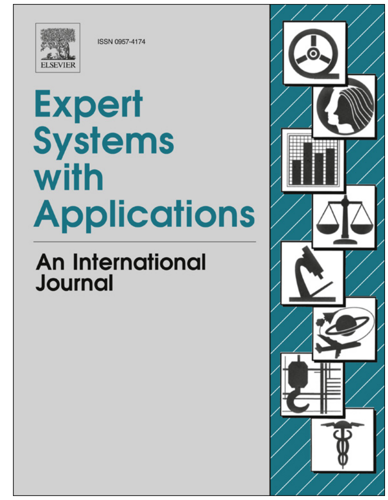

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Assessment of the influence of navigation control and screen size on the sense of presence in virtual reality using EEG

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Abstract: In the Virtual Reality field, presence refers to the sense of "being there" in the virtual world. Our aim in this work is to evaluate the usefulness of the Emotiv EPOC EEG device to measure brain activations due to the sense of presence in a Virtual Environment (VE), using for the analysis the sLORETA tool. We compare between three experimental conditions: photographs, video and free navigation through a VE. We also compare the differences in the sense of presence due to the visualization of the VE in different screens: a common desktop screen and a high-resolution power wall screen. We monitored 20 healthy subjects, obtaining significant differences between the navigation and video conditions in the activity of the right insula for the Theta band. We also found a higher activation of the insula for the Alpha and Theta bands while navigating, when comparing the two screen types. The insula activation is related to stimulus attention and self-awareness processes, directly related with the sense of presence.

Keywords: EEG, Emotiv EPOC, presence, virtual reality, navigation, screen size

1. Introduction

In the Virtual Reality (VR) field, presence refers to the feeling of being there, inside the Virtual Environment (VE), while your body is physically located elsewhere (Sheridan, 1992). This concept is fundamental for the success of the virtual experience, determining the interaction between the computer-generated world and the subject. In words of Meehan et al. (2002), "virtual environments are the most sophisticated human-computer interfaces yet developed". In this study, our main purpose is to measure the level of presence experienced while navigating through a virtual environment, in comparison with other less immersive conditions, using a wireless portable electroencephalogram (EEG) device as an objective indicator of brain activation. According to Riva et al. (2003), "as media becomes increasingly interactive, perceptually realistic and immersive, the experience of presence becomes more realistic". So we expect to find a higher sense of presence while navigating than while performing other less immersive conditions, in which the interaction with the environment is more restricted. For the measure of brain activations, we will use an Emotiv EPOC headset with which we expect to achieve activations in concordance with those obtained in previous studies carried out with more precise and expensive devices. The use of a wireless portable EEG device will allow a quicker placement of the sensors and a higher degree of movement in the subject, thus favoring a higher level of presence during the experience.

As Loomis (1992) remarked, "presence is a fundamental property of consciousness". Sanchez-Vives and Slater (2005) also pointed out that inside the virtual experience, you are at the same time conscious of the "place" and the "events" and simultaneously conscious of that there are no such place or events; however, you still behave and think as if the place were real and the events were happening. As your consciousness of the differences between the real and virtual place and events blurs, the barrier between your mind and the VE diminishes, improving your interaction with the computer-generated world. As Kober et al. (2012) remarked, the greater the degree of presence the participants feel, the greater the chance they will behave in the VE as they would do in a similar real world setting. This agrees with the view of presence as not only the sense of "being there", but also the ability to "do there" (Sanchez-Vives and Slater, 2005).

Another purpose of the present study is to evaluate the influence that the visualization system has over the level of presence in the different interaction conditions. There are previous studies that have analyzed changes in the feeling of presence due to the size and realism of the screen used to display the environment. For example, Kober et al. (2012) compared the presence elicited by two visualization systems: one based on a high-immersive VR wall (3D) and another based on a low-immersive 2D desktop screen. Similarly to this, in the present work we divided the subjects into two groups, based on the kind of screen used: the first group performed the task in a common desktop screen (DS) and the second group viewed the environments in a high-resolution power wall screen (PW). According to the previous literature, we expect to find a higher stimulation of the sense of presence in the PW group than in the DS group.

For the assessment of the sense of presence, we need a measure reliable, valid, sensitive, and objective (Meehan et al., 2002). The traditional methods used questionnaires for this purpose, obtaining valid yet subjective results. Since the tests are carried out after the virtual experience, they do not provide information of the temporal evolution and are influenced by the subject's opinion. This can be observed, for example, in the study from Usoh et al. (2000), who used questionnaires to distinguish between the sense of presence experienced while performing a task in the real world and inside a virtual environment. They passed different questionnaires to the subjects after both experiences, obtaining only a marginally higher presence rate in the real scene.

Another way of evaluating presence is the use of physiological measures, taken during the virtual experience and not at the end of it, so they can be used as real time monitoring during the task. Between the measures available, we can remark techniques such as heart rate, skin conductance, eye movement or surface electromyography. For example, Meehan et al. (2002) used heart rate, skin conductance and skin temperature for the measure of presence in a stressful virtual environment. Their hypothesis was that the more real the environment seemed, the greater sense of presence the subject would feel. They concluded that the best assessment of the presence experience was obtained with the heart rate response.

