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Use of Auditory Event-Related Potentials to Measure Immersion during a Computer Game

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ABSTRACT

The degree of engagement in a computer game is determined by sensory immersion (i.e. effects of display technology) and challenge immersion (i.e. effects of task demand). Twenty participants played a computer game under two display conditions (a large TV vs. head-mounted display) with three levels of cognitive challenge (easy/hard/impossible). Immersion was defined as selective attention to external (non-game related) auditory stimuli and measured implicitly as event-related potentials (ERPs) to an auditory oddball task. The Immersive Experience Questionnaire (IEQ) was used to capture subjective indicators of immersion. The type of display had no significant influence on ERPs or responses to the IEQ. However, subjective immersion was significantly enhanced by the experience of hard and impossible demand. The amplitude of late component ERPs to oddball stimuli were significantly reduced when demand increased from easy to hard/impossible levels. We conclude that ERPs to irrelevant stimuli represent a valid method of operationalising immersion.

Keywords Auditory ERP · Immersion ·Task Demand · Attention

INTRODUCTION

To be immersed in an activity, such as reading a book or playing a computer game, implies a psychological state where an intrinsic motivation to engage with the activity is the primary driver of selective attention, to the extent that the person attends exclusively to task-related stimuli and loses awareness of other sensory stimuli in the environment. Jennett et al (2008) described this heightened state of selective attention as a graded experience ranging from engagement with activity (some awareness of external environment) to total immersion (a sense of sole occupation within a virtual world).

Research on immersion originally focused on interaction with digital worlds (McMahan, 2003; Lombard and Ditton, 1997), particularly computer games and virtual reality environments (Slater, Lotto, Arnold & Sanchez-Vives, 2009). McMahan (2003) made a distinction between immersion or presence as a sense of being “caught up” in a virtual world and engagement with the inherent goals of a virtual task. This division between immersion and engagement leads to two respective aspects of an interaction with a digital world: (1) the hardware used to render the digital world and (2) the degree of effortful engagement that is required to accomplish task goals within that digital world. For interactive digital tasks, the degree of immersion is determined by variables related to sensory experience, such as increasing screen size, sound quality, graphical fidelity or adding 3D display capabilities. There is some evidence that sensory immersion (Ermi and Mayra, 2005) is driven by audiovisual properties of gaming hardware; for example, increased screen size has been associated with greater immersion across a number of studies using desktop displays (Hou et al., 2012; Wu et al, 2011; van den Hoogen et al., 2009), touchscreen systems (Thompson et al., 2012) and head-mounted displays (Tyndiuk et al, 2004; Bowman & McMahan, 2007; Schnall, Hedge & Weaver, 2012). Alternatively, the degree of immersion may be determined by the intrinsic capacity of a task to motivate and engage the cognitive capabilities of the individual. The influence of cognitive immersion is independent of sensory factors and reflects the intrinsic motivation of the task at hand. Several researchers (Chen, 2007; Nacke and Lindley, 2008) have described optimal states of challenge immersion that maximise the engagement of the person in terms of flow states (Csikszentmihalyi, 1990) but these taxonomic models are highly descriptive. Research on cognitive determinants of immersion is limited but it has been demonstrated that immersion increases with cognitive challenge (Cox et al., 2012; Qin et al, 2009). These findings suggest a relationship between immersion and cognitive demand that is synonymous with the association between demand and effort described by the motivational intensity model (MIM) (Wright, 1996). According to the MIM framework, effort is predicted to peak when task demand is high and success is possible. If success likelihood is low, effort falls dramatically due to disengagement. It is hypothesised that the experience of challenge immersion is enhanced in a state of peak effort or engagement, which can only be attained when successful completion of task goals is likely or at least possible.

The operationalisation of immersion has emphasised the collection of subjective data, such as the Immersive Experience Questionnaire (IEQ) (Jennett et al, 2008). This approach is logical as immersion is closely tied to the phenomenological experience of the person. However, subjective measures have significant weaknesses (Nisbett & Wilson, 1977) and should be augmented with other measures (Darken et al, 1999). Jennett et al (2008) characterized immersion in terms of reduced awareness of sensory stimuli in the environment that were unrelated to the primary task. This explanation emphasises the role of selective attention as the central mechanism underpinning the experience of immersion. According to this conception, an immersive task (e.g. reading a book, playing a computer game) competes for selective attention with other stimuli in the external environment (e.g. background music, conversation). If the individual is highly motivated by the immersive task, attention is devoted primarily to task-related stimuli with a correspondent loss of awareness of other stimuli in the sensory environment that are deemed to be irrelevant to the task.

The current study will quantify the degree of immersion in a digital world by measuring the amplitude of event-related potentials (ERPs) to task-irrelevant stimuli. A broad and contemporary review of ERP and EEG theory and methodology can be found in Luck (2005). When stimuli are presented repetitively to experimental participants, "raw" EEG recordings (i.e. the synchronous voltage values over approximately one second per stimulus presentation) can be mathematically averaged to produce event-related potentials, or "ERPs". ERPs are a graphical representation of the "average" changes in the EEG signal in response to having perceived or e.g consciously responded to a physical or mental stimulus. As the signals are weak (typically measured in microvolts), and may also arise from non-conscious, non-deliberate and routine metabolic activity, repetitively averaged ERPs highlight prominent, conscious cognitive mental activity in response to environmental changes or internal mental states. Jasper (1958) standardised the placement of EEG electrodes on the scalp into the International 10-20 System, giving electrodes names representative of placement over particular regions of the scalp and brain. A huge literature has arisen listing many replicable methodologies and characteristic ERP responses (or "components") such as the P300 (Sutton, Braren, Zubin and John 1965; Tueting, Sutton and Zubin ,1970), the N400 (Kutas & Hillyard 1980) and P600 (Osterhout & Holcomb 1992). The nomenclature of ERPs (e.g. P300, N400 etc.) describes the polarity and the approximate onset time of segments of the full waveform after stimulus presentation; thus the P300 is positive waveform component which arises approximately 300 milliseconds after stimulus presentation, and the N400 is a negative-going waveform component approximately 400ms after presentation. ERP responses are typically examined with regard to their onset latency, where later voltage deflections typically reflect aspects of stimulus or response complexity, and their voltage amplitude, where larger amplitudes may have required the mobilisation of greater neurological resources (i.e.relatively larger populations of neurons) to perform the required task.

