The Meaning of Being There is Related to a Specific Activation in the Brain Located in the Parahypocampus

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Abstract

Recent studies report that presence depends on immersive properties and how an individual interprets the virtual environment based on his or her individual cognitive predisposition. No studies have yet looked at the areas of the brain specifically associated with presence. The aim of this pilot study is therefore to investigate the neural correlates of the illusion of presence in VR. Five right-handed adults were scanned in the fMRI and were immersed in two conditions: high and low presence, where the exact same stimulus was presented to participants during each condition but the context (narrative) provided differed significantly. Results show that presence differed by 7 points between the high and low presence conditions and showed a clear and significant involvement of the parahippocampal area, the brain area responsible to give contextual meaning of places.

Keywords--- **Presence, fMRI, parahypocampus, virtual reality**

1. Introduction

Being immersed in virtual reality (VR) can create the subjective impression of being "there" in the virtual environment (VE) [1,2]. The illusion of presence requires processing multimodal input (visual, auditory, tactile, kinaesthetic or olfactory) from the VE be combined to form coherent perceptions so the VE be recognized as "real", and integration of these multimodal stimuli into some egocentric reference frame so the user feels that he or she is within the environment.

Most relevant to this study are the recent reports that presence depends not only on immersive properties of the VE but also on how an individual interprets the VE based on his or her individual cognitive predisposition [2,3]. A study conducted in our lab studied presence using a virtual environment designed to treat specific phobias (musophobia) with VR. Participants in both conditions were immersed in the same VE containing a rodent, yet in one condition they were deceived and led to believe that they were actually being immersed in real time in the physical room with the rodent. The deception used a blend of mixed videoconference-VR technologies, display of high-tech hardware relaying the videoconference and the VR computers, and false instructions stating that they were "currently live in the real room" or that they were "seeing a fake 3D copy of a room". Presence was significantly higher when participants were told they were seeing the "real" room that was being projected in the HMD in real time [4]. This study opens up the possibility of manipulating presence without changing any objective properties of the VE. It enables studying neural correlates of presence by manipulating presence during functional brain imaging without creating artifacts inherent to modifications of the stimuli (i.e., comparing immersions with / without sound, or in mono / stereoscopy would predictably stimulate different brain areas).

Magnetic resonance imaging (MRI) is an imaging technique that allows measuring structure, function, connectivity and chemistry in any part of the body. It is based on the absorption and emission of energy in the radio frequency range of the electromagnetic spectrum. The human body is mostly made of fat and water – the body tissues that have many hydrogen atoms. The hydrogen nuclei form the basis for the signal in the MRI. In a magnetic field, as the MRI scanner, the magnetic orientation of each hydrogen atom is aligned to the magnetic field and spins around this orientation. If a brief electromagnetic magnetic (radiofrequency) pulse is applied, it temporarily distorts alignment to the magnetic field. When the radiofrequency pulse ends, the atoms start to realign in the magnetic field, a process called relaxation. It is during this phase that the atom loses energy by emitting its own energy, providing information about the environment. Blood oxygen level dependent (BOLD) functional Magnetic Resonance Imaging (fMRI) is the most used and well known way to assess brain activation with MRI. Brain activation changes the relative concentration of oxygenated and deoxygenated hemoglobin in the local blood supply. While oxygenated blood is diamagnetic and does not change the MRI signal, deoxygenated blood is paramagnetic and leads to a drop in the MRI signal. If there is more deoxygenated blood in a region it therefore leads to a drop in the BOLD signal and more oxygenated blood in a region leads to a higher signal.

In sum, fMRI allows observing which areas of the brain are more activated when contrasting the state of the brain from a controlled condition to an experimental condition.

Several researchers have measured brain activation using fMRI when people were immersed in VR. Although presence is mentioned is some studies, each study published so far have been conducted to measure brain areas associated with the tasks performed in VR (e.g., see Astur et al. [5]) or the impact of immersion on psychological states [6] . No studies have yet looked at the areas of the brain specifically associated with presence.

The aim of this pilot study is therefore to investigate the neural correlates of the illusion of presence in VR.

2. Method

This study was conducted in two sessions. During the first session held in our lab, five adults (all right-handed, three females, two males, mean age of 33) provided their informed consent and were submitted to a standardized psychiatric assessment to ensure qualification for study participation based on several selection and exclusion criteria. The psychiatric health of participants was assessed with the Structured Clinical Interview for DSM-IV-Non-Patient Edition (SCID-NP) [7] to exclude participants who would suffer from a mental disorder. Subjects also complete the Edinburgh Handedness Inventory, the Immersive Tendencies Questionnaire and a Medical questionnaire.

