Objective Presence Measures through Electric Brain Activity

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Abstract

This article presents results on objective measures concerning the sense of presence in virtual environments. Electric brain activity of seven students was recorded and analyzed during their interaction with four different versions of the same virtual environment, a representation of a room. Our aim was to detect if some sensory, realism and distraction factors that are related with presence result on differences in electric brain activity, indicating attentional activity and visual awareness as a virtual environment is enriched with textures and objects. Our results show both an alpha band decrease and a gamma band increase with the virtual environment enrichment with textures and objects. These are indications that factors related with the sense of presence in virtual environments affect electric brain activity. Electric brain activity could be considered as an objective measure of presence in virtual environments.

1. Introduction

Presence is the main attribute, the defining experience for virtual reality (VR), appearing in almost all the definitions researched by specialists coming from different fields.

From a philosophical perspective, researchers such as Heim [1], Zhai [2] and Lévy [3] refer to Heidegger's work "Being and Time" for whom presence is synonymous with being and is a function of temporality.

In the sociological context, Riva and Mantovani [4], Heeter [5], Lombard and Ditton [6], as well as Shuemie et al. [7] proposed a cultural concept for presence.

From a psychological perspective, presence is the defining experience for VR [8]. Biocca stated that presence oscillates among the three poles of physical, virtual and imaginal environments [9] and Lombard defined presence as a psychological state or subjective perception in experiences generated by human-made technologies [10].

In the research on presence in virtual environments (VEs), three important topics are under consideration:

1. Theories and taxonomies
2. Attributes and factors that contribute to a sense of presence
3. Methodologies for presence estimation and measurement.

Concerning the theories for presence, Schuemie et al. referred to several models [7]. Concerning these models, we believe that presence as non-mediation, exclusive presence and estimation theory could be considered as theoretical models for presence. With regard to presence taxonomies, Heeter has proposed three dimensions of presence: personal presence, social presence and environmental presence [5].

Concerning the attributes of presence, Witmer and Singer began from the necessary conditions for presence, arguing that it depends on the ability to focus on one meaningful, coherent VE set [11]. Regarding the factors that contribute to presence, Witmer and Singer considered a number of factors that influence presence, namely control factors, sensory, distraction and realism factors [11].

Independently of the methodology for presence measurement, one could formulate presence as the sum constructed out of the above factors, as proposed by Slater [12].

Concerning presence measurements, many researchers categorized them as subjective and objective measures. Subjective measures have been based on questionnaires, developed by many groups, and are the most commonly used. Slater et al. developed and tested their questionnaire, which pays much attention to the subjects' sense of "being there" [13, 14]. Witmer and Singer constructed the Presence Questionnaire (PQ) based on their approach of involvement and immersion [11]. Schubert et al. developed the Igroup Presence Questionnaire (IPQ) based on the two previous ones [15]. Kim and Biocca constructed a questionnaire using a metaphor of transportation from a real to a virtual environment [16]. Lessiter et al. developed the ITC Sense Of Presence Inventory (ITC-SOPI) attempting to create a measure that would apply across a range of media [17]. Lombard and Ditton also created a cross media presence questionnaire [18].

Concerning objective measures, Schuemie et al. categorized them in behavioral and physiological measures [7]. Behavioral measures follow Slater's approach corresponding to observable responses to various stimuli measured for example by log files [13]. Physiological measures concern measurements using skin conductance, skin temperature and heart rate giving some positive results, although these types of measures are probably related to arousal and not directly to presence [19]. Electric brain activity might give some positive results on presence in VEs, as our first measurements on cognitive processing that takes place in VEs have shown [20].

Presence, as a key feature of VEs, plays an important role in all the domains of VR applications. Education is a domain where VR seems to be a powerful and promising tool. Pedagogical models have been proposed for the exploitation of VR in the educational process giving emphasis on constructivism [21]. Educational VEs have been developed and evaluated in various disciplines [22].