ERPs have several uses as an experimental technique in psychology. EEG as a procedure is non-invasive with an excellent temporal resolution and subsequent ERP responses can be uncontroversially causally linked with stimulus events. As ERPs are recorded with millisecond-to-millisecond fidelity, they are relatively immune to the types of participant bias or compliance that can arise when using subjective self-report data. In the present study, we have used the auditory oddball irrelevant probe task as a means to examine attention. In this methodology, beeping tones are played at regular intervals to establish a regular, "background" sensory context for participants which is reflected in their ERP. Randomly, this beep tone will be replaced by a higher-pitched beep tone which violates the established context and generates an aberrant ERP response through drawing the participants' attention to this "new" and irregular event. The P300, N200 and later ERP responses are often associated with the oddball experimental paradigm (Luck, 2005).

The approach to ERP analysis taken in the current work is based upon the reciprocity hypothesis (Wickens et al, 1983; Rosler et al, 1997) which describes an inverse relationship between the task demand/immersion and the level of attentional capacity held “in reserve”, hence ERP responses to task-irrelevant stimuli tend to decrease in amplitude as the attentional demands of the primary task increase. A number of early studies were performed using a dual-task methodology (Isreal et al, 1980a; Isreal et al, 1980b) whereas later work employed an irrelevant-probe technique where participants focused exclusively on a primary task whilst simultaneously being presented with probe stimuli that were completely unrelated to the primary task (Sirevaag et al, 1993; Ullsperger et al, 2001). The irrelevant probe approach represents an implicit method for capturing 'spare' attentional capacity whilst participants engaged with a primary task. It is assumed that the amplitude of ERPs to task-irrelevant stimuli are determined by the amount of 'spare' attentional capacity that has not been invested in the primary task (Kok, 1997). These irrelevant probe studies incorporated an oddball paradigm into the methodology wherein ERP amplitudes to an infrequent stimuli presented within a stream of frequent stimuli were assessed whilst the participant was engaged in the primary task.

The present study measured ERP amplitudes to task-irrelevant probes whilst a person was playing a computer game in order to capture residual awareness of the physical environment. This particular study utilised a futuristic racing game called "WipeOutHD Fury" (Sony) where players compete against seven computer-controlled opponents over a short circuit. Allison and Polich (2008) used a modified auditory oddball as an irrelevant probe when participants either viewed a computer game or played the game at three different levels of difficulty. They reported that amplitudes of N2, P2 and P3 diminished as game difficulty increased from easy to hard. Miller et al (2011) recorded ERPs to irrelevant auditory stimuli whilst participants played the computer game Tetris at easy and hard levels of demand; they reported that amplitudes of N1, P2, P3 and late positive potential (LPP) were inversely related to the difficulty of the game; these ERPs were recorded from midline electrode sites (Fz, Cz, Pz: see Figure 1). Subjective measures of presence have been related to ERP responses to irrelevant stimuli during exploration of a virtual environment (Kober and Neuper, 2012) where the authors observed an inverse relationship between late negative slow wave amplitudes particularly in the frontal area (Fz: Fig. 1) and subjective feelings of presence in a virtual space.

INSERT FIGURE 1 HERE

Figure 1. Illustration of the International 10-20 system (Jasper, 1958)

It is known that hardware characteristics and the level of task demand have respective influences on sensory and cognitive immersion. The primary goal of the current study was to assess the influence of both aspects within the same experimental study. Hence, we manipulated sensory immersion by comparing two types of screen display; a large LCD TV screen and a head-mounted display (HMD). In order to assess the influence of cognitive immersion, participants were exposed to increasing levels of task demand. It was anticipated that immersion would be higher in the HMD condition and, in line with the motivational intensity model (MIM) (Wright, 1996), we anticipated cognitive immersion to peak at hard demand compared to easy or impossible levels of demand.

The degree of sensory and cognitive immersion was assessed using the irrelevant-probe technique to quantify participants' awareness of task-irrelevant sensory stimuli during engagement with the game. The advantage of this approach is that awareness of task-irrelevant stimuli offers a quantifiable index of immersion (i.e. residual attention to the environment in the presence of a gaming task) that can be captured in real-time without causing significant disruption to performance on the primary task. We hypothesised that display type and demand would exert a specific effect on those late negative slow wave (SW) components of the ERP that have been associated with central cognitive processing (Kober and Neuper, 2012).

Specifically, we expected the HMD to maximize the amplitude of SW amplitudes in comparison to a conventional LCD display as an indication of increased sensory immersion. With respect to demand, it was anticipated that ERP amplitudes would reach maximum levels during the hard task that represented the peak of challenge immersion.

METHOD

Participants

Participants were 20 students (13 male) with a mean age of 23.67 years (st.dev. = 4.23 years), recruited under a voluntary basis. Three participants were left-handed. None of the participants had any previous experience of playing the game used during the experiment. All participants were paid for taking part in the study and the experimental protocol was approved by the University Research Ethics Committee prior to data collection.

Experimental Design

We used a mixed 2x3 design where the type of display functioned as a between-participants factor and game difficulty was manipulated on a within-participants basis. Participants were randomly allocated to one of two groups (N=10) who played the game using either a large LCD TV screen, or a head-mounted display. All participants experienced all 3 levels of game difficulty (Easy, Hard and Impossible) using the display type to which they were assigned. The order of presentation of game difficulty conditions were rotated across participant sessions, beginning with the Easy>Hard>Impossible sequence for the first participant and rotating through all difficulty conditions every six participants.

Participants viewed either a Samsung LE40B550 40” LCD TV (viewing angles: 18.7° (vertical) x 32.6° (horizontal) at a distance of 1.5 metres) or a Silicon Micro Display ST1080-10V1 head-mounted display (viewing angles: 20.16° (v) x 40.27° (h) at a fixed 4.5cm from the eyes). Both devices displayed the game using their native 1920x1080 resolution. We output audio from the Playstation3’s SP/DIF optical output via a FiiO D3 digital-to-analogue converter to a Studiomaster 2000 analogue mixing console, then to earbud-type headphones to the participant. The audio presented to all subjects varied only in that the music soundtrack routinely changes songs over time; the volume levels for game audio and auditory tones were kept constant throughout.

Prior to the experiment proper, we recruited and observed 15 non-experimental volunteers playing the game in order to observe performance under different difficulty settings for piloting purposes. Individual races typically lasted from 95 to 110 seconds dependent upon the player’s ability, and after approximately 40 minutes of play-time, all but two pilot volunteers were able to achieve a finishing position from 1st to 4th (out of eight) under the “Easy” (“Novice”) game settings. Under the “Hard” (“Skilled”) setting, all but two volunteers were able to achieve higher than 4th place. No participant successfully won the race under the “Impossible” (“Elite”) difficulty setting. This information was used to modify the instructions to the actual participants in order to create easy/hard/impossible levels of demand during the actual experiment.

