USING ELECTROENCEPHALOGRAPHY TO SURVEY THE PHYSIOLOGY OF IMMERSION AND FLOW

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ABSTRACT

Deep focus states, like Immersion and Flow are important parameters when it comes to an enjoyable experience during learning activities. Exploring the Physiology of deep focus, in the course of prior studies, physiological data of participants was recorded during activities and inspected for correlations with Flow and Immersion. As no significant correlations were found, the experimental setup was extended by Electroencephalography (EEG) sensors to broaden the sprectrum of physiological data available for analysis, before further studies were conducted. In this paper, after shortly revisiting prior research, the results of the EEG-measurements are presented.

KEYWORDS

Electroencephalography, Flow, Immersion, Serious Games

1. INTRODUCTION

One of the central questions in games research and psychology and of particular interest for the development of serious games is how video games are percieved as enjoyable, more so how this fun can be transferred into learning or working contexts, as enjoyment is proven to be linked to an effective learning process (Deci and Ryan, 1985; Krapp, 2009).

Mihály Csíkszentmihályi defined "the optimal experience of an action" as Flow, which is achieved when the individual is so engrossed in the activity that nothing else seems relevant anymore. It is a deep sense of enjoyment, that occurs when a "person’s body or mind is stretched to its limits in a voluntary effort to accomplish something difficult and worthwhile" (Csikzentmihaly, 1990). A similar experience in the video game domain is commonly called Immersion, describing the transfer of consciousness into a virtual world. Cairns et al. define game Immersion by dividing it into three levels: Engagement, Engrossment, and Total Immersion. These levels are used to describe the degree of involvement with the game (Brown and Cairns, 2004; Cairns et al. 2006).

Both Flow and Immersion are linked to an intrinsic motivation in the task or game, which means deriving enjoyment from the action itself rather than from external gains like money or a fear of punishment for not completing a task. Due to the similarities of definitions and conditions for Immersion and Flow, authors suggest on unifying and not separating both terms for further research, especially in the video game domain (Michailidis et al., 2018). A combined model of Immersion and Flow based on the definitions by Csíkszentmihályi and Cairns was proposed (Kannegieser et al., 2018) and later extended by additional emotional dimensions (Kannegieser et al., 2021) which builds the theoretical basis for the following work.

Until now, the method of choice to measure Flow and Immersion has been the usage of questionnaires, which are answered by the subject after the task at hand. However, this method is potentially inaccurate due to the delay in elicitation and the subjectivity of the answers. An alternative way of measuring deep focus states could be, to record subjects' physiological data during an activity and look for correlations between the physiological data and elicited states of Flow and Immersion, thus establishing a more robust and objective measurement method, theroretically rendering the usage of questionnaires obsolete.

Beside various physiological channels like galvanic skin response (GSR) and electrocardiography (ECG), the subjects' brain activity, measured using electroencephalography (EEG) is of particular interest, and will be the focus of this paper: By non-invasively recording the electrical brain activity from the scalp, EEG is easy to use in medicine and research and still provides a lot of information on the mental states of subjects.

Based on previous studies and experiences gathered in the previous iterations (Kannegieser et al. 2018; Kannegieser et al. 2021) a study was conducted with 23 participants, in which EEG data were analyzed and evaluated for potential correlations with states of deep focus. Thus, this work will concern itself with the following hypotheses:

H1: States of deep focus will result in different activations of specific frequency bands between the activity and a neutral state of mind (baseline).
H2: States of deep focus will result in different activations of specific frequency bands during the activity at hand.

2. RELATED WORK

EEG is a common method for measuring the electrical activity of the brain by recording voltage fluctuations between electrodes positioned on the scalp. The fluctuations are mostly generated by the firing of cortical neurons, which are located on the outer layer of the brain and range between 5 and 100μV (Hu and Zhang, 2019). They result in typical sinusoidal wave shapes which are analyzed for amplitude and frequency. In general, the waves are classified into different frequency bands: Delta (1-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Beta (13-30 Hz), and Gamma (30-40 Hz). The frequency bands are associated with different levels of brain activities. When the subject is awake mostly alpha and beta waves are noticed. The alpha waves are the most extensively studied rhythm of the human brain and can be usually observed while being in a relaxed awake state or having eyes closed (Teplan et al., 2002). They are associated with cortical inactivity and mental idleness as well as attentional demand (Ray and Cole, 1985). Beta waves indicate a normal state of wakefulness and are usually most evident in the frontal cortex. They are connected to cognitive processes, decision making, problem solving and information processing (Ray and Cole, 1985). Delta and theta waves are most prominent during sleep (for adults). Delta waves are more present at deep sleep, more specifically during non-rapid eye movement (NREM) phases (Teplan et al., 2002). Theta waves play a greater role in REM sleep and general drowsiness (Teplan et al., 2002). They are also connected to daydreaming, creativity, intuition, memory recall, emotions, and sensations (Aftanas and Golocheikine, 2001). In some cases, gamma waves can be observed at very high concentration and Flow of information. It is also seen during cross-modal sensory processing (combining two or more senses, such as sound and sight) (Kisley and Cornwell, 2006) as well as deep meditation (Vialatte et al., 2009).

