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Electroencephalographic Assessment of Player Experience: A Pilot Study in Affective Ludology

Lennart E. Nacke[1], Sophie Stellmach[2], and Craig A. Lindley[3]

Abstract

Psychophysiological methods, such as electroencephalography (EEG), provide reliable high-resolution measurements of affective player experience. In this article, the authors present a psychophysiological pilot study and its initial results to solidify a research approach they call affective ludology, a research area concerned with the physiological measurement of affective responses to player-game interaction. The study investigates the impact of level design on brainwave activity measured with EEG and on player experience measured with questionnaires. The goal of the study was to investigate cognition, emotion, and player behavior from a psychological perspective. For this purpose, a methodology for assessing gameplay experience with subjective and objective measures was developed extending prior work in physiological measurements of affect in digital gameplay. The authors report the result of this pilot study, the impact of three different level design conditions (boredom, immersion, and flow) on EEG, and subjective indicators of gameplay experience. Results from the subjective gameplay experience questionnaire support the validity of our level design hypotheses. Patterns of EEG spectral power show that the immersion-level design elicits more activity in the theta band, which may support a relationship between virtual spatial navigation or exploration and theta activity. The research shows that facets of gameplay experience can be assessed with affective ludology measures, such as EEG, in which cognitive and affective patterns emerge from different level designs.

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affect, affective ludology, EEG, electroencephalography, emotion assessment, engagement, game design, gameplay experience, gaming, human-computer interaction, level design, physiological signal processing, player experience, psychophysiology, quantitative study, self-report measures, user experience

Digital games are today among the favorite leisure activities of billions of people around the world. They compete for a share of most people's individual leisure time with other more ordinary activities such as reading books, watching movies, or listening to music. Digital games have matured from their early forms and their focus on a young player demographic to being played by many adults around the world today. In the application area of digital games, we also find novel research challenges for many scientific disciplines—new and old. John von Neumann (1928) was one of the first researchers to discuss games scientifically and establish a theory of games by asking what the optimal strategy would be to achieve a desirable result for a player p_m in a set of n players (p_1, . . ., p_n) playing a given parlor game G. He outlined that the fate of each player is dependent on the actions of his coplayers. An optimal strategy for a player is to evaluate each game situation numerically and choose the best move that is left. According to his theory, a player will try to maximize his or her minimal payoff while minimizing the maximal payoff of the other players. This lead to the establishment of the set of fundamental principles today known as game theory (von Neumann & Morgenstern, 1944), which have been highly influential in economics and as guidelines for strategic behavior.

Huizinga (1949) later focused on the activity of play, especially competition, and its transformative power for cultural development. This was taken up by Caillois (1958), who defined four different elemental structures of gameplay (i.e., the activity of playing a game): *agon* (i.e., conflict or competition), *alea* (i.e., chance), *mimesis* (i.e., imitation or role-playing), and *ilinx* (i.e., vertigo or sudden shock). He also classified games along an activity dimension, ranging from structured *ludus* (i.e., a rule-based playing activity) to unstructured *paida* (i.e., spontaneous playful activity). These works have been highly influential in game design and game research, because they make an attempt to structure gameplay. Thus, scientific studies of games have been around for much longer than the popularizing of the term *ludology* by Frasca (1999) for this field of game research, which is broadly understood as the *study of games*. While the term itself was popularized by the work of Frasca (1999, 2003), it has been traced back by Juul (2005) to an abstract from Csíkszentmihályi (1982).

Modern ludology or game science today draws its research methods and theories from a wide array of scientific communities, such as human-computer interaction (Barr, Noble, & Biddle, 2007; Fabricatore, Nussbaum, & Rosas, 2002), user research (Isbister & Schaffer, 2008; Pagulayan, Steury, Fulton, & Romero, 2004), and psychophysiology (Mandryk, Inkpen, & Calvert, 2006; Ravaja, Saari, Salminen, Laarni, & Kallinen, 2006; Ravaja, Turpeinen, Saari, Puttonen, & Keltikangas-Järvinen, 2008). The improvement of scientific methodologies for studying players and games will help us understand the aesthetics of digital games better and the underlying processes involved in creating individual player experiences. For example, studies from Ravaja (2004), Salminen, Kivikangas, Ravaja, and Kallinen (2009), Mandryk and Inkpen (2004), Hazlett (2006), and Chanel, Rebetez, Bétrancourt, and Pun (2008) have successfully demonstrated how psychophysiological techniques–such as electromyography (e.g., measuring facial muscle contractions) and electroencephalography (EEG; i.e., measuring brain activity with physiological sensors)—can indicate human emotions and cognitive activity during gameplay. Based on these fundamental pioneering research studies, the term *affective ludology* was proposed by Nacke (2009) for referring to investigations of affective player-game interaction to understand emotional and cognitive player experiences (Nacke & Lindley, 2009). Avedon and Sutton-Smith (1971) discussed very early that cognitive implications of gameplay form an important new research area concerning games. Affective ludology should investigate cognition, emotion, and goal-oriented behavior of players from a scientific perspective by establishing rigorous methodologies (e.g., psychological player testing or physiological response analysis of players).

In the experiment presented here—see also Nacke and Lindley (2008a)—we created modifications (i.e., game levels) of a first-person shooter (FPS) for use as experimental stimuli. FPS is a genre of digital games that are action focused and emphasize shooting enemies from a perspective that simulates the view through the eyes of the game protagonist (i.e., the player avatar). Thus, players feel like they are acting directly and explicitly in the virtual game world. In an FPS, the virtual game world is three-dimensional (3D) and simulates an—often hostile—environment with highly realistic graphics and sounds. Part of the display in the first-person view usually shows the weapons or hands of the protagonist and some essential game data in a semitransparent or nonobtrusive way, such as ammunition, health, armor, and type of weapon being used. A major feature of many FPS games played on a personal computer (PC) is that they come with free level editing tools, so-called *mod* (i.e., modification) tools. Sometimes these mod tools consist of the same tools that were used by game developers to create the game, such as level editors, programming libraries, animation applications, texture editors, and compilers. We used the mod tools of the game HALF-LIFE 2 (2004), a science fiction FPS game, to create three different game levels for testing level design guidelines derived from experiential gameplay constructs (boredom, immersion, flow), which will be discussed below. We will refer to these guidelines as level design guidelines (LDGs) for the remainder of the article. The LDGs were iteratively developed by game designers, students, and game researchers and tested for half a year using a pool of students to gather feedback (Nacke, 2009; Nacke & Lindley, 2008a).

The study presented in this article will thus investigate whether and how LDGs influence EEG activity and subjective responses from players. Thus, we pursued two goals with this research: (a) establish a methodology for and (b) discuss the results from an exploratory EEG study in affective ludology. In the following section, we will discuss how the LDGs (for the experiential constructs immersion, flow, and boredom) were established based on related literature and testing. In addition, the game level creation process using mod tools from HALF-LIFE 2 (2004) is described conceptually.

Following this, we will give a quick overview of psychophysiological methodology, especially EEG measurement in a game research context. Next, we present the method and results of our exploratory pilot study. Finally, we conclude with a discussion of the results and future work in affective ludology.

