BIAL FELLOWSHIP

105/10

FINAL PROJECT REPORT

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Table of Contents

Executive Summary

The concept of immersion describes a graded psychological experience that corresponds to the way in which we engage with tasks or stimuli. There are two criteria that must be fulfilled to enable immersion in an activity (e.g. solving a problem, playing a game, reading a book), these are: (1) high motivation, i.e. the person is engaged in goal-directed activity, and (2) attentional focus, i.e. the person focuses on stimuli related to this activity to the exclusion of other stimuli in the environment. It has also been argued that immersion may be partial or total depending on the degree of attention directed towards the activity.

Selective attention is the psychological mechanism at the heart of an immersive experience. It is also known that selective attention may play an important role during the perception of pain, there is evidence that distraction from painful stimuli can increase pain tolerance. This convergence has led to a line of research where immersion in virtual tasks (e.g. computer games) is utilised for therapeutic purposes and pain relief.

The purpose of the current Fellowship was to perform basic research in order to explore the complimentary nature of immersion and pain experience in the context of computer game play. Our preliminary research goal was to develop an unintrusive method for capturing immersive experience that did not interfere with gameplay. Our second goal was to explore the relative contribution of perceptual factors (display size) and psychological variables (intrinsic motivation) to the experience of immersion. Finally we wanted to explore how the experience of painful stimuli was influenced by immersion in a computer game and whether the introduction of painful stimuli can be used to capture the 'depth' of immersion.

The first experiment adopted an Evoked Response Potential (ERP) methodology based on the auditory oddball paradigm. We developed a methodology where participants played a computer game whilst being exposed to a series of tones that were irrelevant to the game. We proposed that ERP responses to the oddball tone would be modulated by the immersive experience of gameplay. Our participants were exposed to the oddball paradigm during several game conditions. The degree of demand experienced by participants was manipulated to yield easy, hard and impossible levels of difficulty. Participants experienced these three levels of difficulty on three display types: a small 5" display, a large TV display and a Head-Mounted Display (HMD). We hypothesised that immersion would be maximised during a game where demand was hard and presented on a HMD. Our

findings revealed that immersion was highest during hard/impossible levels of demand that increased the intrinsic motivation of the participant. However, we found no effect of display type on immersion.

Our second experiment focused on the motivational aspects of immersion and we once again exposed our participants to easy, hard and impossible levels of demand. Instead of using an auditory oddball task to capture ERP modulation, participants were exposed to repeated painful stimuli based on contact heat applied to the forearm. The aim of this experiment was to investigate whether ERP responses to painful stimuli were modulated by the level of game demand. This experiment failed to reveal any statistically significant findings and there were a number of methodological issues that may have been responsible for this null finding.

The background literature and full reports for both experimental studies are included in the current report. We conclude that auditory oddball methodologies may be successfully used to investigate immersive experience, however the relationship between immersion and pain requires further methodological refinement.

1. INTRODUCTION

Recent research indicates that immersive virtual reality (VR) technology can be used for the treatment of acute pain (Keefe et al., 2012). An early study compared pharmacological analgesia with analgesia induced by VR gaming in pediatric patients with acute burn injuries and reported that pain reduction was higher in the VR condition (Das et al., 2005). The effectiveness of pain relief in clinical settings has been explored with reference to several key variables. Early work compared low-tech and high-tech versions of VR display (i.e. high-tech display included wide field of view, head tracking, sound whereas low-tech display did not), pain reduction was enhanced when the high-tech version of the display was used (Hoffman et al., 2004b). A later study compared pain reduction in VR systems that differed in terms of the field of view provided (60 degrees vs. 35 degrees); the authors reported that 65% of participants in the 60-degree condition showed a clinically-significant reduction of pain compared to 29% in the 35-degree group (Hoffman et al., 2006). A combination of brain imaging, VR and experimental pain induction was used to explore how VR experiences affected brain regions associated with pain perception (e.g. thalamus, insula, somatosensory cortex) (Hoffman et al., 2004a); this study reported a significant reduction of pain-related activity in those areas during exposure to thermal pain. It should also be noted that the effects of VR on the modulation of the pain experience do not appear to diminish with repeated exposure (Hoffman et al., 2001) as would be expected if pain reduction was a novelty effect. The use of VR is currently being tested as a therapeutic tool in combination with pharmacological analgesia (Sharar et al., 2007) and in a randomised control trial for physical therapy with pediatric burns (Schmitt et al., 2011).

Whilst the potential of VR technology to alleviate pain has been demonstrated, our understanding of the psychological factors responsible for this effect remains relatively unclear. Pain is known to interrupt and demand attention; therefore, engagement with a VR environment achieves its analgesic properties by distracting attention from the pain experience. Distraction is commonly used as a pain coping strategy in everyday situations, and distraction techniques form part of some clinical interventions that have been shown to be effective, e.g. imagery, hypnosis and cognitive behavioural therapy. However, distraction has not always been found to be an effective strategy for pain reduction; it has been argued that many studies fail to test engagement with the distraction task making interpretation of the results difficult (Eccleston and Crombez, 1999).

The potential of VR technology to distract attention from a painful experience is governed by the psychological qualities of the VR experience. (Lombard and Ditton, 1997) were among the first to describe the concept of presence as an artificial sense that a virtual environment is unmediated, i.e. that the individual themselves exists within that environment. The same authors outlined a number of features that contributed to a sense of presence, some of which are obvious (perceptual realism, quality of social interaction) and some less so (intelligence of the environment). The same authors also included a factor called psychological immersion to represent the engagement of the individual with the virtual task or virtual environment. The concept of immersion is associated with the engagement of an individual with any goal-directed activity and is not specific to technology;one may be immersed whilst reading a paperback book or listening to a piece of music. One specific issue for VR experiences, such as playing a VR game, is how to untangle the related concepts of presence and immersion. According to one analysis (Slater et al., 2009), presence refers to the propensity of individuals to respond to virtual stimuli as if they were real whereas immersion describes the objective technical characteristics of the display in terms of: number of sensory modalities, field of view, frame rate, head-tracking, and quality of sound. In other words, an immersive display tends to induce presence as an experience. An alternative formulation is provided by Jennett et al. (2008) for whom immersion describes the graded experience of psychological involvement with a virtual task - in the case of their particular analysis, a computer game. Jennett et al (2008) describe three distinct levels of immersion. The first is termed *engagement* and describes the process of skill acquisition where the player is required to invest some time into learning how to play a game and how to operate the controls. It is assumed that engaging with the game sufficiently to master its controls represents the gateway to deeper levels of immersion. Once engagement has been achieved, the player may enter a state of *engrossment* where the psycho-motor requirements of game control have been automated and emotions are directly affected by the gaming experience. A state of engrossment leads to a reduced awareness of one's physical environment and lowered self-awareness. The ultimate level of immersion is called *total immersion* where the player is solely focused on the game to the exclusion of all other sensory phenomenon and cognitive activity. Total immersion requires the complete attention of the individual and is rarely achieved compared to lower- level states of engagement and engrossment.

The experience of immersion in a computer game as described by Jennett et al (2008) is based upon two fundamental psychological phenomena: selective attention (i.e. the ability to attend selectively to stimuli in the environment) and intrinsic motivation (i.e. the desire to achieve a task

goal in the absence of extrinsic incentives). In this context, selection attention refers to the prioritization of sensory stimuli related to gameplay. Given that attentional capacity is finite (Wickens, 2002), it is logical that the ability of the player to perceive non-game related stimuli (related to their physical environment) is often compromised during the gaming experience. The same selective quality of attention is true when watching a movie, listening to music or reading a book. The motivational properties of computer games are best characterized in terms of self-determination (Ryan et al., 2006), i.e. gaming is initiated and sustained because the experience of gameplay is innately interesting, satisfying and rewarding. The combined "pull" of selective attention and intrinsic motivation exerts a crucial influence on the gradation or 'depth' of immersive experience.

Other analyses (Ermi and Mayra, 2005) have posited a distinction between categories of immersion, such as sensory immersion (the contribution of audiovisual characteristics on gaming experiences), challenge immersion (the effect of game demand on experience) and imaginative immersion (the impact of characterization and narrative on immersion). The concept of sensory immersion is very close to the definition of presence (Slater et al., 2009) that was described earlier. Challenge immersion is closely related to the definition of task engagement (Fairclough and Venables, 2006) and may be aligned to the investment of mental effort as an act of active coping (Obrist, 1981). The motivational intensity model (MIM) (Brehm and Self, 1989; Wright, 2008; Wright and Kirby, 2001) was developed to describe the relationship between task difficulty and mental effort. The MIM framework emphasises a compensatory dynamic where mental effort is increased in response to rising task demand; however, this relationship is nonmonotonic and includes a 'tipping point' where reactivity may abruptly decline due to an appraisal of impossible or unachievable task demands (Brehm and Self, 1989; Richter and Gendolla, 2007; Wright and Kirby, 2001). It has been argued that challenge immersion may be maximized just prior to this tipping point (Fairclough et al., in press).