Experimental Task

Participants played the Playstation3 game “WipeoutHD Fury” (Sony Liverpool Studios) using a conventional PS3 controller. WipeoutHD Fury is a racing-type video game; players compete against 7 other computer-controlled vehicles simply to cross the finish line first; details and screenshots can be found at <http://en.wikipedia.org/wiki/Wipeout_HD>. We chose this particular game as the control scheme and general game mechanics are simple to understand.

Experimental Measures

EEG and oddball task: Our oddball probe task closely resembled a “classic” ERP oddball methodology (Naatanen, Gaillard and Mantysalo 1978). Audacity software (audacity.sourceforge.net) was used to create pure-tone 1Khz “standard” and 2Khz “oddball” beep tones with virtually instantaneous rise-times to the target frequency. 90 standard and 20 oddball tones were played back in random order during each race using E-Prime v2.0. We mixed the beep tone audio via the mixing console, and checked by asking participants that the tones were clearly audible within WipeoutHD’s normal audio soundtrack. EEG responses to the standard and oddball tones during gameplay were recorded from 64 EEG channels in an extended 10-20 system montage using a Biosemi ActiveTwo ADC-12 amplifier. EEG was recorded at 1024Hz, and referenced post-hoc to linked earlobes. We removed gross artifacts and eyeblinks from the EEG and band-pass filtered the signal between 0.1 and 30Hz post-hoc, using BESA Research 5.3, averaging the standard and oddball tones separately. After filtering and corrections, typically 15 oddball tones per race played were suitable for grand-averaging, resulting in grand averages combined of approximately 60 oddball samples (i.e. 15 samples * 4 races) per racing condition per participant - e.g. 60 total oddball samples from 4 races at Easy, 60 samples from 4 races at Hard, and so on.

Subjective Questionnaire: The subjective gaming experience was quantified using the Immersive Experience Questionnaire (IEQ; 31 items, Cronbach's α = 0.89) (Jennett et al. 2008; appendix B from the source). As a factor structure was not available from the source publication, we chose the Appendix B variant as the majority of the items directly address issues of attention, effort, immersion and enjoyment of a game as an overall subjective experience. We reverse-scored items 6, 8, 9 and 10 as they pertained to subjects' awareness of the external world during the gaming experience, thereby indicating measures of distraction rather than immersion.

Procedure

During the experimental procedure, EEG responses to an auditory oddball task were recorded while participants played four races of a video game at 3 difficulty settings (i.e. 4 races at Easy/Novice difficulty, 4 races at Hard/Skilled difficulty and 4 races at Impossible/Elite difficulty), and also during 4 blocks of "pure oddball" auditory-only stimuli without the game. While the EEG electrodes were fitted (~40 minutes), participants practiced playing the game at their own pace on the "easy" difficulty for familiarity and their finishing positions were noted. During the experiment proper, under the "hard" or "impossible" conditions, participants were instructed to achieve a race position at least one position higher than their previous best during practice in order to evoke continuously high performance demands. During the "easy" condition, participants were instructed to relax, enjoy the game and remain at the back of the racing pack if possible (if we had instructed participants not to try to win at all, they could have simply not respond until all the computer-controlled players had finished the race). During the auditory-only conditions, the display device and game console were switched off, and participants were instructed to keep their eyes open and listen to the beep tones. Whilst playing the game, participants were instructed to try to attend to the oddball beeps by simply listening to the beeps, but were informed that they were not required to count or otherwise mentally manipulate the tones etc. After each set of 4 races in one difficulty setting was complete, participants completed the IEQ variant.

RESULTS

Grand average ERPs obtained during the study are presented in Figures 2-4. Plots of standard and oddball tones are presented in Figure 2 during the ‘pure’ oddball condition (i.e. ERP data collected in the absence of game play) in order to provide an indication of ERP morphology to oddball and standard auditory tones. In Figure 2, ERPs to oddball tones during the ‘pure’ condition displayed a well-modulated ERP, varying in amplitude throughout the course of a 931ms recorded epoch along the midline Fz, Cz and Pz sites.

We confined our statistical analyses to those ERP oddball responses that were obtained during the game (Figures 3 and 4) as the focus of the experiment concerned the relative size of ERP amplitudes during different conditions of game play. The range of ERP amplitudes obtained through the ‘pure’ epoch illustrated in Figure 2 are notably larger than those displayed in Figures 3 and 4 which were recorded during game play. The same effect was observed by Allison and Polich (2008).

INSERT FIGURE 2 HERE

Figure 2 : Oddball and standard tones at midline sites in the absence of gameplay demands.

Grand Average ERPs for oddball tones are presented in Figures 3 and 4, comparing overlays of game difficulty levels at each of five electrode sites for both display conditions. A visual inspection of the Fz site (Figures 3 and 4) indicated two regions of interest at the frontal Fz site, spanning the P1 peak at 320-475ms, and a late Slow Wave (SW) deflection at 476-685ms. At Cz, C3, C4 and Pz, we analysed the P1, SW, and a late negative (LN) component at 315-460ms, 461-720ms, and 721-933ms respectively

INSERT FIGURES 3 AND 4 HERE

Figures 3 and 4: Grand average ERPs to oddball tones obtained during gameplay conditions from each display device.

Main Effects of Game Difficulty

A series of repeated-measures 2 x 3 ANOVAs were performed, examining the effects of game difficulty and display type within each electrode site (Fz, Cz, C3, C4, Pz) and region of interest (P1, SW, LN). These analyses yielded no significant effects for the display type manipulation nor any interaction effects. The significant main effects of these analyses for the game demand manipulation are summarised in Table 1 followed by post-hoc contrasts in Table 2. With respect to Table 1, we found the late Slow Wave (SW) deflections were sensitive to game demand at Fz, C3 and C4 whereas the effect of demand on P1 and LN was only significant at C4. The post-hoc tests in Table 2 indicated that the SW component was significantly lower during Easy demand compared to Hard or Impossible (see Figure 5). The same effect for SW was apparent at C4. The earlier P1 component distinguished easy from impossible demand but only at C4 and this effect was also observed at C4 with respect to the LN component.

INSERT TABLE 1 HERE

Table 1. Summary of significant main effects due to game demand for ERP components

INSERT TABLE 2 HERE

Table 2. Mean Amplitudes (S.D.s) for significant post-hoc comparisons of ERP components across the game demand manipulation.

A main effect of game difficulty emerged for the SW component at Fz and C3 and all three ERP components at C4 (Table 1). All significant post-hoc comparisons in

Table 2 indicate that mean ERP amplitudes evoked under the Easy condition were of significantly lower magnitude than both the Hard and Impossible difficulty settings. The mean values for the SW component at Fz are illustrated in Figure 5 to represent the characteristic pattern of the main effect for game demand.

