Stereoscopic perception of women in real and virtual environments: A study towards educational neuroscience

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Abstract. Previous studies report the involvement of specific brain activation in stereoscopic vision and the perception of depth information. This work presents the first comparative results of adult women on the effects of stereoscopic perception in three different static environments; a real, a two dimensional (2D) and a stereoscopic three dimensional (3D), all with the same content. Electric brain activity of 36 female students was analyzed at θ, α, β and γ frequency bands. Results in alpha rhythm as well as alpha desynchronization showed that the topology of cerebral activity is the same in the three environments. The participants experienced three similar and non-demanding environments without specific memory requirements and information encoding. Statistical differences in theta activity showed that the real and 3D environments caused similar cognitive processes, while the 2D caused an increase of anxiety indicating that perhaps participants were looking for the third dimension. Beta and gamma activity showed that participants perceived the third dimension of the stereoscopic environment as in the real one, something that did not happen in the 2D environment. Our findings indicate that stereoscopic 3D virtual environments seem to approximate the real ones as far as it regards the cognitive processes they cause. Three dimensional stereoscopic environments increase users' attention over the 2D and cause less mental effort. These experimental results support the new field of educational neuroscience and its potential to the design of digital learning environments.

Keywords: Stereoscopic perception, brain activity, EEG, virtual environments, educational neuroscience

Introduction

Stereoscopy is one of the main technological characteristics of three dimensional (3D) digital environments and virtual reality (Alexander, Conradi & Winkelholz, 2003). Stereoscopic viewing seems to be important for visually guided reaching tasks. Stereoscopic depth has been shown to improve performance for tasks in 3D environments (Arsenault & Ware, 2004; IJsselsteijn et al., 1998). As far as it concerns Educational Virtual Environments (EVEs), stereoscopy and 3D perception seem to contribute to conceptual learning and positive learning outcomes (Salzman et al., 1999). Stereoscopic vision seems to contribute to the perception of the physical world in EVEs (Thompson, Thompson & Wenqing, 2007). Stereoscopic visualisations also help students to acquire better conceptual understandings in Physics and Chemistry (Trindade, Fiolhais & Almeida, 2002; Wu & Shah, 2004). Moreover, stereoscopy in immersive EVEs contributes to effective memorization and may improve the performance of abstract mental activity (Ragan et al., 2010).

Since stereoscopy in both real and virtual environments has to do with the sense of vision and mental processes (Rosas et al., 2007), we believe that physiological measures are necessary for the estimation of stereoscopic vision and can be used corroboratively to subjective methodologies such as questionnaires. Brain studies seem to be a methodology for the estimation of stereoscopic vision in both real and synthetic environments. At least for real environments, the visual system offers a unique possibility to study electrophysiologically cortical neuronal mechanisms (Skrandies, 2001). Few are the studies on brain measurements and stereoscopy in Virtual Environments (VEs) and EVEs. Data from functional Magnetic Resonance Imaging (fMRI) have shown that neural activity in the lateral occipital cortex increased with the presentation of 3D volumes (Moore et al., 2001). Low resolution electromagnetic tomography (LORETA) measurements have shown that stereoscopic presentation induced processes of object localization or spatial search and provided new information processed within the frontal cerebral regions (Fischmeister & Bauer, 2006).

During the last few years, a new field in educational research, that of educational neuroscience or neuroeducation, emerges (Howard-Jones et al., 2010; Howard-Jones, 2011). According to educational neuroscience, under a biological basis and as a renovation of cognitive science in education, learning is defined as the process of "making neuronal connections in response to external environmental stimuli" (Ferrari, 2011; Koizoumi, 2011). Recently, neurophysiological data have shed light to basic aspects of Science, Technology, Engineering and Mathematics (STEM) learning (Kelly, 2011). Neuroimaging techniques such as Positron Emission Tomography (PET) and fMRI have shown that visualisations supporting visual perception and visual imagery activated the two thirds of the brain (Kosslyn, 2011). Regarding virtual environments, Andreano and colleagues (2009) have measured neural activity by using fMRI in two different levels of immersion. Their results have shown increased activity in both auditory and visual sensory cortices and reported that auditory cues in VEs increased activation in the hippocampus, a brain region associated with learning and memory.