The current research programme is concerned with the investigation of immersion in the context of pain reduction. We plan to manipulate both sensory immersion (display size) and challenge immersion when participants are engaged with a computer game. Our main hypotheses state that: (1) immersion will be enhanced when display size is increased, and (2) immersion will be maximised when the level of game demand is high but not unachievable. There is also a strong methodological component to our work. Previous research has focused on retrospective subjective questionnaires in order to capture immersion or used methodologies that disrupt the immersive

experience, e.g. BIPS (Breaks in Performance) where the task is interrupted to assess immersion or task-switching (the capability of players to switch from one task to another). We intend to use event-related potentials (ERPs) from the EEG to assess immersion. The first study is concerned with the use of ERP responses to an auditory oddball during gameplay. This technique may be used to index attention to non-game related stimuli (auditory tones) in the environment without requiring participants to break from the game. The second study will expose the participants to painful stimuli during gameplay. The impact of pain stimuli on the participant will be assessed using pain-related ERPs; this case we are capturing the level of immersion in the gaming experience by measuring an implicit response to sensory stimuli known to interrupt and distract attention.

2. EXPERIMENTAL STUDIES

2.1 The Effects of Demand and Display Modality on Evoked Response Potentials (ERPs) to Auditory Oddball Stimuli

Abstract: A study was conducted to compare the impact of sensory and cognitive influences on immersion during a computer game. 30 participants played a racing game under three display conditions (small display, large display, head-mounted display). Participants also experienced three levels of game demand (easy, hard, impossible). Immersion was captured as attention to external (non-game related) stimuli in the environment via event-related potentials (ERPs) to an auditory oddball task. The results revealed an absence of any statistically significant effect on subjective immersion or ERP components to the manipulation of display. There was a significant impact of cognitive immersion (game demand) on subjective immersion, which peaked during high demand compared to easy and impossible conditions. We also found evidence that late components of the ERP were modulated in response to game demand, i.e. ERP amplitudes to oddballs were reduced when the game was hard or impossible. The study concluded that the immersive effect of game experience was primarily influenced by cognitive demand rather than display characteristics.

2.1.1 Introduction

The current study is concerned with immersion via gameplay in a digital world (McMahan, 2003). Detailed analysis of immersion (Jennett et al., 2008) emphasized the propensity for players to "lose" themselves in gaming activity. Jennett and colleagues characterized immersion in terms of reduced awareness of sensory stimuli associated with the external (i.e. non-game) world; they also argued for evidence of distorted time perception as well as a sense of presence (Lombard and Ditton, 1997). This sense of immersion is described as a graded experience, from engagement with game activity (some awareness of external environment) to total immersion (a sense of solely occupying the digital world) (Jennett et al., 2008). There is 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 (Hou et al., 2012; van den Hoogen et al., 2009) and touchscreen systems (Thompson et al., 2012). The influence of challenge immersion (Ermi and Mayra, 2005) is more difficult to ascertain as the

experience of challenge represents an interaction between the skill of the player and the objective demands of the game. Several researchers (Chen, 2007; Nacke and Lindley, 2008) have characterized optimal states of challenge immersion in terms of flow states (Csikszentmihalyi, 1990); other have reported how immersion increases in line with level of cognitive challenge experienced by the player (Cox et al., 2012). With respect to challenge immersion, the motivational intensity model (Wright, 2008) emphasizes a compensatory dynamic where task effort is increased in response to rising demand; however, this relationship is nonmonotonic and includes a 'tipping point' where the investment of effort and inclination to continue the task or game may abruptly decline due to overload and an appraisal of unachievable demand. It has been argued that challenge immersion may be maximized just prior to this tipping point (Fairclough et al., in press).

The goal of the current study is to investigate the contribution of both sensory and challenge immersion by manipulating the type of display and level of game demand. Our study is designed to contrast the effect of three screen types (small 5" screen, large LCD screen, head-mounted display) on sensory immersion. We have also manipulated challenge immersion by exposing our participants to easy, hard and impossible levels of demand.

We have used event-related potentials (ERP) from the electroencephalogram (EEG), specifically the auditory oddball paradigm, in order to index cognitive processing resources (Kok, 1997) during gameplay. This methodology involves exposing the player to non-game related auditory stimuli as a secondary task whilst they are engaged with the primary task of gameplay; in this case, participants hear a series of discrete tones including a subset of "oddballs" which differ from the majority of tones in pitch. ERP responses to the oddball tone are characterized by latencies and deflections in the amplitude of the ERP wave, i.e. P300 = positive deflection approximately 300ms after the oddball is heard. This approach to capturing attentional capacity has been successfully used in the past to gradations of game demand (Allison and Polich, 2008) and different levels of presence experience (Kober and Neuper, 2012).

In line with the paper published recently by Kober and Neuper (2012), we anticipate that display type and demand will influence the late negative slow waves (SW) associated with central cognitive processing. Specifically, we expect the head-mounted display (HMD) to maximize slow-wave deflections whilst the small screen will have a minimal effect. With respect to demand, we expect SW deflections (and immersion) to reach maximum levels during the hard task that represents the peak of challenge immersion.

2.1.2 Methodology

Participants: Participants were 30 under- and postgraduate students (13 male) with a mean age of 23.67 years (st.dev.= 4.23 years) in the faculty of Natural Sciences and Philosophy at Liverpool John Moores University. Three participants were left-handed. All participants were paid for their participation.

Design and Procedures: Prior to the experiment proper, we observed 15 non-experimental volunteers playing the game in order to observe their abilities under different difficulty settings for piloting purposes. Individual races typically lasted from 95 to 110 seconds, and after approximately 40 minutes of play-time, all but two pilot volunteers were able to achieve a finishing position from 1st to 4th under the "Easy" game settings. Under the "Hard" setting, all but two volunteers struggled to finish any better than 4th place. This information was used to modify the instructions to the actual participants to maintain suitable levels of task demand during the experiment proper. During the experiment proper, EEG responses to an auditory oddball task were recorded while participants played 4 races of a video game at 3 difficulty settings, and from 4 blocks of "pure oddball" auditory-only stimuli. We used a mixed 3x3 experimental design incorporating visual display type as a between-subjects factor (either a head-mounted display, a 40" LCD-TV, or a 5" LCD display) and video game difficulty level (easy/novice, hard/skilled and "impossible"/elite) as a within-subjects factor.

While the EEG electrodes were fitted (~40 minutes), participants practiced playing the game at their own pace on "easy" difficulty for familiarity, noting their finishing positions throughout. 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 race pack between 8th and 5th position. Racing and auditory-only conditions were counterbalanced across sessions. During the auditory-only conditions, the display device was switched off, and participants were instructed to keep their eyes open and simply listen for the tones. After each set of 4 races in one difficulty setting was complete, participants completed the IEQ variant. The participants were instructed to try to attend to the oddballs whilst playing the game by simply listening to the beeps, but were informed that they were e.g. not required to count or mentally manipulate the tones etc.

Figure 1. Screen shot of WipeoutHD Fury

Measures: Three groups (each N=10) played the Playstation3 game "WipeoutHD Fury" (Sony Liverpool Studios) (Figure 1) using a conventional PS3 controller. Within the game, weapons were disabled and piloting assistance was activated. All participants repeatedly played the "Vineta-K" track using the "Feisar" vehicle. Each group used either a Samsung LE40B550 40" LCD TV, a Silicon Micro Display ST1080-10V1 head-mounted display, or a Lilliput 569GL, 5" LCD camera monitor. All devices were connected to the Playstation3's HDMI output, and displayed the game using their native 1920x1080 resolution. Visual angles for the LCD TV were 18.7° (vertical) x 32.6° (horizontal) at a distance of 1.5 metres, and 20.16° (v) x 40.27° (h) for the head-mounted display, with the distance from the eyes to the head-mounted display being fixed at 4.5cm by the size and shape of the device itself. The head-mounted display was modified with felt cloth patches to mask ambient light from above and below the eyes. As the 5" display was considerably smaller than the TV, it was moved closer to the participant for viewing clarity, resulting in viewing angles of 3.72° (v) x 6.12° (h) at a distance of 1m from the participant. 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 Klipsch headphones to the participant.