Game Levels Design Conditions for Immersion, Flow, and Boredom

Immersion

Jennett et al. (2008) give an extensive overview of immersion such that it can be differentiated from other concepts of engaging experiences such as *flow* (Csíkszentmihályi, 1990), *cognitive absorption* (Agarwal & Karahanna, 2000), and *presence* (Lombard & Ditton, 1997; Zahorik & Jenison, 1998). They define immersion as a gradual, time-based, progressive experience that includes the suppression of all surroundings (spatial, audiovisual, and temporal perception), together with *attention* and *involvement* within the sense of being in a virtual world. Thus, immersion is likely to share at least some properties with flow, such as a distorted perception of time and contextual surroundings, as well as being engaged in a task that provides challenge to a person. Another account describes three gradual phases of immersion along a single dimension: *engagement*, *engrossment*, and *total immersion*, where total immersion is a fleeting experience of total disconnection with the outside world (Brown & Cairns, 2004). This definition overlaps with flow and potentially presence and points to the problem of no clear boundaries between constructs of gameplay experience. To our mind, immersion could also be an *umbrella* experience, which in its different stages could incorporate notions of presence and flow.

Ermi and Mäyrä (2005) developed the SCI model of immersion, which splits immersive game experiences into *sensory* (S), *challenge-based* (C), and *imaginative* (I) immersion based on qualitative player surveys. *Sensory immersion* can be enhanced by amplifying a game's audiovisual components, for example using a larger screen or a surround-sound speaker system. *Imaginative immersion* describes absorption in the narrative of a game or identification with a character, which is understood to be synonymous with feelings of empathy and atmosphere. The dimension of *challenge-based immersion* conforms closely with the description of flow (Nakamura & Csíkszentmihályi, 2002). More precisely, challenge-based immersion describes the emergent gameplay experience of players balancing their abilities against challenges of the game. The construct we found most distinct in these accounts is sensory immersion and we will later discuss what features a design for sensory immersion could include.

Immersion game level. The immersion game level uses assets (i.e., textures, models, skybox, lights, animations) from the *Ravenholm* (d1_town) set available in the mod tools of HALF-LIFE 2 (2004). Ravenholm is the name of a level in HALF-LIFE 2 that uses a highly atmospheric horror setting to guarantee an affective experience. The layout in bird's-eye view of the game level is shown in Figure 1. We aimed to create a compelling atmosphere by placing lights and special effects in several outdoor areas in this level.

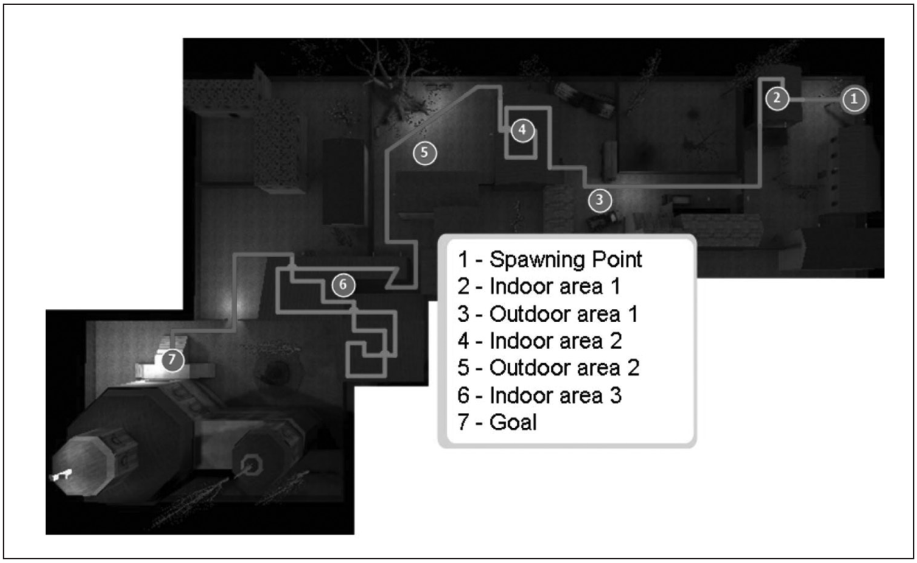

Figure 1. Immersion level overview

This was done to address the aspect of imaginative immersion. However, initial play testing soon showed that a good architectural balance between outdoor and indoor areas was needed so that players would feel like they were exploring a large environment. In addition, a motivation or goal to progress through the level needed to be provided to provide a basic challenge to be overcome (challenge-based immersion); we did so, by placing an indicative text message at the start of the level. It informed the player that the game level goal was to reach the church building (a large 3D model visible from most of the outdoor areas). The path to the church building was linear, meaning that our game level architecture did not allow multiple ways for reaching this building, but all players had to progress through indoor and outdoor combat areas on exactly the same path. A major reason for this was to provide comparable experiences for each player in our experiment. While a game level itself can already be seen as a very complex stimulus for a psychological study, this level was designed to provide the same immersive player progression for each player participating in the study. For the final design, the ratio of indoor versus outdoor areas was equal. Small transition regions between indoor and outdoor areas were created as reward-and-relief points, where players could power up before the next combat encounters. Regarding enemy numbers, subsequent areas were designed to gradually increase the numbers of enemies and their strength. In the early parts of the level, the player engages in little combat with weak enemies and in the later parts, the player has to face multiple combat situations with stronger enemies. This was done to account for the gradual nature of immersion (from engagement to total immersion) as discussed above. Our play tests revealed that players would play this level for

10 minutes on average (depending on the skills and experience of the player with other FPS games). The following design guidelines for an immersion level were created in the process:

- For the FPS game level in the experiment, given a set of indoor level parts I and a set of outdoor level parts O, the immersive FPS game level L should be a set union of outdoor and indoor level parts $L = \{I,O\}$, so that $I \cup O := \{x \mid (x \in I) \vee (x \in O)\}$.
- If we assume a spatial progression unit p to indicate progression through a game level (i.e., the advancement of the player toward a goal), and an enemy type with a certain strength t_m of n enemy types (t_1,..., t_n), the player challenge function $f_{\mathrm{ch}}(p)$ describing an encounter with an enemy type of strength t_m at progression point p should increase exponentially in an immersion and flow level, so that $f_{\mathrm{ch}}(p) = t_m^p$. This would likely provide challenge-based immersion in the SCI model (Ermi & Mäyrä, 2005).
- Given n effects in a game level L with different effect kinds, such as sets containing at least one member of fire effects, $X_f = \{x_{fi}, \ldots, x_{fn}\}$, lighting effects $X_l = \{x_{li}, \ldots, x_{ln}\}$, animations, $X_a = \{x_{ai}, \ldots, x_{an}\}$, and sounds, $X_s = \{x_{si}, \ldots, x_{sn}\}$, L becomes more atmospheric and fosters imaginative immersion if $L = \{X_f, X_l, X_a, X_s, \ldots, X_n\}$, meaning that at least one effect of each kind should be included in the level.
- For a player progression point after a set progression interval p_{i} for n intervals in a game level with $p_i \in (p_1, \ldots, p_n)$, a reward type r_t from a set of n rewards $R = \{r_1, \ldots, r_n\}$ should be given to the player, such as ammunition or health packs.
- "In an ideal immersive scenario S, all play elements ε_p could be similarly parts of a set of narrative elements N and a set of gameplay or ludological elements Λ so that $S = \{\Lambda, N\}$ with $\Lambda \cap N := \{\varepsilon_p \mid (\varepsilon_p \in \Lambda) \Lambda (\varepsilon_p \in N)\}$." However, this was not implemented in this level due to experimental time limitations.

