From Presence Towards Consciousness

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Abstract

Immersive virtual environments can break the deep everyday connection between where our senses tell us that we are and where we actually are located and whom we are with. 'Presence research' studies the phenomenon of acting and feeling that we are in the world created by computer displays. We argue that presence is a phenomenon worthy of study by neuroscientists and may help towards the study of consciousness, since it may be regarded as consciousness within a restricted domain.

Suppose that you are in a place that you know to be fictitious. It is not a 'place' at all in any physical sense, but an illusion created by a virtual reality system. You know that there is no place, and you know that the events you see, hear and feel that are happening there are not really events in the every day physical meaning of that word. You are conscious of that 'place' and those 'events', and simultaneously conscious of that the fact that there is no place and there are no events. Yet, you find yourself thinking, feeling and behaving as if that place were real, and as if those events were happening. For example, you see a deep precipice in front of you that you know is not really there in a physical sense. Your heart races and you are frightened enough by what you see to be very reluctant to move yourself closer to the edge. From a cognitive point of view you know that there is nothing there, but both unconsciously (e.g., heart rate) and consciously (your awareness of your own fear) you respond as if there is something there. How is this possible? This paradox, observed daily in virtual reality laboratories around the world, is at the root of the concept of 'presence' studied by virtual reality specialists, and also relates to many of the concepts studied by neuroscientists ranging from perception through to the consciousness.

Immersive Virtual Environments

In 1980 Marvin Minsky introduced the concept of telepresence to describe the feeling that a human operator may have while interacting via a teleoperator system [1]. The human operator sees through the eyes of the remote machine, and uses his or her own limbs to manipulate its effectors. A sense of being at the distant place may develop, with the body of the machine 'becoming' the body of the human. This experience of telepresence was thought to be conducive to effective task performance of the operator in the remote environment. The concept of telepresence has also been applied to experiences within virtual environments. In this case the person is immersed within an environment that is realised through computer controlled display systems, and may be able to effect changes in that virtual environment. A feeling of being present may develop in the same way that Minsky noted for physical teleoperator systems.

A rigorous discussion of the concept of a 'virtual environment' has defined virtualisation as "the process by which a human viewer interprets a patterned sensory impression to be an extended object in an environment other than that in which it physically exists"[2] (see Box 1). A virtual environment (VE) should incorporate the participant as part of the environment, so that head motions result in motion parallax from the participant's viewpoint, and a number of physiological and vestibular responses associated with focusing and object tracking are stimulated.

Clearly there are many parameters that control the quality of the experience that a person may have in such a system. The visual display, for example, may have greater or lesser *field-of-view* – the effective horizontal and vertical angles through which the world can be seen. A head-mounted display (HMD) system typically delivers a relatively low field of view. For example, 60 degrees diagonal – compared with the more than 180 degree horizontal and 120 degree vertical in normal vision. Second, the visual display may have more or less *resolution* – the number of pixels per unit projected visual area. For example one popular HMD model has pixel resolution of 640 by 480 on a 3.3cm diagonal liquid crystal display (per eye). The *frame-rate* achieved by the computer system is a critical factor in maintaining the illusion of there being 'extended objects' in an environment. The frame-rate is the number of frames a second that the computer graphics system can deliver. Although the display will always be refreshed at a constant cycle (e.g., 60Hz) the computer graphics rendering system may not always be able to maintain this speed of new image generation as a function of head movement and animation in the scene. If the scene is particularly complex in the direction of the current view then the computational load on the system may be so high that as the participant's head moves the rendering system cannot keep up with the changes fast enough. This would result in discontinuities in overall image motion – for example, an object that moves across the field of view of the participant may appear to jump suddenly from one location to another. Frame rate is one factor in overall system latency. The *latency* is the time between the participant initiating an event (such as a head turn) and the time that the system responds (the images update accordingly). There are many contributory factors to latency – such as the frame rate, the speed of the tracking devices, the communication speeds across the different devices including network speeds, and so on. Note that frame rate can be very high but latency very low (for example, because of communication bottlenecks) and this would result in smooth motion but always some milliseconds behind the initiating actions of the participant.

Typically the visual fidelity of a virtual environment display in comparison to physical reality is low. This is for several reasons. Today's computer graphics hardware cannot simulate the complexity of global light transport without substantially sacrificing real-time performance. Second, the physical world is exceedingly complex, with infinite layer of detail: imagine rendering a human face, with full subtlety of expression, all the micro-muscle movements that go into the making of a facial expression, the physical dynamics of hair, skin, muscle movements and so on. Of course computer graphics has to rely on abstractions and models that are far removed from physical reality, and most especially if real-time display and interaction is necessary.

Although we have concentrated here on the visual aspects of virtual environments the same may be said of the generation of sound and haptics (comprising touch and force feedback). Although the technology for producing highly convincing auditory output is advanced [3] generating this on the fly in real-time in a dynamically changing situation is not possible. Haptics is possible within a limited domain of application. There are typically two major approaches. The first is to limit haptics to the end-effector of an instrument which is manipulated by the human user [4,5]. Users can feel as if they are touching objects with the tip of the instrument as they move it around, with its virtual representation within the VE. As this virtual representation collides or makes friction with virtual objects, the user is able to feel this, and it can be extremely convincing. Another approach is to fit the human user partially within the frame of an exoskeleton, which is mechanically controlled to impart forces on the user according to how the user interacts with objects within the VE[6]. For example the sensation of the weight of an object can be imparted to the user in this way.