At the following visit, at the fMRI clinic, participants first visited a staff room adjacent to the scanner room and were informed that during their brain scan they would at times see a live video-feed from this room (high presence condition) or a good 3D copy of the room (low presence condition). Participants were scanned in the fMRI using a 1.5 T Siemens Magnetom Symphony System scanner (Siemens AG, Erlangen, Germany) at St. Joseph MRI in Gatineau, Quebec. Diagnostic (FLARE), structural (T1), functional (BOLD) and anatomical connectivity (DTI) scans were acquired during the 35 minute scanning session. A preliminary rapid sagittal T1-weighted scan was used as a localizer to verify participant head position and image quality. A low angle recalled echo (FLARE) sequence was acquired in the axial plane to produce images suitable for review by a radiologist to rule out clinically significant abnormalities, hydrocephalus or intra-cranial masses. For the experimental scan, a three-dimensional gradient echo acquisition was used to collect 160 contiguous, 1 mm T1 weighted structural images in the sagittal plane for corregistration with the Echoplanar images (EPI). Structural images were acquired using the modified International Consortium for Brain Mapping (ICBM) T1 Protocol with the following parameters: repetition time [TR] = 22 ms; echo time [TE] = 9.2 ms; Bandwidth = 70 Hz/Px; field of view [FoV] = 256 mm; Flip angle = 30°. Blood oxygen level dependent (BOLD) signals were obtained using 32 contiguous, 4 mm axial slices, positioned parallel to the hippocampus and covering the entire brain (64 by 64 matrix; TR = 3000 ms; delay in TR = 219 ms; TE = 50 ms, FoV = 256 mm, Flip angle = 90°). The HMD was a MRI-compatible VR system (Silent VisionTM Model SV-7021 Fibre Optic Visual System with In Control Software, Avotec, Inc.) allowing to project the virtual environment to participants while were inside the scanner. A set of noise cancellation headphone were used to reduce the loud noise caused by the scan. The atlas chosen to localize brain areas of significant activation was the Wake Forest University PickAtlas version 2.3.

2.1. Experimental manipulation

For the high and low presence conditions, the exact same stimulus was presented to participants during each condition. However, the context (narrative) provided to the participants differed significantly (see details in the following paragraph). In the high presence condition, participants were informed via instruction provided in the HMD that the image were coming directly from the adjacent staff room, “relayed in real time from the real staff room”. In the low presence condition, they were informed via instruction provided in the HMD that the images were copies of the adjacent staff room. The paradigm we used was a repeated measures condition where each participant saw the “real staff room”, then the “copy of the staff room”, followed again by the “real” and the “copy” of the staff room. During each immersion, participants observed as the camera flew over the virtual environment and were asked to look at the details of the VE.

When participants arrived at the fMRI clinic, events unfold as followed: (a) they were met by a licensed MRI technologist for routine information about the scan to come and a confirmation that did not had any metal on them; (b) they disrobed in a private room; (c) they met our research assistant who provided a visit of our experimental set-up in the staff room (see Figure 1) and explained that “We want to know which areas of the brain are involved in the experience of virtual reality by using a high tech device that will take images of your brain in action. For the very first time, we were able to create a system that allows projecting, in real time, images taken from this adjacent staff room and project it directly, live, in the fMRI scanner.

Figure 1 View of the staff room

You will therefore be able to see this room, as you are just doing now, but seeing through the eyes of virtual reality. Our cameras (see Figure 2) will record images in real time as they move in the room, send them to our computers and our virtual reality software; they will recreate the virtual reality and send it directly into the scanner.

The cameras will move along a predetermined path so you won't have anything to do but letting yourself be immersed in the virtual environment and looking around. We also built a copy of this staff room. After having the unique chance of being immersed in the real staff room, we will also show you a copy of the staff room. The experience will be repeated twice, so you will again see the real room and the copy of the room. "; (d) they were placed in the fMRI scanner by the MRI technologist (see Figure 3), the HMD was adjusted for clear vision and a first 20 minutes scan (FLARE, described above) was performed to ensure participants had no brain abnormalities; (e) the instructions were projected in the HMD once more "In this unique experience, you will visit the real staff room, then a copy.

Figure 2 The mock-up VR-generating device

This will be repeated twice. Let go, observe these virtual environments and we will talk about it after the scan"; (f) a message appeared in the HMD indicating "Live staff room. Let go of yourself and take the time to observe the virtual environment"; (g) the immersion in the VR environment began, for 60 seconds; (h) a message appeared in the HMD indicating "Copy of staff room. Let go of yourself and take the time to observe the virtual environment"; (i) the immersion in the VR environment began, for 60 seconds, with the exact same environment as in "g"; (k) steps "f" to "i" were repeated once; (l) participants stepped out of the scanner and were debriefed.