Flow

Csíkszentmihályi (1975) first introduced his flow concept based on studies of intrinsically motivated behavior of chess players, musicians, and sports players. He observed that this group was rewarded by executing actions per se, experiencing high enjoyment and fulfillment in the activity itself. Csíkszentmihályi describes flow as a peak experience, the "holistic sensation that people feel when they act with total involvement." (p. 36) Thus, complete mental absorption in an activity is fundamental to this concept. Arguably, flow is then mainly elicited in situations with maximum cognitive loading in relation to capacity accompanied by a feeling of pleasure. According to a more recent description from Nakamura and Csíkszentmihályi (2002), the conditions for entering an experiential state of flow include the following:

- A matching of challenges or action opportunities with an individual's skill
- Clear and close goals with immediate feedback about progress

It is important to note that these descriptions of prerequisites for experiencing flow have never been empirically tested and are based on a qualitative method called experience sampling, which Csíkszentmihályi used in his conception of flow (Nakamura & Csíkszentmihályi, 2002). Thus, the term *flow conditions*, while being often used, might not be very accurate as none of these conditions was ever empirically tested. Neither are these descriptions clear enough to design a falsifiable hypothesis around them. For example, one would need to be able to break down *challenges* into certain metrically accessible game elements. In combat games such as FPS, these could consist for example of firepower, armor strength, health, or other variables. However, these game elements interact at a very fine-grained level to create player challenges, such as aiming skill. Accurate measurement would require us to assess player skill (and its development over time) as well as to develop a challenge metric that incorporates the gameplay elements in the game creating this challenge. This highlights a major caveat of the prerequisites for entering flow experience, they are in their current definition not empirically testable, and they themselves are based on fuzzy conceptualizations like challenge and skill. The same is true for the definition of clear goals, which begs for a measurable definition of what *clear* actually means. Getting the balance of skills and challenges right is often problematic for game designers, which led Chen (2006) to propose different *flow zones* for hardcore and novice players and an optimal intersection, within which the experience converges toward an optimal match of challenges and abilities.

Another caveat of approaching flow from a level design perspective is the different definitions that are around, because a study by Novak, Hoffman, and Yung (2000) shows there are many different concepts used for studying flow. In their meta-review, they report 16 flow studies between 1977 and 1996, all of which use different concepts and definitions of flow. The only commonly used questionnaire, the flow state scale (Jackson & Marsh, 1996), was designed for sports research and would need extensive adaption of the questions to fit a digital game research scenario. The best we can do for designing a game level for flow is to try to approximate challenge levels of opponents and their placement in a level.

Flow game level. The flow game level uses assets from the *City 17* (d1_trainstation) set available in the mod tools of HALF-LIFE 2 (2004). City 17 assets are used in the first level of HALF-LIFE 2, which takes place mainly inside regular city buildings. The indoor level layout in bird's-eye view of the game level is shown in Figure 2. We decided to only use indoor architecture, so that the player had to follow a very constricted path without any choices to explore the environment. This shifted the focus of the level design to designing incremental combat challenges. The game level features three subsequent rooms that are connected with a door. The door only opens when all enemies within one room are eradicated. Thus, advancing in the game level is only possible by overcoming the combat challenges in each section. The third room has a door at the end that quits

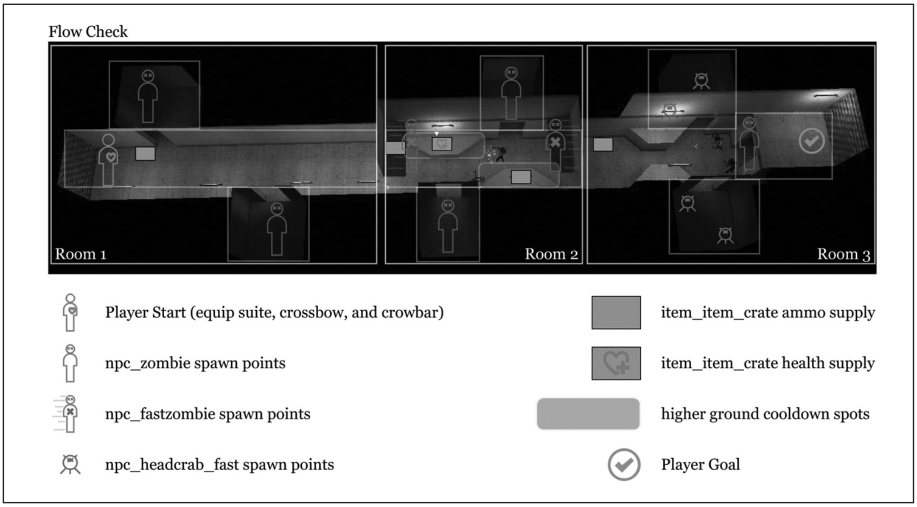

Figure 2. Flow check level design overview

the level. Each death of the player results in restarting the level with the same series of rooms in the same order. No restoration points are set between the rooms and rewards are given at the start of each room, so that the player has to decide whether to first pick up the reward and then engage in combat or the other way around. Rewards were placed in cover spots, which were points of higher ground that blocked enemy attacks of for a short while. The first room features slow melee types of enemies that pose not much of a challenge for experienced FPS players. The second room features both fast and slow enemies, which constantly engage the player into combat. The third and final room has many small and fast enemies that are difficult to attack and avoid. Thus, the only way to survive this last room is for the player to evade the attacks by climbing up a ladder to an exit door. As an extra challenge, the player has only a melee (crowbar) and a slowly reloading sniper weapon (crossbow) with limited ammunition. The ammunition is scattered across the rooms, but not enough ammunition is available to shoot every enemy. We wanted to explore how players react to the gradual combat challenges in this level. The design guidelines that we used for the implementation are the following:

- In a starting room $R1$, given a weapon w and a number of n enemies, the initial amount of ammunition a_i should be equal to half the number of enemies $\frac{n}{2}$ (i.e., $a_i = \frac{n}{2}$). An item crate c_j should contain ammunition of the same amount $a_i = a_j$. Weapon w with ammunition $a_{i,j}$ can eradicate each enemy with one shot.
- In a second room $R2$, given a weapon w and a number of n enemies of different types e_x and e_y, an item crate c_j should contain ammunition $a_j = (e_x + e_y)/2$ and an item crate c_h that refreshes player health by $h = h/2$. Weapon w with ammunition a_j can eradicate enemy type e_x with one shot and enemy type e_y with two shots.

- In a final room $R3$, given a weapon w and a number of n enemies of different types e_x and e_z , no item crates should be available and the speed s_z of enemy type e_z should be more than twice as fast as player speed s_p, so that $s_z > 2 \times s_p$. Weapon w with ammunition a_j can eradicate enemy types $e_{x,y}$ with one shot.
- If we assume a spatial progression unit p to indicate progression through a game level (i.e., each room being a unit) and an enemy type with strength t_m of n enemy types $(t_1, \ldots, t_n)$, the player challenge function $f_{\mathrm{ch}}(\mathrm{p})$ describing an encounter with an enemy type of strength t_m at progression point p should increase exponentially in a flow level, so that $f_{\mathrm{ch}}(p) = t_m^p$. This guideline is similar to the one used in our immersion level and accounts for the potential overlap of challenge-based immersion and flow.

Boredom

Fisher (1993) defines boredom as an unpleasant, transient affective state in which the individual feels a lack of interest in and difficulty concentrating on the current activity. Relating to Csíkszentmihályi's (1975) flow concept, boredom is a state where skills are much higher than the challenge provided by an activity. In his early flow model, it is opposite to what he defines as anxiety, where challenges are too difficult and cannot be matched with the current skill. Boredom in level design could thus be achieved by providing a linear spatial layout. However, boredom in a game context can be seen as the counterpart to engagement (as supposedly elicited by the immersion and flow designs).