All the factors that we have been analysing define what is called *immersion*, a term that refers to what the overall VE system can deliver: the extent of field of view, the number of sensory systems it simulates, the quality of rendering in each, the extent of tracking, the realism of the displayed images, the frame-rate, latency, and so on. Of particular importance is the degree to which simulated sensory data matches proprioception – for example, as the participant's head turns how fast and how accurately does the system portray the visual and auditory effects of this. Or in a system such as a head-mounted display where all real-world visual input is removed, the extent to which the participant sees a virtual body that correctly correlates with the proprioceptive model of the feeling of the actions of that body.

The degree of immersion is therefore an objective property of a system that in principle can be measured independently of the human experience that it engenders. Presence, however, is the human response to the system, and there are many ways in which the meaning of presence have been formulated.

The Concept of Presence

If immersive virtual environment systems were able to deliver the perfect illusion of being and acting in a virtual world then probably the issue of 'presence' would never have arisen. It is important though because of the need to optimally allocate scarce computational, display and tracking resources within given economic and technical constraints. One way to do this would be to follow an application specific route and optimise resources based on task performance of users. For example, if a VE were used for the training of surgeons, then transfer of skills from the virtual to real world performance may be used to indicate the effectiveness of the VE. Presence though is more like a global currency, a concept that applies across applications, where generic knowledge about factors influencing presence can be applied in many different scenarios. But what is 'presence'?

There are several different approaches. According to one definition 'experiential presence' is 'a mental state in which a user feels physically present within the computer-mediated environment'[7]. This is a way of expressing the common view that presence is the sense of 'being there' in the virtual environment or similarly the sense of being in the place depicted by the virtual reality rather than in the real physical place where the participant's body is really located[8-12].

A fundamentally different view [13,14] is that presence is '... tantamount to successfully supported action in the environment.' It is argued that reality is formed through action, rather than through mental filters and that '...the reality of experience is defined relative to functionality, rather than to appearances'. What is important in this approach is action (how things are done) and the affordances offered in the virtual environment, rather than just appearances, and that the sense of 'being there' is grounded on the ability to 'do' there. These ideas have been expressed in other 'body centred' approaches where it is argued that it is essential for there to be a close match between kinesthetic proprioception and the stream of sensory data[15,16]: for example, if the participant is supposed to be moving through an environment by walking, then when visual flow indicates walking presence will be higher the more that the person's bodily movements correspond to real walking.

As discussed earlier a distinction is made between *immersion* and *presence* by many researchers[7,12]. Immersion is simply a description of overall fidelity in relation to physical reality provided by the display and interaction systems. In this view, presence research is essentially that of carrying out experiments that manipulate the variables that make up immersion, in order to build an equation with presence on the left hand side, and the factors of immersion on the right hand side. Individual psychological differences between people can be also included as variables on the right hand side[17,18]. This is a worth-while effort in the quest to produce a statistical model of how presence and immersion may be related, based on empirical data (for example [18-22]) but it does not enhance understanding of the processes involved.

Measuring Presence

A major challenge in presence research is how to measure presence at all. The normal approach is to use *questionnaires*. Participants carry out some task within a virtual environment, and then after their experience they answer a questionnaire. The questions have ordinal scales that anchor responses between two extremes – for example 1 meaning 'no presence' in the virtual environment and 7 meaning 'complete presence' (see Box 2 for examples) [23-25]. The earliest questionnaires were derived from observing and listening to subjects in debriefing interviews[26]. Some later questionnaires were derived by factor analytic studies from earlier ones[16,25,27-29].

Questionnaire based presence assessment methods have been shown to be unstable in the sense that prior information can change the results[30]. There is also evidence to suggest that typical questionnaires cannot discriminate between presence in a virtual environment and physical reality[31]. The use of questionnaires has been challenged through the observation that they cannot avoid a methodological circularity – that the very asking of questions about 'presence' may bring into being, post-hoc, the phenomenon that the questionnaire is supposed to be measuring[32].

A second method for measuring presence is *behavioural*. If participants within a virtual environment behave as if they were in an equivalent real environment then this is a sign of presence. Examples include the looming response[8], postural sway[33,34], after-effects[35] and the resolution of conflicting multi-sensory cues[21]. These behavioural measures typically require the introduction of features into the environment that would cause a bodily response (such as swaying in response to a moving visual field, or ducking in response to a flying object).

A particular specialisation of the behavioural approach is to use *physiological measures*, such as those derived from EKG recordings or galvanic skin response. The idea in this case is that if the normal response of a person within physical reality to a particular situation is known and they exhibit the same response within a virtual environment then this is a sign of presence. The use of physiological measures as surrogates for presence has been attempted – but have been limited to situations where the physiological response is obvious (e.g., such as a response to a feared situation) and the results have been positive[36]. The drawback here is that physiological responses to mundane situations such as being in a virtual room which has a table and some chairs are not obvious.

Another method for measurement of presence is based on the idea of eliciting moments in time when *breaks in presence* (BIPs) occur[37]. A BIP is any perceived phenomenon during the VE exposure that launches the participant into awareness of the real-world setting of the experience, and therefore 'breaks' their presence in the VE. Examples include gross events such as collisions with the equipment, through to more subtle effects such as revelations that come from seeing a tree as a pixel map rather than a solid object. We proposed a stochastic model that allowed the construction of a presence measure from knowledge of moments in time when participants reported such BIPs. This estimator was shown to be correlated with traditional questionnaire measures. This approach also provides an alternative strategy to the use of physiological measures. Rather than limiting the application of these to stress-inducing environments, it tries to find the physiological signature of a BIP, since there is evidence that breaks in presence are associated with physiological responses[38]. Because BIPs may occur in any environment, it provides a more general approach – in particular the environments do not need to be stressful.