We believe that presence is one of the main attributes of VR that differentiates it from other Information Technologies giving learners an active role, which is one of the most important characteristics in the teaching and learning processes. This is in agreement with Slater et al.'s statement that, if humans are required to perform tasks within VEs, then surely it would beneficial for them to feel present in the environment in which the task was taking place [23].

The goal of this article is exploratory. We record the users' electric brain activity in virtual environments in order to investigate the sense of presence using objective measures. The research is in accordance with findings showing that electroencephalography (EEG) can be used to probe the relation of hemispheric functioning to both emotion and cognition [24, 25].

2. Previous Research

Only a few studies report results on brain activity in virtual worlds that may lead to conclusions concerning presence.

Maguire et al. applied Positron Emission Tomography (PET) to measure regional cerebral blood flow changes while 11 normal subjects explored and learned in two virtual environments, one containing salient objects and textures and the other one was empty [26]. The findings showed that learning in both cases activated a network of bilateral occipital, medial parietal, and occipitotemporal regions. The first environment resulted in increased activity in the right parahippocampal gyrus, while the region was not activated in the empty environment. The authors suggested that these findings contribute to the encoding of object location into virtual environments. We believe that Maguire et al.'s data are related to factors that contribute to a sense of presence. Steuer's vividness [8] and Witmer and Singer's sensory factors environmental richness and active search [11] are attributes that affect users' explorations in the Maguire's VEs.

Schier recorded electric brain activity during a driving simulation task [27]. Alpha activity (8 – 13Hz) decrease was interpreted as users' more attentional activity. Greater alpha activity was consistent with fewer attentional resources required for an experienced driver. These data are related to Witmer and Singer's sensory factor degree of movement perception, realism factors such as scene realism and information consistent with objective world, control factors such as the degree of control, the immediacy of control and anticipation of events, as well as distraction factor selective attention [11].

Mikropoulos reported electric brain activity during the navigation of 12 students in a VE [20]. The students showed more attentional activity in the virtual rather in the real environment and lower theta activity (4 – 8Hz) in the VE indicating less mental effort. These results are consistent with Witmer and Singer's distraction factor selective attention.

Moore and Engel's fMRI study recorded increased brain activity in the occipital complex during users' interaction with VEs [28]. Their findings showed a neural activity increase with perceived volume in comparison with two dimensional shapes. We believe that these results are correlated to scene realism and information consistent with the objective world.

Bischof and Boulanger proposed theta activity as a measure for evaluating VEs by assessing the ease of navigation in virtual mazes [29]. These results are related with active search, degree of movement perception and physical environment modifiability, factors that affect presence.

Farrer et al. investigated the feeling of being causally involved in an action that is a constituent of the sense of the self [30]. They studied eight subjects' degree of control of the movements of a virtual hand in four different conditions using PET. Their results showed that the less the subject felt in control of the movements of the virtual hand, the higher was the level of activation in the inferior part of the right parietal lobe, as well as a reverse covariation in the insula. The data are closely related to presence.

All the above references are indications that brain activity could be an objective measure for the sense of presence in virtual environments.

3. Methodology

3.1. Participants

The participants were seven (7) students (mean age 25). All students were right-handed, did not report any medical problems, neither had they used any medication, alcohol or drugs in the last 24 to 48 hours before the experimental procedure.

3.2. Procedure and materials

The virtual environment we designed was a representation of a real room. We have developed it using the SUPERSCAPE Virtual Reality Toolkit on a windows based personal computer. Four different versions of the VE were projected on VR glasses with a head tracker. Each student was sequentially interacted with:

1. an empty virtual room without textures (VE1)
2. the same empty virtual room with textures (VE2)
3. the same virtual room enriched with three solid objects without textures (VE3)
4. the same virtual room with three solid objects and textures (VE4).

Each student was progressively interacted with a more enriched environment involving more scene realism and virtual objects that could drive active search and selective attention. This was done because we would like to study some of the factors affecting presence, starting from simple, empty virtual environments. There was a rest period with closed eyes between each VE.