Boredom game level. The boredom game level uses assets from the *Ravenholm* (d1_town) set available in the mod tools of HALF-LIFE 2 (2004). The level was designed to evoke a feeling of boredom in reasonably skilled FPS players. In some ways, the level provided a similar environment to the immersion level, but we left out most combat challenges and used an outdoor area with a linear path directly to the goal direction of the level (the church building; see layout in bird's-eye view of the game level in Figure 3). Because boredom can come from repetitive design elements, we used the same enemy type (i.e., slow melee attack zombies) throughout the level. Seeing boredom as a relative experience at the lower end of a scale of engagement, we propose the following design criteria for a less engaging experience:

- Assuming a spatial progression point p to indicate game level progression and a set E of n enemies of an enemy type e_a with constant strength $a = 1$ smaller than player strength $b > a$, the player challenge function $f_{ch}(p)$ for an encounter k with enemies type e_a at progression point p should remain constant throughout the boredom level, so that $\forall n \in \mathrm{E} f_{ch}(p)$.
- Given n textures of texture set T with texture $x_t \in T = \{x_a, x_b, x_c, x_t, \ldots, x_n\}$, in a game level L, L becomes less interesting if containing less elements m of T, so that $L = \{x_t, \ldots, x_m\} \subseteq T$ and $m < n$. This means that less variety in textures will likely be visually boring for the player. The same should be taken into consideration for variety of enemy types, items, 3D models, and sound effects.

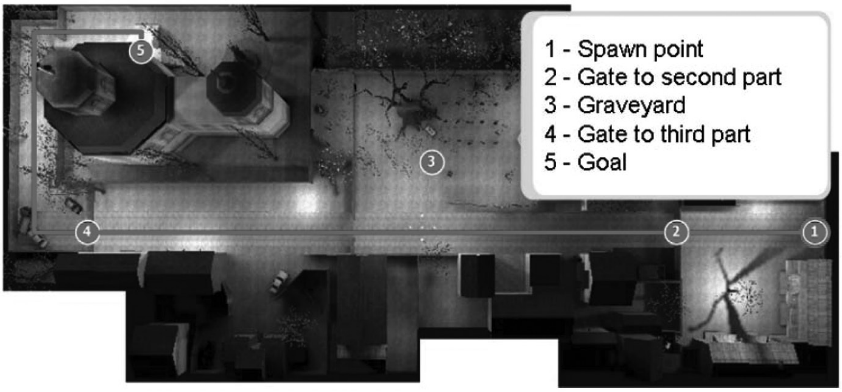

Figure 3. Boredom level overview

- For each progression unit p the player should be constantly rewarded with $n = p$ item crates i that refresh player health value i_n and ammunition value i_a, so that full player ammunition supply $A = \sum_{a=0}^{n} i_a$ and full player health $H = \sum_{h=0}^{n} i_h$ is reached in sum. Constant rewards will likely foster competence and eliminate challenge and motivation, leading to boredom.
- No real winning condition C is given, so that $C = \phi$.

Primer of Psychophysiology and EEG Measurement

In human-computer interaction and user experience research, Norman (2004) has stressed the importance of emotion for cognition and design. For example, he describes a clear distinction between affect and emotion, where affect is a discrete, conscious, subjective feeling that contributes and influences users' emotions while emotion is seen as consciously experienced affect. Psychophysiology investigates the relationships between psychological manipulations and resulting physiological responses per definition, measured in living organisms to promote understanding of mental and bodily processes and their relation to each other (Andreassi, 2000). Specific types of measurement of different responses are not per se trustworthy signs of well-characterized feelings or thoughts (Cacioppo, Tassinary, & Berntson, 2007). In addition, the many-to-one relation between psychological processing and physiological response (Cacioppo et al., 2007) allows linking of psychophysiological measures to a number of psychological constructs (e.g., attention or mental processing). Using an activity profile for a set of physiological variables enables scientists to go into more detail with their analysis and allows a better correlation of physiological and psychological events (Chanel, Kierkels, Soleymani, & Pun, 2009; Mandryk, 2008; Nacke, Grimshaw, & Lindley, in press; Ravaja, 2004).

EEG is one type of psychophysiological measurement. Typically, an EEG measures the voltage recorded between electrodes on the scalp. Electrodes are placed in standard

Figure 4. The electrodes are applied to a participant and EEG electrodes are placed on scalp locations with a cap

positions distributed over the head, usually aligned with a cap (see Figure 4). Each electrode is color- and letter coded to indicate its positioning (e.g., 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 a rudimentary representation of neural activity, because the electrodes only register the attenuated signal of neuronal activity near the brain's surface. Thus, signals need to be appropriately filtered before the analysis to be distinguishable from muscular scalp activity for example.

In our laboratory setup, we recorded brain activity using 32 BioSemi pin-type active electrodes and did not use a ground electrode, because the BioSemi Common Mode Sense active electrode and Driven Right Leg passive electrode replace the ground electrodes used in conventional systems. Thus, EEG activity from the BioSemi system is generally average referenced (i.e., not using a specific reference electrode, but the average electrical activity as a reference). Brain waves are usually described in terms of frequency bands, such as delta (1-4 Hz), theta (4-8 Hz), alpha (8-14 Hz), beta (10-30 Hz), and sometimes gamma (30-50 Hz).

Alpha power increases have been associated with cortical inactivity and mental idleness (Pfurtscheller, Zalaudek, & Neuper, 1998) as well as attentional demand (Ray

& Cole, 1985). Beta activity is most evident in the frontal cortex and is connected to cognitive processes, decision making, problem solving and information processing (Ray & Cole, 1985). Theta activity seems to be connected to daydreaming, creativity, intuition, memory recall, emotions, and sensations (Aftanas & Golocheikine, 2001). Delta waves are most prominent during deep sleep and could be associated with unconscious processes, such as trance (Cacioppo et al., 2007).

In prior studies, EEG was used for classifying cognitive and memory work load (Grimes, Tan, Hudson, Shenoy, & Rao, 2008), for task classification (Lee & Tan, 2006), for monitoring task loading to improve the usability of interfaces (Smith, Gevins, Brown, Karnik, & Du, 2001), and also in assessing learnability by discriminating EEG activity averages of top and weak performers (Stickel, Fink, & Holzinger, 2007). In addition, we have seen much research effort in the area of brain-computer interfaces in recent years (Wolpaw, Birbaumer, McFarland, Pfurtscheller, & Vaughan, 2002), where EEG is used as an input device for game interaction. However, only a few studies have used EEG as an analytical tool for validating and improving game designs, for example, by looking at the brainwave responses to different controller designs for game interaction (Nacke, 2010).

EEG studies on game players have shown increased frontal and parietal alpha power activity during a racing game (Schier, 2000) or increasing theta activity during long gaming tasks as an indicator of mental load (He, Yuan, Yang, Sheikholeslami, & He, 2008). Another study has investigated EEG modulation in children during digital gameplay activity (Pellouchoud, Michael, Linda, & Alan, 1999). The study found frontal midline theta activity to increase and alpha activity to attenuate as mental load in games increased. Event-related EEG data were reported for wounding and killing events in a digital console game (Salminen & Ravaja, 2008). 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, several different approaches have examined EEG 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 so far. No direct correlation between cumulative EEG activity and subjective gameplay experience constructs exists, although we have recently seen research approaching this area (Salminen et al., 2009). One of the driving questions for this pilot study was to assess whether different game levels (designed for boredom, immersion, or flow experience) will result in objectively measurable discrepancies. In the following, we will describe the setup and results of our experiment with focus on cortical activity measured with EEG.