Experimental Studies of Presence

What do we know about the factors that influence reported presence in virtual environments? There have been several factorial design experimental studies, the vast majority of which have examined the influence of various display and interaction styles – essentially following the traditional paradigm of experiments in psychology.

Display Parameters. Higher graphics frame-rate is positively correlated with reported presence. The critical minimal frame-rate appears to be around 15Hz[24]. A study exploiting changes in heart rate as a surrogate for presence when subjects looked over a virtual precipice usually referred to as the 'pit room' scenario (see Figure 4)[36] also found that 15Hz was the minimal critical value. In general, a lower latency between head movement and display update (see above) was found to be positively associated with increases in heart rate in response to the same stressful environment[39].

Other investigations have concentrated on the influence of head-tracking, stereopsis and geometric field of view[20,40-42]. The results suggested that these all were associated with higher reported presence.

Visual Realism. It is surprising that the evidence to date does not support the contention that visual realism is an important contributory factor to presence. Only one study has clearly found this in the context of a driving simulator application[43]. Although another study found that the display of dynamic shadows in an environment was associated with higher reported and behavioural presence compared to static or no shadows, this cannot directly be attributed to visual realism, but to the more convincing display of dynamics[21]. In other experiment a group of people carried out a task in a simplistic virtual simulation of a real laboratory delivered through a head-tracked HMD, and another group of people carried out the same task in the real laboratory. Two different presence questionnaires were administered to each group in randomised order after the experiment, and there was no significant difference in the mean reported presence between the two groups[31]. Another recent experiment that has directly tackled the issue of realism found no relationship with presence[44].

Sound. What difference does sound make to presence in VEs? Anecdotally people report that sound makes a very significant impact, but there have been few studies of this. One found that there was a significant effect of sound on reported presence, with spatialised sound associated with higher reported presence than either no sound or non-spatialised sound[45]. Another found that the use of person-specific head-related transfer functions (HRTFs) was significantly and positively associated with reported presence and illusory self-motion.[46]

Further evidence relating to the importance of the auditory modality for presence is found in studies of a sort of 'inverse presence' – what happens to people's 'presence' in physical reality when they experience a sudden and lasting loss of hearing. It appears that the impact on their sense of reality and their sense of being in the real world is profoundly altered[47,48]. Sometimes sound may be so important for presence that illusory auditory events may be perceived, as happened in a paranoia experiment (see Figure 6).

Haptics. There have been some studies on the influence of haptic feedback on presence. One study investigated the influence of haptics on co-presence,[49] the sense of being with another person together in a virtual environment[50]. The experiment was designed so that subjects located at remote sites without seeing or hearing each other could nevertheless feel the forces that each exerted on the hand of the other, by jointly moving a ring along a wire within a virtual environment. The results showed that for each subject, and independently of order of presentation, visual plus haptic feedback was associated with greater reported co-presence than visual feedback of the ring and wire alone[49]. A similar cross-Atlantic experiment was conducted where the haptic feedback was transmitted via the internet between MIT and UCL[51], [52].

Although general haptic feedback is today not attainable, it can be very cheaply simulated with so-called 'static haptics'. Suppose that a virtual environment is delivered through a HMD so that the participant cannot see the surrounding real world and that there are simple versions of physical objects (such as table-tops) in registration with their virtual counterparts. When a person reaches out to touch a table top they may indeed feel a simple plasterboard version of one – at least in the same physical place if not with the exactly expected tactile characteristics. In the same pit-room experiment referred to earlier,[36] another group of subjects stood on a small wooden ledge in registration with the edge of the pit, so that their feet would feel as if they were astride the edge. This condition again significantly increased heart-rate compared to the other conditions.

Virtual Body Representation. When a virtual environment is delivered through a head mounted display the participant cannot see their own body. Indeed anecdotally it can be a shock while in such an environment to look down and not see a body – it is like being 'the invisible man'. There have been some studies which have considered the relationship between the participant and their 'virtual body' and its influence on presence. One found evidence that reported presence was higher for those subjects whose body was represented by a complete (if crude) virtual body, compared to those simply represented by a 3D arrow cursor[18]. In this experiment when subjects moved their real right arms they would see their virtual right arms move in synchrony (or alternatively the 3D arrow cursor). However, if they moved their real left arms the left virtual arm would not move (since it was not tracked). Some subjects found this disturbing. For example, they wrote in their debriefing questionnaires statements such as "I thought there was really something wrong with my [left] arm" ", suggesting a fast internalisation of the virtual body, and others who found this dissociation disturbing wrote of their virtual bodies being – "a dead weight", "a useless thing", "nothing to do with me. It was also noticed that some would go to great lengths to align themselves with their virtual bodies, positioning their feet exactly where they saw their virtual feet to be, and so on. There was further evidence of this in a follow up study, where some subjects always moved their real left arm in synchrony with movements that they saw their virtual left arm making (which had been programmed to symmetrically mirror the movements of their real right arms). [17]

Body Engagement. When participants wear a HMD they are usually tethered by cables from the back of the HMD into the main computer. Although they are able to stand and move around, the range of movement with a traditional electromagnetic tracker is limited. Therefore in order to cover extensive distances within the virtual environment some other method than physically walking has to be used – and the usual solution is to employ a mouse button press on the 3D pointing device that the subject holds in their hand in order to activate movement. It was noticed in early studies that many subjects, especially those reporting a high degree of presence, were almost unable to move by button pressing, but kept attempting to physically walk. A method was derived to reduce this dissociation between proprioception and sensory data by having subjects 'walk in place' as a simulation of walking[19]. Experimental results showed that on the average those subjects who moved through the environment using the walking in place method reported a significantly higher sense of presence than a control group who used the traditional 3D mouse-button method. This study was later extended by the incorporation of another experimental group who were really able to walk significant distances (via a wide-area tracking system)[53]. The results showed that mean reported presence was highest for the 'real walkers', next highest for those who walked in place and lowest for the 3D mouse button pressers.