Apart from peripheral physiological measures, different neuroimagen techniques have been proposed and used for the assessment of the sense of presence inside a virtual environment, such as functional magnetic resonance imaging (fMRI), Transcranial Doppler (TCD) or electroencephalography (EEG). Regarding fMRI, Baumgartner et al. (2008) analyzed brain activations associated with presence in children and adults while watching a VR video of an automatic navigation in a roller coaster scenario. They compared the differences between a high presence and a low presence environment. Results from the fMRI analysis showed that the presence experience evoked by the virtual roller coaster scenario was associated with an increase in activation in a distributed network. As discussed later by Jäncke et al. (2009), the distributed network that is activated during the presence experience includes the dorsal and ventral visual stream, the parietal cortex, the premotor cortex, the mesial temporal areas (including the hippocampus, amygdala and insula), the brainstem and the thalamus. In a previous study carried out by our group (Clemente et al., in press), fMRI was also used for the measure of presence in a virtual environment, comparing three experimental conditions: photographs, videos and free navigation through the environment. We found significant differences in the level of presence experienced while navigating compared with the other two conditions, mostly in the insula, the cuneus and the parietal lobe. With regard to TCD, two recent studies (Alcañiz et al., 2009; Rey et al., 2010) proposed that TCD could be used as a brain activity measurement technique to study presence in virtual environments. Results of these two studies showed changes in blood flow velocity in the major cerebral arteries of the participants during moments associated with different levels of presence in different immersive and navigational conditions.

The other technique that has been proposed and applied for presence measurement is the electroencephalography (EEG), due to the freedom of movement the subject has once the electrodes are placed, especially in comparison with techniques that impose severe restrictions to movements such as fMRI. EEG measures the electric activity in the brain; more specifically, it measures the synaptic potentials in the cerebral cortex. EEG signals show the difference in potential between two electrodes, an active one and a reference one. The time resolution of the technique is of the order of milliseconds, allowing the measure of the fluctuations in the EEG signal due to the tasks developed.

Until now, several studies have been made combining VR with EEG to measure the sense of presence experienced by the subjects. For example, Baumgartner et al. (2006) evaluated the cerebral activity related to the sense of presence using a multichannel EEG, applying the low-resolution brain electromagnetic tomography (LORETA) method to study the cortical structures that produce the neurophysiologic activation. They compared activations between children and adolescents while viewing a video of a rolling coaster, and found activation in the parietal areas of the brain.

More recently, other studies were developed in interactive environments where the navigation through the virtual environments was allowed, in order to increase the sense of "being there". In the previously mentioned study from Kober et al. (2012), which compared two systems for the presentation of the virtual stimuli, one based on a high-immersive VR wall (3D) and another based on a low-immersive 2D desktop screen, it was observed that the 3D screen system showed a greater presence sense associated with an increase in the Alpha band for the parietal TRPD ("Task-related power decrease"), related to the parietal activations. The lower presence experience in the 2D screen was accompanied by a strong functional connectivity between the frontal and parietal areas of the brain, pointing out that the communication between those areas is crucial for the experience of presence.

In another study which followed a different EEG-based approach for the evaluation of presence, Kober and Neuper (2012) studied the Event-Related brain Potentials (ERP) of the EEG signal, which were elicited by tones that were not related with the VR experience. They found a correlation between the increase in the presence experience and the decrease in the late negative slow wave amplitudes, related to the central stimulus processing and the allocation of the attentional resources. According to this conclusion, an increase in presence is related to a greater pay of attention to the virtual environment, which leads to a decrease in the attention paid to the irrelevant stimulus of the VR (decrease in the ERP components due to the tones).

Recently, several studies have been carried out using the Emotiv EPOC headset, trying to demonstrate its usefulness and practical applications. Given its portability and its low-cost in comparison with other EEG devices, it is widely being used (especially in BCI applications) due to its high temporal resolution compared to other non-invasive techniques such as MEG, fMRI or the traditional EEG (Duvinage et al., 2012). For example, Campbell et al. (2010) used it as an interface to communicate the brain with a mobile phone application, in order to command it just with mental orders. More precisely, in this study there appear a sequence of photos of contacts in the phone and when the showed photo matches that of the contact the user wants to dial, a P300 brain potential is elicited. In another study, Khushaba et al. (2012) explored the brain activations elicited while performing a task where decision making is involved. They used an Emotiv EPOC headset to measure the brain activity, as well as a Tobii-Studio eye tracker system to capture the participants' choice based on their preference in looking at. In a posterior study, the same group (Khushaba et al., 2013) explored the commercial applications of this decision making measures for the guidance to choose the marketing that better fits the consumer preferences. In this concrete study, they used again the Emotiv EPOC headset to measure brain activity while performing a choice task to choose among the user's preferred shape, flavor and topping in biscuits.