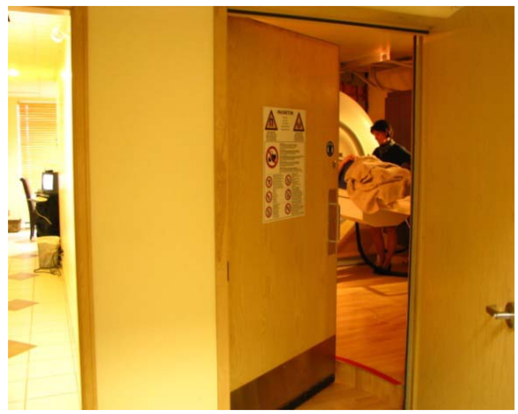

Figure 3 View of adjacent staff room and patient in the fMRI scanner

2.2. Questionnaires

Among the measures administered, let's mention three that were used for participant's selection. The Edinburgh Handedness Inventory [8] is a 10-item questionnaire used to determine the participant's handedness and determine the "dominant" hemisphere of the brain. The Medical Questionnaire confirmed the participant's ability to undergo fMRI scanning using questions about past injuries and surgeries, as well as metal implants that may warrant exclusion from the study. The Structured Clinical Interview for DSM-IV-Non-Patient Edition. (SCID-NP) [7] was used to ensure that no current or past history of Axis I psychiatric disorders could bias the results. Presence felt during the last 60 seconds was assessed after each immersion with a one-item question rated on a 0 to 100 scale.

2.3. Results

Presence differed by 7 points between the high and low presence conditions. The fMRI data were subjected to a within subject analysis to verify differences between the experimental immersion (high presence) and the control immersion (low presence). Interesting, the results were strong, simple and unequivocal. Significant differences were found in only one structure, located in the medial temporal lobes. Both the right and left parahippocampus (uncorrected, $p < 0.001$) were significantly activated by the experimental manipulation. Significant cluster of voxels in the right parahippocampal gyrus (MNI 28 -4 -36) cluster size KE= 5 cluster was activated, as well as a significant cluster in the left parahippocampal gyrus (MNI -28 -16 -24) cluster size KE = 5 cluster.

Conclusion

Despite the small sample size, clear and significant results were obtained in one specific region, the parahippocampal cortex. For several years, the parahippocampal cortex was dubbed as the “place area” to describe the growing body of knowledge suggesting that is was not related to recognition and retrieval of information related to places, but to the current perception of places [9]. During those years, there as a debate among researchers to decide whether the parahippocampal cortex was related to episodic memory or to place-, scene, and navigation-related processing. In 2008, Bar, Aminoff and Schacter [10] published results that reconciled both positions and showed that this area of the brain mediates the representation and processing of contextual associations. The parahippocampus provides contextual meaning of scenes and places. Our results follow this recent finding and suggest that contextual processing is involved in feeling where events are happening in a virtual environment, or where the person is during the immersion in virtual reality. We propose that activation of the parahippocampus is associated with presence, and more specifically with the *there* portion of the definition, that is the contextual meaning of the experience felt when being immersed in VR.

Current research projects in our lab are suggesting that presence is essentially a perceptual illusion based on the integration of sensory information. We should therefore distinguish several components of presence, and each of them involves different brain areas. When stimuli are presented during an immersion, presence would be incrementally influenced by: (a) automatic factors involving basic perceptual processes, cognitions and emotions, (b) more reflexive factors associated with consciousness and involving meaning given to event, location and ownership of actions, (c) self-reflexive thinking about the events, and (d) cognitive dissonance caused by a strong but imperfect illusion, leading to the “wow reaction” that many people experience when they feel present in a VE. As the immersion becomes more sophisticated and confounds the integration of multisensory information, the illusion of presence emerges.