There are several different types of EEG devices or systems to choose from, e.g. headsets, single electrodes or closed electrode caps. While closed electrode caps usually provide better conduction quality (Hu and Zhang, 2019), smaller devices like headsets offer better mobility and comfort. Electrodes are positioned after the International 10-20 system, which uniquely labels each electrode with letters for the brain area (F: Frontal, C: Central, P: Parietal, T: Temporal, O: Occipital) and numbers for the horizontal position (odd numbers left hemisphere, even numbers right hemisphere; higher numbers are more outward than lower ones) encoding the exact position on the head. The voltage is measured between an active electrode and one of two additional reference electrodes placed on the bone behind each ear.

The neural basis of Flow has been analyzed in several studies in the past as shown in the review article by Alameda (Alameda et al., 2022), who reviewed 25 studies, which were related to measuring brain activity in the context of Flow. While EEG measurement seems to be the most popular way of recording brain activity, there are also studies involving functional magnetic resonance (fMRI), functional near-infrared spectroscopy (fNIRS) or even the manipulation of brain activity with transcranial direct stimulation (tDCS).

Apart from different physiological measurements studies also differ in the elicitation methods of the Flow state. Many studies use a difficulty-based approach, where the same task is carried out with different levels of difficulty (e.g., Ulrich et al., 2014; Katahira et al., 2018; Knierim et al. 2018). As Flow is connected to a balance of challenge and skill, this approach is evident, and allows a direct comparison of Flow levels for the same subject. However, often the tasks are very small and do not last longer than 10 minutes, which could make it hard for participants to deeply immerse into a different world. Another approach more similar to the work in this paper are video game studies (e.g., Klasen et al., 2012), where subjects are assigned to play a certain video game for a longer period of time without interruption. Afterwards researchers analyzed the game's content and classified situations based on Flow dimensions (e.g., skill-difficulty balance, focus, clear goals, and control) to identify high probability Flow moments. A problem with this method is the subjectiveness of the researchers and the players not assessing their mental states themselves.

Studies involving the measurement of EEG report different results when it comes to linking the Flow state to specific brain rhythms (i.e., theta, alpha, beta and gamma). Katahira et al. as well as other authors observed higher power in theta activity in the frontal electrodes during Flow, which might be related to the high cognitive control demands required by the task. Also, they report a rising power in alpha activity with increasing difficulty. Lim et al. found a higher beta activity in the frontal, temporal and occipital lobe to be involved in the Flow state (Lim et al. 2019). Wolf et al. observed a higher asymmetry between the temporal lobe of the left hemisphere and the temporal lobe of the right hemisphere during Flow states, which they link to a suppression of analytical-verbal activity and irrelevant cognitive processes (Wolf et al., 2015).

In a previous study (Kannegieser and Ratz, 2021), a method of measuring EEG in the context of game Immersion and Flow was presented. The experiment was tested with an initial test study involving three participants. The data recorded during this experiment was analyzed for correlations with elicited states of deep focus. This analysis resulted in the average spectral power density in the respective frequency band per channel for each of the five mental states (Baseline, Engagement, Engrossment, Total Immersion, and Flow).

In the study, theta power appeared to increase compared to baseline in the frontal areas during Engagement and especially Engrossment. Total Immersion and Flow on the other hand did not show a big difference to the baseline. Beta activity was overall higher compared to baseline during both Immersion and Flow. The other frequency bands did not show any correlations. Throughout all frequency bands, Total Immersion and Flow are very similar in their power distribution, which could indicate a close relation between total Immersion and Flow as suggested by our proposed model. Although the results indicated a correlation between Immersion, Flow and EEG, the statistical significance of its results remained to be proven because of the small number of participants.

3. EXPERIMENT

The experiment's main goal is to gather physiological data during game play that can be used to find a correlation between physiological measurements and Flow/Immersion states. It mainly consists of a custom-made measurement application, which sets the structure of the experiment and manages different data inputs and outputs. Apart from EEG, various other physiological input sources such as sensors for GSR, ECG/heartrate and EMG can be connected, thereby extending the data pool for statistical correlation analysis between physiological data and elicited states of deep focus.