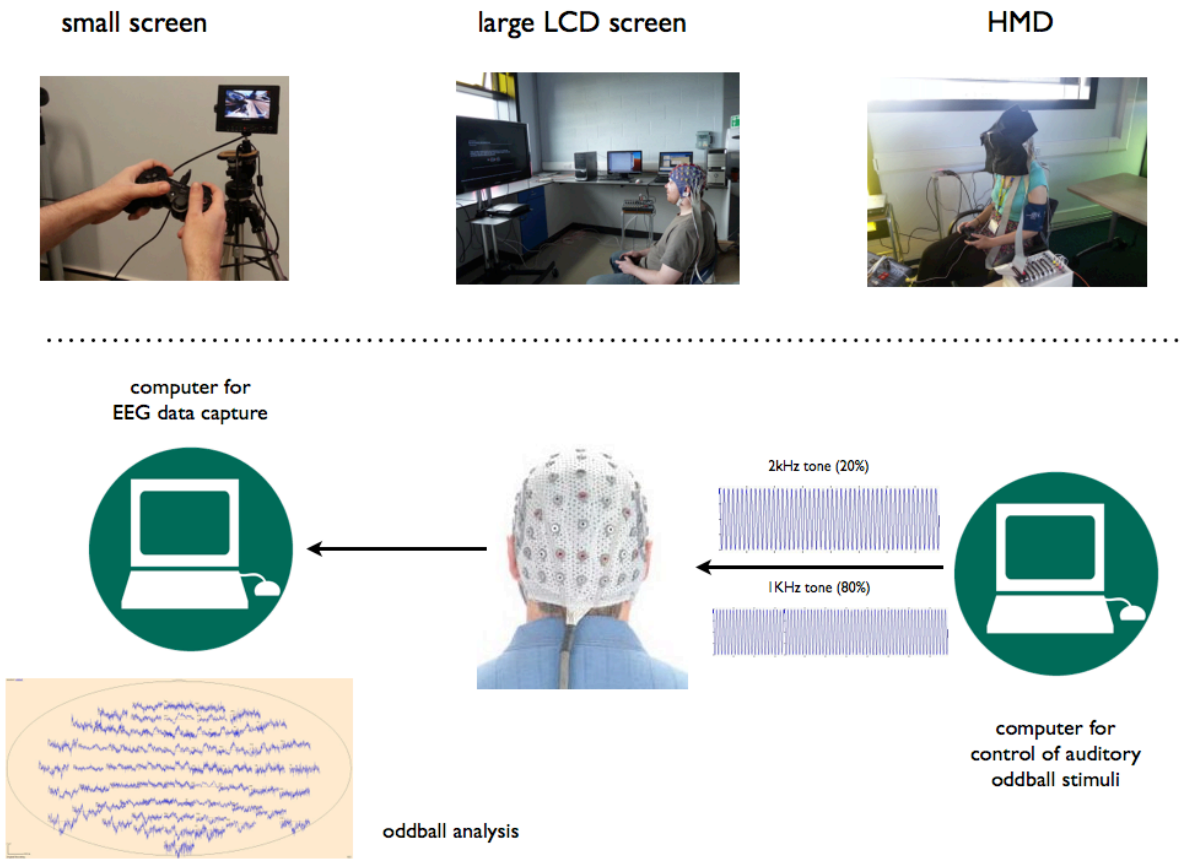

Figure 2. Illustration of Experimental Conditions

Our oddball task closely resembled a "classic" ERP methodology (Naatanen, Gaillard and Mantysalo 1978). Audacity's pure tone generator (audacity.sourceforge.net) was used to create ninety 1Khz "standard" and twenty 2Khz "oddball" beep tones. As pure tones, each beep's auditory rise-time to the specified frequency was virtually instantaneous. A block of 110 tones was played back in random order per race using E-Prime v2.0 (Psychology Software Tools). We mixed the beep tone audio via the mixing console such that the beep tones were audible within WipeoutHD's normal audio soundtrack. We recorded EEG responses to the standard and oddball tones 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 raw signal between 0.1 and 30Hz post-hoc, averaging the standard and oddball tones separately using BESA Research 5.3 (BESA GmbH). After filtering and corrections, typically 15 oddball tones per game played were suitable for grand-averaging.

The subjective gaming experience was quantified using the Immersive Experience Questionnaire (IEQ) (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 addressed issues of attention, effort, immersion and enjoyment of a game as a fuller "experience". Items 6, 8, 9 and 10 were reverse-scored during analysis, as they pertained to subjects' awareness of the external world during the gaming experience, thereby indicating measures of distraction rather than immersion.

2.1.3 Results

As video gaming results in slight but undesirable levels of physical movement and muscle tension in the head and neck, our analyses focused on the Cz and Fz electrode sites as they were least affected by movement artefacts, as well as being sited at the vertex of the skull over the somatosensory cortex (Cz) and the frontal lobes (Fz), which are strongly associated with attentional focus. Grand average ERPs for the oddball-tone responses were produced for each site by compositing all display and game-difficulty conditions with the non-gaming "pure oddball" condition.

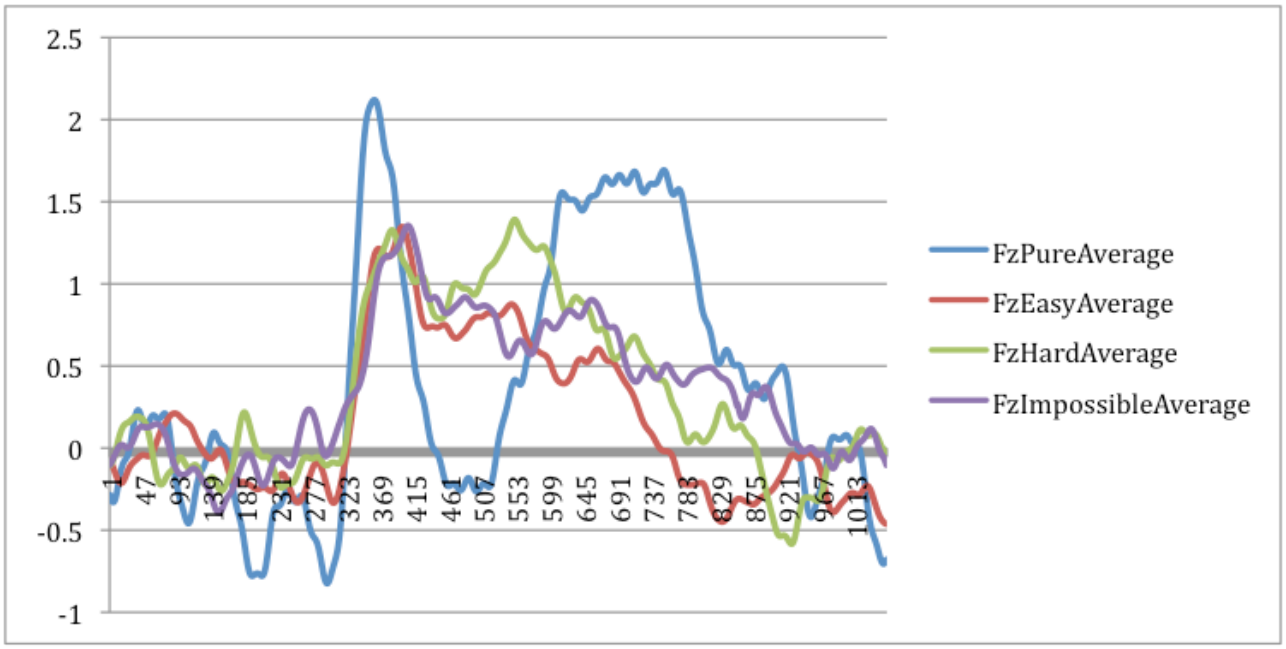

Figure 3. Grand average oddball responses at Fz sites for all display and task-conditions.

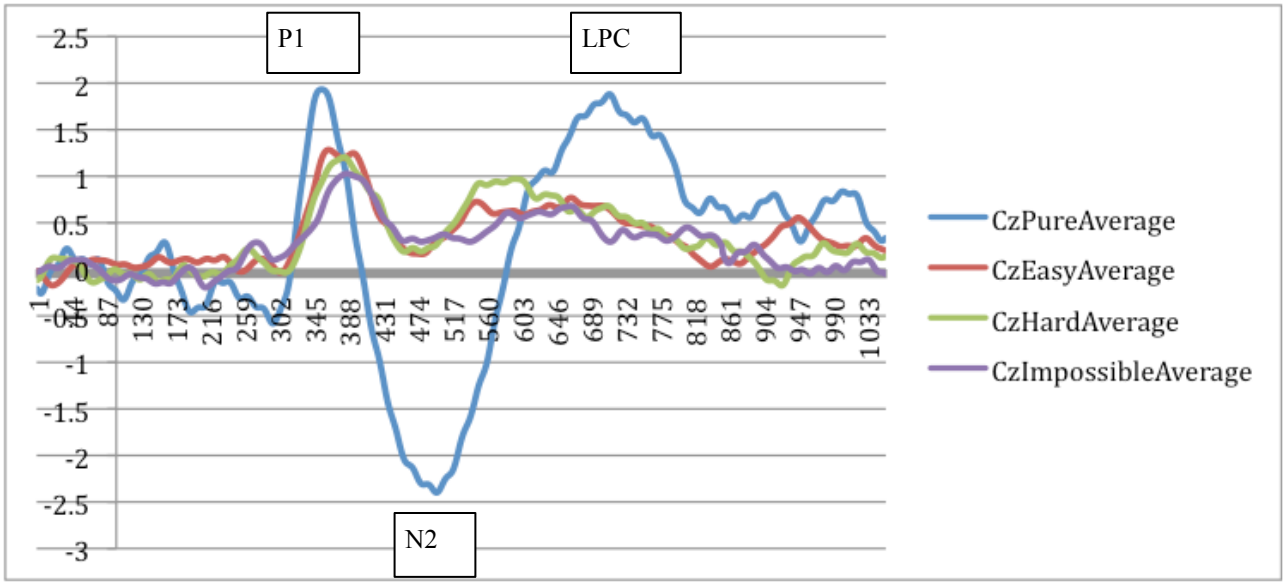

Figure 4. Grand average oddball responses at Cz sites for all display and task-conditions.