The present work proposes the use of digital electroencephalography (EEG) as a high temporal resolution technique for the comparative study of the effects of stereoscopy on adult women's brain activity in three different environments namely, a real, a stereoscopic three dimensional (3D) and a two dimensional (2D) with exactly the same content. The study provides baseline measurements, to be later compared with specific learning task performances and show "the potential of the neurosciences to inform the design and use of technology enhanced learning (TEL)" (Howard-Jones et al., 2010).

Materials and methods

Research objectives

The purpose of the present study was the comparative study of electric brain activity of women during their observation of certain objects in three different static environments (real, stereoscopic 3D and non-stereoscopic 2D virtual environments). The research objectives were to:

- explore possible differences in brain activity connected with attention and mental effort between the three environments
- investigate whether the stereoscopic synthetic version of a real environment approximates it better than its two dimensional equivalent.

Sample

The sample was thirty six (36) students – future teachers, all female volunteers of ages 19 to 22 years (Mean=19.61, SD=1.51). The participants were only women in order to avoid possible different brain activity because of gender differences, as previous research has shown. For example, Kober & Neuper have reported a stronger sensorimotor integration in females than in males, by studying theta oscillations during spatial navigation in virtual environments (2011).

All participants had normal vision, were right – handed native Greek speakers, without certain diagnosed learning difficulties or mental disease. None of the participants received any medication or substances that affected the operation of the nervous system and they had not consumed quantities of caffeine or alcohol in the last 24 hours before the experiment. The alpha rhythm of all the participants was checked and found to be normal (8–12Hz, 10Hz peak). The study conforms to the code of ethics of the University of Ioannina.

Environments and procedure

Three identical static environments representing the surface of a desk were used as the visual stimuli (Figure 1). The real desktop environment consisted of a computer monitor, a keyboard, a mouse, a pair of headphones and speakers, a web camera, a microphone, a memory stick, two books and a CD-ROM disk. The desktop computer setup was chosen because it is a system with educational content and meaning.

The virtual environment was designed using Autodesk 3ds Max 2010. The 3D stereoscopic environment projected on a 22″ stereoscopic LCD monitor with a refresh rate of 120Hz using 3D active glasses. The non-stereoscopic 2D environment was identical to the 3D and displayed on the same monitor without the stereo projection. Both the 3D and 2D digital environments were identical to the real one.

Each participant was comfortably seated 100cm away from and at eye level with the monitor, passively observing each one of the environments (Figure 2). A recommendation was made to the participants, in order to avoid unnecessary movements that could cause artefacts during EEG recordings. In the beginning of the experiment, each participant had few minutes to adapt to the specific conditions, to test their permitted movements, to relax and reduce as far as possible the movements of their eyes.

Figure 1. The real environment

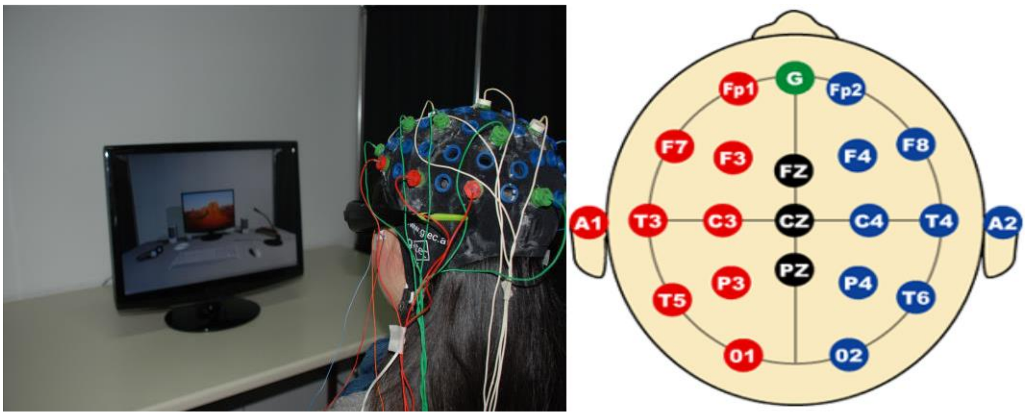

Figure 2. Left: A student observing the 3D environment. Right: Electrodes' position for EEG recordings (10-20 layout)