The Emotive EPOC has also been applied to evaluate brain activations related to emotional induction. In the study from Rodríguez et al. (2013a), virtual environments were used to provoke a negative mood (sadness) in the subjects while their brain activation was measured before and after the negative induction by means of an Emotiv EPOC headset. In another study (Rodríguez et al., 2013b), they also applied this low-cost EEG device, to monitor brain activity during a positive emotional induction (view of validated images from the IAPS system).

Taking into account all this previous research, and since the influence of user-controlled navigation on the presence experience and on the associated brain activations has not been directly evaluated yet, the main goal of the present study will be to compare brain activity due to presence between three experimental conditions associated with different levels of navigation control: the view of still photographs of the virtual environment, the view of a video of an automatic navigation through the environment and a free navigation through the VE. We expect that the sense of presence will be greater in the navigation condition than in the other two conditions, and that there will be differences in brain activation in areas related to presence. Moreover, we will compare the brain activations due to difference in presence depending on the screen used to the visualization of the environments. We expect that the more immersive and realistic screen will generate a higher sense of presence.

2. Material and Methods

2.1. Subjects

For the study, 20 healthy subjects were recruited; being divided into two groups of 10 subjects each. The first group viewed the VR environments by means of a common desktop screen (DS), while the second group viewed the environments on a Power Wall (PW) screen. For the first group (DS), 6 men and 4 women were evaluated, with ages between 22-29 years old. For the second group (PW), 5 men and 5 women carried out the study, with ages between 21 and 29 years old. All the subjects were right-handed. The participants' hand dominance was tested using the Edinburgh Handedness Inventory (Oldfield, 1971). All of them provided signed consent for allowing their data being used in this study. One subject (a woman) from the DS group had to be excluded due to movement during the scan. The experiments were conducted in a laboratory inside the LabHuman group. The EEG signal was monitored by means of a multichannel wireless portable EEG device (Emotiv EPOC) (Rey et al., 2012), which has 14 data-collecting electrodes and 2 reference ones. The handset transmits wirelessly the EEG data to the computer.

2.2. Presence Questionnaire

After the EEG session, subjects had to answer the questions of a SUS questionnaire (Usoh et al., 2000) to evaluate the level of presence that they felt during each task (one questionnaire for each experimental condition). The questionnaire consisted in six 7-point Likert type questions that had to be answered depending on the strength of the "being there" sensation experienced, where 1 corresponded to not feeling there at all and 7 to the highest sense of being there (as experienced in the real world).

2.3. Environments

The virtual environments were programmed using GameStudio software (Conitec Datensysteme GmbH, Germany), which allowed us to develop 3D objects and virtual worlds with which we could interact and navigate. Our virtual environment (VE) consisted of an everyday, clean bedroom (with a bed, a closet, and a desk with some books on it) where participants could navigate freely.

To allow us to identify the specific areas of the brain that were activated for each task, we divided the paradigm into three conditions developed with the same virtual environment: in the first, photographs of the environment were shown; in the second, a video of an automatic navigation through the room is observed; in the third, the participant can navigate freely in the VE. A scheme of the protocol can be seen in Figure 1.

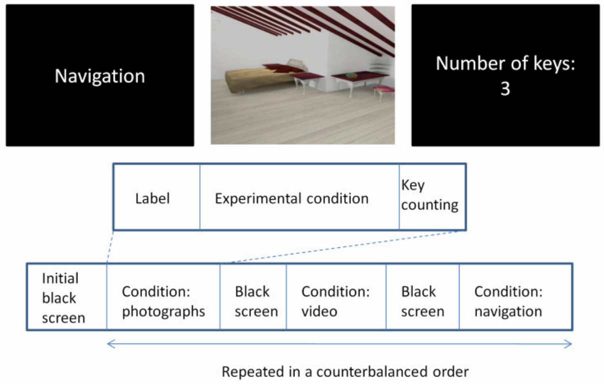

Figure 1. Diagram of the experimental design. In the bottom part of the image, the scheme of the protocol followed in the experiment is shown. Above it, it can be observed a capture of the environment.

Each condition was repeated six times. To learn about the tasks that had to be performed inside the scanner room, subjects underwent a prior training session. In order to prevent differences in activation caused by the motor task, subjects were instructed to move the joystick continuously during the photographs and video tasks in the same way as they did during the navigation period.

2.4. Data Analysis

We analyzed the results of the SUS questionnaires using the program SPSS 17.0 (IBM Corporation, Somers, New York, USA). Apart from the individual responses to the six questions associated with each of the periods (photographs, video and navigation), we calculated an additional measurement: SUS mean. This is the mean score across the six questions that has already been described in previous studies (Usoh et al., 2000). We carried out a non-parametric Friedman Test to compare SUS responses (dependent variables: questions 1-6 and SUS mean) for the different experimental conditions: photographs, video and navigation. Post-hoc tests were made with a Wilcoxon Signed-Rank test with Bonferroni correction.

