

Being in the zone: Using behavioral and EEG recordings for the indirect assessment of flow

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Abstract

As such, video games are enjoyed most when the level and speed of the game match the players' skills. An optimal balance between challenges and skills triggers the subjective experience of "flow", a focused motivation leading to a feeling of spontaneous joy. Here we present the validation of a novel technique to indirectly assess the extent to which subjects experience flow during real game play by assessing attentional engagement; first behaviorally and in a second stage by means of electroencephalogram (EEG) recordings. An auditory novelty oddball paradigm was implemented as a secondary task while subjects played in three conditions: Boredom, Frustration and Flow. We found higher reaction times and error rates in the Flow condition. In a second stage we used advanced techniques to do source reconstruction and to investigate signal changes on both the temporal and frequency domain. EEG analysis revealed a response-locked fronto-central negative deflection significantly delayed during flow, likely signaling the need of re-allocation of attentional resources. Frequency domain analyses revealed significant power increase only in the alpha band for the flow condition. We believe that frontal alpha changes recorded as maximal at the mid- frontal lines during flow might be related with reward related processing.

Keywords: Attention, Flow, EEG, Game play, Oddball paradigm

According to the Entertainment Software Association (ESA) \$22.41 billion were spent by consumers on games in 2014 and it is estimated that about 155 million Americans play video games. Gamers who are playing more video games than they did three years ago are spending less time in mainstream activities such as watching T.V., going to the cinema and watching movies at home (ESA report, 2014).

What makes the gaming experience much more fulfilling than other activities is the enjoyable nature of games. As such, video games evoke most pleasure when the level and speed of the game match the players' abilities e.g. optimal mental and motor capacity (Sherry, 2004). A perfect balance between challenges and skills during game play triggers the subjective experience of "flow", which can be defined as a cognitive state of being completely absorbed by an activity, accompanied by positive feelings. Csikszentmihalyi (1988, 1990, 2000) described the subjective experience of flow as being associated with a number of unique affective and attentional states including feelings of motivation, high energy, immersion, and complete attentional focus. Whilst all these elements are characteristic of the emergence of flow, attentional processes are thought to be crucial. Boredom, and frustration, like flow, are determined by how attention is structured at a given time and by the balance between the challenges and skills of an individual (Csikszentmihalyi, 1992). Specifically, boredom arises when the subjects perceive low challenges mismatching their higher skills. Conversely, frustration emerges when subjects perceive high challenges mismatching their low skills. Both boredom and frustration are thought to lead to attentional disengagement whereas a perfect balance between challenges and skills during game play would trigger the immersive experience of flow.

Although investigating psychophysiological and neural correlates of this subjective experience has sparked interest recently, there is so far no straightforward

solution available for investigating flow in real game play set ups; whereby sometimes hundreds of stimuli occur simultaneously. Specifically, it is almost impossible to conduct traditional experiments where psychophysiological or brain activity can be easily locked to one single type of stimulus or response onsets, given their temporal overlap (but see Mathiak and Weber (2006) for an attempt with fMRI and Mandrik and Atkins (2007) with psychophysiological data). Furthermore, an inherent feature of gaming is that the gaming experience should be enjoyable while standard experimental paradigms used in neuroscience and psychophysiological research might be perceived by subjects as boring, given the repetitiveness of the stimuli and the highly controlled timings, which present an obstacle to “adapting” games to research set ups.

In order to respond to this need, here we present the validation of a novel technique to indirectly assess the extent to which subjects experience flow during real game play by assessing attentional engagement; first at the behavioral level and in a second stage by means of electroencephalogram (EEG) recordings. Our research is based on the assumption that entering in the flow depends on how attention is focused and staying in flow requires attention to be held (Csikszentmihalyi, 1992). Our main goal is two-fold. On the one hand, we aim to provide the field of digital games research a valid and practical tool to investigate flow experience by means of objective behavioral indexes such as reaction times and accuracy rates. On the other hand, using a neuroscience approach we aim to validate a method which is compatible with measurements of brain activity, such as EEG recordings. In fact, it is remarkable that although at the theoretical level important efforts have been done to advance the conceptualization of flow using a neuroscience perspective (see Synchronization theory of flow, Weber et al., 2009, and for a review from a neuroscience perspective Dietrich, 2004) and to provide guidelines to conduct research on this field using

functional neuroimaging (Weber, Mangus and Huskey, 2015) little research has been done in order to validate methods compatible with electrophysiological measurements however.

In the present work an auditory novelty oddball paradigm, which is a paradigm that has been broadly used to investigate attention in the field of cognitive neuroscience (see Squires, Squires and Hillyard, 1975), was implemented as a secondary task while subjects played a game as a primary task in three experimental conditions: boredom, frustration and flow. While participants played a reaction time commercial game as a primary task with the computer's mouse (see supplementary materials for a description), they were requested to press with the left hand index finger a button when an oddball sound was detected. Assuming that there is a limited set of attentional resources for allocation (Weber and Huskey, 2013), two simple but straightforward predictions can be made. First, since low error rates identifying the targets in an oddball task indicate low task difficulty (Debener et al., 2005), we expect participants to commit more errors in the detection of the oddball sounds during the flow condition, where the levels of absorption in the game are higher. Secondly, we expect to observe the same pattern in terms of reaction times. The larger the absorption in the primary gaming task, the slower the reaction times registered in the secondary task. In a second step we further investigated the effects of the three experimental conditions by means of EEG recordings. Advanced EEG methods such as Laplacian transform and source reconstruction (LORETA) were applied. Transient event-related spectral perturbation (ERSP) plots for the three experimental conditions were also obtained. By using these advanced methods we aimed to be able to describe in the greatest detail brain activity changes elicited by the experimental paradigm presented in this study.