Method

Participants

Data were recorded from 25 male university students, aged between 19 and 38 years (*M* = 23.48, *SD* = 4.76). As part of the experimental setup, demographic data were collected with special respect to the suggestions made by Appelman (2007). All the participants owned a PC and 96% rated this as their favorite gaming platform. All participants play games at least twice a week, while 60% play every day, and 84% played between 2 and 4 hours per day. The preferred mode of play was console single player (44%) or PC multiplayer (36%), while 8% rated PC single player as their preferred play mode. A total of 36% rated FPS as their favorite game type. Of the participants, 44% started to play digital games when they were younger than 6 years, and 40% started between 6 and 8 years old. This leaves only 16% that started to play between 8 and 12 years. Therefore, all the participants started playing digital games before 12 years.

Design

We employed a simple one-way design using game LDGs (boredom, immersion, flow) as a three-level within-subject factor for dependent variables. Dependent variables were EEG spectral power estimates and subjective gameplay experience questionnaire (GEQ) responses.

Procedure

We conducted all experiments on weekdays with the first time slot beginning at 10:00 hours and the last ending at 20:00 hours. General time for one experimental session was 2 hours with setup and cleanup. All participants were invited to a laboratory. 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 next one was an optional photographic release form, which most of the participants signed as well. The participants were led to a notebook computer, where they filled out the initial game demographic questionnaire. 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. Then, the participants played the game levels described above. Each game session was specified to be 10 minute long, but in general participants could finish all game levels before this. After each level, participants filled out a paper version of the game experience questionnaire to rate their experience. After completion of the experiment, all electrodes were removed. The participants were debriefed and escorted out of the lab. None of the individuals received any compensation for their participation in the experiment.

Materials and Measures

EEG. We recorded brain activity using 32 BioSemi scalp Ag/AgCl (silver/silver chloride), pin-type active electrodes and with Common Mode Sense active electrode and Driven Right Leg passive electrode as equivalent to ground, allowing for interference-free, extremely low-noise recordings, with the ActiveTwo AD-box at a sampling rate of 2 kHz and using ActiView acquisition software. The 32 electrodes were placed on the scalp via a cap adhering to the extended 10 to 20 system (Chatrian, Lettich, & Nelson, 1988; Jasper, 1958), known as the 10% system. The raw data were 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. Because the BioSemi system uses no ground electrodes, the signal was average referenced in BESA and first filtered using a semiautomatic artifact correction with ±85 μV electrooculography (EOG) thresholds. Ten-minute epochs were selected and visually inspected for artifacts contamination. Those containing artifacts were rejected for all channels. Average power estimates (μV^2) were calculated using fast-Fourier transformation, which was conducted on artifact-free epochs, using 2-second blocks (4,096 points per block) for averaging. 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 electrodes for each frequency band and finally transformed using a natural logarithm (5 + ln) to normalize the data distribution and eliminate negative numbers.

Game Experience Questionnaire. Different components of game experience were measured using the game experience questionnaire (Ijsselsteijn, Poels, & de Kort, 2008). It combines several game-related subjective measurement dimensions: *immersion*, *tension*, *competence*, *flow*, *negative affect*, *positive affect,* and *challenge*. Each of these seven components consists of 5 to 6 question items (e.g., "I was deeply concentrated in the game" is a flow component item). Each question item consists of a statement on a 5-point scale ranging from 0 (*not agreeing with the statement*) to 4 (*completely agreeing with the statement*). The questionnaire was developed based on focus group research (Poels, de Kort, & IJsselsteijn, 2007) and subsequent survey studies.

Results

Results of EEG

A one-way repeated-measures analysis of variance was conducted using LDG as within-subject factor for dependent variables delta (1-4 Hz), theta (4-8 Hz), alpha (8-14 Hz), beta (10-30 Hz), and gamma (30-50 Hz; 5 + ln[μV^2]). A significant difference for delta power estimates was found during the different LDGs, $F(1.5, 26.97) = 4.10$, $p < .05$, $\eta_p^2 = .19$. For delta power, sphericity was violated, $\chi^2(2) = 6.93$, $p < .05$, and corrected using Greenhouse-Geisser estimates ($\varepsilon = .75$). A follow-up test of repeated within-subject contrasts revealed that LDGs had a different impact on delta and theta power estimates. Delta power was significantly increased during the immersion LDG in comparison with the flow LDG, $F(1, 18) = 4.96$, $p < .05$, $\eta_p^2 = .22$ (see Figure 5). Theta power was also significantly increased during the immersion LDG in comparison to the flow LDG, $F(1, 18) = 5.12$, $p < .05$, $\eta_p^2 = .22$ (see Figure 6). This indicates that delta and theta power do not differ much between the boredom LDG and the flow LDG, while the immersion

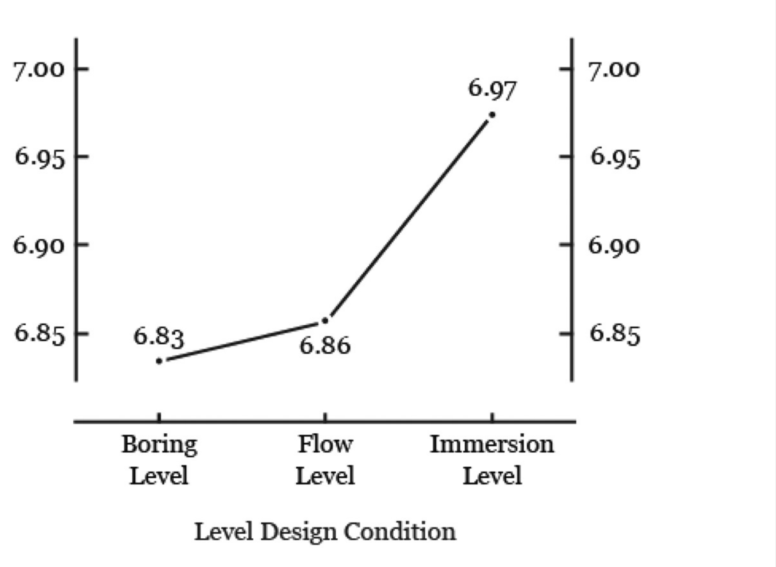

Figure 5. EEG delta power mean values ($5 + \ln[\eta V^2]$) for each level design condition that was tested

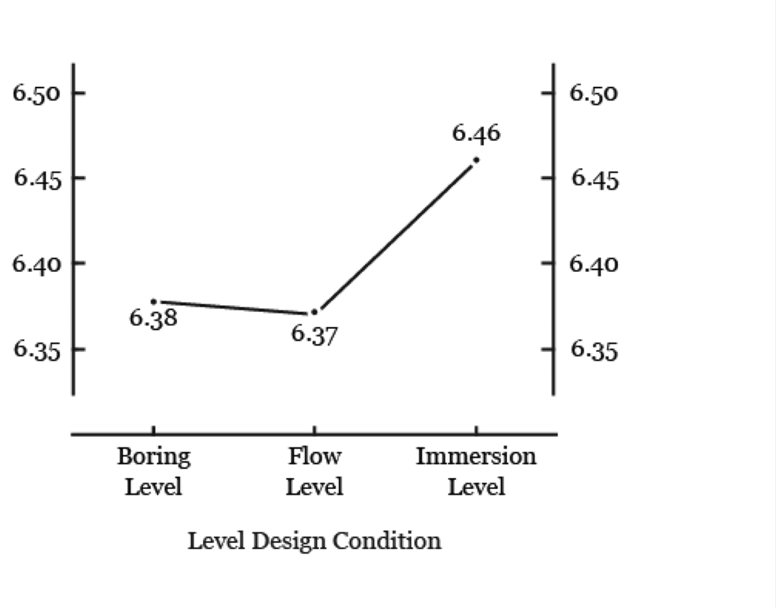

Figure 6. EEG theta power mean values ($5 + \ln[\eta V^2]$) for each level design condition that was tested