The preprocessing of the signals was made by means of the EEGLAB program (Delorme and Makeig, 2004). All recorded EEG epochs were checked for artifacts. First of all, data were digitally filtered using a linear FIR band pass filter (0.5-45 Hz). Then, the electrooculographic (EOG) artifacts were removed applying Blind Source Separation (BSS), using a window length of 10s, with 5s between windows. The electromyographic (EMG) artifacts were removed using also the BSS method.

For the analysis of the activated brain areas, the sLORETA (standardized low-resolution electromagnetic tomography) tool was used (Pascual-Marqui et al., 1994, 1999; Pascual-Marqui, 1999; Frei et al., 2001). The whole brain was analyzed using voxel-wise t-tests for examining the navigation vs. video and navigation vs. photographs conditions in the six frequency bands. Moreover, the same voxel-wise t-tests were used for comparing between the navigation conditions for the two groups (DS vs. PW) in the six frequency bands.

3. Results

3.1. Questionnaire Results

The answers to the SUS questionnaire showed between subject variations. Mean values in each condition are shown in Table 1. Results from applying the non-parametric Friedman Test showed that there were significant differences between the three experimental conditions for all the questions and the SUS mean (results can be observed in Table 1, columns 5 and 6). If we observe the results for each question, we can see that for the DS group, the greatest Chi-square value ($\chi 2 = 16.222$, $p < 0.001$) was observed for questions 1 and SUS mean; while for the PW group, the greatest Chi-square value ($\chi 2 = 13.556$, $p < 0.001$) was observed for questions 1 and 3.

Post-hoc analyses based on Wilcoxon Signed-Rank Tests were conducted on the SUS mean results with Bonferroni correction, resulting in a significance level set at $p < 0.0167$. For the DS group, there were no significant differences between the photograph and video tasks ($Z=2.082$, $p=0.037>0.0167$), but there were for the comparisons navigation vs. video ($Z=2.668$, $p=0.008<0.0167$) and navigation vs. photograph ($Z=2.668$, $p=0.008<0.0167$). For the PW group, there were no significant differences between the photograph and the video tasks ($Z =2.380$, $p = 0.017 > 0.0167$) and between the photographs and navigation tasks ($Z=2.366$, $p=0.018>0.0167$). However, there was a statistically significant increment in the SUS mean in the navigation condition compared with the video condition ($Z =2.521$, $p = 0.012 < 0.0167$). Those results are contained in Table 2. Finally, we should mention that no significant difference was found for the questionnaire answers between groups (DS vs. PW) for any of the three experimental conditions.

Table 1. SUS responses to questionnaires for each task (mean score and standard error of the mean) and results of the Friedman Test for each question and the mean score

		Photograph	Video	Navigation	χ^2	P
SUS question 1: feeling of "being there"	DS	1.89±0.35	3.11±0.31	4.89±0.39	16.222	0.000
	PW	2.90±0.33	3.80±0.26	4.80±0.41	13.556	0.001
SUS question 2: feeling that the room is real	DS	2.22±0.43	3.00±0.33	4.78±0.40	12.400	0.002
	PW	2.40±0.23	3.70±0.35	4.30±0.39	12.286	0.002
SUS question 3: how real do you remember the room?	DS	1.56±0.24	2.67±0.24	4.11±0.39	15.548	0.000
	PW	2.20±0.34	3.40±0.32	4.50±0.39	13.556	0.001
SUS question 4: feeling of being inside the room or observing it	DS	2.00±0.37	2.89±0.51	4.78±0.49	14.813	0.001
	PW	2.50±0.28	3.40±0.28	4.80±0.44	12.600	0.002
SUS question 5: memory of the room as similar to being in other places	DS	2.89±0.42	2.89±0.39	3.78±0.49	10.800	0.005
	PW	2.90±0.46	3.70±0.32	4.70±0.39	9.680	0.008
SUS question 6: did you think you were really in the room?	DS	2.33±0.37	3.22±0.28	4.78±0.47	9.800	0.007
	PW	2.60±0.48	3.40±0.36	4.40±0.48	10.000	0.007
SUS mean	DS	2.15±0.28	2.96±0.24	4.52±0.35	16.222	0.000
	PW	2.58±0.27	3.57±0.23	4.59±0.36	12.839	0.002

Table 2. Results of the Wilcoxon Signed-Rank Test for the comparison of the SUS mean results between experimental conditions

	DS		**PW**	
SUS mean	Z	P	Z	P
Navigation>Video	2.668	0.008	2.521	0.012
Navigation>Photographs	2.668	0.008	2.366	0.018
Video>Photographs	2.082	0.037	2.380	0.017

3.2. EEG Results

For the DS group, the comparison between the Navigation and Video conditions using voxel-wise t-test for all the frequency bands revealed significant differences in the Alpha-band (8-12 Hz) and Theta-band (4-7 Hz), for $p<0.05$. Alpha and Theta band power was decreased in the Navigation condition in the right Insula (BA 13), indicating increased activity in this region during the free navigation task.