At both sites, a recognisable P1>N2>LPC (Late Positive Component) waveform complex was obtained. The experimental design was validated by the visually larger and more strongly-defined peaks and troughs of the pure-oddball condition, where the additional attentional demands of the game were absent, allowing participants' mental responses to the differentiation of the beep tones to predominate. Visual inspection of the waveforms indicated two regions of interest at the frontal Fz site, spanning the P1 peak at 320-475ms, and a Late Positive Component at 476-685ms. At Cz, the P1>N2>LPC components were visually apparent at 315-460ms, 461-720ms, and 721-958ms.

The pure-oddball condition was not subjected to any statistical analyses as there were no equivalent task conditions for comparison, and the magnitude of participant's responses was visually pronounced – i.e. it is so much larger in comparison to any of the gaming conditions that it requires the waveforms to be re-scaled to compensate. Initially, we conducted five ANOVAs, examining game difficulty (3 levels) x display type (3) for the three Cz and two Fz components, but examination of the group means revealed that trends in the data from the 5" display were substantially different from the other two display formats in a manner which was not readily explicable. While the group mean trends for the HMD and LCDTV conditions were broadly similar, the 5" display means did not conform to those trends at all, illustrated in the following figures :

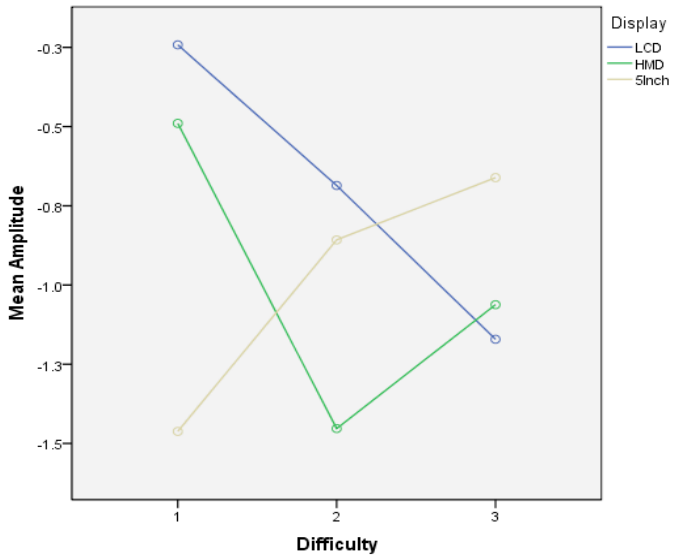

Figure 5. Trends for mean amplitudes, Fz Site, Region of interest 1, 320-475ms. Key: 1 = easy demand, 2 = hard demand, 3 = impossible demand

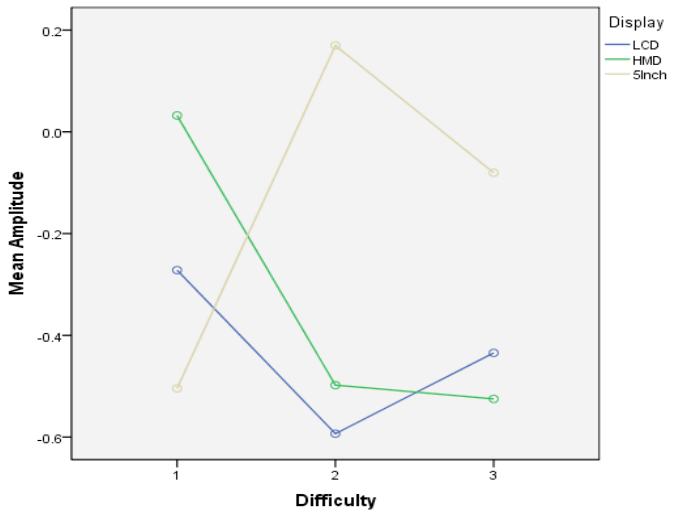

Figure 6. Trends for mean amplitudes, Cz Site, Region of interest 3, 721-958ms. Key: 1 = easy demand, 2 = hard demand, 3 = impossible demand

Given the difficulties in interpreting the data from the 5" screen, we instead decided to pursue a new analysis examining the more apparent trends in the LCD-TV and HMD conditions, and recomputed the original ANOVAs with only those data (i.e. N=20). From these analyses, a main effect of task difficulty emerged as influencing the late-positive ERP components at the FZ

site from 476-685ms (F(2,36)=4.017, p<0.027). The earlier epoch at Fz (320-475ms) similarly shows a marginally non-significant result (F(2,36)=2.629, p<0.088), but which nonetheless indicates the Fz and frontal sites as influential in the direction of attentional processes during this task.

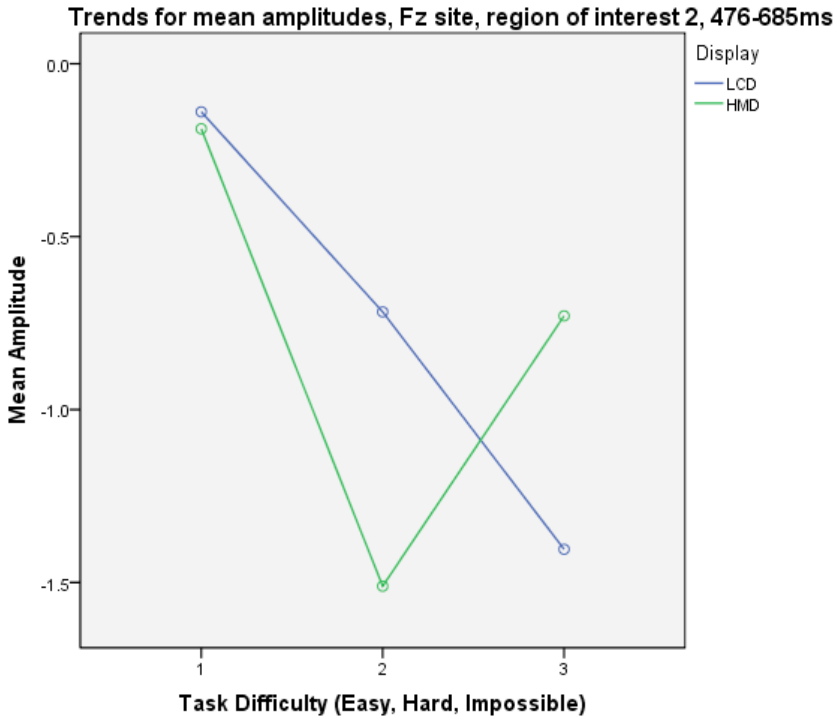

Figure 7. Trends for mean amplitudes, Fz Site, region of interest 2, 476-685ms. Key: 1 = easy demand, 2 = hard demand, 3 = impossible demand

Differences in ERP amplitude during Fz ROI-2 were due to the enhanced attentional demand of the Hard and Impossible difficulty settings when compared to the Easy settings, where participants were purposefully instructed not to attempt to win (Easy vs. Hard, t(19)=2.546, p<0.020); Easy vs. Impossible t(19)=2.248, p<0.037).

IEQ Questionnaire

Reliability tests of the IEQ for N=30 produced a Cronbach's Alpha value of 0.885, and 0.89 for N=20, indicating an acceptable level of construct validity. As participant numbers were insufficient for a full factor analysis (and the source article does not include such), we computed total scores for the IEQ under each of the game difficulty settings. Data for one participant was not available for the Easy condition. For the N=30 dataset, a 1x3 ANOVA indicated that significant differences (F(2,91)=13.934, p<0.0001) were present due to comparisons of Easy vs. Hard

($p<0.0001$) and Easy and Impossible ($p<0.005$) difficulty settings after Bonferroni correction. Mean scores indicated that the Hard difficulty setting produced the greatest immersion scores (115.32) versus either Easy (96.83) or Impossible (108.29). Broadly similar results were obtained using N=20 ($F(2,59)=10.223$, $p<0.0001$) with differences attributable to the Easy vs. Hard ($p<0.0001$) and Easy vs. Impossible comparisons ($p<0.015$). Again, mean scores indicated the Hard difficulty condition was the most immersive (115.4) versus either Easy (95.95) or Impossible (108.5).

