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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.

1. 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 et al., 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 and McMahan, 2007; Schnall et al., 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 (Fairclough et al., 2013). 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., 2010). 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, 2008). 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

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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 and Wilson, 1977) and should be augmented with other measures (Darken et al., 1999). Jennett et al. (2008) characterised 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 (Figure 1); it is important to understand EEG topography in the context of ERP analysis. A huge literature has arisen listing many replicable methodologies and characteristic ERP responses (or “components”) such as the P300 (Kok, 2001; Tueting et al., 1970), the N400 (Kutas and Hillyard, 1980) and P600 (Osterhout and 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 ms after stimulus presentation, and the N400 is a negative-going waveform component approximately 400 ms 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 (the "oddball") 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, 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 are presented within a stream of frequent stimuli whilst the participant is engaged with a 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

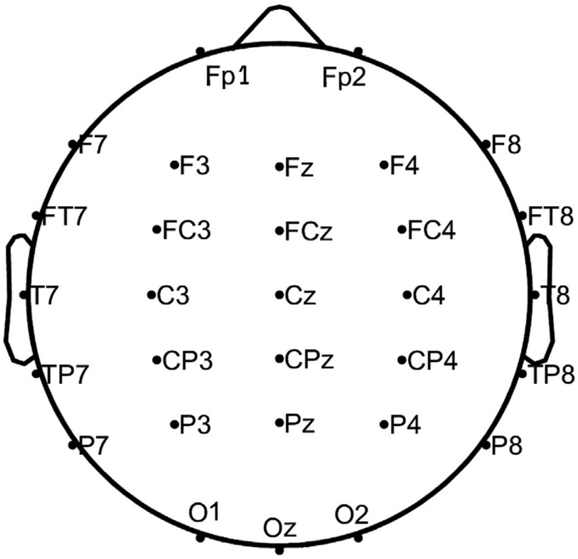

Fig. 1. Illustration of the International 10-20 system (Jasper, 1958).