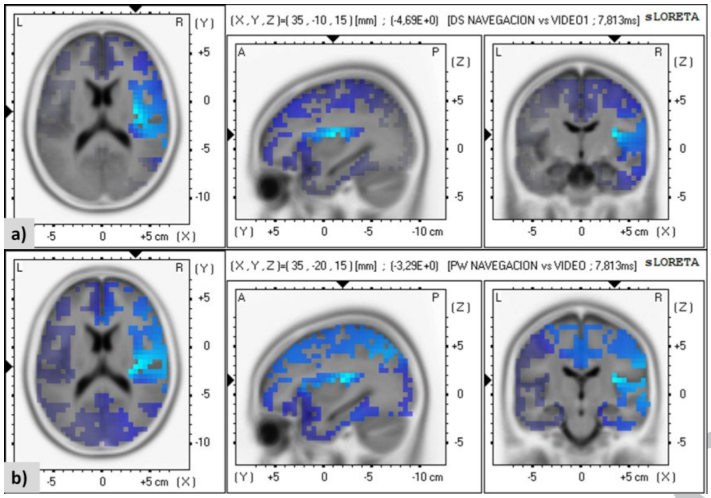

Figure 2. Results for the Navigation>video contrast for both experimental groups. Captures of sLORETA activation for the navigation>video contrast in the Theta band for: a) DS group, b) PW group

For the PW group, the same comparison between the Navigation and Video conditions, again using voxel-wise t-test for all frequency bands, revealed significant differences in the Theta-band (4-7 Hz), for $p<0.05$. Theta band power was decreased in the Navigation condition in the right Insula (BA 13), indicating increased activity in this region during the free navigation task. There has been also found a trend ($p<0.1$) to increased activity in the Insula (BA 13) and in the Parietal Lobe (BA 40) for the Alpha-band. A comparison between the results for the navigation>video contrast in the theta band can be seen in Figure 2. All the results for this contrast are contained in Table 3.

Table 3. Comparison of the results for the DS and PW groups for the navigation>video contrast

Group	Brain Area	Band	Hemisphere	p
DS	Sub-Lobar, Insula (BA13)	Theta	Right	<0.05
DS	Sub-Lobar, Insula (BA13)	Alpha	Right	<0.05
PW	Sub-Lobar, Insula (BA13)	Theta	Right	<0.05
PW	Parietal Lobe, Inferior Parietal Lobule (BA40, 39, 7)	Alpha	Right	<0.1
PW	Parietal Lobe, Precuneus (BA19)	Alpha	Right	<0.1
PW	Parietal Lobe, Angular Gyrus (BA39)	Alpha	Right	<0.1
PW	Parietal Lobe, Superior Parietal Lobule (BA7)	Alpha	Right	<0.1
PW	Sub-Lobar, Insula (BA13)	Alpha	Right	<0.1

Regarding the results for the comparison between the conditions of Navigation and Photographs, we did not found any significant results for any group, but we found several areas with tendency to significance in the PW group. For the Alpha band, the DS group presented a trend to activation for $p>0.1$ in several frontal and temporal areas, as well as in the parahippocampal gyrus. For the PW group, also in the Alpha band, we found the major significance result in the Uncus of the parahippocampal gyrus, part of the Limbic Lobe; and tendency to significance in other areas of the temporal and frontal areas. The complete results for this contrast are contained in Table 4.

Table 4. Comparison of the results for the DS and PW groups for the navigation>photographs contrast

Group	Brain Area	Band	Hemisphere	p
DS	Sub-Lobar, Insula (BA13)	Alpha	Right	>0.1
DS	Frontal Lobe, Subcallosal Gyrus (BA34, 13)	Alpha	Right	>0.1
DS	Frontal Lobe, Inferior Frontal Gyrus (BA47, 13, 11)	Alpha	Right	>0.1
DS	Frontal Lobe, Orbital Gyrus (BA47)	Alpha	Right	>0.1
DS	Frontal Lobe, Middle Frontal Gyrus (BA11)	Alpha	Right	>0.1
DS	Frontal Lobe, Medial Frontal Gyrus (BA25)	Alpha	Right	>0.1
DS	Limbic Lobe, Uncus (BA20, 28, 34)	Alpha	Right	>0.1