3.1 Study Conduct

A study was conducted with 23 self-selected participants (21 male, 2 female), most of them university students in their twenties who all had at least some experience with video games in the past. Participants were gathered using posters and word-of-mouth advertising, thus representing a group of people interested in gaming and the study itself. One underage person with a lot of gaming experience participated with full parental consent.

The study took place in a prearranged lab room, containing the experimental setup including a PC system for gaming and data recording as well as the physiological sensors. EEG was measured using the Emotiv EPOC+, a 14-channel EEG headset, that only requires its electrode covering felt pads to be covered in a saline solution before attachment. It offers a sampling rate of 256 Hz and uses a wireless connection via Bluetooth, making it easy to install and comfortable to wear during the experiment. This increases the likeliness for participants to reach the desired mental states compared to closed electrode caps, which use a contact gel for conduction and are possibly less comfortable to wear.

3.2 Procedure

The experiment was split into four phases: Setup, Baseline, Gaming and Assessment. During the setup phase, the game was selected, and the sensors are placed on the participant. Game selection was free, as participants were allowed to bring their own games or use a distribution platform like Steam to install a game of their choice, with Minecraft, Valorant, and League of Legends beeing the most popular game titles. Free game selection was chosen to improve the odds of players reaching higher Flow and Immersion states, at the cost of game-specific analysis options. While there can be benefits in evaluating the same game among all participants, the goal for this study is rather to find general correlations between any reported deep focus states and physiological measurements.

During the second phase of the experiment, the baseline phase, physiological data is recorded for one minute, while the subject is in a calm state of mind. The physiological measurements were monitored by the examiner of the study on a separate monitor screen, showing the incoming data streams in real time. After finishing setup, the gaming phase began, in which the subject played the chosen game for 30 minutes without interruption. The duration was chosen based on test runs, as 30 minutes were found to be sufficient to reach the Flow / Total Immersion states. While the participant was playing, the physiological data as well as the gameplay and webcam footage was recorded and stored for analysis.

During the assessment phase, participants watched a recording of their game session as well as web cam footage of themselves. While watching this footage, Flow and Immersion questionnaires about how immersed the participant was at the time of the recording were answered repeatedly, thus gathering more accurate data without interrupting the Flow/Immersion during the game session itself, as shown in a similar study by Rajava and Kivikangas (Ravaja and Kivikangas, 2008).

Three questionnaires were used in the experiment, with one of them being split into two parts. The first questionnaire used was the Immersion questionnaire presented by Cheng et al. based on their improvement upon the hierarchical model presented by Cairns (Cheng et al., 2015; Cairns et al. 2006). The questionnaire was chosen, as it can be used to measure the likeliness to be in each of the individual Immersion levels. As the questionnaire was too long to be measured multiple times without worsening the results, it was split into an Immersive Tendency questionnaire asked at the beginning of playback and an iterative questionnaire asked every minute during playback. For Flow, the Flow Short Scale questionnaire by Rheinberg was used (Rheinberg et al., 2003). It was originally designed for being used multiple times in a row, making it perfect for this iterative approach. During playback, it was asked every two minutes. The final questionnaire used was the Game Experience questionnaire (IJsselsteijn, et al., 2013). It measures a more general set of questions and was asked once after playback was finished.

An overview of the experimental structure is presented in figure 1.