INSERT FIGURE 4 HERE

Figure 5: Amplitude of SW component at Fz site for Easy, Hard and Impossible Levels of Game Demand

Subjective Measures - IEQ Questionnaire

As participant numbers were insufficient for a full factor analysis (and the source article did not include such), we computed total scores for the IEQ under each of the 3 game difficulty settings. Data for one participant was not available for the Easy condition due to a technical issue with the online form. A one-way ANOVA indicated that significant differences ($F(2,57)=10.22$, $p<0.01$, $\eta^2 =0.26$) were present due to comparisons of Easy vs. Hard ($p<0.01$) and Easy and Impossible ($p=0.02$) difficulty settings after Bonferroni correction and irrespective of display condition. It was apparent that subjective immersion was highest during the Hard condition (M = 115.8, SD = 0.5) compared to either Easy (M = 98.2, SD = 4.5) and Impossible (M = 108.4, SD = 0.07).

DISCUSSION

It was expected that ERP amplitudes to the auditory oddball stimuli would decline as immersion increased as predicted by the reciprocity hypothesis (Wickens et al, 1983). Specifically, we expected ERP amplitudes to decline when game demand was hard, but neither easy nor impossible, in accordance with the predictions of the MIM (Wright, 1996). It was also anticipated that immersion would be maximised during the HMD condition due to sensory immersion as this type of display completely occupied the visual field, i.e. ERPs would be of generally lower amplitude in the HMD condition compared to the LCD condition.

Our analyses revealed that the SW component at Fz showed a significant decline when game demand increased from easy to hard, and from easy to impossible (Table 2 & Figure 5). The sensitivity of SW amplitude to challenge immersion duplicated a similar effect observed by Kober and Neuper (2012) who used the same ERP methodology to assess presence in a VR environment; however these authors used individual differences with respect to subjective presence as their primary independent variable whereas hardware and task characteristics were manipulated directly in the current study. Unlike the study performed by Allison and Polich (2008), the current study employed ERP responses to infrequent and distinct ‘oddball’ tones as opposed to the series of standard tones used in the earlier study. Like Miller et al (2011), we manipulated game difficulty in order to index residual attentional capacity as measured by ERP responses to oddball auditory stimuli with the caveat that the current study was performed to assess the relative impact of both cognitive challenge and sensory immersion due to the manipulation of visual display characteristics.

The SW components were particularly sensitive to game demand at Fz, which was unsurprising given the proximity of the frontal lobes to this site and the association between the frontal cortex and attentional control (e.g. Posner and Petersen 1990). However, the effect of game demand on SW components at Fz did not follow the prediction of the MIM as there was no difference between hard and impossible game conditions (Figure 5). It is assumed that attention to the game was engaged at an equivalent level in response to both hard and impossible levels of demand, which was surprising given there was no realistic chance of success in the impossible gaming condition. The preservation of attention to the game in the face of impossible demand may reflect of the high level of intrinsic motivation engendered by entertainment software as opposed to the cognitive psychology tasks traditionally used to explore the MIM, i.e. participants may have refused to “give up” the race during the “impossible” condition. However, subjective self-report data from the IEQ (Jennett et al, 2008) supported the main hypotheses of MIM, with immersion significantly peaking at hard demand compared to easy or impossible conditions.

This divergence between ERP data and subjective measures may reflect greater inclusivity of the IEQ as a measure of immersion, encompassing aspects of motivation and emotion as well as attention within its suite of questions. On the other hand, the measurement of the ERP was employed to operationalise a specific aspect of immersion, namely selective attention to auditory stimuli in the environment that were irrelevant to the game. In addition, the IEQ is a retrospective measure of the gaming experience whereas ERP represents a cumulative neurological response to repeated stimuli that was captured in real-time. Responses to the IEQ may be distorted by the demand characteristics of the impossible game scenario, i.e. participants were aware that success likelihood was zero and adjusted subjective responses retrospectively in order to achieve a level of consistency with their performance during the game. However, ERPs do not incorporate conscious biases due to their immediacy. We would argue that the ERP methodology offers the most accurate and reliable index of immersive experience because these data are captured in real-time and avoid subjective bias.

The effects of game demand on ERP components were also observed at C3 and especially C4 (Tables 1 and 2), although we feel these effects may have been more related to readiness and voluntary movement than motivation-related cognition; the Lateralised Readiness Potential and Bereitschaftspotential can both be obtained through electrode placement and data manipulations from the vicinity of the C3 and C4 sites (e.g. De Jong et al. 1990; Deecke and Kornhuber 1978). The majority of participants were right-handed and the standard control layout for game console controllers, including the Playstation 3, is for the left analogue joystick to control gross movement of the player's racing craft. As constantly fine-tuned movement is required as a normal part of the game, it is perhaps unsurprising that participants showed prominent activity at the C4 site throughout all difficulty conditions, close to the somatosensory cortex for the left side of the body (i.e. manipulating the left-side joystick on the PS3's controller), which was most pronounced when increased difficulty required greater input and fine levels of motor control.

The influence of display type on both ERP and subjective measures of immersion was striking by its absence in this particular study. There was no statistical evidence that the HMD increased immersion from either ERP analysis or participants' responses to the subjective questionnaire, and this null finding indicated that the level of cognitive challenge was the primary driver of immersion in this particular experiment. The two display types were selected because they represent different categories of technology, however we did not formally control for perceptual variables, such as field of view (Bowman & McMahan, 2007) that perhaps exert a greater influence on sensory immersion than the literal category of display technology. For example, as detailed in the Method section, the viewing angles for both TV and HMD displays did not differ by a substantial margin. This aspect should be explored in any replication of the current study.

The study had a number of weaknesses that we would seek to address in future research using the same methodology. Direct comparisons with the large body of existing auditory oddball literature are problematic in the current study (for a review, see Näätänen (1992)). The primary purpose of the study was to explore the use of the irrelevant-probe task as a marker of immersion, hence ecological validity demanded that we use commercial software that is designed with the primary purpose of entertainment. There was a price to be paid for this level of ecological validity with respect to both experimental control and the atypical characteristics of our ERP data. The perceptual demands of game control and the probabilistic flow of events in the game world meant that mental and physiological states could not be tightly controlled as would ordinarily be expected in a laboratory scenario. This influence can be appreciated by comparing the oddball ERPs at the midline sites from Figure 2 (no game) with those grand averages illustrated in Figures 3 and 4. In addition, the constant activity of the hands required to use the controller appears to have generated considerable activity at the lateral parietal sites, as well producing as an oscillation of the baseline in our grand averages due to continually varying activity during gameplay (see Figures 3 and 4). Another potential source of noise may have been small head-movements from individuals wearing the HMD, which presented them with a first-person view of their on-screen actions. The study also suffered with respect to relatively low sample size used in the design, an analysis of statistical power indicated that the results of the post-hoc t-tests listed in Table 2 should be treated as preliminary and require replication with a larger number of participants.