Method

Study 1

Participants and procedure

19 participants (8 females and 11 males: $M = 25.5$ $SD = 4.33$) were tested. When enquired for their gaming experience (*How would you better define your game playing abilities for casual games (e.g. tetris, candy crush, angry birds, flappy bird etc.)*) 2 participants self-reported to be novice, 2 avid and 15 casual players. The average amount of played hours per week (including weekdays and weekends) when considering all game genres (action, role-playing, strategy, simulation, etc) and all gaming interfaces, was 1 hour and 52 minutes for this sample. As a primary task participants were instructed to play the game Star reaction (<http://loveisgames.com/action/1979/star-reaction>) (see Supplementary Material section Game description) in a within-subject experimental design with three counter-balanced conditions; Flow vs. Boredom (too low challenge, high skills) vs. Frustration (low skills, high challenge). In the Boredom condition participants were requested to repeatedly play the level one of the game. In the Flow condition participants started at level two and were requested to try to complete as many successive levels as possible. In the Frustration condition, participants were requested to repeatedly play the most difficult level of the game (Weber & Huskey, 2013).

In all three conditions participants were asked to also perform the secondary task (see Figure 1). As a secondary task an auditory novelty oddball task as reported in Debener et al. (2005) was introduced (= 960 trials total / 320 each experimental condition: 10 % deviant stimuli + 10 % novelty + 80 % standard stimuli). Two sinusoids of 339 ms duration (350 and 650 Hz) served as frequent and rare tones. Assignment

of the two tone frequencies to the rare or frequent stimulus class was counterbalanced across subjects. The novelty stimuli consisted of 90 unique, novel environmental sounds (mean duration: 338 ms, range: 161–402 ms). Novelty sounds were taken from the online available sample of Fabiani and colleagues (1996). Each environmental sound was presented only once. The experimental session was subdivided into three blocks consisting of 180 stimuli each, separated by 1-min breaks. Inter-stimulus interval varied pseudo-randomly between 960 and 1360 ms. For more details please refer to Debener et al. (2005). Reaction times to the oddball stimuli were recorded by means of a response box (see Figure 1). Participants were instructed to react as fast and accurate as possible when detecting the onset of an oddball sound, while keeping in mind that the primary task was the game. Objective performance in each of the levels of the game was recorded (see Supplementary Material section Objective game performance). Performance in the primary task was relatively good, participants successfully achieved on average until the level 8 out of 13 game levels. Also manipulation check questions aimed to assess the extent to which participants experienced having the skills according to the task demands (self-reported perceived skills/challenge score) and the participants' perception of the secondary task were administered at the end of each experimental condition (Supplemental Material section Questionnaires)



Figure 1. Experimental set up. Participants were requested to perform a secondary oddball task while playing a game as a primary task while EEG signals were recorded.

Data analysis

For the reaction times (RTs) analyses a one-way repeated-measures ANOVA on RTs of correct trials was conducted. Likewise, error rates were investigated by an one-way repeated measures ANOVA. Both false positive (responses in the absence of an oddball sound) and omissions (not responding when an oddball sound was present) were counted as errors. Finally also the self-reported scores of the perceived balance between challenge and skill were analyzed by a one way repeated measures ANOVA. For all analyses the Greenhouse Geiser correction was applied when there was more than one degree of freedom in the numerator. Additionally all Post hoc test were corrected for multiple comparisons using the Tukey's honestly significant difference (HSD) procedure.

Study 2

Participants and procedure

The methods used were the same as in Study 1, but data of 21 participants were collected while EEG signals were recorded. However due to excessive signal noise and one technical problem data of 3 participants should be removed. Here data of 18 participants is reported (9 females and 9 males: average age 28.5 SD 4,65). When enquired for their gaming experience 2 participants self-reported to be novice, 5 avid and 11 casual players. The median of the amount of played hours per weeks (when considering all games genres) was 1 hour and 16 minutes. Brain waves were recorded with 31 Ag/AgCl active system electrodes according to a modified 10–20 setting. EEG was filtered off-line with a band pass filter of 0.1-30 Hz. Two extra questionnaires to assess flow were administered (taken from Engesser & Rheinberg, 2008 & Sherry et al. 2006), to validate the assessment of the subjective experience of the participants (see Supplementary material section Questionnaires).