Two other experiments examined the relationship between body engagement and presence – the hypothesis being that the more participants would use their bodies within virtual environments to effect changes in a natural way, the greater the sense of presence. In other words they become 'anchored' into the environment through significant and meaningful motor activity. Each study found a significant positive association between overall body mobilisation and reported presence[15,37].

Further Evidence for Presence – Applications in Therapy

A class of applications that cannot work without presence involves the exploitation of virtual environments for various forms of psychological therapy, typically for the management of anxiety. As part of a treatment programme a patient may eventually be placed in a VE that depicts a situation that triggers their anxiety. To what extent is their response similar to that which would occur when facing the same situation in real life? The greater the similarity in response, the greater the chance that the virtual environment can be successfully utilised as part of the therapy programme. This is just another way to say that a necessary condition for any therapeutic intervention to be successful is that the patient becomes present in the VE. In this section we present some evidence that indeed this does occur, and which therefore provides further evidence for the existence of the presence response. For an overview of the application of virtual environments to psychotherapy see[54,55].

Some Specific Phobias. The first reported psychological intervention in this domain was the application of virtual environments to acrophobia (fear of heights). In an initial pilot study[56] it was found that subjects would exhibit acrophobia signs and symptoms within a virtual environment exposure, and as the authors noted therefore exhibited a high degree of presence. The scenarios included an elevator ride, a bridge and a view from a tall building. A study that used this virtual environment in a graded exposure therapy found that the experimental group showed significant reductions in anxiety over an eight week period, compared to a control group on a waiting list[57]. Of course this did not show that the virtual environment itself was implicated in the improvement, since any kind of intervention compared to doing nothing may have helped. Another study that did not have this defect, however, found the same result, where an *in vivo* treatment group was compared with a virtual reality exposure group. This study resulted in similar imrovements in both groups, as measured by on a battery of tests including a behavioural avoidance test demonstrating that the virtual reality exposure was equivalent to *in vivo* exposure[58]. A similar study on fear of flying[59] also found no difference between an *in vivo* exposure group and a virtual reality group, and both groups were compared to a waiting list control group. Six month and one year follow-up studies showed that the improvements had been maintained.[60] Arachnophobia has also been studied with similar methods[61-63].. In these studies the idea of 'static haptics' was employed, where a physical toy spider was registered in the position of the virtual spider so that eventually subjects could feel as well as see the spider. It was found that the tactile augmentation led to better treatment results than the visual simulation alone.

Social Anxiety. Anxiety that involves other people is more difficult to deal with within a VE. Depicting a bridge, for example, is technically far less challenging that depicting a group of people. The modelling and dynamic rendering of a virtual human that can purposefully interact with a real person – for example, through speech recognition, generation of meaningful sentences, facial expression, emotion representation, skin colour and tone, modelling and rendering of muscle movements and joints, accurate depiction of a live acting human body – these are all beyond the capabilities of today's real-time computer graphics and artificial intelligence, in spite of what may be possible in special-effects movie creation. Yet here is also a surprise – the evidence suggests that people respond to relatively crude virtual humans as if they were real people, that a virtual human that seemingly looks the participant in the eye and frowns has a similar impact as if that behaviour had been carried out by a real person.

We considered a particular type of social phobia, fear of public speaking. A study was carried out in which subjects were exposed to virtual audiences in a seminar-style setting. The subjects had a normal range of public speaking anxiety. The experimental factor was to have audiences with three different types of behaviour – they were either static and neutral, dynamic and showing very positive responses towards the audience, or dynamic and showing very negative responses towards the audience[64]. Each person experienced only one of these conditions. Some examples of the positive and negative audiences are shown in Figure 5, each consisting of the same eight male virtual characters who changed posture and facial expression, and also made verbal comments during the progress of the 5 minute talk. The statistical results indicated that for those who were immersed with the positive or static audience their reported anxiety as a result of the talk correlated with their usual anxiety in everyday life with respect to fear of public speaking. However, irrespective of everyday life anxiety in relation to public speaking, the general trend for those who experienced the negative audience was a very strong anxiety reaction. The experimenters noted anecdotally that such subjects had changes in body posture and skin colour, and overall demeanour after experiencing the negative audience indicating a strong negative reaction.

More interesting than the statistical results were the comments made by the subjects in debriefing interviews (Figure 5). It may seem that these comments are not surprising – especially the reactions to the negative audience – for after all, their behaviour *was* hostile. However, it is important to remember that *there was no audience there.* The situation was entirely virtual. What happened expressed the power of the virtual reality to evoke a response that was similar to that of reality – a ‘presence’ response.

Paranoid Ideation. Paranoid ideation is the typical pattern of thinking displayed in cases of paranoia. It is characterised by suspiciousness and beliefs that one is being followed, plotted against, persecuted, and so on. There are degrees of paranoid tendencies in a population – ranging from none at all, all the way through to psychotic illness. An experiment was carried out that tested whether the range of paranoid thoughts typically present in a normal population (but excluding people with psychosis) would be reproduced within a virtual reality[65]. The subjects, whose degree of paranoia had been assessed in advance using standard scales, had a simple task to move through a virtual library. The characters in the library would look at them and make some facial expressions, maintaining a neutral attitude towards the subjects. Statistical analysis of subsequent questionnaire results supported the hypothesis that paranoid thoughts were triggered in the virtual reality in correlation with subjects' propensities to experience these in everyday reality. It should be noted that there were no sounds in these environments – so that comments that some of the subjects heard were illusory. The results were quite remarkable – people reacted strongly to the virtual characters, even though objectively everyone knew that there were no people there at all. This study has been followed up and repeated again, with publications pending[66,67].