The EEG recording took place in three stages. Firstly, the participant was familiarized with the virtual environment wearing the 3D glasses and observing a 3D environment different than the one under study. After that, the participant closed her eyes and stayed relaxed for two minutes. When she opened her eyes, the VE under study was displayed. The participant was asked to open and close her eyes in certain intervals in order to minimize the artefacts during the EEG recording. The process included 10 repetitions of EEG recordings. After the completion of this stage, the participant closed her eyes; the glasses were taken away and stayed relaxed for few minutes. The same procedure took place for the real and the 2D environments respectively.

Experimental Setup

EEG was recorded using a g.tec 36 channel amplifier with 256Hz sampling rate. The digital EEG data acquisition system had a 1 – 48Hz band pass filter. EEG activity was monitored from 19 Ag/AgCl electrodes using an electrode cap with a standard 10-20 International Electrode Placement System layout. Raw EEG data was recorded from Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3 Pz, P4, T6, O1, and O2 (Figure 2). All leads were referenced to linked ear lobe and a ground electrode was applied to the forehead. Horizontal and vertical eye movements were recorded simultaneously using four electrodes round the eyes. The electrodes impedance was kept below 5KΩ.

After removing eye movement and other artefacts, single trials were averaged per environment and subject. Moreover, the grand mean for each environment across all subjects was calculated. A Fast Fourier Transform was applied to the raw EEG data. Theta (θ, 4–7Hz), lower alpha (α-1, 8–10Hz), upper alpha (α-2, 11–12Hz), total alpha (α, 8–12Hz), beta (β, 13–32Hz) and gamma (γ, 33–48Hz) frequency bands were studied. The processing and analysis of the signals were performed by using the gBSanalyze and Matlab software packages. The signal comparisons between the three environments and their representations on the scalp were performed by using the EEGproccessing application, developed in our lab.

Results

After the observation of the environments, all subjects reported the perception of depth while viewing the stereoscopic, clearly distinguishing it by the 2D environment. For comparison reasons, the results are presented in pairs of environments. The power values (μV^2) of the EEG signals in each pair of brain maps are normalised, so that same colours represent same values in both environments. Warm colours such as brown and red correspond to high power values, while cool colours such as blue and green correspond to low power values.

Real and 2D Virtual Environment

Figure 3 shows the brain maps for the real and 2D virtual environments for each one of the frequency bands under study. Theta activity appeared in both environments, but in different cerebral areas. In the real environment, theta was diffused almost in the whole scalp, while it was mostly located in the temporal and occipital lobes in the 2D environment. The strong theta signals in the occipital lobes corroborate the visuospatial processes. The statistically significant higher power at the frontal area (Fp1, Fp2) in the real environment (Table 1) shows that this required a greater attention as far as it regards the visuospatial component of the task (Hinterberger et al., 2008). The prefrontal and frontal activation of the midline for the real environment reveals the processing of complex sensorial stimuli (Basar et al., 1999), voluntary attention (Lazarev, 1998), vigilance (Caldwell, Prazinko & Caldwell, 2003), and memory operations (Bastiaansen & Haggort, 2003). The temporal activity in both environments indicates attention processing (Aftanas & Golocheikine, 2001), retrieval of information from long-term memory (Gruber et al., 2008), and spatial learning (Caplan et al., 2003).

Alpha activity was strong and diffused in the scalp and had the same topology in both environments. This reveals that participants experienced similar and non-demanding tasks without certain memory requirements or information encoding. The stronger signals in the occipital lobes for the real environment show less mental effort and attentional demands (Klimesch, 1999; Donner et al., 2007). The topology as well as the power of the lower and upper alpha bands is similar. These strong signals in the upper alpha frequencies might be an indication of similar semantic information processing and in particular of "searching, accessing, and retrieving information from long-term memory" (Antonenko, Paas, Grabner & Gog, 2010).