The use of commercial gaming software during the experiment led to other limitations. We would have preferred to use game software where the level of demand could be manipulated with greater precision in order to create an easy task that required minimal effort; somewhat paradoxically, instructing participants not to try to win (i.e. to remain at the rear of the pack in the "easy" condition) may have required some mental effort on their part, and thus exacting experimental control can be difficult to achieve. In addition, we did not investigate the relationship between performance during each game condition (i.e. race position) and immersion (captured via IEQ or ERP); it is logical to assume that immersion would have increased due to good performance but our study made an assumption about participants' performance based on the level of demand. The commercial availability of game means that some participants may have experience of the game prior to taking part in the experiment, in addition, some participants may have more experience with similar types of games from everyday life. We did not control for prior experience of computer games in general, reasoning that the simplicity of the game controls rendered the game play accessible even to an absolute novice. This was problematic when performance during the race was used to distinguish different levels of demand. For example, the same two participants in our sample failed to complete the race in the top four positions in both the Easy and Hard versions, which seemed to indicate that these two people had less experience with gaming than the majority of our participants. In addition, their presence in the sample reduces the degree of differentiation between easy and hard demand as an independent variables. Future work should consider the influence of prior gaming experience as a mediator of immersion and attentional capacity as indexed by ERPs. Secondly, we would also have preferred to acquire greater numbers of oddball trials for averaging; as the ERP signal-to-noise ratio is reduced as the square root of the number of averaged trials (Handy 2005), the resolution of the ERPs was constrained here by the typical time taken per race limiting the total number of trials which could be presented. Our ultimate approach seems validated, however, by the robust morphology of the waveform generated during the “pure oddball” condition depicted in Figure 2. The enhanced amplitudes of the pure oddball ERP’s major components in comparison to the gameplay conditions, where mental effort was otherwise invested in playing the game rather than attending to the oddball probe, would seem to indicate that we were successfully recording ERP components with a genuine and morphologically distinctive cognitive origin.

The results of our study demonstrated that the auditory oddball task as an irrelevant probe technique was sensitive to challenge immersion (Ermi and Mayra, 2005) as a reduction in an implicit attention to the surrounding physical environment, due to the expenditure of attention and cognitive effort on an engaging primary task. Similarly to Kober and Neuper (2012), and despite substantially different methods, we found significant variations in late-positive ERP activity in the fronto-central regions of the head, despite the perceptual and experiential differences between typical recreational video-gaming and the more specialised virtual reality environments used in the earlier work. The absence of any effect due to display type suggested that sensory immersion did not exert the same level of influence over the experience as challenge immersion, although this hypothesis requires further research.

The study demonstrated the feasibility of the auditory oddball task as an index of immersion. The approach has several strong points: (1) by linking immersion to selective attention and attentional capacity, we have operationalised immersion as attention to task-irrelevant stimuli and thus improved the scientific definition of this construct, (2) the amplitude of the ERP delivers a quantitative index to represent the graded nature of the immersive experience, and (3) the measure can be captured in real-time and with minimal disruption to the primary task. This approach provides a common metric that can be used to investigate the relative impact of sensory and cognitive aspects of immersion as demonstrated in the current study.

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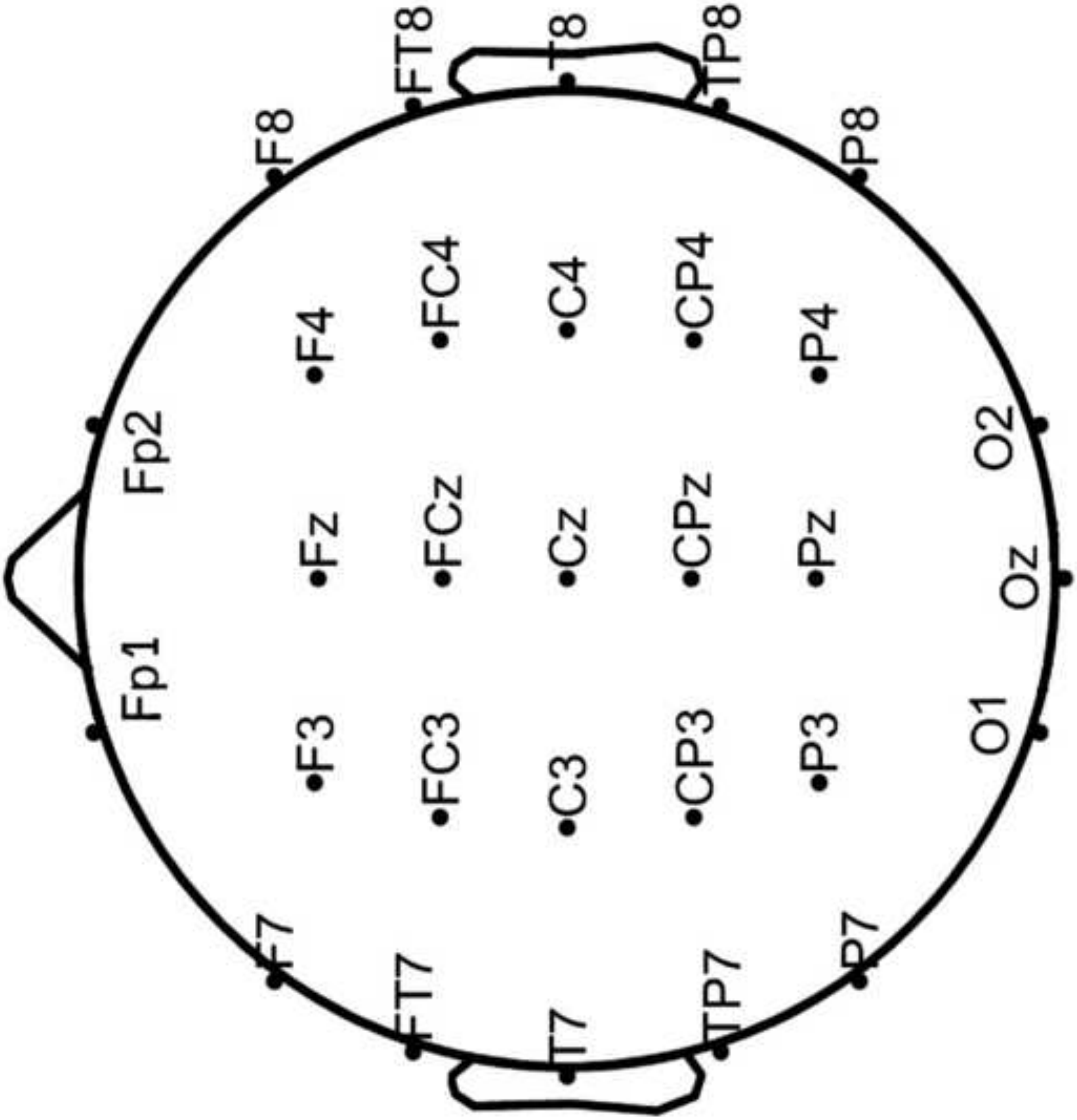
Site	Component	F(2,36)	Sig.	Partial Eta^2
Fz	SW	4.02	.03	0.289
C3	SW	4.34	.05	0.266
C4	P1	4.47	.02	0.326
C4	SW	5.74	.01	0.349
C4	LN	5.88	.01	0.387