Data analysis

The EEG was recorded continuously with a sampling rate of 200 Hz. The electrooculogram (EOG) was recorded with bipolar montage. The vertical EOG was measured with two electrodes placed above and below the left eye; the horizontal EOG was measured with two electrodes placed on the left and right cantus and two reference electrodes were placed behind the ears on the mastoid bone. The signal was re-referenced offline to the average signal of the electrodes placed on the left and right mastoid for the time domain analyses. The continuous EEG was filtered off-line with a band pass filter of 0.1-30 Hz filter. Eye movement artefacts were removed from the EEG recordings using Independent Component Analysis (ICA) (Delorme, 2004).

All other artifacts were rejected manually by visual inspection on the raw traces, with the experimenter not being aware of the nature of the trials. EEG waves for correct responses were time-locked to the response onset (stimulus onset effects of the experimental conditions are reported elsewhere, Antons et al., manuscript in preparation). To analyze activities associated with correct responses Laplacian transform on the monopolar data was conducted in order to improve the spatial resolution of the activities (a technique also called “current source density” or CSD). This method acts as a high-pass spatial filter by removing the blurring effect due to volume conduction (Babiloni, Cincotti, Carducci, Rossini, & Babiloni, 2001; Núñez & Srinivasan, 2005) and is considered as a correct approximation of the electrocorticogram (Gevins, 1989). In this work, we used a standard surface Laplacian transformation, as implemented in Brain Vision Analyser software (Munich, Germany) using 3 as the degree of spline and 15 as a maximum of degrees for the Legendre polynomial (Perrin, Bertrand, & Pernier, 1987; Perrin, Pernier, Bertrand, & Echallier, 1989).

For the time domain analyses, the negative component maximal at FCz visible in Figure 4 A after surface Laplacian transformation (units of voltage per unit- area), was defined as the maximal negative deflection over FCz after the response onset peaking around 170 ms in the Flow condition; for the other conditions, this maximal negative peak occurred on average 24ms earlier. To compute statistics the difference of the negative peak (smallest voltage) in a time window 0-300 ms relative to button press onset and the preceding positive peak (highest voltage) in the time window -100 to 0 ms was used to determine both the component amplitude (peak-to-peak) and latency (time-to-peak). These estimations are similar to the ones used for other negativities elicited by the response onset such as the Correct Related Negativity

(CRN) or the Error Related Negativity (ERN) (e.g. Falkenstein, Hoormann, Christ, & Hohnsbein, 2000, Eppinger, Kray, Mock, & Mecklinger, 2008; Ullsperger & von Cramon, 2006). The amplitude and latency data were subjected to repeated-measures ANOVA with the factor Condition (Boredom vs. Flow vs. Frustration).

To localize the neural sources of this component, the standardized Low Resolution Electromagnetic Tomography (LORETA) method as implemented in the Brain Vision Analyzer software (BrainProducts), which uses a normalized form of the minimum norm constraint, was used (see Pascual-Marqui, 2002 for technical details). Figure 4C presents the sLORETA solution obtained for the grand average of the flow condition, estimated between 160 and 170 ms after response onset on the monopolar data. In a next step, for the frequency domain analyses the band power of the EEG signal was computed by employing a standard fast Fourier transform (FFT)(resolution= 3.125 Hz) applied to time window 0 - 250 ms, which is the time window where the effect is maximal at frontal sites (see Figure 2b). From this, the power in the alpha frequency band (8.5–12.5 Hz), theta frequency band (3.5–8.5 Hz) and beta frequency (12.5–30 Hz) was extracted for the electrodes Fz, FCz and Cz. Statistical analyses were conducted for apart for each band by entering average power for each frequency band into a repeated measures ANOVA with 3 conditions (Boredom, Flow, Frustration) x 3 Electrode position (Fz, FCz, Cz) as factors. Please not that each ANOVA was conducted independently for each frequency band.

Finally in order to visualize the changes in frequency domain composition while keeping the time domain information, event-related spectral perturbations (ERSP) were plotted for each condition. ERSPs were calculated using a wavelet-based analysis implemented in Brain Vision Analyzer 2.0 software. We used a continuous wavelet transform (WT) with complex Morlet wavelets (Morlet parameter c 5; 30

frequency steps from 1 to 30 Hz) to examine the frequency composition of single-trial epochs. The magnitudes of the WTs of single-trial epochs were then averaged to compute the total power of activity. For each condition a baseline correction was applied by subtracting the mean amplitude within the -200 to 0 ms time window from each data point after response onset, which was the same baseline used for the time domain analyses (see Figure 5).

Results

Study 1

The results suggest that behavioral indexes were modulated by the levels of immersion on the primary task. Specifically, our results demonstrated that reactions to the oddball sound were delayed in the Flow condition (see figure 2). A one-way ANOVA revealed a significant main effect of Condition $F(2, 36)=6,21$ $p = 0,005$, $\eta_p^2 = 0,26$. Post hoc tests showed greater reaction times in the Flow condition when compared with Boredom ($M = 675,82$ vs. $M = 624,80$ $p = 0,001$) and Frustration ($M = 675,82$ vs. $M = 644,80$ $p = 0,044$).