DS	Limbic Lobe, Parahippocampal Gyrus (BA36, 35, 34, 28, 27)	Alpha	Right	>0.1
DS	Temporal Lobe, Fusiform Gyrus (BA20)	Alpha	Right	>0.1
DS	Temporal Lobe, Inferior Temporal Gyrus (BA20)	Alpha	Right	>0.1
DS	Temporal Lobe, Superior Temporal Gyrus (BA38)	Alpha	Right	>0.1
DS	Occipital Lobe, Lingual Gyrus (BA18)	Alpha	Left	>0.1
PW	Limbic Lobe, Uncus (BA28)	Alpha	Right	>0.05
PW	Limbic Lobe, Uncus (BA28, 36, 34, 20, 38)	Alpha	Right	<0.1
PW	Limbic Lobe, Parahippocampal Gyrus (BA34, 35, 28)	Alpha	Right	<0.1
PW	Temporal Lobe, Superior Temporal Gyrus (BA38)	Alpha	Right	<0.1
PW	Temporal Lobe, Inferior Temporal Gyrus (BA20)	Alpha	Right	<0.1
PW	Temporal Lobe, Middle Temporal Gyrus (BA38)	Alpha	Right	<0.1
PW	Frontal Lobe, Subcallosal Gyrus (BA34)	Alpha	Right	<0.1
PW	Frontal Lobe, Inferior Frontal Gyrus (BA47)	Alpha	Right	<0.1

Finally, we found, using voxel-wise t-test for all frequency bands, significant differences when comparing the Navigation condition between both experimental groups (DS vs. PW) for the Theta and Alpha bands. For the Theta band, we found activation in the insula, the parahippocampal gyrus and several areas from the temporal and frontal lobes in the left hemisphere; and in the subcallosal gyrus of the frontal lobe in the right hemisphere. For the Alpha band, we found similar activations in the Insula, parahippocampal gyrus and several temporal and frontal areas, all of them in the left hemisphere of the brain. A comparison for the navigation condition between the brain activations for DS and PW groups is shown in Figure 3. The complete results are contained in Table 5.

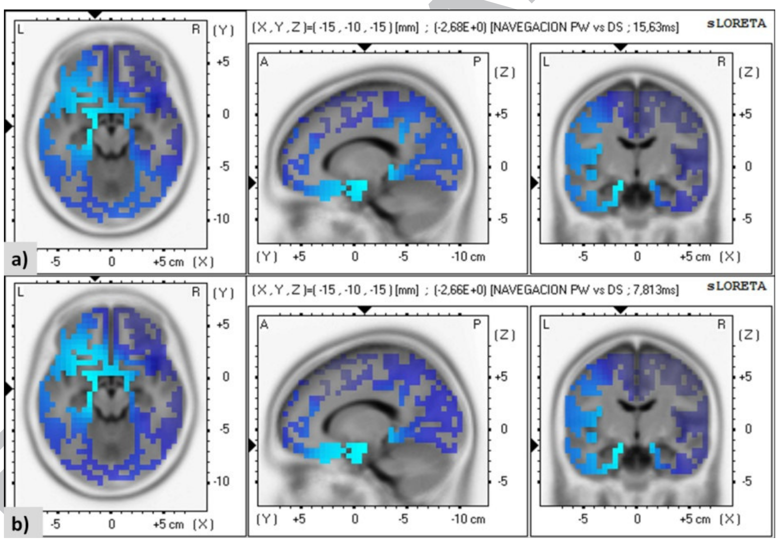

Figure 3. Results for the navigation condition between groups. Captures of sLORETA activation for the navigation condition in the DS vs. PW comparison for: a) Alpha band, b) Theta band

Table 5. Comparison of the results for the navigation condition between DS and PW groups

Brain Area	Band	Hemisphere	p
Sub-Lobar, Insula (BA13)	Theta	Left	<0.05
Sub-Lobar, Extra-Nuclear (BA13, 47)	Theta	Left	<0.05
Limbic Lobe, Uncus (BA34, 28, 36, 38, 20)	Theta	Left	<0.05
Limbic Lobe, Parahippocampal Gyrus (BA28, 34, 35, 36)	Theta	Left	<0.05
Temporal Lobe, Inferior Temporal Gyrus (BA13)	Theta	Left	<0.05
Temporal Lobe, Superior Temporal Gyrus (BA38)	Theta	Left	<0.05
Frontal Lobe, Subcallosal Gyrus (BA34, 13, 25)	Theta	Left	<0.05
Frontal Lobe, Inferior Frontal Gyrus (BA47, 13, 11)	Theta	Left	<0.05
Frontal Lobe, Orbital Gyrus (BA47)	Theta	Left	<0.05

Frontal Lobe, Middle Frontal Gyrus (BA11)	Theta	Left	<0.05
Frontal Lobe, Medial Frontal Gyrus (BA25)	Theta	Left	<0.05
Frontal Lobe, Rectal Gyrus (BA11)	Theta	Left	<0.05
Frontal Lobe, Subcallosal Gyrus (BA25)	Theta	Right	<0.05
Sub-Lobar, Insula (BA13)	Alpha	Left	<0.05
Sub-Lobar, Extra-Nuclear (BA13)	Alpha	Left	<0.05
Limbic Lobe, Uncus (BA28, 34)	Alpha	Left	<0.05
Limbic Lobe, Parahippocampal Gyrus (BA28, 34, 35, 27)	Alpha	Left	<0.05
Temporal Lobe, Superior Temporal Gyrus (BA38)	Alpha	Left	<0.05
Frontal Lobe, Subcallosal Gyrus (BA34)	Alpha	Left	<0.05
Frontal Lobe, Medial Frontal Gyrus (BA25)	Alpha	Left	<0.05
Frontal Lobe, Inferior Frontal Gyrus (BA47, 13)	Alpha	Left	<0.05