Site	Component	Easy (µV)	Hard (µV)	Impossible (µV)	Significant Contrast (t(19))
Fz	SW	-0.16 (1.35)	-1.11 (1.14)	-1.06 (1.45)	Easy vs. Hard 2.55, p<0.02
Fz	SW	-0.16 (1.35)	-1.11 (1.14)	-1.06 (1.45)	Easy vs. Imp. 2.55, p<0.04
C3	SW	-0.01 (0.99)	-0.70 (0.61)	-0.43 (0.81)	Easy vs. Hard 2.61, p<0.02
C4	P1	-0.06 (0.83)	-0.63 (0.94)	-0.83 (0.61)	Easy vs. Imp. 3.02, p<0.01
C4	SW	0.34 (1.05)	-0.32 (0.85)	-0.55 (0.59)	Easy vs. Hard 2.016, p<0.04
C4	SW	0.34 (1.05)	-0.32 (0.85)	-0.55 (0.59)	Easy vs. Imp. 3.166, p<0.01
C4	LN	0.63 (1.23)	0.14 (0.84)	-0.46 (0.85)	Easy vs. Imp. 3.417, p<0.01

HIGHLIGHTS

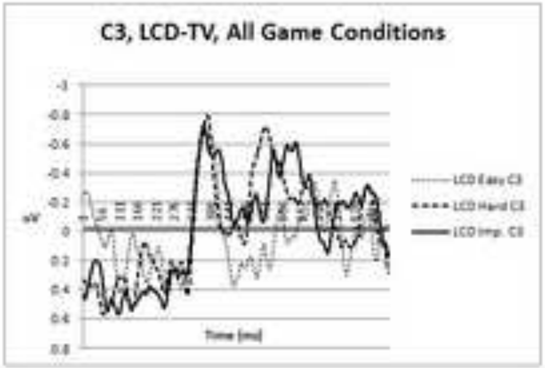
- Irrelevant probe technique used as implicit measure of immersion
- Late negative ERP amplitudes decreased when game demand was easy
- No effect of display type on ERP amplitudes were found