2.1.4 Discussion & Conclusions

It was expected that ERP amplitudes to the auditory oddball stimuli would decline as immersion increased. Specifically, we expected ERP amplitudes to decline as game demand changed from easy to hard and for the ERP to increase from hard to impossible. These predictions are in line with MIM, i.e. immersion will decline when the game is assessed to be too easy or impossible. It was anticipated that immersion would be maximised during the HMD condition as this form of display completely occupies the visual field, i.e. ERPs would be of generally lower amplitude in the HMD condition compared to the LCD or small 5" screen condition. We also predicted that the LCD display would create greater immersion in the game compared to the 5" display due to the former having a larger field of view.

With respect to the ERPs that were observed at P1 and Late Positive Components (LPC) (Figures 5 and 6 respectively) the 5" screen condition produced a completely different trend in response to game demand relative to other two display conditions. The disparity in mean amplitudes during the 5" condition are theoretically difficult to explain. We suspect that as the viewing angles for the 5" screen were substantially smaller than either the HMD or LCD-TV, although this did not impair participants' ability to play the game, the focus of their visual attention may have been divided between the relatively small viewable area of the screen itself, and a much larger peripheral scene surrounding it. This effect may have produced a counterintuitive reduction of ERP amplitude during the easy condition as the combination of low demand and the need to ignore the peripheral scene around the display forced players to actively invest effort. Paradoxically the need for active effort investment is reduced as game demand increased, which may have accounted for the counterintuitive increase of ERP amplitudes observed during the hard and impossible conditions.

Our decision to focus on the HMD and LCD display conditions provided some support for our original hypotheses. Our analyses revealed that LPC at Fz showed a significant decline when game demand increased from easy to hard (Figure 7). It should also be noted that LPC amplitude increased during the transition from hard to impossible demand, but only for the HMD display condition. The direction of this effect is identical to the one observed by Kober and Neuper (2012) who used individual differences in the LPC component of the ERP to differentiate high from low presence in a VR environment, i.e. reduced amplitude to an auditory oddball was equated with greater presence. The effect of game demand was only apparent at Fz, an effect that was unsurprising given the proximity of the frontal lobes to this site and the association between that area and attentional control. The subjective self-report data obtained via the IEQ (Jennett et al, 2008) supported the main hypotheses for challenge immersion. Our analysis revealed that subjective immersion increased when demand changed from easy to hard and significantly declined when the game became impossible.

The influence of display type on immersion was striking by its absence from our statistical analyses. We had assumed that HMD would lead to greater immersion but there was no evidence for this effect from either the ERP analysis or participants' responses to the subjective questionnaire. This null finding appeared to indicate that game demand for an active, goal-directed task was the primary influence on immersion compared to sensory variables such as display type.

The study had a number of weaknesses that must be addressed in future research. The instructions to participants to "take it easy" and stay in the lower positions during the race proved to be problematic. Participants had to actively resist the temptation to race competitively and staying in the lower positions may have required active attention. It was felt that this condition was somewhat counterintuitive for our participants since the game had been designed to motivate them in the opposite direction. Future work should consider using a game where the level of demand can be manipulated with greater precision in order to create an easy task that requires no additional effort. We used three categories of display that were commercially available to ensure that our technologies were representative. However, the comparison between the three conditions was not controlled with the degree of precision that we would have liked. There was a pragmatic constraint in that the participants could only play each level of the game for a finite period. Through extensive piloting testing, we developed a schedule that maximised the number of auditory oddball stimuli whilst prevent excessive fatigue or boredom for the participant. However, as a result of the pragmatic constraints, we were only able to present 80 oddball stimuli in total per condition, which

was a relatively low number and possibly contributed to increased variance in the ERP data. In all ERP methodologies, the signal-to-noise ratio (i.e. the ratio of the signal due to the experimental effect versus the signal due to normal "housekeeping" metabolic activities within the brain) is lowered as the square root of the total number of valid trials (Handy, 2005), and therefore, a much larger number of oddball tones overall would have enhanced the ERP effects in general.

This effect demonstrates that the auditory oddball task is sensitive to challenge immersion (Ermi and Mayra, 2005). However, we did expect challenge immersion to significantly decline during impossible demand and we did not observe this effect. The absence of any effect due to display type suggests that future research on the therapeutic potential of VR and similar technologies should focus on the properties of the virtual task as opposed to the technology per se.

2.2 The Effects of Demand on Evoked Response Potentials (ERPs) to Experimental Pain

Abstract: A study was conducted to investigate the effect of game demand on pain ERPs. 12 participants volunteered to take part in the experiment. They were required to play a video game at two levels of demand (hard, impossible) whilst receiving thermal contact pain on the arms. EEG and subjective measures were recorded. The mean amplitude for the N150 and P260 components of the ERP were extracted from three sites (Fz, Cz, Pz). We found no evidence for any statistically significant modulation of either early- or late-components of the pain ERP. The reasons for this null result are discussed.

2.2.1 Introduction

Previous research has indicated that the experience of pain may be mediated by interaction with a virtual reality systems (Keefe et al., 2012). The influence of VR experience on brain structures associated with pain perception has been demonstrated (Hoffman et al., 2004a) and a number of RCT are in progress to test this technology with patients (Schmitt et al., 2011; Sharar et al., 2007). Despite this promising initiative, the psychological mechanisms underpinning this effect remain relatively unexplored. It has been demonstrated that pain relief is sustained over repeated sessions (Hoffman et al., 2001) and that display characteristics (size of field of view, quality of graphics) can influence the efficacy of pain reduction (Hoffman et al., 2006).

It may be argued that immersion in the virtual world represents a psychological mechanism to facilitate pain reduction. Immersion has been described by Jennett et al. (2008) as a graded

psychological involvement with a virtual task. The degree of immersion in a computer game is determined by selective attention (i.e. the ability to attend selectively to game-relevant stimuli to the exclusion of non-game stimuli) and intrinsic motivation (i.e. the desire to achieve a task goal in the absence of extrinsic incentives) (Ryan et al., 2006). It may be argued that immersion reduces the experience of pain via distraction (Eccleston and Crombez, 1999) and the potential to distract is related to the capacity of the game to engage the individual on an attentional and motivational level. The relationship between pain and immersion is complimentary, where immersion may be manipulated to moderate the experience of pain; however, the introduction of experimental pain may also be used to probe the level of immersive experience. With respect to the latter, it could be argued that the introduction of pain represents a sensory category of stimuli that is unrelated to gaming activity, in much the same way as auditory tones were introduced during Study One.

The purpose of the second study was to investigate whether ERPs to pain stimuli were affected by cognitive demand, i.e. manipulation of game difficulty. No statistically significant effects of display characteristics were found during the previous study and so this factor was omitted from the current experiment. Experimental pain was elicited using contact heat via a CHEPS device (Roberts et al., 2008; Warbrick et al., 2009) attached to the arm of the player. As in the previous study, pain stimuli were introduced to elicit an ERP response in order to 'probe' awareness of stimuli that were unrelated to the game. A number of earlier studies adopted a similar methodology to investigate modulation of pain experience during the viewing of emotional (Kenntner-Mabiala et al., 2008) and aesthetic images (de Tommaso et al., 2008). These researchers focused on ERPs elicited at the vertex (Cz) that approximates the somatosensory cortex. Both captured two ERP components, the N150 with a latency between 130-190ms and the P260 with a latency of 250-380ms. Different components of the pain ERP have been associated with distinct aspects of information processing related to nociceptive stimuli; typically early processing is associated with attention orientation/spatial localisation of painful stimuli whereas cognitive activity occurs at a later point (Legrain et al., 2012).

This second study will investigate whether pain ERPs are influenced by the level of game demand experienced by the player. It is anticipated that sensory processing during the early stages of the pain experience will remain unaffected whilst later components will have a lower amplitude when the task is hard because they are associated with cognitive/emotional processing of painful stimulation; i.e. cognitive modulation of painful stimuli will be most affected when immersion is at a maximum level.

2.2.2 Methodology

Participants

12 under- and post-graduate students (7 male) with a mean age of 20.75 years (st.dev.= 1.65 years) in the faculty of Natural Sciences and Philosophy at Liverpool John Moores University took part in the study. One participant was left handed. All participants were paid for their participation.

Design

Participant's EEG responses to contact-heat pain were recorded while they played 6 races of a video game at two difficulty settings (hard and impossible), and during 6 blocks of pain-only stimuli. During the pain-only condition, participants kept their eyes open, looking ahead onto a blank wall, with all audio-visual stimulation switched off. We used a 2-way experimental design with game difficulty as a within-subjects factor, whilst the pain-only condition served as a measure of objective pain responses for later, visual-only verification of the experience of the pain as a stimulus.