Post Traumatic Stress Disorder (PSTD). PSTD can occur when a person is subject to life-threatening catastrophic events. People who develop PTSD have difficulties in settling down to a normal life, have recurrent flashbacks, sleep disturbances and a host of other debilitating symptoms. The group most studied in relation to virtual reality therapy have been Vietnam War veterans. Two main scenarios have been developed – a helicopter flight over hostile terrain and a clearing in the jungle where helicopters may be landing. Desensitisation treatment of Vietnam War veterans led to significant improvements in their symptoms[68,69]. A recent study with a survivor of the September 11th 2001 attack on New York also led to significant improvements although no longer term follow up study was reported[70].

Pain Distraction. The idea of presence in a virtual environment involves transportation – it is as if the consciousness of the participant has been transported to a place that is different to where their physical body is actually located, so that they feel and act as if they are in that other place. Pain distraction is a potentially powerful application of this process, since if the body is experiencing a situation that would be experienced as pain in physical reality, but the person feels present in a virtual reality, they should perceive less pain. There are some experimental studies that provide at least preliminary evidence that lends weight to this. For example, pain during physical therapy for severe burns treatment was signicantly reduced while subjects experienced HMD delivered virtual reality studied [71]. Similar results have been described in other studies lending weight to the importance of immersion[72,73], [74], [75]. A typical strategy is to present subjects with a situation that is counter to the kind of pain that they are experiencing. For example, when undergoing burns treatment they may be placed in an environment that depicts snow and ice, and have a task to throw snowballs[76]. Overall although none of these studies are methodologically watertight, the evidence does point in the direction that the 'transportation of consciousness to another place' involved in presence in a virtual environment is strong enough to diminish sensations of pain.

Neuroscience and Presence Research

Presence research was initiated and has largely remained within the ambit of technologically oriented research departments, and more recently has been of interest to psychologists and clinical psychologists. The field has remained quite separate from neuroscience, illustrated by the fact that not a single reference to presence research appears in the neuroscience literature. With this review we wish to alter this situation and introduce some of the overlapping areas between the two fields.

First it should be noted that VE technology provides an excellent tool in general for neuroscience research. It allows the creation of experimental conditions for human subjects that are almost identically replicable, under full control of the experimenter, including the creation of scenarios and conditions that are either too expensive, dangerous or even not possible at all in physical reality. It also easily supports the creation of 'magical' scenarios – for example, the dissociation of sensory modalities from one another. However, here we differentiate between the use of VEs as a *tool* in neuroscience studies (as it is useful in other fields such as archaeology, design or architecture) from the essential interactions between the issues that are subject of study in the fields of presence and neuroscience research. A case in which VE can be just a tool, for example, is the 3D visualization of biological structures and in this case in particular, neural structures - both static and dynamic - which may report benefits in the planning of surgical strategies[77-79] or in general in the interpretation of morphological data (pattern distribution, interneuronal relationships, etc). Other possible uses of VE as a tool, but where at the same time in order to be successful presence is required, are those applications in different types of training (neurosurgical training, emergency responses), psychotherapy (see review above) or in neuro-rehabilitation[80].

What we would like to highlight here are the conceptual interactions between the apparently distant fields of presence and neuroscience research. We start with a consideration of perception. In the presence studies reviewed above it is clear that the characteristics of display of sensory data within a VE are critical to induce higher presence – head tracking is better than no head tracking, stereo is better than mono, faster frame-rate is better than lower frame-rate, shorter latency is better than longer latency, sound is better than no sound, auditory display that takes account of the individual person's head and ear shape is better than a general auditory display function, and interaction methods that utilise the body in a manner similar to real-world interaction is preferable to traditional computer interface styles. In other words, data has to be delivered to participants in forms that are structurally similar to real world sensory data acquisition, and participants interact with the virtual world in a similar manner as they would in the real world. However, one result was unexpected and surprising: the *realism* of what is displayed seems to be far less important for presence. No one could ever be fooled into believing in the reality of any virtual environment that is capable of being displayed in real-time with today's equipment. Yet people become anxious when seeing a virtual precipice, are upset by virtual characters who behave badly in an audience and even seem to generate paranoid thoughts in relation to such virtual people.

This result has led to the concept of *minimal cues*, the minimal elements that a VE must include in order to induce presence[81] and an area of work in presence research since it is directly related to the economy of the system. How much can we simplify 'reality' within a VE and still induce presence in the subject? How many sensory modalities should be stimulated to induce presence? Which minimal multi-sensory stimulation works the best for different tasks? To any neuroscientist studying perception it would seem obvious that such questions go to the roots of the mechanisms of sensory perception: what are the building blocks of our perceived world? How much of our perception is actually determined by the external world and how much by our internal state? Or, what is the balance between bottom-up and top-down processing? Clearly there *must be* minimal cues, since presence is reported in very simplistic environments, and the fact that minimal cues are enough to induce presence implies that the absence of part of the sensory information is not distracting, probably being filled in by cortical processing[82,83]. Top-down influences on perception can also be investigated by giving specific tasks or prior information to subjects going into VEs and subsequently determining how their perception was affected. These studies can comprise from perception of simple stimuli all the way up to perception of social situations, using virtual characters. Actual stimuli received by the subject are reconstructed (including eye tracked visual scenes) and compared to the perceived one as evaluated by different means. Therefore, we could consider that when studying perception both, neuroscience and presence research are asking similar questions from different starting points, and additionally the use of VE provides a unique tool to be able to answer those questions.