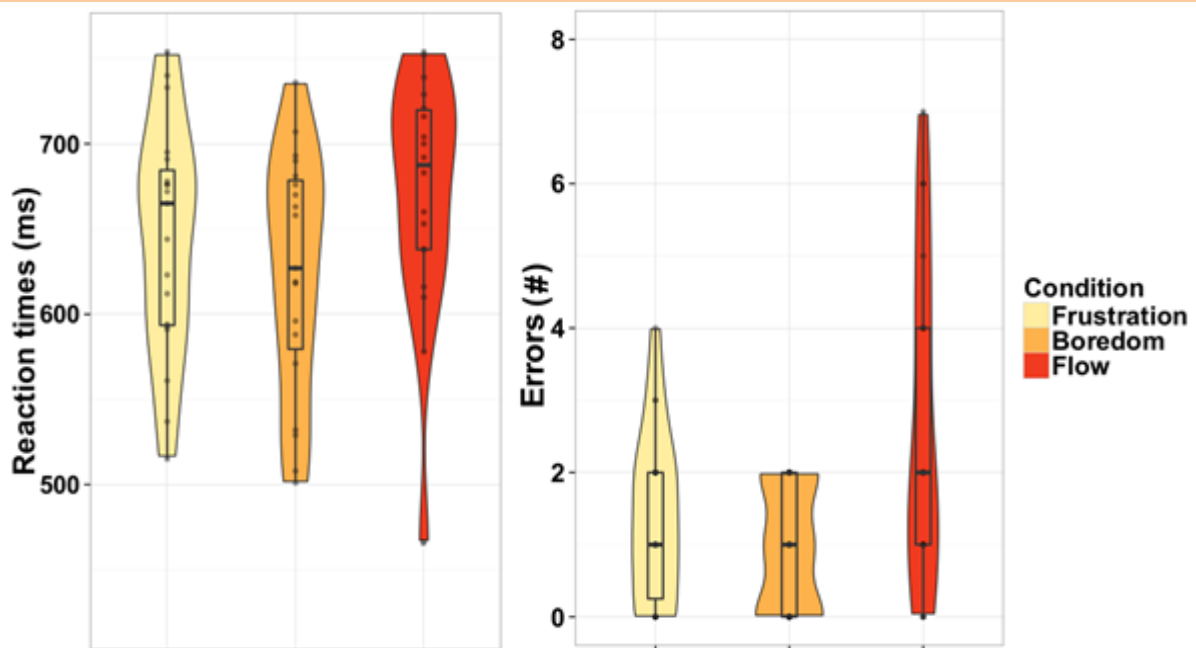


Figure 2. Violin plots of reaction times and accuracy rates per condition in the secondary task. Left reaction times , Right error rates. Inside each violin plot a box plot summarizing ranges - black line indicating the median per condition - and dots representing individual means are depicted. The upper and lower hinges of the box plots correspond to the first and third quartiles (the 25th and 75th percentiles)

Accuracy rates followed a similar pattern (see figure 1B). A one-way ANOVA revealed a significant main effect of Condition $F(2, 36)=3,89$, $p = 0,029$, $\eta_p^2= 0,18$. Post hoc tests showed higher error rates in the Flow condition when compared with Boredom ($M = 3,00$ vs. $M = 1,47$, $p = 0,012$) and Frustration ($M = 3,00$ vs. $M = 1,79$, $p = 0,043$). Importantly these results are in line with the results obtained by means of the short self-reported questionnaires. Our results revealed that participants' self-reported scores of flow were higher in the flow condition, showing a main effect of Condition $F(2, 36)=23,78$, $p < 0,001$, $\eta_p^2= 0,57$, with participants reporting an almost

perfect balance between the perceived skills and challenge (see Supplementary material *Figure 3*).

Study 2

Behavioral data

Replicating study 1, we observed greater reaction times to the oddball sound in the Flow condition. A one-way ANOVA revealed a significant main effect of Condition $F(2, 34)=5,50$, $p = 0,009$, $\eta_p^2 = 0,24$. Post hoc tests showed that reaction times were significantly greater in the Flow condition, when compared with the Boredom ($M = 736,72$ vs. $M = 674,13$, $p = 0,006$) and but not with the Frustration condition ($M = 736,72$ vs. $708,50$, $p = 0,307$). Likewise, error rates showed a similar pattern. The result revealed a significant main effect of Condition $F(2, 34)=6,03$, $p = 0,006$, $\eta_p^2 = 0,26$, with error rates being greater in the Flow condition, when compared with the Boredom ($M = 6,27$ vs. $M = 1,38$, $p = 0,005$) and when compared with the Frustration condition ($M = 6,27$ vs. $M = 3,44$, $p = 0,088$). Two self-reported questionnaires were added to assess flow (see Supplementary material section Questionnaires) and they both corroborated that participants experienced more flow in the Flow condition. Also when considering the other experimental conditions, participants reported more frustration in the Frustration condition and more boredom during the Boredom condition, confirming that the task elicited the expected levels of flow (see Supplementary material section Questionnaires).