Experimental Task

Participants played the Playstation3 game "WipeoutHD Fury" (Sony Liverpool Studios) using a conventional Playstation3 controller. Within the game, weapons were disabled and piloting assistance was activated. All participants repeatedly played the "Vineta-K" track using the "Feisar" vehicle. The game was displayed on a wall in front of the participant using a Sanyo PLV-Z3000 projector, using the game and projectors' native 1920x1080p high-definition resolution. The projector was placed 2.15m from the wall, resulting in a large 1.875m diagonal image. Participants' heads were approximately 1.9 metres from the wall, producing a visual angle of 47.61 degrees (horizontal) by 27.05 degrees (vertical). We output audio from the Playstation3's optical output via a FiiO D3 digital-to-analogue converter to a Studiomaster 2000 analogue mixing console, then to earbud-type Klipsch headphones to the participant.

EEG Data Capture

Each participant's EEG data was recorded via 32 channels arranged in a standard 10-20 System montage using a Biosemi ActiveTwo ADC-12 EEG amplifier. EEG was recorded at 1024Hz, and re-referenced offline to linked earlobes. Gross artifacts and eyeblinks were removed

from the EEG offline, and we band-pass filtered the signal between 0.1 and 30Hz before averaging using BESA Research 5.3 (BESA GmbH). A 100ms baseline was applied throughout each epoch.

Pain Administration

Contact-heat pain was administered to each participant using a Pathway Pain & Sensory Evaluation System (Medoc Advanced Medical Systems Ltd, Israel) fitted with a Contact Heat Evoked Potential Stimulator (CHEPS) thermode. The CHEPS thermode comprises an external heating foil, a Peltier heating thermode, and a water-cooling thermode. The thermode is capable of heating the contact surface at 70C per second, and cooling to ambient temperature again at 40C per second. We used E-Prime 2.0 (Psychology Software Tools) to deliver each block of pain stimulation. For each pain stimulation, the Pathway software's "ramp and hold" function was used to shift the thermode from 30C to a one-second-long 50C heat stimulation before returning to 30C again. Upon commencement of any block of pain stimulation, the first stimulation was delivered after 3 seconds, with all subsequent stimulations featuring a random inter-stimulus interval ranging from 10-15 seconds. During gaming conditions, this permitted a maximum of 8 heat pulses to be delivered over approximately 1m50s before each race ended – race durations varied slightly according to each subject's abilities and in-game events . In the pain-only conditions, 9 pulses were delivered over 2 minutes as there were no time constraints.

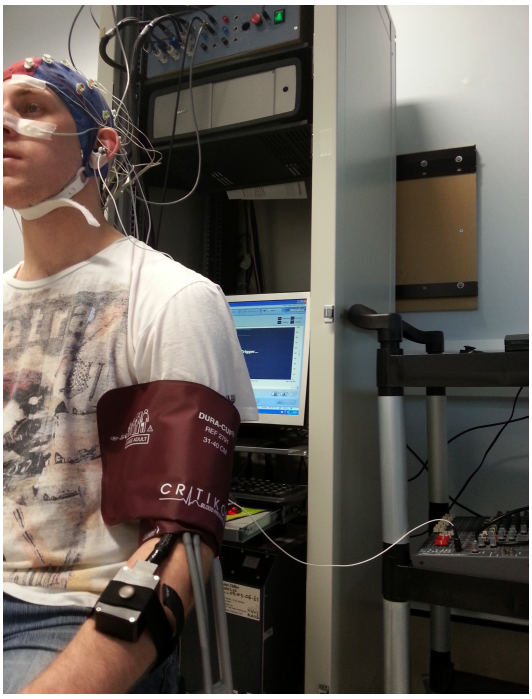

Figure 8. Participant during pain experiment wearing thermode on the forearm

We affixed the thermode to the participants' volar (i.e. inner) forearm. After any single block of stimulation (i.e. one race, or one sequence of 9 stimulations in the pain-only condition), we re-located the thermode to the opposite side of the forearm, alternating between dermatomes C6 and C8, close to the elbow. After every second block of stimulation, we re-located the thermode to the participant's other arm in an attempt to minimise attenuation of the pain sensation through habituation.

During initial pilot testing using the CHEPS thermode in "pulse" mode (i.e. a rapid rise to the target temperature with a duration of milliseconds at the target temperature), we found that the pain stimulation was subjectively very easy to ignore due to the distractions of the game and the arm/hand movements required to play the game. We elected to use the "ramp and hold" function instead to deliver a much longer, 1-second long 50C stimulation for each block of trials, and to lengthen the ERP epoch to 2000ms as the pain stimulation was ongoing throughout the initial 1000ms of the ERP.

Psychometric Measures

As with the previous study, we again used the Immersive Experience Questionnaire (IEQ) (Jennet et al. 2008; appendix B from the source), reverse-scoring items 6,8,9 and 10 for the same reasons as previously.

Procedure

Upon first entering the lab, participants were given the opportunity to experience one or two pulses of contact-heat pain, and the opportunity to continue or withdraw from the study at this point. Participants who chose to continue then practised playing the game (on "novice" or "easy" difficulty) for approximately 30 minutes for familiarity whilst the electrodes and cap were fitted. During the experiment proper, participants began with 2 blocks of 9 pain-only stimulations, then played 6 races at either the "skilled" (hard) or "elite" (impossible) difficulty settings within the game. Under the Skilled/"Hard" difficulty condition, it is possible for able participants to win the race albeit with considerable difficulty, although no participant was able to exceed 4th place in the races. Under the "Elite/"Impossible" difficulty condition, no participant was observed to exceed last place, and in general, the player's best efforts are required simply to keep the computer-controlled opponents within sight in the distance, let alone overtake them.

Participants were instructed simply to try to win the race under both conditions. Upon completion of a racing block, participants completed an Immersive Experience Questionnaire (IEQ)

regarding their motivation and enjoyment of those races. After the first block of 6 races and the first questionnaire was complete, participants experienced another 2 pain-only blocks, before completing another 6 races at the remaining difficulty setting, followed by a final IEQ questionnaire. Each experimental session concluded with 2 pain-only blocks. The order of the racing difficulty settings was counterbalanced across participants. In all, participants completed 6 races at the "hard" difficulty setting, 6 races at the "impossible" difficulty setting, 6 blocks of pain-only stimulation, and 2 questionnaires.

2.2.3 Results

After offline processing of the ERP responses to the pain stimuli under all experimental conditions, we averaged a total of 390 responses under the pain-only condition (mean=5.16 per participant), 377 responses under the "hard" gaming condition (mean=5.43 per participant), and 378 responses under the "impossible" gaming condition (mean=5.37 per participant). Although a 2000ms epoch was recorded, we focused on the earliest stages of the pain stimulation, and created grand averages for and subsequent analyses of the first 1000ms of the recording.

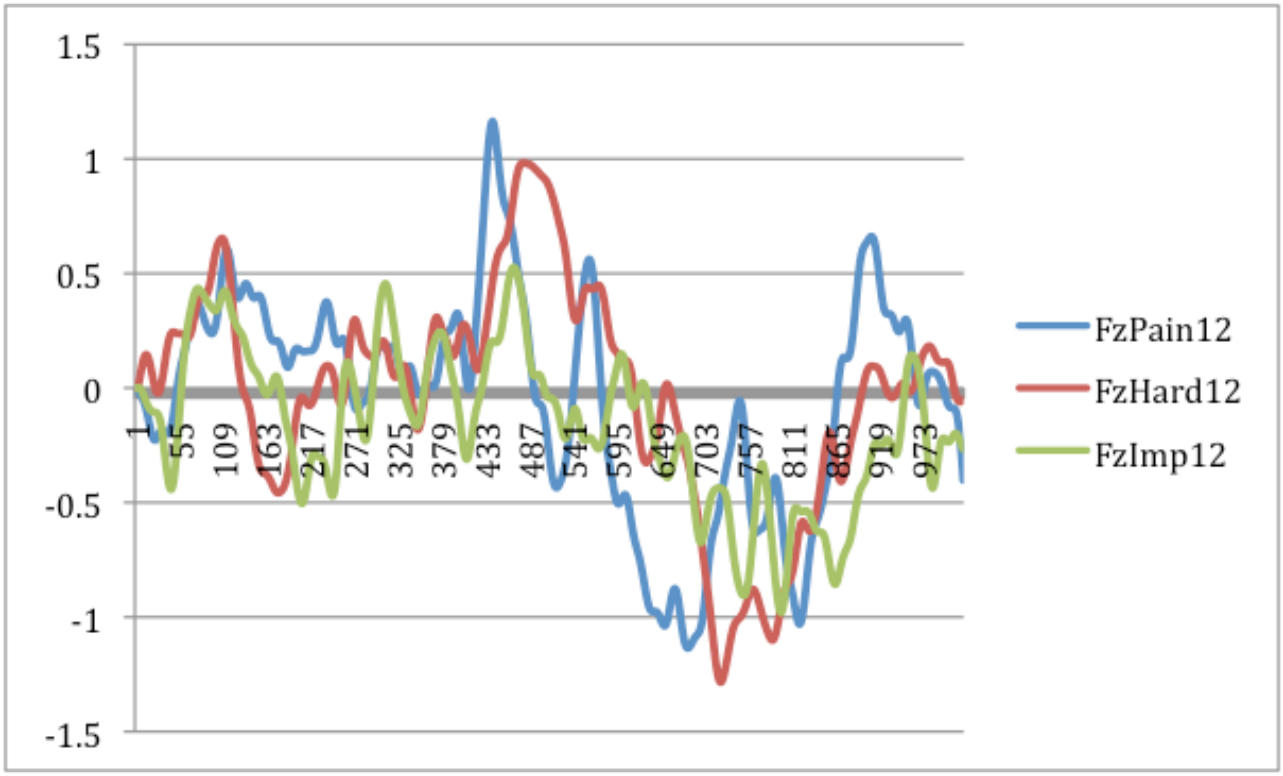

Figure 9. Grand Averages to pain stimuli for Fz for all three experimental conditions (Pure Pain, Hard game demand, Impossible game demand)