Table 1. Average EEG Spectral Power (5 + ln[μV^2]) and Standard Errors for Alpha (8-14 Hz), Beta (10-30 Hz), and Gamma(30-50 Hz) Frequencies in the Different Level Design Conditions

	Level Design Condition	Mean	Standard Error
Alpha	Boredom level	5.21	0.10
	Flow level	5.19	0.11
	Immersion level	5.27	0.10
Beta	Boredom level	6.58	0.09
	Flow level	6.62	0.10
	Immersion level	6.67	0.08
Gamma	Boredom level	4.77	0.12
	Flow level	4.91	0.12
	Immersion level	4.87	0.11

Note: EEG = electroencephalography.

LDG elicited increased delta and theta power estimates. The descriptive results of the remaining EEG power estimates (alpha, beta and gamma) are shown in Table 1.

Simple contrast analyses also indicated a significant difference between the flow LDG and the immersion LDG for delta and theta power averages (see Table 2). Interestingly, these contrasts also indicated a significant difference between boredom and immersion LDG for beta power averages. This means that beta power was significantly higher in the immersion level compared with the boredom level.

Results of the GEQ

A more detailed report on the subjective GEQ results can be found in Nacke and Lindley (2008b). We will quickly revisit some of the main results here for comparative purposes. The GEQ dimensions challenge, $F(2, 40) = 32.54, p < .001, \eta_p^2 = .62$, and tension, $F(2, 40) = 7.98, p < .01, \eta_p^2 = .29$, were significantly different in all three LDGs. According to the expectation from the level design, *challenge* was most pronounced in the flow LDG, less in the immersion LDG, and least in the boredom LDG. This lends support to our intended focus on challenge in the flow level, which was perceived to be truly challenging (but in a positive way as the “positive affect” ratings show).

However, *tension* was also rated highest in the flow LDG compared with the other LDGs. It was rated lowest in the immersion LDG. A follow-up test of repeated contrasts revealed a significant difference in *sensory immersion* between the boredom LDG and the immersion LDG, $F(1, 20) = 4.58, p < .05, \eta_p^2 = .19$, supporting the assumption that our intended immersion level design was actually rated higher in immersion than the boring level design. This validates the design intent for the immersion level. Interestingly the contrast analysis also pointed to a significant difference in *tension* between the immersion LDG and the flow LDG, $F(1, 20) = 13.74, p < .01, \eta_p^2 = .41$, but not the boredom LDG and the immersion LDG. For challenge, the main analysis of variance result was supported, indicating significant contrasts between the boredom LDG and

Table 2. Simple Within-Subject Contrast Analysis for Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-14 Hz), Beta (10-30 Hz), and Gamma (30-50 Hz) Spectral Power Estimates

	Level Design Guideline	*F*	Significance	Partial η^2
Delta	Boredom versus immersion level	14.40	.00	.44
	Flow versus immersion level	4.96	.04	.22
Theta	Boredom versus immersion level	5.58	.03	.24
	Flow versus immersion level	5.12	.04	.22
Alpha	Boredom versus immersion level	2.53	.13	.12
	Flow versus immersion level	3.50	.08	.16
Beta	Boredom versus immersion level	6.70	.02	.27
	Flow versus immersion level	1.06	.32	.06
Gamma	Boredom versus immersion level	2.11	.16	.10
	Flow versus immersion level	0.28	.61	.02

the immersion LDG, $F(1, 20) = 6.71, p < .05, \eta_p^2 = .25$, and the immersion LDG and the flow LDG, $F(1, 20) = 33.21, p < .001, \eta_p^2 = .62$.

Discussion

The questionnaire results of this study generally support our game design guidelines for flow, immersion, and boring game experiences. For example, for our flow level high ratings for the questionnaire dimensions challenge, flow, and tension lend support to our level design guidelines. The flow level provides challenges that seem appropriate for our experimental sample together with immediate goals ("kill all enemies") and feedback about progress (doors to next room open only after all enemies are killed). These were the prerequisites for flow described by Nakamura and Csíkszentmihályi (2002). In the boredom level, players felt high competence and high negative affect, but they did not feel very challenged or immersed. Consequently, the boring level is somewhat the experiential opposite of the flow level in terms of challenge. Players of the immersion game level rated it highest in immersion and positive affect and lowest in negative affect and tension. Arguably, immersion may come from the architectural complexity of the level, which fosters exploration of the environment. This may also be associated with low tension, because the environment provides enough cover spots for the player to avoid combat, if desired. This might also explain similar competence ratings to the boredom level, but the increased challenge rating. Possibly, players seek the challenge themselves in the immersion level as the design only provides combat (i.e., challenge) opportunities, whereas in the flow level, the combat is a necessity to advance in the game and the choice of engaging in it is taken away from the player. Nevertheless, it has to be kept in mind that our experimental sample consisted largely of male hard-core players, so that the level design guidelines may need to be adjusted for a different demographic.

An unexpected result was the low theta and delta EEG activity measured in the flow (and boredom) levels in comparison with high theta and delta EEG activity in the immersion level. Both the flow and the boredom level share a linear structure of the game level, meaning that the player does not have to worry about navigating through the environment but mostly has to follow along a given path. Thus, the high theta activity in the immersion level could perhaps be attributed to the architectural complexity of the level, requiring the player to navigate using landmarks and memory. Episodic and semantic memory, path integration and landmark navigation have all been associated with theta activity before (Buzsáki, 2005). However, the high delta activity of participants playing the immersion level is a bit harder to explain. High delta activity is uncommon in waking adults but has been related to intoxication, trance, and delirium (Boutros, Thatcher, & Galderisi). It seems in contrast to the theta activity finding that the immersion level could, on one hand, activate mental processes for spatial navigation and, on the other hand, have an intoxicating effect on players. We could explain this with the tonic nature of these measures, so that areas of the game level require more mental activity for spatial processes, while other areas would be more intoxicating through the environmental design or effects. It could also mean that in parts of the immersion level, the participants were drowsy, while in other parts they had to make more decisions than in the other levels. For example, they would need to decide which area to explore and how to move through the indoor areas (supported by high beta activity). This would also explain the low delta activity in the boring level, which was very dull and thus elicited less delta activity. The high theta activity lends support to the aesthetic traits of the immersion game level, potentially being a sign of sensory impact of the level design.

