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Using auditory event-related EEG potentials to assess presence in virtual reality

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Abstract

The feeling of presence in a virtual reality (VR) is a concept without a standardized objective measurement. In the present study, we used event-related brain potentials (ERP) of the electroencephalogram (EEG) elicited by tones, which are not related to VR, as an objective indicator for the presence experience within a virtual environment. Forty participants navigated through a virtual city and rated their sensation of being in the VR (experience of presence), while hearing frequent standard tones and infrequent deviant tones, which were irrelevant for the VR task. Different ERP components elicited by the tones were compared between participants experiencing a high level of presence and participants with a low feeling of presence in the virtual city. Early ERP components, which are more linked to automatic stimulus processing, showed no correlation with presence experience. In contrast, an increased presence experience was associated with decreased late negative slow wave amplitudes, which are associated with central stimulus processing and allocation of attentional resources. This result supports the assumption that increased presence is associated with a strong allocation of attentional resources to the VR, which leads to a decrease of attentional resources available for processing VR-irrelevant stimuli. Hence, ERP components elicited by the tones are reduced. Particularly, frontal negative slow waves turned out to be accurate predictors for presence experience. Summarizing, late ERPs elicited by VR-irrelevant tones differ as a function of presence experience in VR and provide a valuable method for measuring presence in VR.

Keywords: Event-related potentials; Spatial presence; Measuring presence; Virtual reality; Attention allocation; VR-irrelevant stimuli

1. Introduction

In virtual reality (VR) research, spatial presence or the "sense of being there" in a virtual environment became one of the most important factors in evaluating a VR (Witmer and Singer, 1998), because the sense of presence in VR is considered as the propensity of VR users to respond to virtually generated sensory data as if they were real (Slater et al., 2009). Additionally, an increased presence experience in VR should foster the transfer of knowledge acquired in the virtual environment to corresponding real world behavior (Slater et al., 1996). Although there is a large body of literature examining the feeling of presence in VR, it is a concept without a valid measurement. The aim of the present study is to find a new and capable method to measure presence.

Because of the subjective nature of presence, it is obvious that self-report questionnaires were the first attempt to measure presence (Insko, 2003). After VR exposure, the participants have to rate the strength of their presence experience in the VR. Using questionnaires to assess presence is a common technique in VR research. However, presence questionnaires are associated with some disadvantages. Most questionnaires are post-immersive, which leads to the problem of inaccurate recall and memory effects such as recency (Freeman et al., 1999). The term presence is not well known

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to the general public. Hence, for some participants it might be difficult to quantify and rate this subjective experience. There is evidence that questionnaire based presence assessment methods are unstable, because their results can be influenced by prior experiences (Insko, 2003; Freeman et al., 1999; Usoh et al., 2000). Nevertheless, note that we do not suggest that self-report measures are inappropriate or incorrect. Self-report questionnaires are generally used as baseline metric and the combination with other quantitative metrics for presence would be an excellent augmentation to the existing measures (Darken et al., 1999). An alternative approach to avoid the subjective nature of questionnaires is to measure behavioral responses. If participants behave within a virtual environment in the same way as if they were in an equivalent real environment, then this might be a sign of presence. Therefore, automatically produced behavioral responses without conscious thought are recorded. One example for such a behavioral response is ducking in response to a flying object (Insko, 2003; Slater et al., 2009). A further objective way to assess presence experience in VR is examining physiological measures of heart rate, skin conductance, respiration rate, or peripheral skin temperature. If the physiological response of a person to a particular situation is the same in equivalent real and virtual environments, then this might be a sign of presence (Slater et al., 2009). The physiological measurements are objective and continuous measures. Hence, these measures allow an indication of how levels of presence change over time (Insko, 2003). On the other hand, the physiological measures are limited to situations where the physiological response is obvious, like, for example, stress-inducing situations. The physiological responses to mundane situations, like being in a virtual room, which has a table and a chair, are not that obvious (Slater et al., 2009). Because of the lack of standardized objective presence measures, the present study aims to find a new, objective and valid measure for the presence experience. Therefore, event-related potentials of the electroencephalogram (EEG) elicited by tones, which were not related to VR, were used as indicators for the subjective feeling of presence within a virtual environment.

Components of event-related potentials (ERP) have been frequently investigated as indicators for allocation of cognitive processing resources (Kok, 1997). In the context of multiple resource models and the concept of limited resources, divided attention paradigms like dual-task experiments have often been used to examine resource allocation (Wickens, 1980, 2008; Rösler et al., 1997). In these dual-task paradigms attention must be divided between two qualitatively different tasks: A primary task like, for example, operating a flight simulator or performing a visual search task, and a secondary task like, for example, counting infrequent target tones and ignoring frequent standard tones (auditory oddball paradigm). Generally, an increase in difficulty or priority of the primary task leads to a decrease of cognitive resources which are available for processing of stimuli in the secondary task, and thus lead to an amplitude reduction of ERP components elicited by stimuli of the secondary task (Kok, 1997). The same rational underlies the so-called irrelevant probe technique, in which the participants do not have to respond to the stimuli of the secondary task. Hence, the stimuli of the secondary task, like, for example, different tones, are task-irrelevant, but nevertheless it is assumed that the ERPs to these task-irrelevant probes will absorb the spare cognitive capacity that is not invested in the primary task (Kok, 1997). In the present study, this irrelevant probe technique was used to assess allocation of attentional resources between a primary navigation task in a virtual environment and a secondary auditory oddball paradigm. Participants navigated through a virtual city and rated their sensation of being in the virtual environment while hearing infrequent deviant tones and frequent standard tones, which were irrelevant for the navigation task. We assume that an increased presence experience in the VR should be associated with a strong allocation of attentional resources to the virtual environment. The sensation of being in a VR requires the construction of a mental model of the virtual situation including space related information (Wirth et al., 2007). Wirth et al. (2007) mentioned that this forming of a mental model is based on attention allocation. In this context, the authors described attention allocation as the devotion of mental capacities to the VR. Darken et al. (1999) also argued that feeling present in an alternate world is associated with focusing the attention there rather than on the real world, and consequently related attention to presence. Hence, it is hypothesized that an increased feeling of presence in the VR is related to focusing the attention on the virtual world. That leads to a decrease of attentional resources available for processing the VR-irrelevant tones, which should lead to an amplitude reduction of ERP components elicited by the tones.

In auditory oddball sequences, event-related potentials like the N1, P3, the mismatch negativity (MMN), and late negative-going slow waves (SW) are typically analyzed. The N1 is a negative component peaking around 100 to 150 ms after sound onset with a fronto-central maximum. This component is assumed to reflect effects of attention on specific cortical areas that encode elementary stimulus features. It is associated with allocation of perceptual resources (Kok, 1997; Näätänen et al., 2011). In contrast, the P3 is associated with allocation of both perceptual and central resources. The P3 is a positive-going component of the ERP waveform, which peaks within a time window between 300 and 600 ms after an eliciting event. It is maximal at posterior-parietal electrodes and has been regarded as a sign of processes of memory access that are evoked by evaluation of stimuli in tasks that require a response (Kok, 1997; Kok, 2001; Donchin et al., 1986; Polich, 2007). The mismatch negativity (MMN) is especially elicited in auditory oddball sequences through the use of deviant-standard difference waveforms. It is seen as a fronto-central negativity, occurring in a latency range of 100–250 ms after stimulus onset. The MMN reflects automatic auditory processing (Duncan et al., 2009; Näätänen