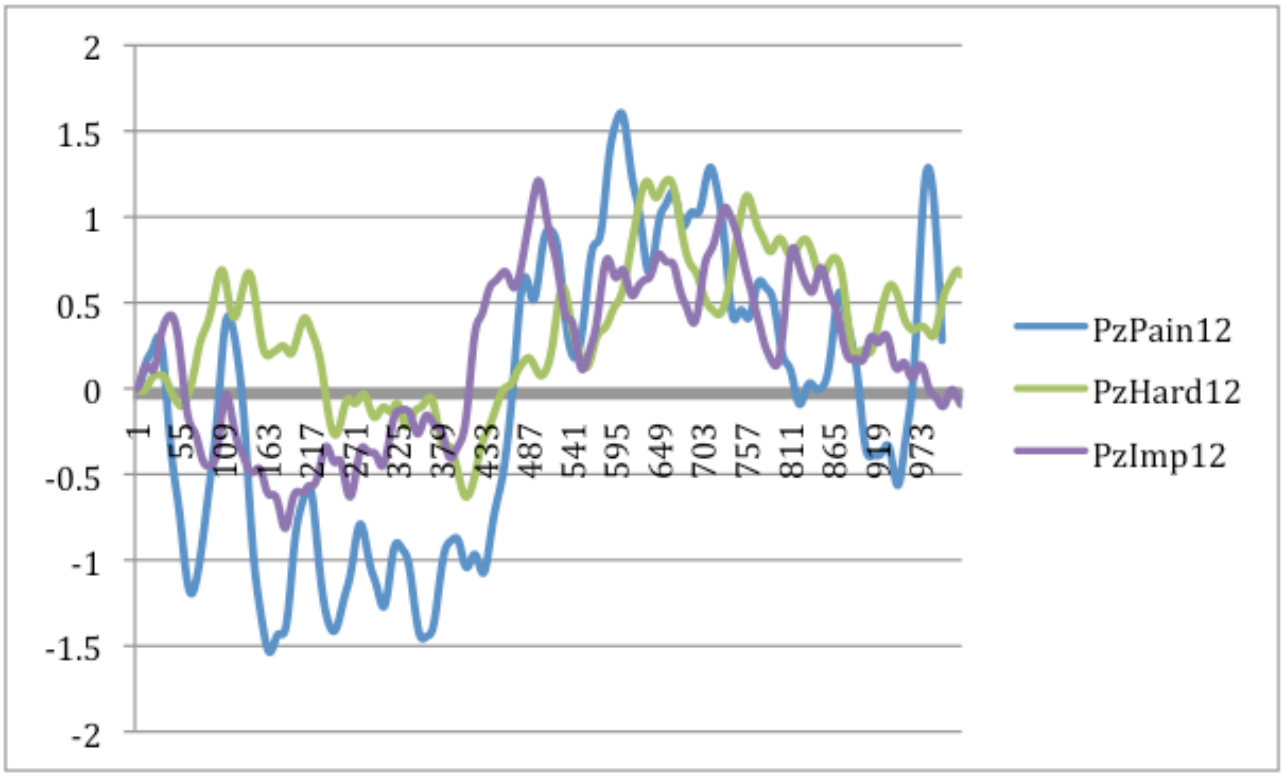

Figure 10. Grand Averages to pain stimuli for Pz for all three experimental conditions (Pure Pain, Hard game demand, Impossible game demand)

As the postcentral gyrus of the primary somatosensory cortex is closest to the Cz or vertex electrode site, we chose regions of interest from that grand average as it was likely to show stronger electrophysiological responses to the pain stimulus. Previous literature has suggested that heat-pain components are typically present as N1 and N2-P2 components (e.g. Greffrath, Baumgartner and Treede 2007), and we attempted to find their analogue in our own data.

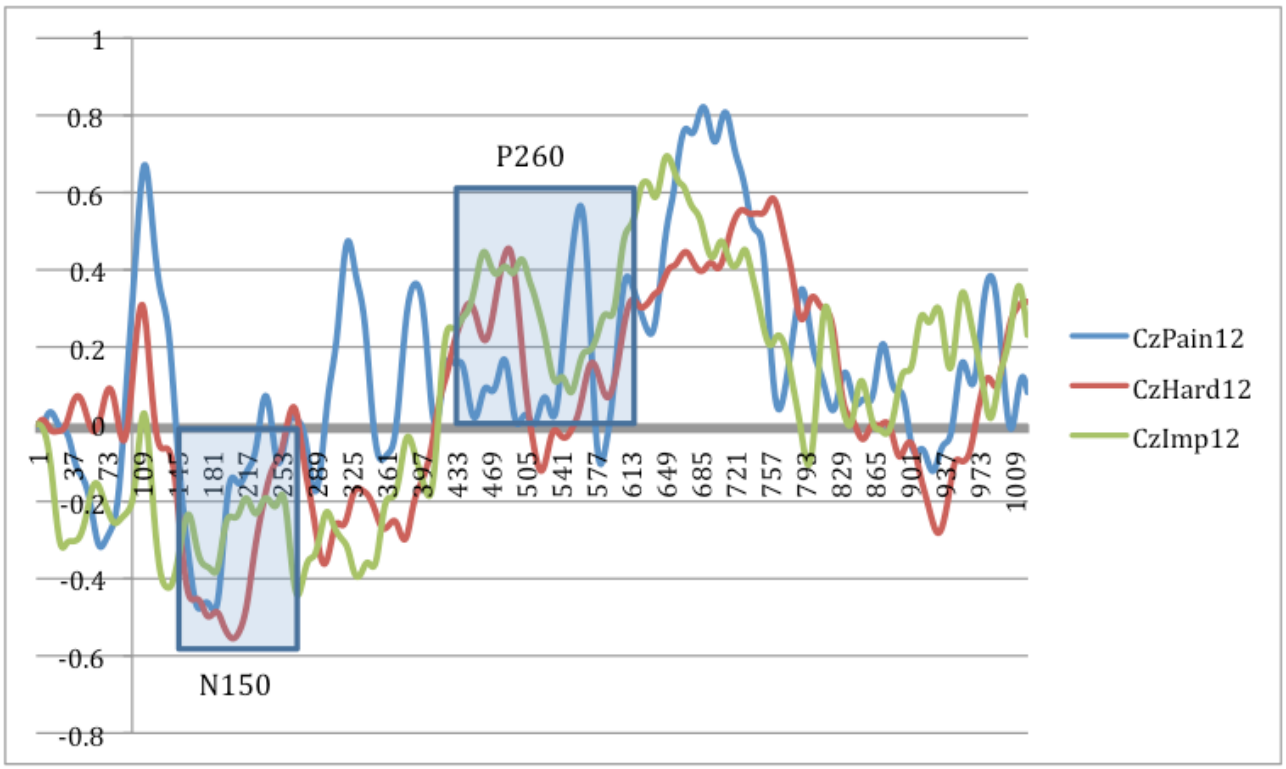

Figure 9. Grand Averages to pain stimuli for Cz for all three experimental conditions (Pure Pain, Hard game demand, Impossible game demand) with highlighted regions for N150 and P260.

Unlike ERPs from traditional cognitive experimentation where extremely tight control of participants' experiences and behaviours is possible, our ERPs showed distinctly larger and more irregular peaks, which we suspect was due to a combination of fluctuating mental responses to the demands of the game, and in the pure pain condition, possibly anticipation of each pain stimulus over the 2 minute period. We defined the relevant component regions as N150, corresponding to primary somatosensory pain at 45-150ms, and the P260, representing cognitive responses to pain, at 300-460ms. From these regions, we extracted peak amplitudes at Fz, Cz and Pz for each of the pain, hard racing and impossible racing conditions.