Electrophysiological data

As can be seen in Figure 2a the topography voltage maps show a negative deflection peaking approximately 170ms maximally over the FCz electrodes (see Figure 3) following the onset of correct responses. At FCz, by visual inspection it is possible to observe a delay in the peak of this component during the flow condition. In order to further investigate this, a one way repeated measure ANOVA with the factor Condition (Boredom. vs. Flow vs. Frustration) was conducted and revealed a significant main effect of condition when considering the component's latency ($F(2,34) = 5,56$, $p = 0,008$, $\eta_p^2 = 0,25$) with an increased delay for Flow in comparison to Frustration ($M = 225,06$ vs. $M = 155,5$, $p = 0,008$) and with Boredom ($M = 225,06$ vs. $M = 172,5$, $p = 0,053$). However with regard to the component's amplitude no main effect of the Condition ($F(2,34) = 0,23$, $p = 0,228$, $\eta_p^2 = 0,01$) was found.

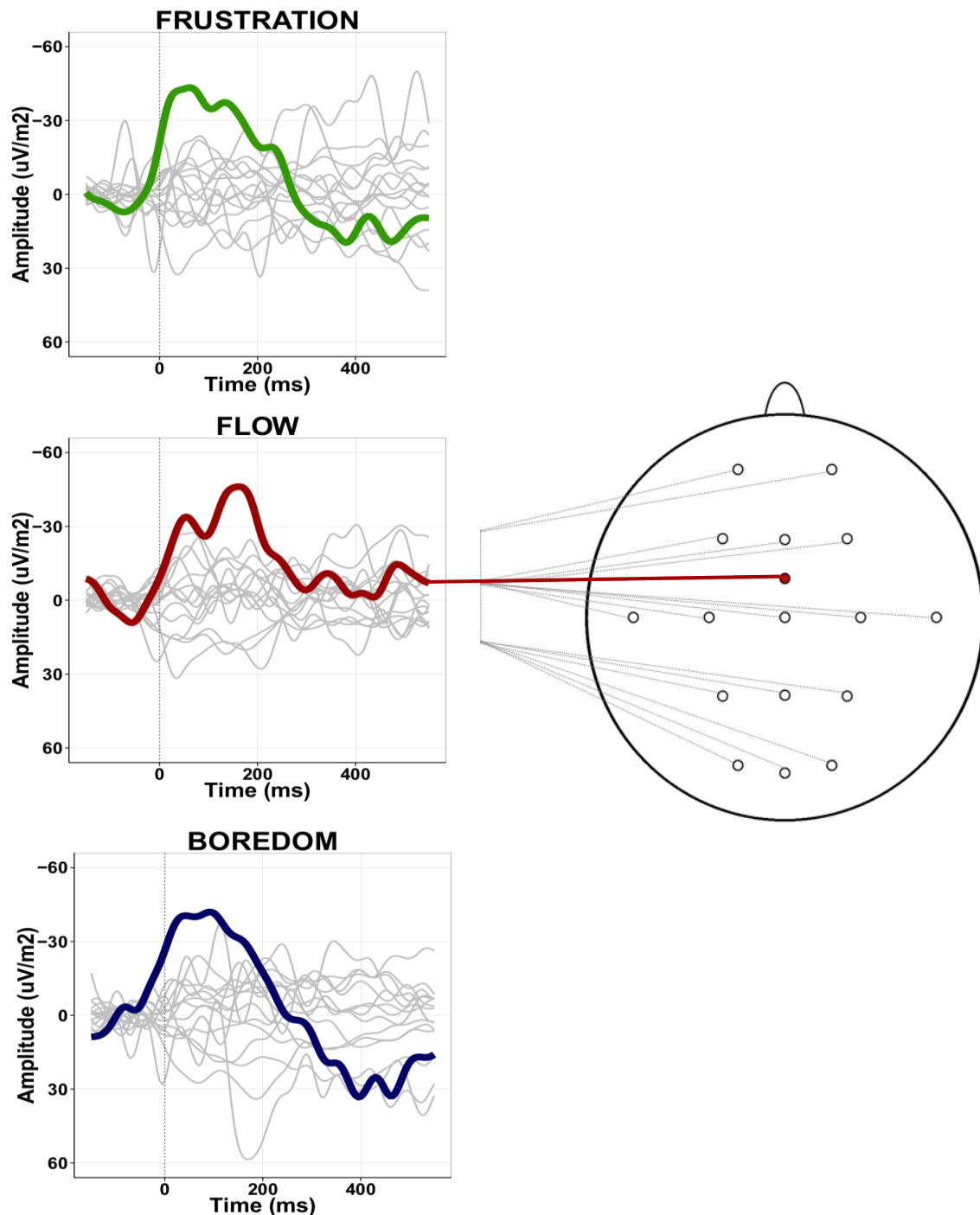


Figure 3. Grand averaged ERPs. Laplacian transformed data. All plots are time-locked to the onset of correct responses. Event-related potentials at 16 frontal, central and parietal representative channels (Fp1, Fp2, F3, Fz, F4, T8, C3, Cz, C4, T8, P3, Pz, P4, O1, Oz, O2) are depicted in grey and at the fronto-central electrode FCz in color for each experimental condition

Figure 4A shows the differences between conditions in the timing of this component, which peaked on average 24ms later on the Flow condition when compared with the other two experimental conditions. Importantly this component was absent in errors trials (see Supplementary material Figure 6), which suggest that it is elicited only when the target has been correctly detected and attentional resources should be re-allocated to the primary task.