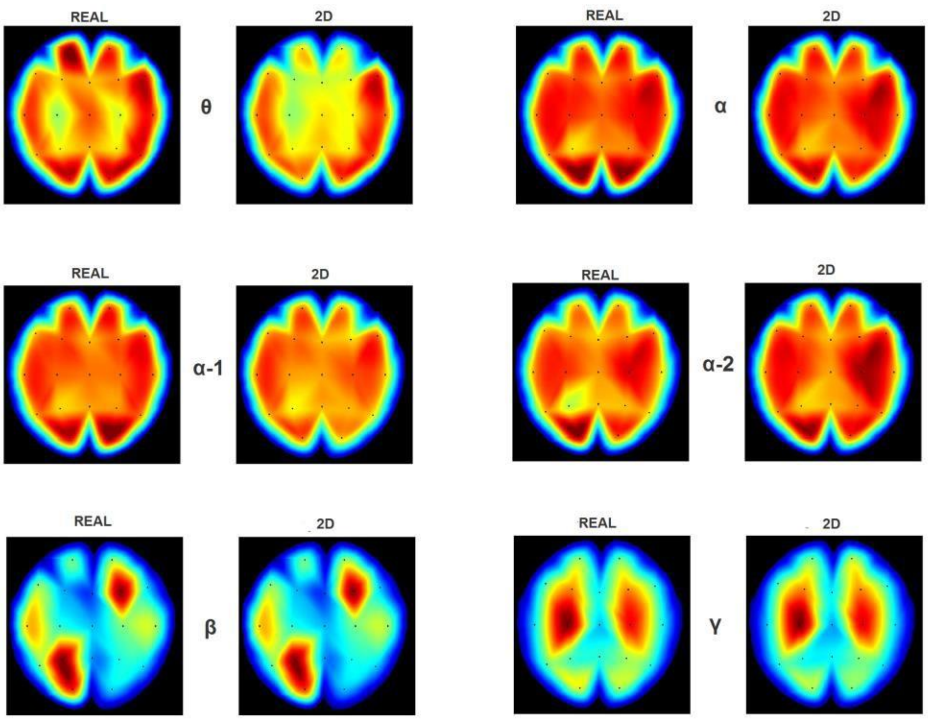

Figure 3. Power and spectral distribution for the real and 2D environments

Table 1. Statistically significant power differences for the real and 2D environments (significance threshold: .05)

Rhythm	REAL higher	2D higher
Theta (θ) (4-7 Hz)	Pre-frontal (Fp1, Fp2) Left Frontal (F3) Left Central (C3) Left Occipital (O1)	No statistically significant differences
Lower α, (α-1) (8-10Hz)	Right Occipital (O2)	No statistically significant differences
Upper α,(α-2) (11-12 Hz)	No statistically significant differences	No statistically significant differences
Alpha (α) (7.5-12.5 Hz)	Right Occipital (O2)	No statistically significant differences
Beta (β) (13-32 Hz)	Left Frontal (F7) Middle Frontal (Fz) Right Central (C4) Right Temporal (T6) Left Occipital (O1)	Right Pre-Frontal (Fp2) Left Frontal (F3) Right Frontal (F4)
Gamma (γ) (33-48 Hz)	Right Frontal (F4) Left Central (C3) Left Temporal (T5) Parietal (P3-Pz-P4)	Right Pre-Frontal (Fp2) Right Central (C4)

Beta activity was mainly located in the right frontal area in both environments. This is an indication of attention allocation and visual search (Buschman & Miller, 2009). Especially, the significantly higher value for the 2D environment shows a higher level of anxiety that might be an indication that the participants were waiting for "something to happen", something like the search for the third dimension.

Gamma activity was similar in both environments and reflects an active information processing. Gamma activity was statistically higher in many scalp areas for the real environment, showing that the 2D environment required a greater visual and selective attention (Womelsdorf & Fries, 2006).