4. Discussion

In the present study we used an Emotiv EPOC headset to evaluate the level of presence experienced while navigating in a virtual environment, in comparison with two other experimental conditions (view of photographs and videos of the virtual environment). Several theories have related the sense of presence with the capability "to do" inside the virtual environment, so a higher immersive and commanding task should enhance the sense of presence. The subjects were divided into two groups, depending on the screen used to display the environments. The first group performed the task in a common PC desktop screen (DS) while the second group performed it in a power wall screen (PW). According to the literature (Ijsselsteijn et al., 2001; Slater et al., 1995; Kober et al., 2012), a larger and more realistic screen should enhance a major sense of "being there" in the subject; so we expect to find higher levels of presence in the PW group than in the DS group. As Kober et al. (2012) pointed out, "the screen size enhances the psychological impact of motion stimuli, because a larger portion of peripheral vision is being stimulated". So, in conclusion, we will search for differences in the sense of presence due to two conditions: the possibility of "doing" inside the virtual environment (comparison between experimental conditions) and the influence of the kind of screen used for the display of the environments (comparison between groups, DS vs. PW).

We will analyze first the results related to the "to do" theory. Both for the group with the desktop screen and the group with the power wall, we have found activation in the insula while comparing the navigation and video conditions. What is more, we have also found significant differences in the questionnaire results (Wilcoxon Signed-Rank test) between the SUS mean values for both conditions; so the greater sense of presence is experienced during the navigation condition.

The insula is related to emotion and regulation of the body's homeostasis, which includes among other functions self-awareness or the sense of agency and body ownership (Karnath et al., 2005). The sense of body ownership is the property which allows you to discriminate your own body and perceptions; forming the "body schema" which guides your behavior (Haans and IJsselsteijn, 2012). Recent works (Dodds et al., 2011) have found evidence that the right insula may be activated by a combination of attentional and response control demands, playing a role in the processing of sensory stimuli that are relevant to the current goals. While navigating in a VE, you make decisions all the time, based on the evaluation of the sensory stimuli that guides our behavior in the VE. Our results suggest that the insula may play a key role in guiding behavior in the virtual environment based on the presented stimuli and the sense of presence. Moreover, according to Sjölie (2012), attention and behavior are essential to develop the sense of presence, increasing the precision in the predictions about the environment and the synchronization with it, and avoiding prediction errors from sources outside the VE.

In the study of Baumgartner et al. (2006), they also found activation in the insula while evaluating the sense of presence experienced while watching a video of high and low arousing VEs using EEG. The subjects under study where divided in two groups, one of children and another of adolescents. They found activation in the insula for both groups while comparing the high arousal condition with the control one. As they concluded, the insula "receives homeostatic afferents from several modalities, including temperature, pain, proprioception, and the viscera and, thus, is involved in the mapping of body related sensations".

Regarding the study of Kober and Neuper (2012) using event-related brain potentials of the EEG to indicate the level of presence experienced in a VE, they found an increased presence experience associated with a decrease in the late negative slow wave amplitude, related to the central stimulus processing and the allocation of attentional resources. In concordance with what has already been exposed, they found a direct relation between the attention to the VR and the increase in the sense of presence.

In another previous study about presence with EEG (Kober et al., 2012), they compared the presence-related activations while navigating through a VR world in two conditions: visualization in a Desktop-VR-condition and in a Single-Wall-VR-condition. They found a more intense presence experience in the Single-Wall-VR-condition than in the Desktop-VR-condition, accompanied by an increased parietal TRPD in the Alpha band. Moreover, they found a stronger functional connectivity between the frontal and parietal regions during the Desktop-VR-condition. The activation in the parietal area is close to some of our results (we also found activation in this area for the PW group when comparing between the navigation and video conditions).

In a previous study carried out by our group (Clemente et al., in press) using fMRI to measure presence while navigating in the same virtual environments, we also found activation in the insula (among other areas) when comparing the conditions of navigation and video. Moreover, the results showed a parametric increase in the right insula activation among the three experimental conditions.

Apart from that result, for the navigation>video comparison the PW group also showed a tendency to significance for the Alpha band in the right parietal lobe. More precisely we have found activations in the superior and inferior parietal lobules, precuneus and the angular gyrus. The superior parietal lobule is mainly involved with spatial orientation (Karnath, 1997; Corbetta et al., 1995), which makes sense due to the increased necessity of orientation while navigating than while viewing a video. The inferior parietal lobule has been involved in the interpretation of sensory information (Radua et al., 2010), which the subject receives in a higher amount while navigating. The precuneus has been widely related to presence and navigation, being involved in directing attention in space (Cavanna and Trimble, 2006). At last, the result of the angular gyrus is quite interesting. This area is related to the sense of self-awareness and the developing of Out-of-body experiences (Arzy et al., 2006). Several studies have been carried out to study this phenomenon (Blanke et al., 2002; Arzy et al., 2006), concluding that it is attributed to a discrepancy between the actual position of the body and the mind's perceived location of the body. This statement agrees with the theory of presence.