Our research axis was to detect alpha-band oscillations decrease and gamma-band increase as a result of attentional activity [20, 27] and visual awareness [31] coming from the virtual environment enrichment. The factors that contribute to the sense of presence are involved in the four virtual environments and are related with attentional activity and visual awareness are vividness, sensory factors such as the environment enrichment, realism factors such as the scene realism and information consistent with the real world, as well as distraction factors such as selective attention.

3.3. EEG recordings

Brain wave activity was recorded using a Micromed 98 system with 256Hz sampling rate. The digital EEG data acquisition system had a bandpass of 3.5 – 70Hz. EEG activity was monitored over 19 scalp locations, using the 10-20 Electrode Placement System. All leads were referenced to linked ear lobes and a ground electrode was applied to the forehead. Horizontal and vertical eye movements were recorded with four electrodes placed round the eyes, used for EOG rejection. Electrode impedance was maintained below 20KΩ. For each condition (eyes closed, eyes open, VE1, VE2, VE3, VE4) a fast Fourier transform (FFT) was performed on artefact-free data in order to derive estimates of absolute spectral power in different frequency bands. EMG artefacts were controlled. For each VE the artefact-free epoch was 2s. The bands of interest for the present work were alpha (a = 7.5 – 12.5Hz) and gamma (γ = 30 – 70Hz). The signals presented in this work concern frontal (F3, F4), parietal (P3, P4, Pz) and occipital (O1, O2) lobes.

4. Results

Figure 1 shows alpha band activity for the four different versions of our virtual environment. The brain signal represents power density. By power density we mean the normalized % percentage of the power (μV^2) that is distributed in a specific frequency band.