Real and 3D Stereoscopic Virtual Environments

Figure 4 shows the brain maps for the real and 3D stereoscopic virtual environment.

Theta activity had a similar topology in both environments. The statistically higher frontal signals (Table 2) in the real environment shows that the real environment required a greater attention (Antonenko et al., 2010), and had the same behaviour as described in the previous section. The lower theta activity in the virtual environment is also an indication that the participants placed less mental effort in it (Mikropoulos, 2001).

Alpha, lower alpha and upper alpha activity was strong and diffused in both environments with no significant differences. This is an indication that both environments did not require certain mental effort, but anticipation of visual data (Mathewson, Gratton, Fabian, Beck & Ro, 2009). The similar beta and gamma topology and power with non-significant differences, except only three points (Table 2), shows that both the real and 3D environments required similar attention. The statistically significant higher power at the left occipital area for the 3D virtual environment is probably connected with the stereoscopy of the 3D presentation (Tallon-Baudry, 2004).

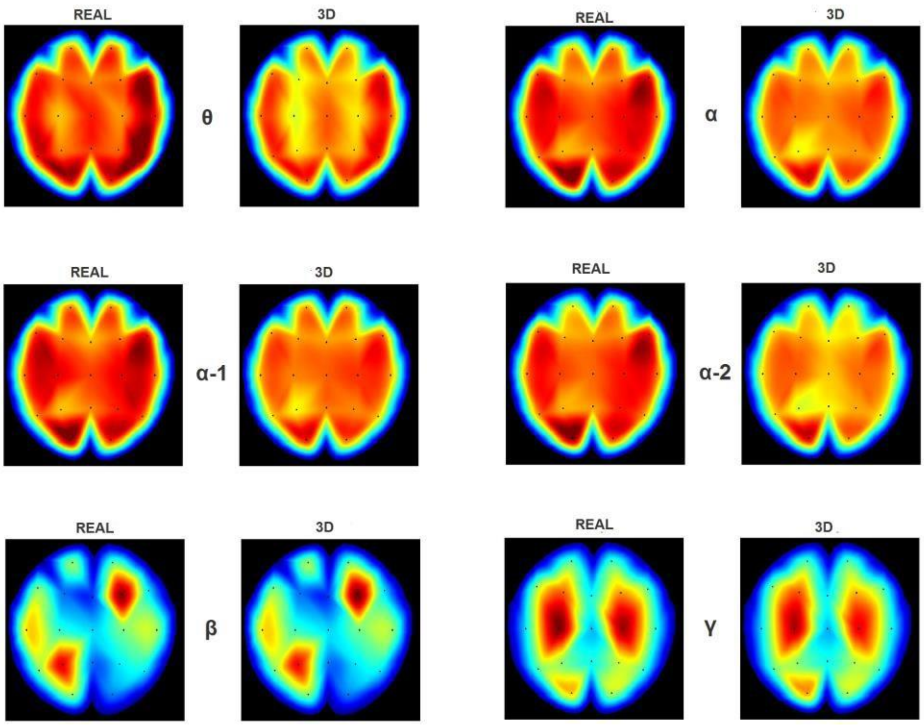

Figure 4. Power and spectral distribution for the real and 3D environment

Table 2. Statistically significant power differences for the real and 3D environments (significance threshold: .05)

Rhythm	REAL Higher	3D Higher
Theta (θ) (4-7 Hz)	Left Frontal (F3) Right Frontal (F4)	No statistically significant differences
Lower α (8-10Hz)	No statistically significant differences	No statistically significant differences
Upper α (11-12 Hz)	No statistically significant differences	No statistically significant differences
Alpha (α) (7.5-12.5 Hz)	No statistically significant differences	No statistically significant differences
Beta (β) (13-32 Hz)	Left Occipital (O1)	No statistically significant differences
Gamma (γ) (33-48 Hz)	Left Frontal (F7)	Left Occipital (O1)

3D Stereoscopic and 2D Virtual Environments

Figure 5 shows the brain maps for the 3D and 2D virtual environments. Theta activity was diffused over the scalp in the 3D environment, while it was located in lateral and occipital lobes in the 2D environment. This shows that there is an increase of attention for the 3D environment. The frontal activation of the midline for the 3D environment is similar to that of the real environment (Figure 3), indicating the processing of complex sensorial stimuli, voluntary attention, vigilance, and memory operations, processes that did not seem to predominate in the 2D environment. The statistically significant high power values in the frontal and occipital lobes (Table 3) shows an increase of visuospatial information processing for the 3D environment compared to the 2D (Sarnthein, Petsche, Rappelsberger, Shaw & Von Stein, 1998).