In a second step we searched for the brain regions responsible for the genesis of this negativity maximal at fronto-central locations. The LORETA results indicated the gravity center to be located in the medial and middle frontal gyrus (Brodmann area 6). The figure 4C depict in an axial, a sagittal and a coronar slice the activity through the reference brain at the component peak.

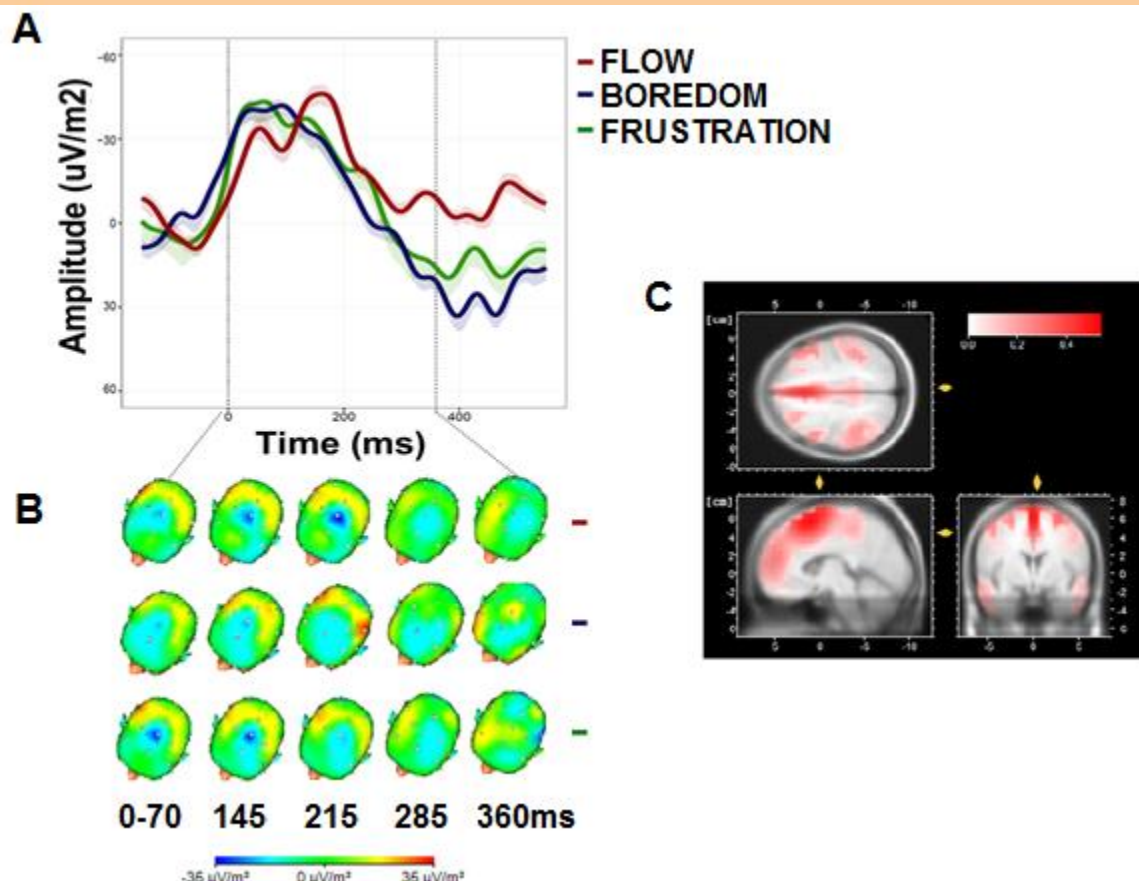


Figure 4 A. Laplacian transformed data – activity locked to the onset of correct responses per condition at electrode FCz. The shaded area indicates the 95% confidence interval B. Scalp maps corresponding to the first 360ms following the response onset C. LORETA results showing activity at the negativity peak in the flow condition as maximal at the medial and middle frontal gyrus ($X=5$, $Y=5$, $Z=45$, Brodmann area 6)

In a second step, we investigated the decomposed signal on the frequency domain. Analyses to compare the differences between conditions were conducted separately for each band by means of a repeated measures ANOVA with the factor Condition 3 (Boredom, Flow, Frustration) x 3 Electrode position (Fz, FCz, Cz). The results revealed for all frequency bands a significant main effect of Electrode position; alpha ($F(4,68) = 4,82$, $p = 0,014$, $\eta_p^2 = 0,22$), beta ($F(4,68) = 4,70$, $p = 0,016$, $\eta_p^2 = 0,22$), theta ($F(4,68) =$

3,90, $p = 0,030$, $\eta_p^2 = 0,19$). However, the main effect of the Condition was significant for the alpha band analyses only; alpha ($F(4,68) = 3,73$, $p = 0,034$, $\eta_p^2 = 0,18$), beta ($F(4,68) = 1,60$, $p = 0,217$, $\eta_p^2 = 0,09$), theta ($F(4,68) = 1,70$, $p = 0,323$, $\eta_p^2 = 0,06$). Post hoc analyses revealed an increase in the alpha band flow condition when compared with frustration ($M = 46,08$ vs. $M = 27,96$, $p = 0,045$) and with boredom ($M = 46,08$ vs. $M = 29,99$, $p = 0,083$). For all frequency bands the interaction effect was not significant: alpha ($F(4,68) = 1,71$, $p = 0,158$, $\eta_p^2 = 0,09$), beta ($F(4,68) = 1,03$, $p = 0,399$, $\eta_p^2 = 0,06$), theta ($F(4,68) = 0,36$, $p = 0,835$, $\eta_p^2 = 0,02$). The figure 5 shows the ERSP for the three experimental conditions at the electrode FCz. Differences in the alpha band following the response onset can be observed.