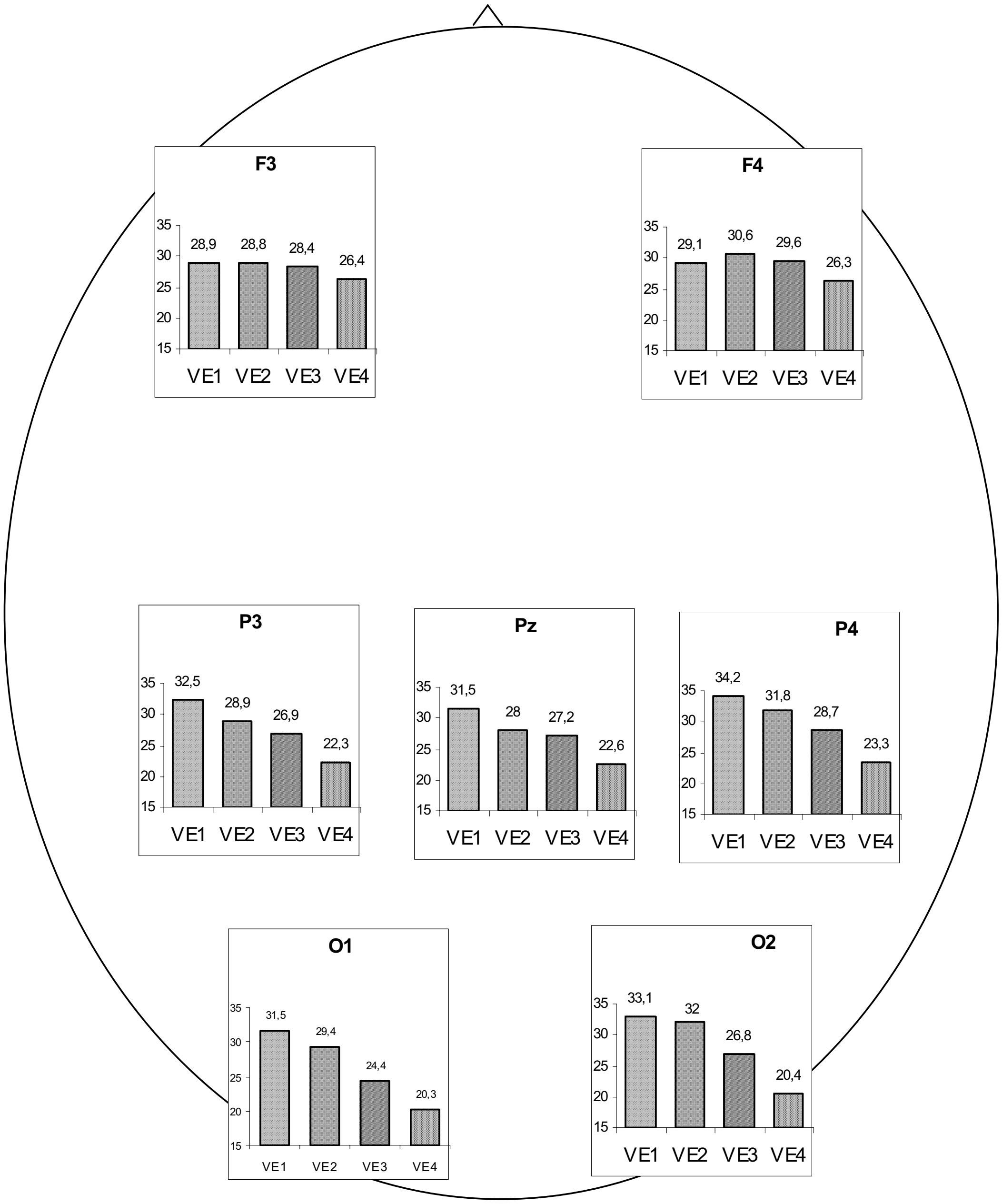

Figure 1 Mean values for alpha band activity for the four VEs

Alpha desynchronization is observed in frontal (F3, F4), parietal (P3, P4, Pz) and occipital (O1, O2) lobes. The students' alpha waves decrease when the students navigate into a virtual room with textures. A further decrease is shown when the three objects without textures appear on stage, with the greater decrease observed in the enriched environment with textures and objects with textures. All signals for VE2 to VE4 are lower in the occipital lobe, since this is mainly responsible for visual stimuli. The results give evidence of attentional activity and visual awareness during the students' interaction with the four virtual environments. Moreover, these results show a greater attentional activity and visual awareness as the virtual environments go from an empty room to the same empty room enriched with textures, to the room with solid objects without textures, to the room with the objects and textures.

Figure 2 shows the mean gamma band activity (power density) for the four virtual environments and the same lobes.

