow ratings, with theta power for both IMs. Since increased theta power is related to mental processing, a worthy future endeavor would be to analyze immersion and flow with respect to attenuation in theta activity.

5. DISCUSSION AND FUTURE WORK

In our user study, we found a main effect of IM on EEG delta power, where playing with the Wiimote showed increased delta activity. This is somewhat surprising and hard to interpret, since increased delta power usually indicates sleep or drowsiness. Skill level seemed to have been the moderating factor for this result (see again Figure 3). This could indicate that hardcore players simply did not need to concentrate when playing with the Wiimote. It would be in line with the attenuated beta for single player hardcore gamers in the interaction of IM × SL × PP, which would indicate less information processing for this group when playing with the Wiimote. However, this would contrast the finding that people with prior playing experience of RE4 showed increased beta power with the Wii, possibly because they did not play this version before and information processing was increased for learning the input controls. This could give another explanation for the increased delta activity, since motion interaction with the Wiimote could also have a fatigue effect on players. Thus, the increase in beta power would indicate increased mental effort, together with the physical effort exerted, could rapidly lead to *interaction fatigue* when using the Wiimote. If this *interaction fatigue* is of a physical nature, the alpha power increase we found for the same interaction effect (IM × PX) could be explained as decreased mental activity leading to fatigue in line with findings stating that as mental load in games increases, alpha activity is attenuated [25]. While there is less alpha power than beta power in both conditions, alpha power is still larger in the Wiimote condition. Since all of these explanations are highly hypothetical, main and interaction effects of IM on brain power estimates remain primarily inconclusive in this study.

EEG Band	IM	Positive Affect	Negative Affect	Immersion	Competence	Flow	Challenge	Tension
Alpha	PS2	-.179	.435*	-.153	.042	-.095	.062	.395*
	Wii	-.177	.398*	-.129	.047	-.206	-.045	.249
Beta	PS2	.247	.116	.083	.156	.190	.258	.076
	Wii	-.248	.160	-.055	-.215	-.001	.015	.331
Theta	PS2	-.340	.376	-.315	.028	-.228	-.080	.348
	Wii	-.244	.205	-.291	-.058	-.319	-.113	.206
Delta	PS2	-.256	.425*	-.263	.007	-.202	-.071	.353
	Wii	-.240	.219	-.323	-.057	-.244	-.172	.194
Gamma	PS2	.365	-.024	.132	.158	.215	.217	-.091
	Wii	-.236	-.026	-.045	-.339	.048	-.027	.288

Table 2. Correlations (Pearson's *r*) in the two IMs between mean EEG ($5 + \ln[\mu V^2]$) and GEQ items (N=27). *p < .05.

However, the correlations that were found between brain power estimates and subjective questionnaire ratings paint an interesting picture of brain power counterparts to subjective experience. First, the interesting correlation of alpha power and negative affect seems to support the notion that if players are not positively challenged, it might be due to low mental workload. Alternatively, the other way around: mental idleness may lead to subjectively experienced negative affect. For the PS2, an additional correlation with delta power was significant. Thus, delta power in this case is likely to indicate a state of low mental load or general sleepiness (potentially not triggered by the game, but by external factors), which then leads to the increased negative affect ratings.

Furthermore, the correlation between tension and alpha activity could indicate that when a game is not mentally challenging enough, possibly leading to attentional demand indicated by an alpha power increase, it is experienced negatively tense. Or on the other hand, when a game is too difficult, the player is likely going to lose interest and thus elicit increased alpha power as an indicator for cortical inactivity. For future studies, employing a success metric for playing (e.g., a high score) could potentially lead to interesting correlations of performance and alpha activity.

The correlation results of the spatial presence questionnaire were even more interesting in the game interaction context. The positive correlation between beta and gamma power and the possible action items seem to support the notion that increased mental activity in a game enhances spatial presence through allowing more actions. In the context of RE4, the game controller might have required a significant amount of cognitive processing for the point-and-shoot task, while the more intuitive Wiimote might have required less cognitive processing (therefore the increased delta). Hence, it would not have significantly influenced SPPA. On the other hand, delta and theta attenuation point to an increased sense of self-location (SPSL) with the Wiimote. Participants that had low delta or theta activation felt a stronger sense of self-location. Self-location could therefore also be a construct fuelled by mental activity for the cognitive effort necessary to suspend disbelief and immerse oneself inside the game world. The negative correlations between theta with immersion and flow all support the idea of active cognitive information processing for mental transference to the game world. Positive game experiences in this context might be related to the cognitive effort involved in creating such experiences. Increased delta power does point to the idea that less mental effort is needed when playing with an intuitive interface.

In summary, we have demonstrated that the accumulated use of EEG spectral power and survey measures can help us understand gameplay experience phenomena from a cognitive processing perspective. We have likely witnessed what we would like to call *interaction fatigue* that can result from physical interaction with a game using sensor controllers like the Wiimote. In the future, we would like to supplement EEG analysis with techniques like fNIR, EMG, and EDA to get a more complete picture of emotional and cognitive engagement with interactive entertainment.

6. CONCLUSION

We have shown that EEG evaluation of UX in games is a valuable tool for understanding the neural underpinnings of qualitative descriptions of experience. In addition, we have provided further support for construct validation of the GEQ with the demonstrated correlations of GEQ results and different EEG patterns. Using our established methodology, interaction designers might be able to validate their designs by correlating brain activation patterns with subjective evaluations of interaction design or game design features. Thus, we have achieved a better understanding of the human component, the user of interactive entertainment, in HCI, which can hopefully inspire new design directions for game and interaction design in the future.

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