Alpha activity had a similar behaviour, but gave stronger signals in the occipital lobe in the 3D environment (Table 3). This is an indication that participant showed increased target detectability and thus experienced a more realistic environment in 3D (Mathewson et al., 2009). The same holds for the higher lower alpha power at O2. The upper alpha band had no differences, indicating that the environments did not demand semantic coding of the visual information (Klimesch, 1999). The stronger beta prefrontal activity in 2D shows an increase of anxiety indicating the "search" for the third dimension in the 2D environment, as showed in the comparison between the real and 2D environments.

Gamma activity had a similar topology in both environments. The stronger 3D signals in many scalp areas (Table 3) show that the 2D environment required a greater selective attention than the 3D (Womelsdorf & Fries, 2006). The statistically significant higher power at the right occipital area in the 3D virtual environment in comparison to the 2D is probably connected with stereoscopy (Tallon-Baudry, 2004).

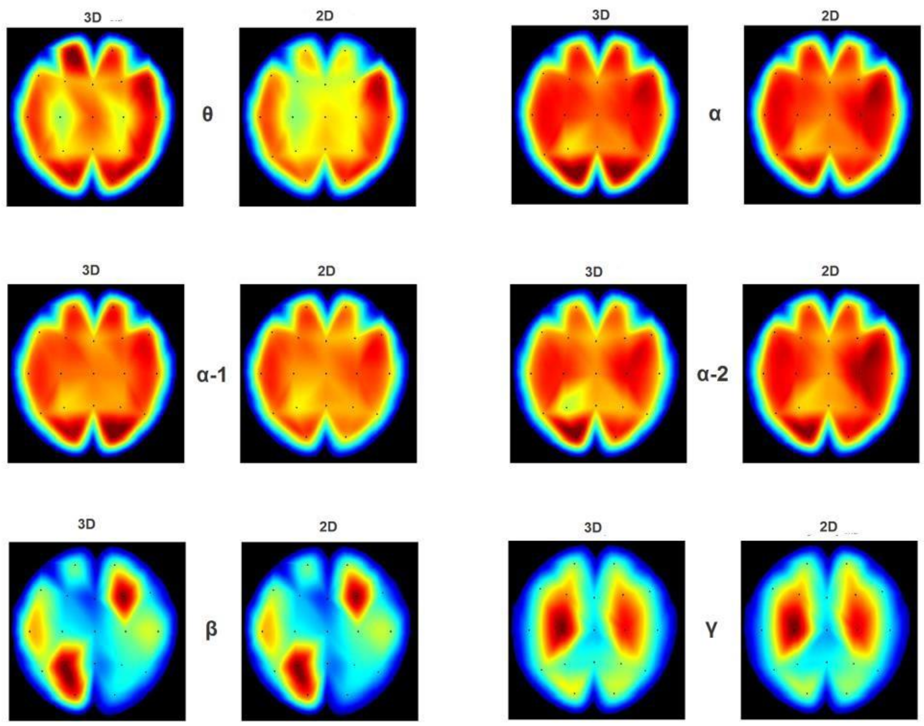

Figure 5. Power and spectral distribution for the 3D and 2D environments

Table 3. Statistically significant power differences for the 3D and 2D environments (significance threshold: .05)