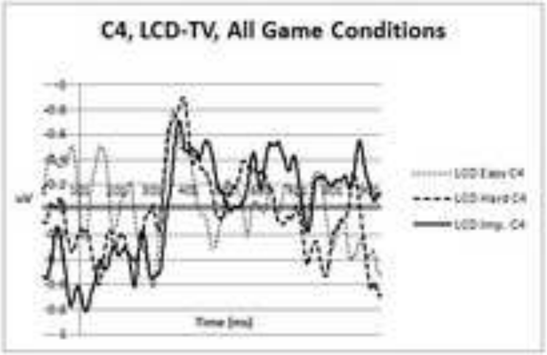

Fp1
Fp2
F7
F3
Fz
F4
F8
FT7
FC3
FCz
FC4
FT8
T7
C3
Cz
C4
T8
TP7
CP3
CPz
CP4
TP8
P7
P3
Pz
P4
P8
O1
Oz
O2

Figure

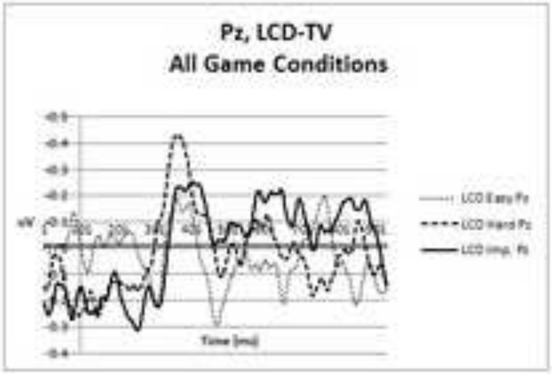
Figure


Fz, LCD-TV
All Game Conditions
uV
Time [ms]
LCD Easy Fz
LCD Hard Fz
LCD Imp. Fz

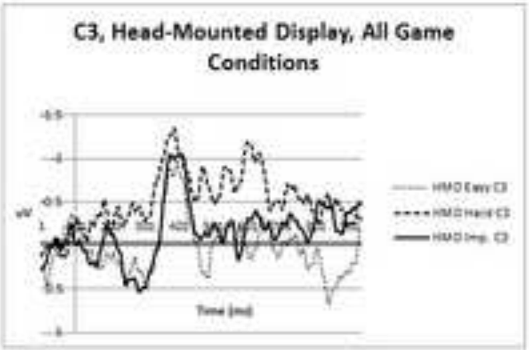

C3, LCD-TV, All Game Conditions
uV
Time [ms]
LCD Easy C3
LCD Hard C3
LCD Imp. C3

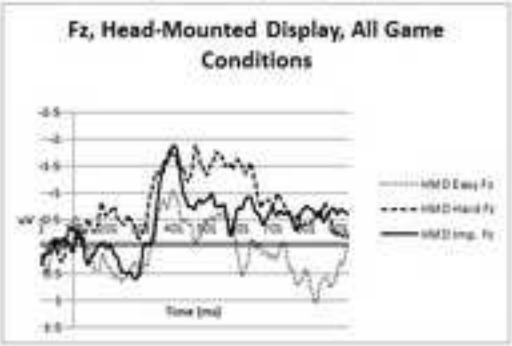

C4, LCD-TV, All Game Conditions
uV
Time [ms]
LCD Easy C4
LCD Hard C4
LCD Imp. C4

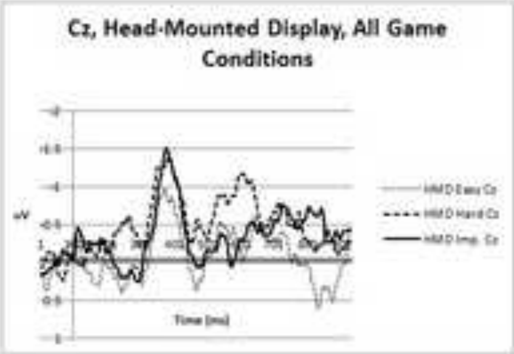

Cz, LCD-TV
All Game Conditions
uV
Time [ms]
LCD Easy Cz
LCD Hard Cz
LCD Imp. Cz

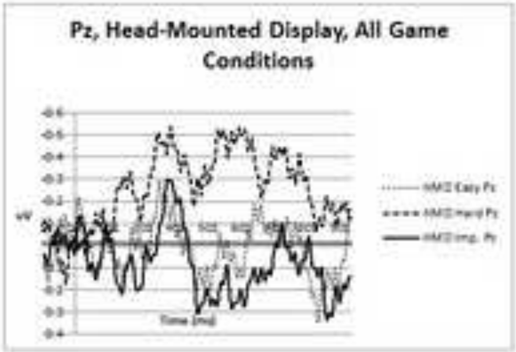

Pz, LCD-TV
All Game Conditions
uV
Time [ms]
LCD Easy Pz
LCD Hard Pz
LCD Imp. Pz