Regarding the results for the navigation vs. photographs comparison, we only found significant results for the alpha band in the right uncus (part of the limbic lobe) for the PW group. This is an important result, because this area plays an important role in the generation of the sense of presence. The uncus is the extreme area of the parahippocampal gyrus. The activation of the parahippocampal gyrus is related to memory encoding and retrieval (Epstein and Kanwisher, 1998). A subsection of this area is the parahippocampal place area (PPA), corresponding to the BA35, which plays a role in the encoding and recognition of scenes over faces and objects. That means that this area is activated while the subject is seeing a topographical scene, as it can be a room (Epstein and Kanwisher, 1998; Aguirre et al., 1996). The activation of this area during the navigation condition and not during the view of photographs means that there is a higher identification of place while navigating through a room than when you only see a picture of it. This area has been described as related to the view of real places and its activation while viewing a virtual place confirms that the subject feels the experience as real.

Apart from the limbic lobe, we have also found tendency to activation in the temporal and frontal areas. Regarding the activations in the temporal areas, the inferior temporal gyrus is normally related to the visual processing associated to complex objects and shape (Chao et al., 1999), while the superior temporal gyrus is more related to the perception of emotions (Radua et al., 2010). Although the function of the middle temporal gyrus is unknown, it has been connected with several functions, such as the view of distance (De Luca et al., 2006).

Regarding the activations in the frontal areas, the subcallosal gyrus is related to the parahippocampal activation, and both areas work together in the periarcheocortex; while the BA47 of the inferior frontal gyrus has been implicated in the processing of syntax in oral, sign and musical languages (Levitin and Menon, 2003).

Finally, we will discuss the results from the comparison between both experimental groups for the navigation condition. Here we found activations in some of the areas related before, although this time on the left side of the brain. The only significant difference obtained in the right side was in the subcallosal gyrus of the frontal lobe for the Theta band (and for both Theta and Alpha bands in the left side), related to the parahippocampal activation, which as aforementioned plays a role in the encoding and recognition of scenes over faces and objects (Epstein and Kanwisher, 1998; Aguirre et al., 1996). The parahippocampal gyrus also presents a significant activation for the left hemisphere in both Theta and Alpha bands. There is a close activation in the superior temporal gyrus, related to the perception of emotions (Radua et al., 2010).

Another remarkable result was the activation of the left insula for the Theta and Alpha bands, involved in self-awareness or the sense of agency and body ownership (Karnath et al., 2005). Apart from these areas, we found other significant activations in different parts of the frontal lobe.

Regarding the questionnaire results, they confirmed that a higher level of presence was induced during the free navigation than during the automatic navigation and the photographs conditions. Specifically, the Friedman Test showed significant differences between the experimental conditions for all the questions and the SUS mean with higher presence values for the navigation condition. Moreover, the Wilcoxon Test showed the existence of significant differences between the navigation and video conditions for both groups (DS and PW). On the other hand, we found no significant differences for each condition between groups. Because each subject only performed the task in one kind of screen, they were not able to compare the changes between the DS and the PW. This is in accordance with the lack of sensibility of the subjective questionnaires, being unable to differentiate between groups, field where the EEG was successful. The answers given to the questionnaires were subjective and relative to what they had experienced, that is to say, they scored the sense of presence in the navigation condition in comparison with the sense experienced in the other two conditions; and not being able to compare between screens, the DS group scored the experience similarly to how the PW group did. However, those changes in the sense of presence were detected by the EEG signals, finding clear significant differences between groups.

Conclusions

In this study, the main goal was to demonstrate the usability of the Emotiv EPOC headset in presence research. We have used it to measure brain activations related to presence in different experimental conditions, obtaining similar results to those obtained in previous works. More precisely, in a previous study of our group (Clemente et al., in press) we found activation in the insula and the parietal lobe (between others) related to a greater sense of presence while navigating in a virtual environment, result that we have also obtained in this work.

Moreover, we wanted to analyze if a bigger and more immersive screen would enhance the sense of presence and show differences in brain activation with less immersive configurations, as postulated by Kober et al. (2012). Our EEG results show significant differences while comparing both conditions in areas related to presence (such as the aforementioned insula). However, those results were not obtained with the questionnaires, which may be explained by the greater sensibility of the EEG measures.

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Highlights

> We analyzed the sense of presence experienced in a virtual environment using EEG. > Free navigation in a virtual environment was compared with video and photographs. > We compared the results obtained using two different screens. > A common Desktop screen and a high-resolution power wall screen were compared. > We used an Emotiv EPOC headset, obtaining activation mainly in the Insula.