We initially conducted a 3x3x2 ANOVA for each of the component windows, comprising electrode site (3) x pain / game- demand condition (3) x participant gender (2). Results showed a marginal effect of electrode site during the N150 ($F(2,20)=3.45$, $p<0.052$) and a strong effect of electrode site during the P260 ($F(2,20)=9.322$, $p<0.01$). Effects of task condition were less pronounced at both sites with both failing to achieve statistical significance ($F(2,20) = 1.055$, p, 0.367; $F(2,20)=2.847$, $p<0.082$). To investigate the effects of electrode site, we conducted three 1-way ANOVAs, evaluating the pain, hard- and impossible racing conditions at the Fz, Cz and Pz

sites during the P260 component. Results from all three tests were non-significant ($F(2,22) = 2.739$ (Fz), 0.220(Cz), and 1.862 (Pz). A single effect of participant gender was present during the N150 component ($F(1,10) = 7.637$, $p<0.020$). Here, peak amplitudes overall were significantly enhanced for female participants only (-0.325uV (males) vs. -1.725uV (females)). We also noted that a single female participant showed excessively high peak amplitudes on 3 variables, and re-ran the preceding analyses after removal of that individual's data; no results were significantly altered after this exclusion.

The lack of statistically significant findings among the EEG/ERP data during the race conditions may be partially explained by the psychometric findings from the IEQ data. After reverse-scoring items 6,8,9 and 10, comparison of total mean scores between conditions showed no difference in the participants' experience of subjective immersion in the game ($F(1,22)=1.406$, $p<0.248$). The IEQ was again judged to be reliable in the current population, with Cronbach's Alpha = 0.801.

2.2.4 Discussion & Conclusions

We encountered several issues in designing the present study to balance between a valid experimental design and inherent issues in the task and data collection whilst maintaining an ecologically valid experience of video-game playing. Our initial tests with the Pathways pain stimulation system showed that, subjectively and anecdotally, the levels of pain stimulation which were possible with the system could be easily tolerated by normally healthy individuals, and further, could be subjectively ignored equally easily once the participant became engaged in playing the game. We attempted to compensate for this by increasing the duration and temperature of the pain stimulus (i.e. from a pulse to a 1-secondlong sustained duration), but casual comments from participants bore out our initial observation, with several participants noting that while the first 2 or 3 pulses were unpleasantly painful, the following 5 or 6 in each race were markedly less so, and more simply regarded as sensations than actual painful stimuli. It is therefore possible that although we were able to collect approximately 1000 artifact-free pain ERP epochs for averaging across conditions, it may be that perhaps only one-third of these epochs (i.e. the first 2 or 3 per block of stimulation) genuinely captured subjective experiences of pain, despite our relocation of the thermode to a different dermatome after each racing trial.

We were similarly concerned by the unconventional appearance of the ERP waveforms generated by the pain-only condition, where participants simply passively experienced the pain in the absence of the distraction of the game. This condition bore the greatest similarity to more

traditional forms of elementary cognitive experimentation, yet failed to result in clearly and cleanly differentiated ERP components in the resultant grand averages. We suspect that the nature of the pain as a longer-lasting sensation - i.e. 1-second "holds" rather than milliseconds-long pulses – may have adversely affected participants' responses here.

During the gaming conditions, however, our experimental manipulation of participants' experiences appears to have been successful. With all participants instructed to "try to win the race", it appears that they did so, with the impossible difficulty condition where they could not possibly hope to win apparently still resulting in an equivalent subjective state of immersion as the "hard" difficulty condition, were some success was possible. Equally, however, the participants' apparent success in becoming immersed in the game resulted in constantly-changing ERP activity during gameplay which we could not readily baseline or otherwise smooth into clearly observable components. Our lack of an "easy" gaming condition (or other condition with alternative instructions to participants) was also likely to have hindered the differentiation of the ERPs. Throughout the experiment, even though it was apparent that winning was either impossible or extremely difficult, it appears that participants continued to try nonetheless. The problem with this approach is that we were unable to differentiate two levels of immersion during hard and impossible levels of game demand. All participants found the game to be challenging and their motivation to play the game was not eroded by the experience of impossible demand as we had predicted.

The experiment demonstrated the difficulties of using commercial software to achieve a controlled gaming experience. In hindsight, it would have been preferable to have used a game that included a SDK (Software Development Kit) so that elements of the game could have been manipulated directly to reliably create easy/hard/impossible levels of challenge. The absence of any modulation of the pain ERP during pure pain and the gaming conditions seemed to indicate that EEG correlates of pain experience remained unaffected by gameplay. This finding appears to contradict previous research using VR(Hoffman et al., 2006) and experimental work on the effects of cognitive distraction (Legrain et al., 2012) and picture viewing (de Tommaso et al., 2008; Kenntner-Mabiala et al., 2008) on pain ERP. However, we did use a sustained pain stimulus (1sec) in order to increase the salience of the stimuli, which makes it difficult to directly compare our experiment to previous work.

The study appeared to indicate that gaming activity had no significant effect on either early or late components of the pain ERP. We are forced to conclude that the experience of pain as registered at the cortex is not affected by immersion in the game.

3. CONCLUSIONS AND FUTURE WORK

Two experimental studies were conducted during the Fellowship to investigate the concept of immersion and the relationship between immersion and the therapeutic properties of computer games for pain relief. The first experiment was performed to investigate the contribution of screen display size and cognitive challenge on the immersive properties of a computer game. It was found that increasing game difficulty to hard and impossible conditions tended to reduce the amplitude of Late Positive Potentials of the ERP that are associated with cognitive activity, e.g. Figures 5 and 6. This effect was supported by the subjective self-reported questionnaire on immersion completed by participants. The effect of display size was more difficult to ascertain. The small 5" display produced a completely different profile of ERP modulation compared to the other two display conditions. It was anticipated that sensory immersion would reach maximum levels during gameplay with the head-mounted display. However, there was no evidence from either ERP or subjective self-report data for any significant effect of display type. The results of this first experiment indicated that immersion is a psychological experience that is primarily driven by the cognitive and motivational properties of the task.

The first experiment utilised an auditory oddball methodology, i.e. participants were exposed to auditory stimuli that were unrelated to the game. This was the first time (to our knowledge) that this methodology had been applied to the measurement of immersion. The justification for this approach rests upon an assumption that the capacity for attention to stimuli that are unrelated to gameplay is reduced during immersion. The second study extended this methodology via the introduction of experimental pain and the measurement of pain ERPs. The rationale for the second study was double-edged: to use painful stimuli in order to capture the degree of immersion and to assess whether gameplay modulated the cortical response to pain. In comparison with auditory stimuli, the introduction of experimental pain represented a category of non-game stimulus that had greater impact on selective attention, i.e. less volitional, greater capacity to 'interrupt' attention to the game, more resistant to the motivational "pull" of the game.

The second experiment failed to yield any statistically significant effects of game demand on either early or late components of the pain ERPs. The conclusion drawn from both experiments was that attention to auditory stimuli was modulated by game demand whereas attention to painful stimuli was not. However, we do have various methodological concerns about the second

experiment concerning the combination of thermal contact pain, ERP measurement and computer games, which were outlined in Section 2.2.4. In essence, we found it difficult to have a realistic gaming experience with sufficient experimental control whilst collecting stable EEG data upon which to analyse the ERP components.

Future work could follow several lines of investigation. Several improvements could be made to the apparatus that we used. For example, our experiments utilised a piece of commercial software for experimental purposes and a greater level of control over variables would have been achieved with developer-level access to the gaming software. The first experiment included three representative types of display but the head-mounted display did not create the magnitude of visual field that was anticipated and perhaps a fixed type of display with a variable field of view would have been superior. The second experiment utilised experimental pain stimuli in combination with pain ERP, but whilst this approach is suitable for research purposes, one does wonder about the ecological validity of the approach and whether pain ERPs have direct implications for pain relief and therapeutic applications. We selected a controlled form of transient thermal pain in order to evoke ERPs from the EEG record. However, there are a number of different types of experimental pain protocol (e.g. the cold pressor test) which offer a pain tolerance scenario - i.e. the cold pressor test involves the participant being able to tolerate a painful stimulus for as long as possible, and which may have provided a more appropriate test of the therapeutic benefits of gameplay. In addition, sustained pain stimuli are probably more representative of certain types of pain (e.g. arthritic pain) that are experienced by clinical populations. The ERP approach was adopted for the measurement of painful stimuli for reasons of consistency between the first and second experimental study, but there are other options available that should be explored.

The research conducted on the Fellowship represented the first attempt to capture the psychological experience of immersion using implicit measures from psychophysiology. Several techniques used to capture immersion involve the completion of questionnaires or the participant being actively interrupted from the immersive task to obtain a data record, i.e. task switching (Jennett et al, 2008). The use of auditory oddball and experimental pain in combination with ERP offers a naturalistic way to gauge immersion in real-time without interrupting the task. This methodology requires refinement but represents an important step towards understanding how psychological immersion may be measured and graded.

4. OUTPUTS

A number of outputs based on the research are under review or under preparation at the time of writing.

1. Fairclough, S.H. & Burns, C.G. (under review). Decomposing Immersion: Effects of Demand and Display Type on Auditory Evoked Potential. Submitted to CHI conference 2013.
2. Fairclough, S.H. & Burns, C.G. (in preparation). Effects of Display Size and Cognitive Challenge on Motivation and Immersion. Motivation & Emotion.

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