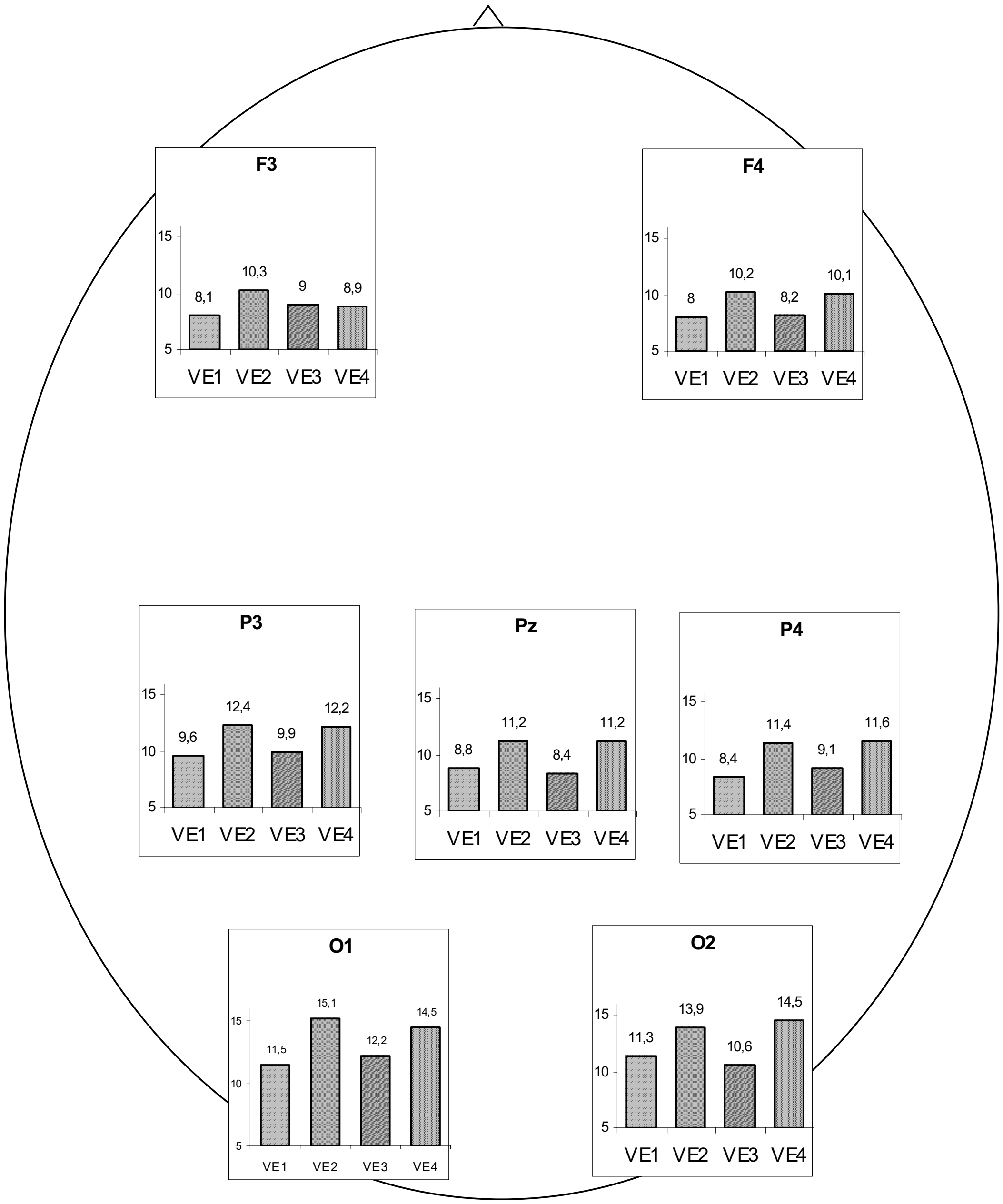

Figure 2 Mean values for gamma band activity for the four VEs

As it is shown, gamma oscillations increase with the enrichment of the virtual environment. These results show a greater visual awareness as the students interact with VE2, VE4 and VE3. The relative decrease of the signal for VE3, is because of the absence of the solid three dimensional objects that appear in VE2 and VE4.

5. Conclusions

The goal of this article was to give data coming from objective measures concerning some factors that are related with the sense of presence in virtual environments. As a start, we allowed seven students to navigate in four different VEs without being able to manipulate and control virtual objects. Our aim was to detect if some sensory, realism and distraction factors result on differences in electric brain activity, indicating attentional activity and visual awareness as a virtual environment is enriched with textures and objects.

Our findings on alpha decrease show an increase in attentional activity and visual awareness with the VE enrichment. We believe that scene realism and information consistent with the real world that are involved in the environment richness and selective attention cause the observed alpha wave decrease in the frontal, parietal and occipital lobes. This conclusion is in coherence with Mikropoulos [20] and Schier's [27] findings on electric brain activity in VEs. This conclusion is also in coherence with other brain measurements, such as Maguire's concerning the encoding of object location into virtual environments [26]. The proposed relationship between presence and visual attention and awareness is based on the findings reported by Steuer [8] and Witmer and Singer [11].

Our findings on gamma increase come as a complement on alpha decrease. We believe that our results correspond with the visual awareness of form and color introduced by the appearance of the three virtual objects [31].

It seems that electric brain activity could be considered as an objective measure for presence that gives results on the various factors related with the sense of presence in virtual environments.

Our research is in progress. Future investigations involve the study of alpha desynchronization as a function of the time a participant stays in changing VEs, as well as the study of other EEG bands as a function of other presence factors.

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