We regard this study as a pilot study, since there is not yet any well-established methodology for examining the impact of game levels on players, although we have seen studies before on the impact of games on EEG (Pellouchoud et al., 1999; Salminen et al., 2009; Schier, 2000; Stickel et al., 2007). While psychophysiological game research still faces the problem of interpreting the quantitative data correctly, using a variety of psychophysiological measures together with questionnaires may be a viable research approach to gain a better understanding of the underpinnings of subjective gameplay experience. This pilot study has shown that the methodology of EEG recording together with a questionnaire works in principle. What is needed as an important next step is the analysis of different brain areas for different EEG bands to be able to associate gameplay experience phenomena more precisely with cognitive activation. Another approach would be to explore EEG activity for a different time resolution, such as analyzing EEG reactions to certain in-game events (e.g., player death, enemy attack). Thus, we would be able to assess smaller scale details of gameplay and have a less complex stimulus providing us with more fine-grained results. Additionally, other psychophysiological measures, such as electromyography, electrodermal activity, and eye tracking should be taken into consideration for a more holistic understanding of players and their gameplay experience. Our ongoing work investigates the relation between psychological states and physiological activity in games with more detail. Ideally, with more research done in this area, we will be able to construct a number of different EEG activity patterns generated by different designs, which might allow us to understand not only the process of game design more thoroughly but also help in creating more meaningful games that will impact the lives of people for the better.

Conclusion

In this article, we have presented a methodology for studying affective ludology using EEG measurement, which addresses the impact of game levels on players' physiological and psychological activity in relation to game design. We have created level design guidelines for gameplay experiences of immersion, boredom, and flow and validated them with a GEQ. We have also found similarities between linear level design in the boredom and flow level and spatial navigation and exploration in the immersion level that possibly evoke similar patterns of EEG activity for our experimental sample. In summary, we have demonstrated the significant impact of game levels on player responses and found indicators for boring, immersive and flow gameplay experiences. We hope to see more researchers study games from an affective ludology perspective in the future to be able to make game design a more scientific process with a detailed understanding of player-game interaction.

Authors' Note

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References

Aftanas, L. I., & Golocheikine, S. A. (2001). Human anterior and frontal midline theta and lower alpha reflect emotionally positive state and internalized attention: High-resolution EEG investigation of meditation. *Neuroscience Letters, 310*, 57-60. doi:10.1016/S0304-3940(01)02094-8

Agarwal, R., & Karahanna, E. (2000). Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. *MIS Quarterly, 24*, 665-694.

Andreassi, J. L. (2000). Human behavior and physiological response. *Psychophysiology, 4*, 1-12.

Appelman, R. (2007, September). *Experiential modes of game play*. Proceedings of the DiGRA 2007 Conference on Situated Play, Tokyo, Japan.

Avedon, E. M., & Sutton-Smith, B. (1971). *The study of games*. New York, NY: John Wiley.

Barr, P., Noble, J., & Biddle, R. (2007). Video game values: Human-computer interaction and games. *Interacting With Computers, 19*, 180-195. doi:10.1016/j.intcom.2006.08.008

Boutros, N. N., Thatcher, R. W., & Galderisi, S. (2008). Electrodiagnostic techniques in neuropsychiatry. In S. C. Yudofsky & R. E. Hales (Eds.), *The American psychiatric publishing textbook of neuropsychiatry and behavioral neurosciences* (5th ed., pp. 189-213). Arlington, VA: American Psychiatric Publishing.

Brown, E., & Cairns, P. (2004). *A grounded investigation of game immersion*. Proceedings of CHI '04 doi:10.1145/985921.986048

Buzsáki, G. (2005). Theta rhythm of navigation: Link between path integration and landmark navigation, episodic and semantic memory. *Hippocampus, 15*, 827-840. doi:10.1002/hipo.20113

Cacioppo, J. T., Tassinary, L. G., & Berntson, G. G. (2007). *Handbook of psychophysiology* (3rd ed.). Cambridge, England: Cambridge University Press.

Caillois, R. (1958). *Les jeux et les hommes*. Paris, France: Gallimard.

Chanel, G., Kierkels, J. J. M., Soleymani, M., & Pun, T. (2009). Short-term emotion assessment in a recall paradigm. *International Journal of Human-Computer Studies, 67*, 607-627. doi:10.1016/j.ijhcs.2009.03.005

Chanel, G., Rebetez, C., Bétrancourt, M., & Pun, T. (2008, October). *Boredom, engagement and anxiety as indicators for adaptation to difficulty in games*. Proceedings of MindTrek '08, pp. 13-17, Tampere, Finland. doi:10.1145/1457199.1457203

Chatrian, G. E., Lettich, E., & Nelson, P. L. (1988). Modified nomenclature for the "10%" electrode system. *Journal of Clinical Neurophysiology, 5*, 183-186.

Chen, J. (2006). *Flow in games* (Unpublished master's thesis). University of Southern California, Los Angeles.

Csíkszentmihályi, M. (1975). *Beyond boredom and anxiety*. San Francisco, CA: Jossey-Bass.

Csíkszentmihályi, M. (1982). Does being human matter? On some interpretive problems of comparative ludology. *Behavioral and Brain Sciences, 5*(1), 160.

Csíkszentmihályi, M. (1990). *Flow: The psychology of optimal experience*. New York, NY: HarperPerennial.

Ermi, L., & Mäyrä, F. (2005, June). *Fundamental components of the gameplay experience: Analysing immersion*. Proceedings of DiGRA Conference on Changing Views: Worlds in Play, Vancouver, British Columbia, Canada.

Fabricatore, C., Nussbaum, M., & Rosas, R. (2002). Playability in video games: A qualitative design model. *Human-Computer Interaction, 17*, 311-368. doi:10.1207/S15327051HCI1704_1

Fisher, C. D. (1993). Boredom at work: A neglected concept. *Human Relations, 46*, 395-417.

Frasca, G. (1999). *Ludology meets narratology: Similitude and differences between (video) games and narrative*. Retrieved from http://www.ludology.org/articles/ludology.htm

Frasca, G. (2003). Simulation versus narrative: Introduction to ludology. In M. J. P. Wolf & B. Perron (Eds.), *The video game theory reader* (pp. 221-235). London, England: Routledge.

Grimes, D., Tan, D. S., Hudson, S. E., Shenoy, P., & Rao, R. P. N. (2008, April). *Feasibility and pragmatics of classifying working memory load with an electroencephalograph.* Proceedings of CHI ’08 (pp. 835-844), Florence, Italy. doi:10.1145/1357054.1357187

HALF-LIFE 2. (2004). Seattle, WA: Valve Corporation.

Hazlett, R. L. (2006, April). *Measuring emotional valence during interactive experiences: boys at video game play*. Proceedings of CHI ’06 (pp. 1023-1026), Montréal, Québec, Canada. doi: 10.1145/1124772.1124925

He, E. J., Yuan, H., Yang, L., Sheikholeslami, C., & He, B. (2008, May). *EEG spatio-spectral mapping during video game play*. Proceedings of ITAB 2008 (pp. 346-348). Shenzhen, China. doi:10.1109/ITAB.2008.4570658

Huizinga, J. (1949). *Homo ludens: A study of the play element in culture*. London, England: Routledge & Paul.

Ijsselsteijn, W., Poels, K., & de Kort, Y. A. W. (2008). *The Game Experience Questionnaire: Development of a self-report measure to assess player experiences of digital games*. FUGA Technical Report D3.3 Eindhoven, Netherlands: TU Eindhoven.

Isbister, K., & Schaffer, N. (2008). *Game usability: Advice from the experts for advancing the player experience.* Burlington, MA: Morgan Kaufmann.

Jackson, S. A., & Marsh, H. W. (1996). Development and validation of a scale to measure optimal experience: The Flow State Scale. *Journal of Sport and Exercise Psychology, 18*, 17-35.

Jasper, H. H. (1958). Report of the committee on methods of clinical examination in electroencephalography. *Electroencephalography and Clinical Neurophysiology, 10* 370-375.