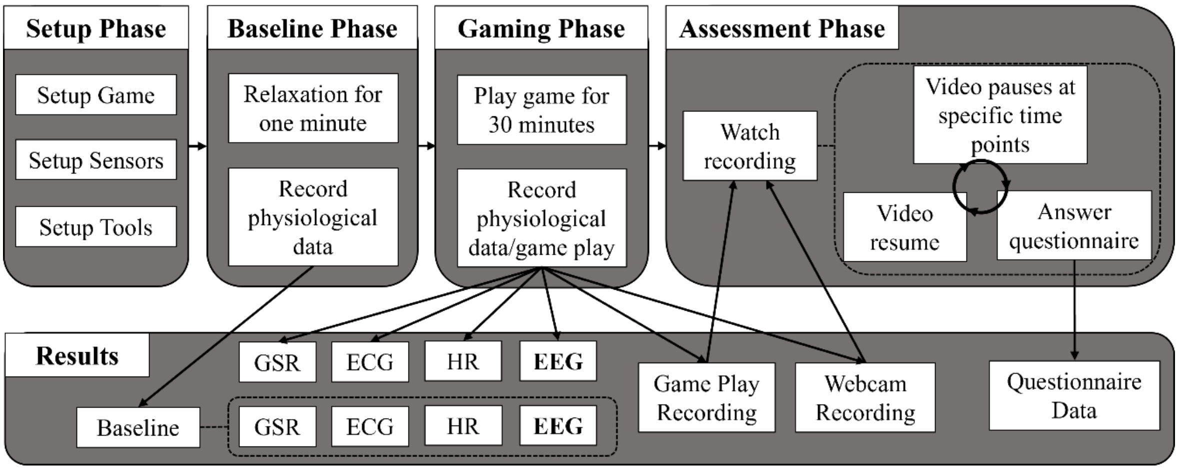

Figure 1. Experiment procedure

3.3 Analysis

The questionnaire data was combined and Engagement, Engrossment, Total Immersion and Flow levels were calculated for each 60 second stage. The raw EEG data was processed using the EEGLAB extension for MATLAB. The data was preprocessed using EEGLAB's inbuilt bad channel removal and independent component analysis functions. The remaining data was subdivided into stages with a duration of 60 seconds, corresponding to the shortest interval covered by a questionnaire. After preprocessing, artefact recognition and removal were performed manually. For the remaining data, the power spectra were averaged per stage and frequency band (Delta: 1-4 Hz, Theta: 4-8 Hz, Alpha: 8-13 Hz, Beta: 13-30 Hz and Gamma: 30-40 Hz) for each channel. Both sets of experimental data and the baseline data were then combined for statistical anlysis. As the results from both the Flow and Immersion questionnaires did not follow a normal distribution, Spearman correlation was used (Landau et al., 2004) to test for H0, H1 and H2.

4. RESULTS

While questionnaires revealed higher Flow possibility, theta activity was significantly higher than in the baseline condition (paired t-test $p < 0.001$). However, Flow level and theta activity during task performance were slightly negatively correlated in the frontal region. Overall, no significant positive correlation between Flow level and theta activity was evident. Additionally, during task performance, there was no statistically significant difference between theta power in Flow and theta power while the subject was not in Flow. This suggests that the increase in theta power is not directly linked to the Flow state but may be due to the nature of the gaming task in general. As Engagement was generally high during task performance and was also high when Flow was rated as low, Engagement may be the main contributor to the increase in theta power (see figure 2).

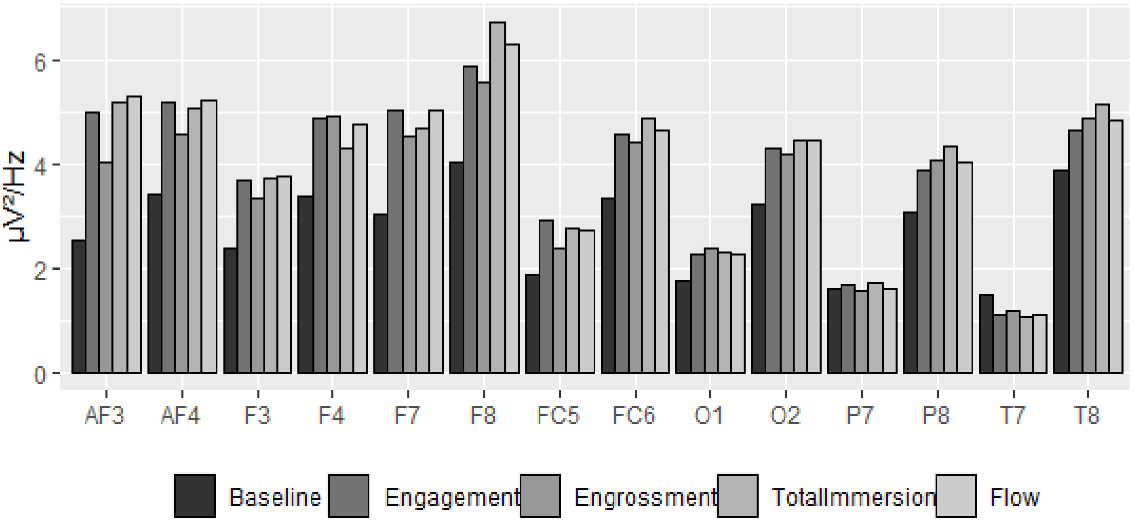

Figure 2. Theta power in each channel regarding different mental states

Frontal EEG asymmetry and particularly asymmetrical frontal alpha activation have also been found as potential neurocognitive indicators of Flow. Activation was measured by calculating the per-subject difference between baseline alpha power and alpha power during task performance. While there was a statistically significant difference between left alpha activation and right alpha activation ($p < 0.005$) while in Flow, there was no significant difference in alpha power while in Flow (see figure 3).