Rhythm	3D Higher	2D Higher
Theta (θ) (4-7 Hz)	Pre-frontal (Fp1, Fp2) Left Frontal (F3) Left Central (C3)) Left Occipital (O1)	No statistically significant differences
Lower α (8-10Hz)	Right Occipital (O2)	No statistically significant differences
Upper α (11-12 Hz)	No statistically significant differences	No statistically significant differences
Alpha (α) (7.5-12.5 Hz)	Right Occipital (O2)	No statistically significant differences
Beta (β) (13-32 Hz)	Left Frontal (F7) Middle Frontal (Fz) Right Central (C4) Right Temporal (T6) Left Occipital (O1)	Right Pre-Frontal (Fp2) Left Frontal (F3) Right Frontal (F4)
Gamma (γ) (33-48 Hz)	Right Frontal (F4) Left Central (C3) Left Temporal (T5) Parietal (P3-Pz-P4) Right Occipital (O2)	Right Pre-Frontal (Fp2) Right Central (C4)

Conclusions

This work presents comparative data on the effects of stereoscopy in three versions of a static environment; a real, a two dimensional and a stereoscopic three dimensional virtual environments. Stereoscopy is related with mental processes, and the methodology used was the measurement of electric brain activity through digital electroencephalography. Although the creation of general prototypes for brain activity is extremely difficult since the brain physiology of cognitive processes is still in its infancy, this study gives significant evidence as far as it concerns brain function in virtual environments.

Our results showed that the topology of women's cerebral activity is the same in the three environments under study. This is rather expectable, since all three environments were of the same content. The participants experienced three similar and non-demanding environments without specific memory requirements and information encoding. This was justified by the similar behaviour of alpha activity (8-12Hz) as well as the alpha suppression or desynchronization recorded in the three environments. Although the topology of brain rhythms is the same in the three environments, statistically significant differences arose among the environments in many lobes. In all three environments, a processing of visual stimuli was recorded.

Theta power signals (4-7Hz) were higher in the real environment, followed by the 3D stereoscopic and 2D environments in descending order. These, together with the prominent theta activity in frontal and frontal midline locations indicate the information processing occurred (Antonenko et al., 2010). Cerebral activity was similar for the real and 3D environments, indicating that the 3D stereoscopic environment caused similar cognitive and visuospatial processes as the real one (Sarnthein et al., 1998). As far as memory concerns, our results are in accordance with those of Bennet, Coxon, and Mania who have revealed better memory of objects when the virtual space was viewed in stereo (2010). In the contrary, the 2D environment caused an increase of anxiety. It seems that participants were looking for the third "missing" dimension in the 2D environment.

Beta activity (13-32Hz) was similar in the real and 3D environments showing that these two were familiar to the participants. Beta activity in the 2D environment was statistically stronger mainly in the frontal lobe, showing that this environment was not as familiar as the other two environments (Macaulay & Edmonds, 2004).

Similar to beta was the gamma activity (33-48Hz), which is responsible for the perception and processing of static objects (Tallon et al., 1995) and stereoscopic vision (Revonsuo et al., 1997). Our findings reveal that the participants perceived the third dimension in the stereoscopic virtual environment, something that did not happen with the 2D virtual environment.

In general, our results show that electric brain activity is similar in real and stereoscopic virtual environments and different than in non-stereoscopic 2D virtual environments. As expected, the real (stereoscopic) environment caused less mental effort than the other two virtual ones. Comparing the 3D stereoscopic to the 2D virtual environment, the 3D caused less mental effort, possibly because of the existence of stereoscopy, as projected through the 3D glasses.

Our results allow us to propose the design, development and exploitation of stereoscopic 3D virtual environments especially for educational purposes. Three dimensional educational virtual environments seem to approximate the real ones as far as it regards the cognitive processes they cause. Three dimensional environments increase users' attention over the 2D and cause less mental effort and anxiety than the 2D virtual environments.

Our study is a first step towards educational neuroscience that aims at the design of teaching interventions for positive learning outcomes through EVEs. Although brain imaging cannot lead directly to educational scenarios, "there is a need for bridging studies that interpret scientific results in terms of possible interventions, and evaluation of these interventions in suitable learning contexts" (Howard-Jones, 2007). A study on gender differences in brain activity is in progress, investigating the need for different design for educational virtual environments, as other studies have proposed (Ross, Skelton & Mueller, 2006).

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