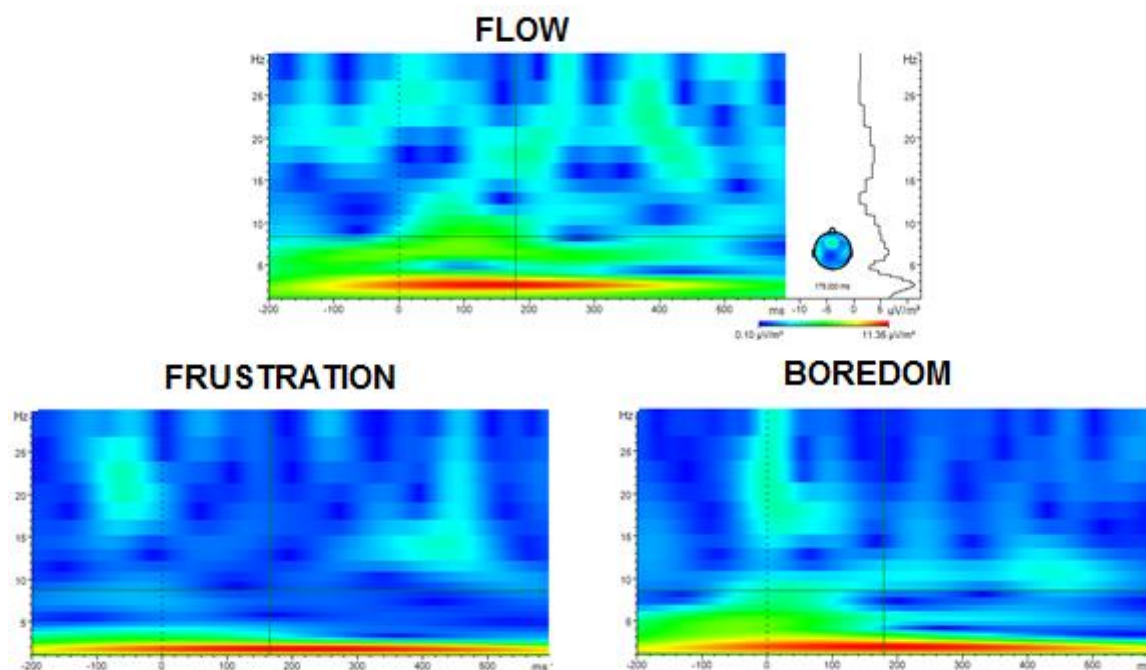


Figure 5. ERSP time frequency plots are given for the Frustration, Flow and Boredom conditions. All data are taken from electrode FCz

Discussion

A novel way to indirectly assess the extent to what subjects experience flow during real game play was presented and validated, initially only considering behavioral parameters and later by analyzing EEG recordings. In Study 1, participants played a game as a primary task while reaction times and error rates were recorded while a novelty oddball paradigm was introduced as a secondary task. Every participant completed the game in three experimental conditions: Boredom, Flow and Frustration. Behaviorally, the results showed slower reaction times and higher error rates in the Flow condition, indicating that when being deeply immersed in the game, performance indexes of the secondary task are negatively impacted. This is in line with the results reported by Weber & Huskey (2013) but when using a visual secondary task. Our results therefore provide further evidence suggesting that recorded error rates and RTs using an auditory oddball as a secondary task could be used to indirectly assess the extent to which subjects are engaged in a game. Future studies should investigate whether this is also the case when assessing other immersive media. In fact, since research on flow has been applied in a variety of contexts such as during internet use (Chen, 2000; Chen, Wigand, & Nilan, 1999, 2000), in computer-mediated environments (Finneran & Zhang, 2002, 2003; Ghani, 1995; Webster, Trevino, & Ryan, 1993) online consumer behavior (Koufaris, 2002) and different disciplines such as sports psychology and arts (e.g. Jackson et al., 2001, Csikszentmihalyi, 1997), we believe the paradigm described here has the potential to be used in wide range of research environments when adapted.

Our Study 2 aimed at validating the use of this paradigm by means of EEG recordings. We were interested in mapping how the re-allocation of attentional

resources occurs once the target has been detected and therefore we explored the differences following the response onset. By doing this we were able to reach one important goal which was to exemplify how using a neuroscience approach researchers could also take advantage of this method to investigate flow. Specifically, in a first stage the response locked ERP correlates were investigated. Our results revealed the presence of a fronto-central negative deflection reaching its peak around 150-170 ms, delayed on average 24 ms in the Flow condition when compared to the conditions of Boredom and Frustration. First of all, it is important to mention this is not the first study reporting this component. This mid-frontal negativity elicited by the response onset has been previously observed (see Kayser et al., 2007). Specifically, a CSD component exhibiting high topographic similarity with components elicited by the response onset such as the ERN, CRN, FRN has been identified during stimulus-locked auditory oddball ERPs peaking at or around the time when subjects pressed a response button or silently updated a target count (Kayser and Tenke, 2006a, 2006b; Tenke et al., 1998, 2008), and for response-locked ERPs of correct trials recorded during auditory and visual recognition memory tasks (Kayser et al., 2007). Although the functional significance of this component has not been broadly discussed and has only been described as being from the family of ERN, CRN and FRN components, it is thought to be related with motivational and/or self-monitoring processes (Kayser et al., 2009).