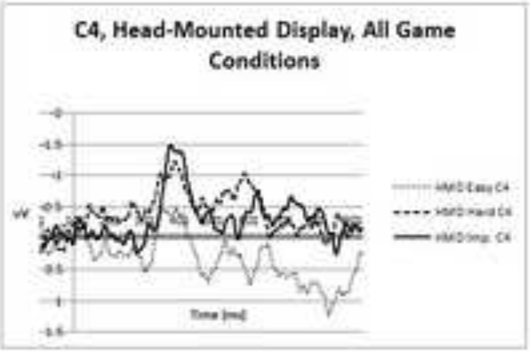
Figure


C3, Head-Mounted Display, All Game Conditions

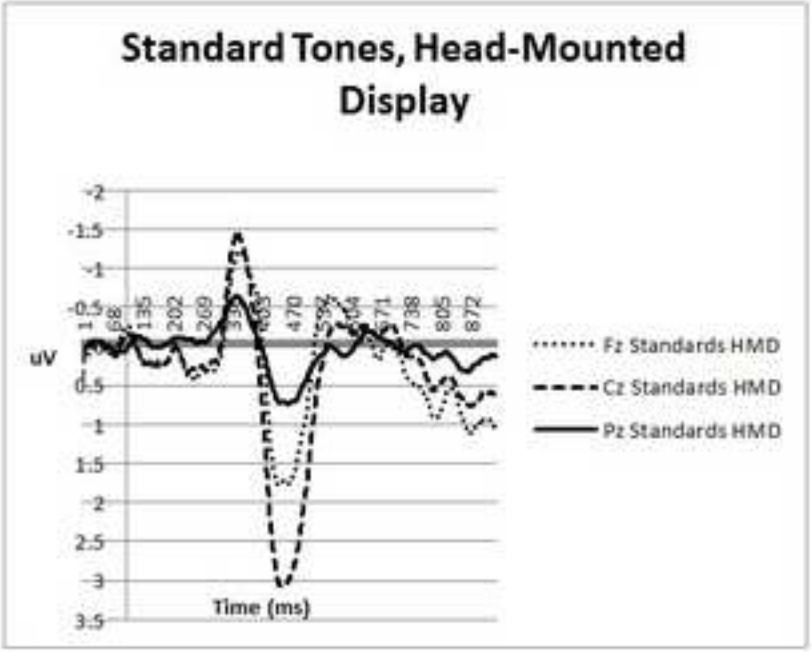

Fz, Head-Mounted Display, All Game Conditions

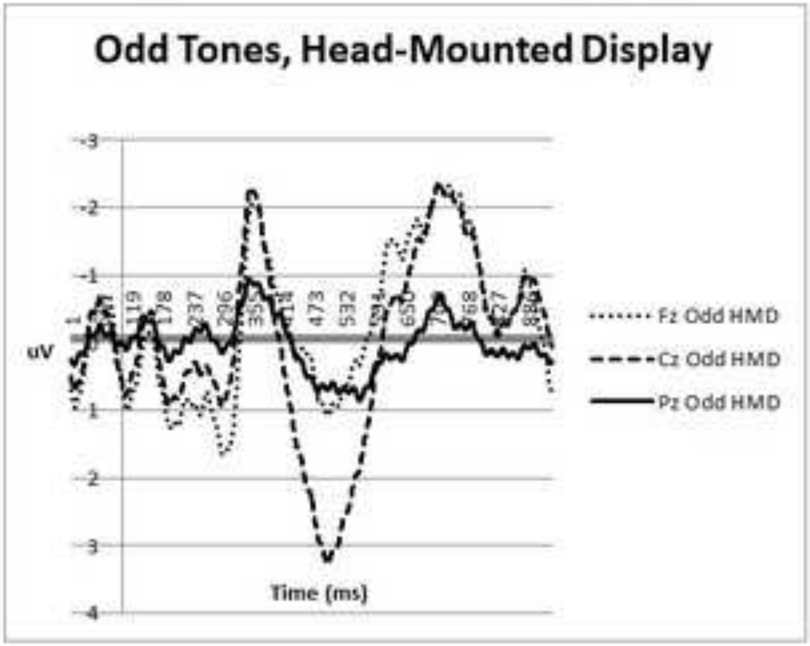

Cz, Head-Mounted Display, All Game Conditions

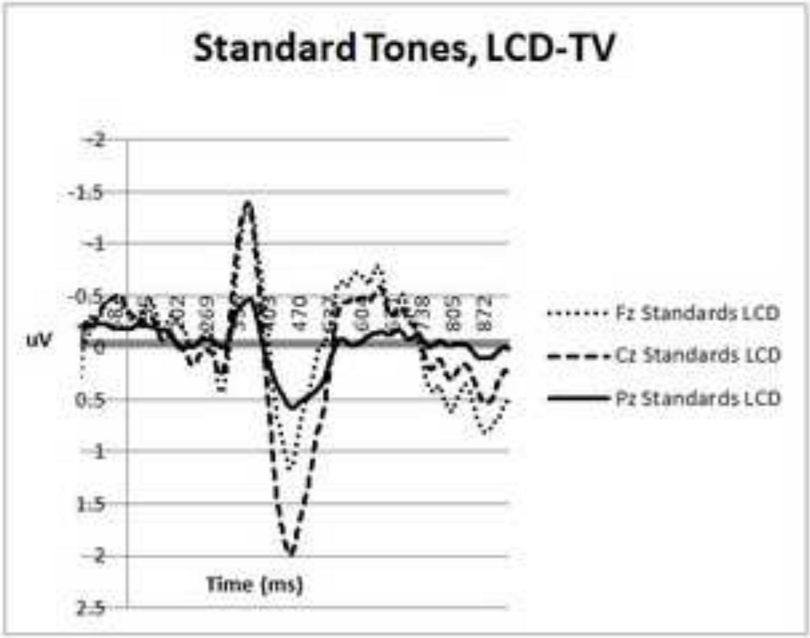

Pz, Head-Mounted Display, All Game Conditions

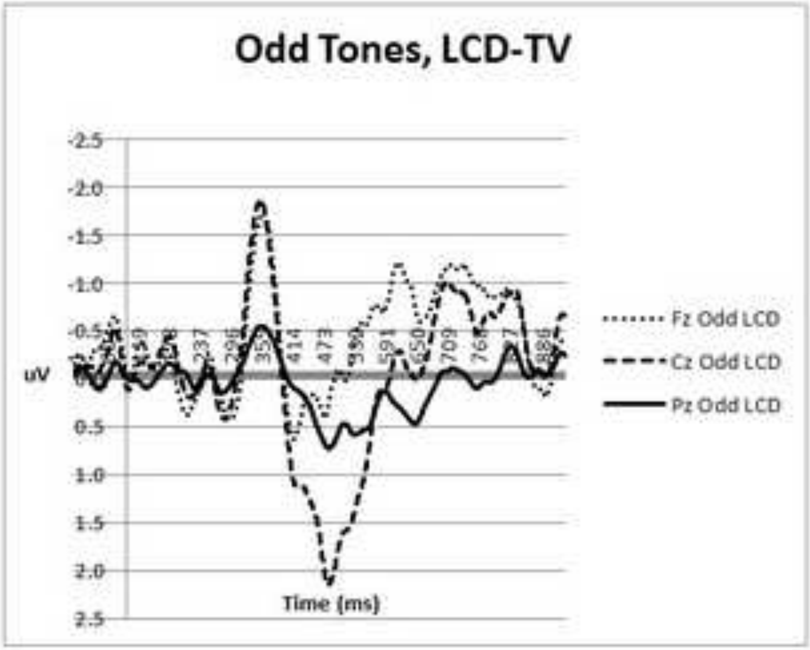

C4, Head-Mounted Display, All Game Conditions

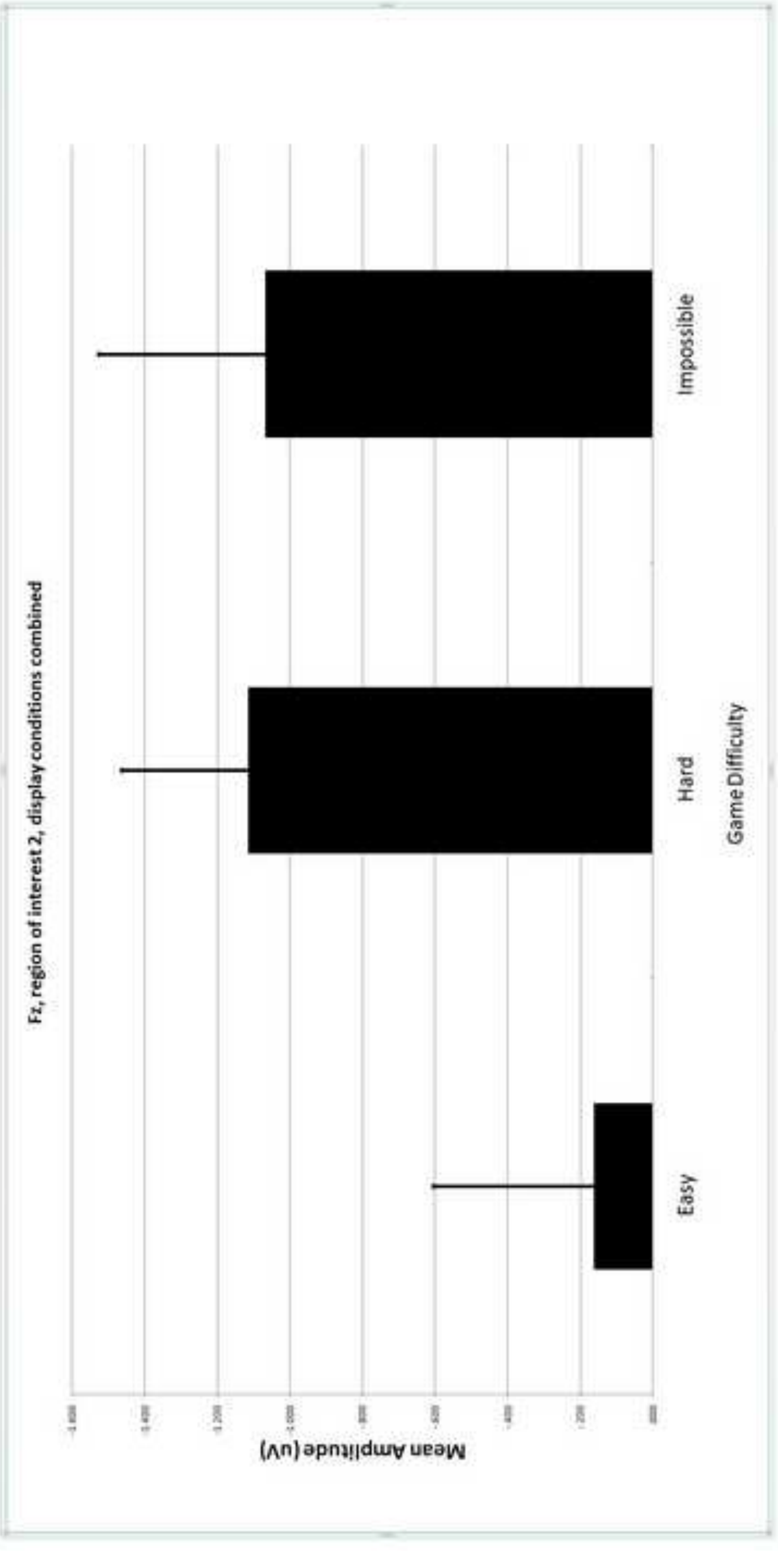
Figure


Standard Tones, Head-Mounted Display


Odd Tones, Head-Mounted Display


Standard Tones, LCD-TV


Odd Tones, LCD-TV


Fz, region of interest 2, display conditions combined
Mean Amplitude (uV)
-1.600
-1.400
-1.200
-1.000
-.800
-.600
-.400
-.200
.000
Easy
Hard
Impossible
Game Difficulty

Figure

image1.png