There are a number of functional imaging studies which focus on neural correlates of vaguely perceptible or barely conscious stimuli and on self-referential processing. For much of the 20th century, conscious and unconscious processes in the brain were avoided by scientists. In the last 15 years, in part because of advances in brain imaging technology such as fMRI, numerous models of conscious processing have been proposed (see Edelman et al. [11] for review). There is growing support that from an evolutionary perspective a key function of consciousness is to produce the best current interpretation of a visual scene in a compact form and to make this information available to regions of the brain involved in planning and executing a response [12]. Based on the various models of conscious processing proposed, a wide range of methods have been devised for studying conscious and unconscious processes in the brain and previously avoided topics likely related to the illusion of presence, such as conscious experience, unconscious processes, mental imagery voluntary control and even the self are now anchored in plausible brain correlates. To date, most neurophysiological studies of conscious processing have been done in the visual system – the sensory system most activated by VR. In a seminal paper, Crick and Koch (1995) extrapolated from results from single-cell studies in the visual cortex of primates during the presentation of visual stimuli and proposed that visual awareness was not encoded in the visual portion of the occipital lobe or the lateral geniculate nucleus, the thalamic visual relay point, but in frontal regions. Since then, many neuroimaging methods such as electroencephalography (EEG) [13] and magnetoencephalography [14], positron emission tomography (PET) [15] and fMRI [16] have been used to confirm that the neural correlates of conscious awareness, in humans involves a wide network of frontal regions mainly frontal, parietal, temporal association cortex and basal ganglia [16,17] While many studies demonstrate widespread cortical area involvement in consciousness processing, other studies have shown varying degrees of activation within unique parts of the network during varying degrees of awareness. The lateral surface of the occipital lobe is known to have general role in object recognition [18], while other areas, such as the fusiform gyrus and the adjacent parahippocampal gyrus, brain region in the ventral temporal cortex, have recently generated much interest as studies emerge showing that these regions are most activated during face (fusiform face area) [19] or object recognition (parahippocampal place area) [20]. We propose that activation in these brain regions contribute, to some extent, to the illusion of presence as VE sensory input is categorized into recognizable object categories

More recent studies have shown select brain activation when participants become aware of visual stimuli. Using fMRI, Christensen et al. [21] correlated neural activity to subjective reports of visual stimuli and found greater activation in frontal and insular regions during the vague perception of visual stimuli. A recent EEG study showed a decrease in activation in portion of the fusiform gyrus when visual stimuli did not reach awareness [22]. Psychophysical studies have shown that the illusion of presence decreases when VR users become aware of a discrepancy between the VE and the physical reality. This awareness of discrepancy may involve activation in brain regions involved in object recognition, lateral surface of the occipital lobe along with the fusiform gyrus and adjacent insula cortex.

Another line of investigation also pertinent to the illusion of presence examines self referential processing – that is those studies comparing neural correlates during processing of stimuli related to the self with those of non-self-referential stimuli. In a recent meta-analysis of imaging studies, Northoff et al. [23] conclude that activation in midline cortical structures underlie processing of stimuli related to the self. Regardless of the nature of the self referential stimuli (verbal, spatial, emotional or facial) activation occurred in both ventral medial and dorsal medial regions of prefrontal cortex. This region is well suited to integrate the multimodal sensory input required for self referential processing because of extensive afferent and efferent connections to frontal regions, for integrating multi-sensory input, and subcortical regions (insula, brain stem regions like the hypothalamus), for the integrating proprioceptive and visceral input. Theoretically, the illusion of presence would be optimal if VR multimodal sensory input and the user's own proprioceptive and visceral input were congruent. In fact, presence is attenuated by the discrepancy between what the user is seeing and the input from his or her joint receptors and viscera. In a recent fMRI study, the neural correlates of a first-person perspective were compared to a third person perspective. Using VR, participants interacted with an avatar, a VR generated figure, in either a first person or third person perspective that is they were asked to solve a visuospatial task from either their own perspective or another person's, the avatar. There results showed both common and differential neural correlates for perspective taking from either someone else's viewpoint or one's own viewpoint. Common areas activated were in parietal regions which they hypothesize are involved in general perspective taking while medial cortical regions and superior temporal sites were more activated when participants took a first person perspective [24]. Another study using VR to compare first-person and third-person perspective during a virtual ball-tossing game also showed greater medial prefrontal region activation during first-person perspective taking [25].

In summary, the neural correlates of presence remain unknown or poorly integrated. However, earlier functional imaging studies of conscious processing of visual stimuli and first versus third person perspective processing suggest that activation in widespread cortical areas along with more specific activation in areas such as ventral temporal areas, fusiform gyrus, the insula and cortical midline structures may contribute to the neural basis of presence. But until now, the geospatial location of the participant in the physical versus the virtual space eluded us. By being able to manipulate presence without changing the objective properties of the stimuli, we were able to influence presence without stimulating other areas ob the brain mentioned in the above three paragraphs. It allowed showing a clear and significant involvement of the parahippocampal area, the brain area responsible to give contextual meaning of places.

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