In line with this idea, the results of low-resolution brain electromagnetic tomography (LORETA) shows this activity as maximal at Brodmann area 6. A previous study that used LORETA to identify cortical sources of the ERN has also reported the strongest activation associated with the ERN/Ne in Brodmann area 6 which corresponds to the Pre-motor/Supplementary motor area (SMA) (Herrmann et al.,

2004). This is line with recent research suggesting anterior cingulate cortex (ACC) and SMA to be involved in the executive control of actions, such as in monitoring conflicting response demands, detecting errors, and evaluating the emotional significance of events (Luu et al., 2003). In the present study we suggest that this medial frontal activity can be considered as the neural correlate of executive related attentional processes. Specifically, generally attention is theorized as involving a network of brain regions meaning that areas engaged in attentional processes are distributed. Posner proposed an influential theory for a three-network view of attention involving alerting, orienting, and executive processes (see update in Petersen & Posner, 2012). Executive networks (which include midline frontal/ anterior cingulate cortex (ACC) according to Petersen & Posner, 2012) might be crucial in orchestrating attentional shifts within a large scale of distributed networks. In fact it has been recently demonstrated that ACC activity increases monotonically with increasing attentional demands and its activity is predictive of activity in major attentional control regions, suggesting ACC monitors conflict and engages the frontoparietal network to control the focus of attention (Walsh et al., 2011).

Frequency domain analyses revealed another interesting finding, namely significant power increase only in the alpha band for the flow condition when compared with frustration and boredom. Frontal alpha changes recorded as maximal at the mid-frontal lines have been associated with monitoring processes encoding for valence, such as positive reward prediction errors (Oya et al., 2005) and to reward and punishment evaluation (Cohen et al., 2009c). At this stage, we can only speculate about the functional significance of this changes, but since one of the main features of being in the flow is the subjective experience of the activity as intrinsically rewarding, we believe changes in the frontal alpha band during flow experiences might be related

with reward related processing. Importantly, at the neuroanatomical level inputs from the medial frontal cortex are gathered by areas that play a major role in reward guided learning and motivation such as the nucleus accumbens (Cardinal, 2006; Carelli & Deadwyler, 1997). Additionally, there is converging evidence suggesting that the medial frontal cortex mediate different aspects of reward-based behaviors, error prediction, value, and the choice between short- and long-term gains (Haber, 2011). Moreover, this interpretation is in line with the recently proposed Synchronization theory of flow (STF) which defines flow as the positive affect that results from an intrinsically rewarding (unconscious) synchronization of attentional and reward neural networks under conditions of balance between challenge and skills (Weber et al., 2011), but further research with different methods is needed to provide evidence for this synchronization.

Aside from its theoretical relevance, two important methodological aspects of Study 2 deserve attention. First, we observed that EEG recordings during game play contain more ocular movements than recordings of traditional experiments. In the present study ocular movements were removed using ICA as a tool to remove eye movement artifacts from EEG given that when compared with standard methods, ICA preprocessing can improve the detection of data epochs containing eye, muscle, and electrical artifacts by 10-20% (Delorme, 2004). So future studies aimed at using EEG recordings during game play are advised to use this ocular artifact removal method. Secondly, although Laplacian transformed ERP waves have principally been interpreted in clinical settings, here we prove that is also a powerful method to improve the spatial resolution of EEG in non-standard set ups. Laplacian is a unique, linear data transformation that maintains the invariant (i.e., reference-independent) aspects of the EEG signal (see for a tutorial Kayser, 2015) but one of its limitations is its low

sensitivity to deep sources. This might potentially be a problem for components with deep sources but at least for components locked to the response onset such as the ERN and the CRN previous research has not reported counterfeit results when comparing it to other methods (e.g. Roger et al. (2010) for a direct comparison between Laplacian transform and ICA decomposition).

Finally, we would like to point out that the potential applications of the present indirect approach are situated in many different areas since it can be applied to investigate flow/immersion with any type of new media technology in combination with the possibility to investigate activity locked not only to the response but also to stimulus onsets with any kind of high temporal resolution recordings such as EEG, heart rate, skin conductance and MEG signals. Here we investigated activity locked to response onsets, but the oddball task embedded could be implemented with the instruction of counting the oddballs instead to pressing a button, which will facilitate its use in other research setups where both hands should be used for the primary task. We are confident that the validation of this technique with one of the most broadly investigated attentional paradigms in the field of cognitive neuroscience, should facilitate the effort to investigate the subjective experience of flow using behavioral and electrophysiological recordings.

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