The possibility of dissociation of stimuli that are invariably inseparable in the real world opens many possibilities in the study of perception, and in particular in the study of human bodily awareness or more generally, self-perception. In this area, virtual reality can replace classical strategies such as the use of mirrors, panels or dummy limbs[84,85] with advantages. We talked earlier about studies that measured the impact of different virtual body self-representations on the presence experienced by the subject in the VE. The fact that subjects do still feel present in environments where their own body is represented by some bizarre form implies that this 'new' body has been somehow internalised. Future studies in VE on how we relate to our virtual body, to the stimuli that it receives or how a virtual body is internalised can be of great importance to understand how our own body internal representation is generated. By disrupting distinct streams of information that are physiologically bound together (visual, motor, propioceptive) we can learn about their individual contributions to the mechanisms of perception and motor control. In the real world we calibrate our movements by feedback that is provided by visual and propioceptive afferents, and by tactile information if we are reaching for something. A virtual world can be programmed such that when our real arm moves up, our virtual arm moves forward and therefore there would be a disruption between visual and propioceptive information[86]. Subjects, however, adapt quite fast to such disruptions, and learn to operate in the new conditions, so that the temporal dynamics of those changes reflecting the plasticity of the system, could be measured.

The exploitation of VEs has also resulted in a useful tool in studies of brain activation during different spatial navigation strategies[87,88]. In a broader sense, VEs provide a frame in which to analyse which factors (auditory, visual, vestibular cues) contribute to inducing spatial aspects of presence, or, in other words, what particular sensory integration is critical to generate a sense of space. The use of VEs also allows the dissociation of navigation from the proprioception associated to locomotion, furthermore, it is compatible with inducing incorrect visual-proprioceptive cues, and therefore it provides a tool to determine the role of visual or proprioceptive inputs in the generation of internal spatial representations in humans.

Moving to the study of consciousness whatever definition is used, it includes several layers that blend together in a unitary awareness that integrates the awareness of the self and of the external world. The phenomenon of presence is based on a transportation of consciousness into an alternative virtual reality. In a way then, presence is consciousness in that virtual reality. The fact that the different layers (external world, self representation and even part of the extended self) can be altered in a highly controlled form in a VE means that virtual reality can be exploited to analyse scientifically the basis of consciousness. We propose that precisely because of its restricted form, it may be more tractable for study than consciousness itself. For example, in one well-known approach it is said that "Consciousness occurs when we can generate, automatically, the sense that a given stimulus is being perceived in a personal perspective; the sense that the stimulus is 'owned' by the organism involved in the perceiving; and, last but not least, the sense that the organism can act on the stimulus (or fail to do so), that is, the sense of 'agency'." [89] Every aspect of this occurs when a person is immersed in a VE, and not only does it occur but many aspects of this can be manipulated experimentally.

Presence occurs when what is said about consciousness occurs within the domain of a virtual reality. What provisional conclusions can we reach about this? First, that it does occur. Immersion in a VE can transform the consciousness of a person in the sense that they respond to the virtual place and to events within that place, and feel their body to be part of that place, even transform their body ownership to the body that they see in that place. This process can have observable impact on the real body of the person, in terms of conscious and volitional behaviours in which they engage (e.g., deciding to walk around the pit rather than fly across it), through to non-conscious behaviours such as changes in heart rate, breathing and skin conductance response. The transformation of consciousness can be to such an extent that pain that should be experienced as a result of activities taking place in the real body is suppressed, and in contrast there is evidence to suggest that events that are activated on the virtual body may result in the sensation of pain[85] (though such an experiment is yet to be carried out in a computer-generated virtual environment). Presence occurs when there is successful substitution of real sensory data by computer generated sensory data, and in a way that people can engage in normal motor actions in order to carry out actions. By 'successful' we mean that the person responds to the virtual stimuli in a manner similar to how they would respond to the corresponding real stimuli. Response should be considered at every level, from unconscious physiological behaviours, through automatic reactions, conscious volitional behaviours, through to cognitive processing - including the sense of 'being there'.

What is also interesting is that this takes place in spite of every participant's absolute knowledge that the virtual environment is fake, is not really there in the everyday meaning of the word. Recall also that these virtual environments are not only fake, but they appear to be fake, certainly in the visual sense. A virtual character does not look or behave much like a real character for example. This implies that the mechanisms that govern the domain of consciousness (i.e., the place and situation to which it is attached at any moment) must have as a necessary condition that combination of parameters that govern the formation of a virtual environment. Consciousness will not transform when, for example, the frame rate is below a certain level, or when the field of view is too narrow – but it may do so when these (and other structural factors) are at appropriate settings, independently of the level of realism of the content displayed in the virtual environment. In this situation a person acts as if conscious in the place and situation depicted by the VE even if at some level there is awareness that in fact this situation is not really happening and the place is not really there. The concept of breaks in presence provides a way to analyse those moments when 'reality' breaks through, so that consciousness shifts back to the surrounding physical environment.