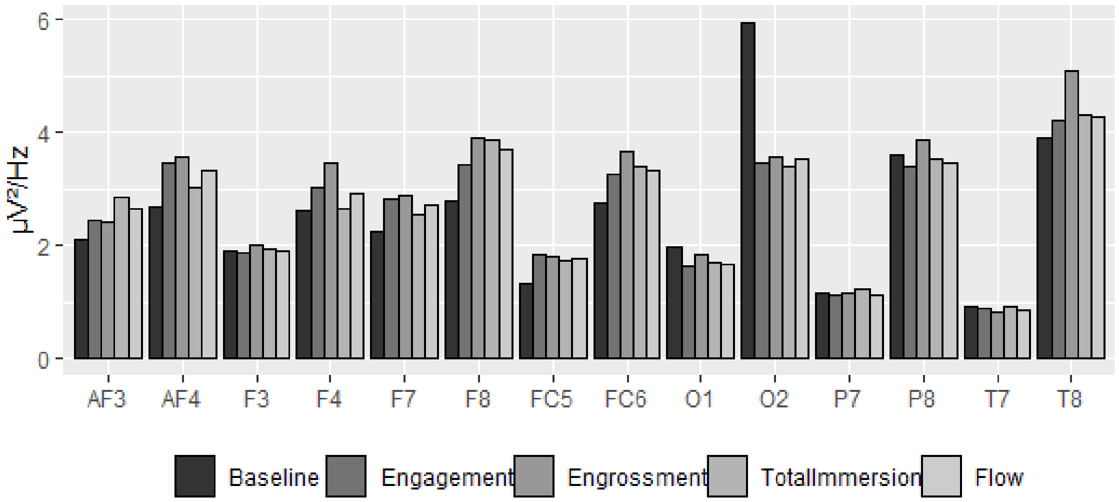

Figure 3. Alpha power in each channel regarding different mental states

Additionally, as with theta power, there was no significant difference in activation between Flow and no Flow during task performance. This further suggests that being in Flow does not explain the observed differences in spectral power density between baseline and experimental condition. Hindering further analysis of potential asymmetries was that across all data obtained during the experiment, electrodes positioned on the right hemisphere consistently measured higher spectral power densities. This might be due to a malfunctioning reference electrode or the equipment used in the experimental setup. Hence, the observed asymmetry is not in line with or comparable to previous findings.

Across all frequency bands, Flow and spectral power were negatively correlated at the dorsolateral prefrontal cortex (F3, F4). The DLPFC is associated with higher order processing, particularly working memory and decision making, but has also shown to be relevant to self-awareness (Yuan, Raz, 2014) and one's sense of time (Fuster, 1995). Therefore, a decreased *activation* in this area may directly tie into the Flow experience. Alpha activation of the DLFPC was not significantly correlated with Flow, though left alpha activation in the Flow condition was negative, whereas right alpha activation was slightly positive. This may be partly explained due to the fact that in young adults, the right and left DLFPC are more specialised with the left DLFPC being activated more strongly during verbal and spatial processing and right DLFPC during visual processing (Reutzer-Lorenz et al, 2000). As the games played involve more visual processing, a higher activation of the right DLFPC can be expected.

The disparities in selected games may account for parts of the activation patterns that were seen. Increased left frontal and temporal alpha activity/activation are associated with enjoyment and positive affect or motivation. If the game includes different design elements, activation patterns may differ based on that, inducing a range of different emotions.

5. CONCLUSION

This paper gave an overview about the current state of work in the field of physiology of Flow and Immersion by means of taking psychophysiological measurements during the activity under test (Kannegieser et al. 2018). Obtained results yielded by a study with an extended sensor set for Electroencepalography (EEG) were explored and the implementation of measuring deep focus states with EEG in addition to the sensor set used in prior studies were discussed in comparison with the initial test study (Kannegieser and Ratz, 2021). While other studies have shown an increase in frontal activity while in Flow (Katahira et al. 2018) and significantly higher theta activity was observed in this study compared to the theta baseline in line with hypothesis H1, no positive correlation for theta activity and alpha/theta power where found during episodes of deep focus contrary to the formulated hypothesis H2.

Further research will focus on improving data bandwith by using more psychophysiological inputs, enhancing data quality, especially dealing with the occurance of EEG-artifcats which invalidated a significant portion of the EEG data available for analysis.

Based on the theory that different game titles might lead to different frequency activations, the sample size for the most favorized game titles/genres will be increased to allow for more statistical relevance and improving task comparability.

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