Jennett, C., Cox, A. L., Cairns, P., Dhoparee, S., Epps, A., Tijs, T., & Walton, A. (2008). Measuring and defining the experience of immersion in games. *International Journal of Human-Computer Studies, 66*, 641-661. doi:10.1016/j.ijhcs.2008.04.004

Juul, J. (2005). *Half-real: Video games between real rules and fictional worlds*. Cambridge: MIT Press.

Lee, J. C., & Tan, D. S. (2006, October). *Using a low-cost electroencephalograph for task classification in HCI research.* Proceedings of the 19th Annual ACM Symposium on User Interface Software and Technology, Montreux, Switzerland. doi:10.1145/1166253.1166268

Lombard, M., & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication, 3*(2), 20. doi:10.1111/j.1083-6101.1997.tb00072.x

Mandryk, R. L. (2008). Physiological measures for game evaluation. In K. Isbister & N. Schaffer (Eds.), *Game usability: Advice from the experts for advancing the player experience* (pp. 207-235). Burlington, MA: Elsevier.

Mandryk, R. L., & Inkpen, K. M. (2004, November). *Physiological indicators for the evaluation of co-located collaborative play*. Proceedings of CSCW 2004, Chicago, IL. doi:10.1145/1031607.1031625

Mandryk, R. L., Inkpen, K. M., & Calvert, T. W. (2006). Using psychophysiological techniques to measure user experience with entertainment technologies. *Behaviour & Information Technology, 25*, 141-158. doi:10.1080/01449290500331156

Nacke, L. (2009). *Affective ludology: Scientific measurement of user experience in interactive entertainment* (Unpublished doctoral thesis). Blekinge Institute of Technology, Karlskrona, Sweden.

Nacke, L. E. (2010, May). *Wiimote vs. controller: Electroencephalographic measurement of affective gameplay interaction*. Proceedings of FuturePlay 2010 (pp. 183-190), Vancouver, British Columbia, Canada.

Nacke, L., & Lindley, C. (2008a, August). *Boredom, immersion, flow—A pilot study investigating player experience*. Paper presented at IADIS Gaming 2008: Design for Engaging Experience and Social Interaction, Amsterdam, Netherlands.

Nacke, L., & Lindley, C. A. (2008b, November). *Flow and immersion in first-person shooters: Measuring the player's gameplay experience*. Proceedings of FuturePlay 2008 (pp. 81-88), Toronto, Ontario, Canada. doi:10.1145/1496984.1496998

Nacke, L., & Lindley, C. (2009). Affective ludology, flow and immersion in a first-person shooter: Measurement of player experience. *Loading, 3*(5). Retrieved from http://journals.sfu.ca/loading/index.php/loading/article/view/72

Nacke, L. E., Grimshaw, M. N., & Lindley, C. A. (in press). More than a feeling: measurement of sonic user experience and psychophysiology in a first-person shooter game. *Interacting With Computers*. doi:10.1016/j.intcom.2010.04.005

Nakamura, J., & Csíkszentmihályi, M. (2002). The concept of flow. In C. R. Snyder & S. J. Lopez (Eds.), *Handbook of positive psychology* (pp. 89-105). New York, NY: Oxford University Press.

Norman, D. A. (2004). *Emotional design*. New York, NY: Basic Books.

Novak, T. P., Hoffman, D. L., & Yung, Y. F. (2000). Measuring the customer experience in online environments: A structural modeling approach. *Marketing Science, 19*, 22-42.

Pagulayan, R., Steury, K. R., Fulton, B., & Romero, R. L. (2004). *Designing for fun: user-testing case studies Funology: From usability to enjoyment* (pp. 137-150). Norwell, MA: Kluwer Academic.

Pellouchoud, E., Michael, E. S., Linda, M., & Alan, G. (1999). Mental effort-related EEG modulation during video-game play: Comparison between juvenile subjects with epilepsy and normal control subjects. *Epilepsia, 40*(Suppl. 4), 38-43. doi:10.1111/j.1528-1157.1999.tb00905.x

Pfurtscheller, G., Zalaudek, K., & Neuper, C. (1998). Event-related beta synchronization after wrist, finger and thumb movement. *Electroencephalography and Clinical Neurophysiology, 109*, 154-160. doi:10.1016/S0924-980X(97)00070-2

Poels, K., de Kort, Y., & IJsselsteijn, W. (2007, November). "*It is always a lot of fun!" Exploring dimensions of digital game experience using focus group methodology*. Proceedings of FuturePlay 2007 (pp. 83-89), Toronto, Ontario, Canada. doi:10.1145/1328202.1328218

Qin, H., Rau, P.-L. P., & Salvendy, G. (2009). Measuring player immersion in the computer game narrative. *International Journal of Human-Computer Interaction, 25*, 107-133.

Ravaja, N. (2004). Contributions of psychophysiology to media research: Review and recommendations. *Media Psychology, 6*, 193-235. doi:10.1207/s1532785xmep0602_4

Ravaja, N., Saari, T., Salminen, M., Laarni, J., & Kallinen, K. (2006). Phasic emotional reactions to video game events: A psychophysiological investigation. *Media Psychology, 8*, 343-367. doi:10.1207/s1532785xmep0804_2

Ravaja, N., Turpeinen, M., Saari, T., Puttonen, S., & Keltikangas-Järvinen, L. (2008). The psychophysiology of James Bond: Phasic emotional responses to violent video game events. *Emotion, 8*, 114-120. doi:10.1037/1528-3542.8.1.114

Ray, W. J., & Cole, H. W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science, 228*, 750-752. doi:10.1126/science.3992243

Salminen, M., Kivikangas, J. M., Ravaja, N., & Kallinen, K. (2009, June). *Frontal EEG asymmetry in the study of player experiences during competitive and cooperative play*. Proceedings of IADIS International Conference on Game and Entertainment Technologies, Algarve, Portugal.

Salminen, M., & Ravaja, N. (2008). Increased oscillatory theta activation evoked by violent digital game events. *Neuroscience Letters, 435*, 69-72. doi:10.1016/j.neulet.2008.02.009

Schier, M. A. (2000). Changes in EEG alpha power during simulated driving: a demonstration. *International Journal of Psychophysiology, 37*, 155-162. doi:10.1016/S0167-8760(00)00079-9

Smith, M. E., Gevins, A., Brown, H., Karnik, A., & Du, R. (2001). Monitoring task loading with multivariate EEG measures during complex forms of human-computer interaction. *Human Factors: Journal of the Human Factors and Ergonomics Society, 43*, 366-380. doi:10.1518/001872001775898287

Stickel, C., Fink, J., & Holzinger, A. (2007). *Enhancing universal access—EEG based learnability assessment universal access in human-computer interaction. applications and services* (Vol. 4556/2007, pp. 813-822). Berlin, Germany: Springer.

von Neumann, J. (1928). Zur Theorie der Gesellschaftsspiele [On the theory of parlor games]. *Mathematische Annalen, 100*, 295-320. doi:10.1007/BF01448847

von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Princeton, NJ: Princeton University Press.

Wolpaw, J. R., Birbaumer, N., McFarland, D. J., Pfurtscheller, G., & Vaughan, T. M. (2002). Brain-computer interfaces for communication and control. *Clinical Neurophysiology, 113*, 767-791. doi:10.1016/S1388-2457(02)00057-3

Zahorik, P., & Jenison, R. L. (1998). Presence as being-in-the-world. *Presence: Teleoperators and Virtual Environments, 7*, 78-89. doi:10.1162/105474698565541

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