Conclusions

We argue that presence research should be opened up, beyond only the domain of computer science and other technologically oriented disciplines, and become a mainstream part of neuroscience. Of course, virtual reality can and is being used as a tool for neuroscience studies. Many of these studies, such as of perception, way-finding, self representation and sense of self, will also contribute to the understanding of presence. But, and this is our main point – not only is virtual reality a tool for neuroscience, but the presence experience that it engenders is also an object of study in its own right. Moreover, this concept of presence is sufficiently similar to consciousness that it may help to transform research within that domain.

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Figure 1| The left pane shows a Cave-like system. This specific model is a Trimension ReaCTor. This system consists of 4 projection surfaces, the front, left and right walls are back-projected acrylic screens while the painted wooden floor is projected from above. The screens are seamlessly joined to provide a continuous projection surface. Only the top and the rear faces of the cube are not projection surfaces. This system is driven by an SGI Onyx 2 computer.
The right pane shows a particular environment (a kitchen) being projected into the ReaCTor. The image is refreshed at 90Hz. A left eye image is shown at 45Hz and a right eye image also at 45Hz. The participant is wearing CrystalEyes stereo shutter glasses which are controlled by infrared signals to be synchronised with the display refresh. Hence the left eye lens is only open during the left eye image display and similarly for the right eye. The participant is wearing an Intersense IS 900 tracking device attached to the top of the glasses. The head-position and orientation is tracked at approximately 120Hz and this information is relayed to the computer at a latency of about 4ms. The computer graphics software uses this information to compute and display the left- and right-eye images. Since the display is from the point of view of the tracked participant the perspective projection does not seem to be correct when looked at by another person. Hence the distortions in the image above. The participant is also holding a hand tracking device which similarly relays its position and orientation to the main computer. This device has buttons that can be programmed to initiate events (such as virtual locomotion, and also can be used for collision detection with virtual objects thus allowing the participant to interact with objects in the scene.

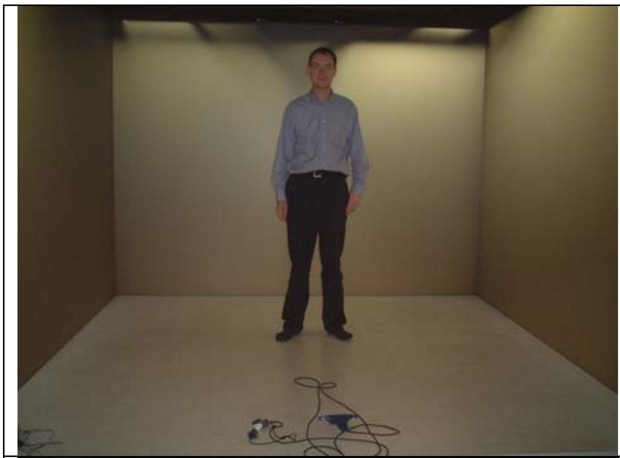

Figure 2a – This shows a person in the ReaCTor Cave-like system, with all the projectors off.

Figure 2b – When the projectors are on the person may be transported into a different world, here interacting with virtual characters in a party scenario.

Figure 3 |The left pane shows a participant wearing a head-mounted display. This ideally blocks out all surrounding light. There are two images displayed, one for the left eye and the other for the right eye. Each image cannot be seen at all by the opposing eye. The head-mounted display position and orientation is tracked, and the computer updates the image according to perspective projections from the point of view of each eye.

The right pane shows a participant in a Cave-like environment. He is wearing 3D shutter glasses and also physiological monitoring equipment so that real-time read-outs of his EKG, GSR and respiration are available. The background scene shows a virtual party which has been used recently in a study of social phobia.

Figure 4 - The ‘pit-room’. This is a virtual environment often used to assess presence. The participant enters into the left-most room which can be used for familiarisation with the virtual environment system and the learning of any procedures such as how to move around or select objects. The participant is then given task to go into the next room, select an object that is left on plank overlooking the pit, and then take it to the chair on the other side. The reactions to the pit are quantified in different forms: behaviourally, through physiological measurements (heart and respiratory rate, galvanic skin response, etc) or through subsequent questionnaires. In the experiments that have been carried out almost all make their way to the chair by edging themselves around the sides of the room along the ledge, even though all subjects know for sure that there is no pit there.
The smaller insets show ‘static haptics’ where participants were positioned by small but real ledges, adding to the effect of standing over a real pit.

Figure 5a | **A snapshot of the positive audience**

Figure 5b | A snapshot of the negative audience

Virtual environment representing a seminar audience. Although the characters certainly do not look realistically human their behaviour has been modelled on observations from real meetings, though greatly exaggerated – both positively and negatively. In these studies the subjects are asked to give short talks to the virtual audience, that could have a positive, negative or neutral attitude towards the speaker. A response to the audience similar to the one that the same person would have to a real audience was subsequently evaluated as a high presence in the virtual environment. The testimonies shown below illustrate that the responses to the virtual characters went above all rational considerations of what is real, along with the physiological responses measured in the subjects illustrated the fact that people responded similarly to a real environment.

Some Responses to the Positive Audience

> ‘It was clear that the audience was really positive and interested in what I was saying and it made you feel like telling them what you know.’
>
> ‘I felt great. Finally nobody was interrupting me. Being a woman, people keep interrupting you in talks much more… But here I felt people were there to listen to me.’
>
> ‘They were staring at me. They loved you unconditionally, you could say anything, you didn’t have to work’.

Some Responses to the Negative Audience

> ‘It felt really bad. I couldn’t just ignore them. I had to talk to them and tell them to sit up and pay attention. Especially the man on the left who put his head in his hands; I had to ask him to sit up and listen…. I entered a negative feedback loop where I would receive bad responses from the audience and my performance would get even worse…. I was performing really badly and that doesn’t normally happen.’
>
> ‘I was upset, really thrown. I totally lost my train of thought. They weren’t looking at me and I didn’t know what to do. Should I start again? I was very frustrated. I felt I had no connection to them. They weren’t looking at me. I just forgot what I was talking about.’

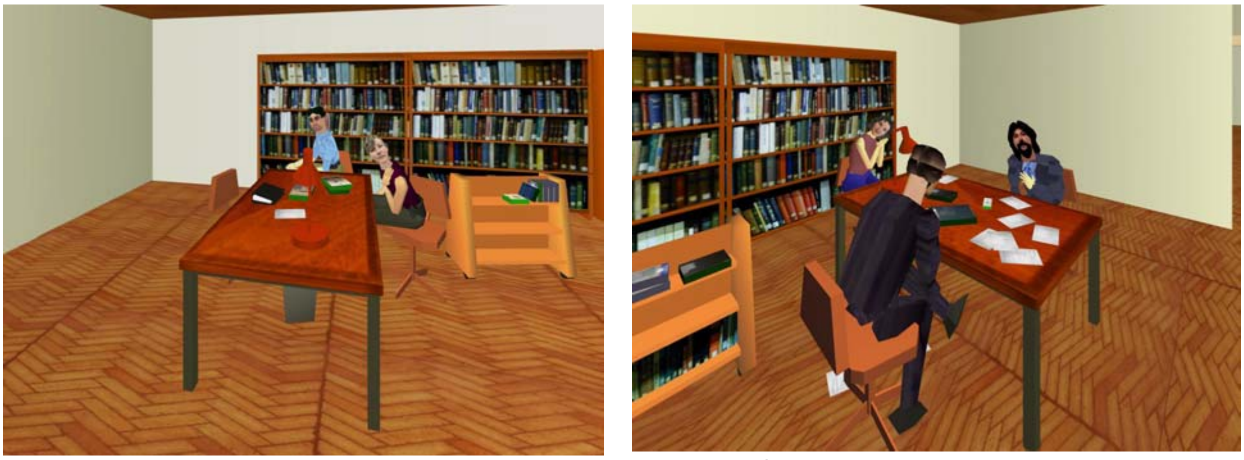

Figure 6 | Virtual environment representing a library that was used in a CAVE during paranoia studies. The subject is asked to walk around the library and report afterwards. Virtual characters in the library do occasionally look at the subject and change facial expressions such as smiling or other emotionally neutral expressions. No sound was delivered during the study.

Here we quote some of the remarks made by the subjects in post-experimental interviews that illustrate the sense of presence that people felt in the environment and their responses to these visually quite unrealistic virtual characters.

> “The two people to the left, I didn’t like them very much – well, I don’t know, maybe because when I entered the room I felt I was being watched and then they started talking about me. The other people were more neutral and more inviting except the guy with the beard.”

> “It was probably more real to me than I expected it to be. At some point, I was trying to navigate around a table and almost found myself saying sorry to the person sitting there. I felt that they were getting annoyed with me for doing that…”

> “It was really weird, because they were all definitely in on something and they were all trying to make me nervous. It was clear that they were trying to mock me, they kept on looking at me and when I looked back, they were uuhh… The guy with the suit was really weird because he kept smiling at me and it was quite sinister.”

Box 1 – Basic Functions of a Virtual Reality System

A virtual reality system typically delivers a left and right eye image forming a stereo pair, ideally with an active stereo system – one in which there is no leakage of the left eye image to the right eye, and vice-versa. The images are generated within the graphics pipeline of a computer system, and updated in real-time. The computer maintains a data base that describes a particular scene – the data base containing geometric, radiant, acoustic, behavioural and physical information about the set of objects comprising the scene. The images that the participant sees are renderings of the data base, perspective projections of the 3D geometry onto the 2D displays, with objects coloured according to computer graphics lighting models. The rendering is from the point of view determined by the head position and orientation of the participant, which must be tracked in real-time by a tracking system. The tracking system continually sends a stream of head-position and orientation data to the computer which is therefore able to generate the appropriate stereo images.

Virtual objects are encapsulations of particular nodes in the data base and the programming scripts that determine their behaviour. They typically represent meaningful aspects of the environment – for example, some geometry plus associated radiant information may represent a chair. Some objects may be passive (for example, representing walls of a room) and others active – for example, representing virtual people. The human participant can therefore interact with objects in the environment to a greater or lesser degree. Typically nothing can be done with entirely passive objects such as the walls of a room, but a chair, for example, may be 'picked up' and moved to another location, and the representation of a virtual human may be aware of the participant, speak to him or her, and may have various levels of behaviour. Of course the program that controls a virtual human will have access to where the head of the real human is located and its orientation direction because it will have access to the head-tracking data. In order for the participant to be able to interact with the environment – such as picking up objects – there must be additional tracking beside head-tracking. Typically at least one hand is also tracked, often simply by the person holding the equivalent of a 'mouse', a 3D pointing device with buttons like a mouse which itself has a 6 degrees of freedom tracker attached to it.

Box 2 | Example of Some Questions from a Presence Questionnaire

1. To what extent did you have a sense of being in place X?

Not at all	1	2	3	4	5	6	7	Very much so

2. To what extent were there times during the experience when X became the 'reality' for you, and you almost forgot about the 'real world' of the laboratory in which the whole experience was really taking place?

Never	1	2	3	4	5	6	7	Almost all the time

3. When you think back about your experience, do you think of the virtual X more as *images that you saw*, or more as *somewhere that you visited* ?

Only as images that I saw	1	2	3	4	5	6	7	Somewhere that I visited