3 Measuring Presence in the Simulating Brain

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Abstract: A description of the brain as an organ for simulating its environment can inform and illuminate a discussion about brain measurements in connection with the sense of presence. Developing theories of how mental simulations and continuous predictions underlie brain function have implications for how presence can, or cannot, be associated with brain measurements. Here, the simulating brain is accepted as a working hypothesis. The resulting implications are discussed and briefly related to how brain measurements have been used to investigate presence in previous studies.

Keywords: Presence; Brain Measurements; The Simulating Brain; fMRI; Predictions.

3.1 Introduction to Chapter 3

The subjective nature of the sense of presence makes it difficult to relate it to objective measurements. One tempting possibility is to target the neural functions underlying subjective experiences by measuring brain activity using methods such as *fMRI* (functional Magnetic Resonance Imaging). The technology and expertise necessary for using such methods has become relatively common over the last decade, and a few studies have been conducted to measure what happens in the brain in connection to a varying sense of presence. However, how such measurements should be interpreted, and how they should be related back to presence in theory and practice, remains an open question. For example, explanations that focus on specific brain areas are not conclusive since most areas of the brain have been shown to be involved in many different cognitive functions and brain function is heavily influenced by context.

3.2 Background

The range of methods used to measure presence has evolved over the years, from pure subjective measures using questionnaires, to more objective measures based on behaviour or physiology (Insko, 2003) and, more recently, including brain measurements (Baumgartner et al., 2008; Clemente, Rodríguez, Rey, & Alcañiz, 2012; Kober & Neuper, 2012). Interested readers are encouraged to look up the references above, for a more complete overview of the background of presence measurements. The rest of this chapter focuses on how brain measurements might be used to measure presence (and associated challenges) based on a theoretical perspective on the brain summarized as “the simulating brain”.

There are many different definitions of presence that may be related to brain function with varying ease. Several definitions relate directly to subjective experiences that are essentially hidden. Two common definitions of presence, as the "sense of being there" or as the "perceptual illusion of non-mediation" (Insko, 2003), both come down to what is actually sensed or perceived "inside of the users mind." That is, to how percepts (sensory input) and information flows through and is processed in the user's brain.

The relation between brain function and definitions such as the ability to "do there" (successful intentional interaction) or responding to stimuli from a virtual environment (VE) "as if they were real" may be less obvious, but the connection has been established explicitly and repeatedly (Jäncke, Cheetham, & Baumgartner, 2009; Sanchez-Vives & Slater, 2005).

This chapter aims to avoid an explicit definition of presence (see Chapters 1 and 2 for a wider discussion about this topic), but important aspects of presence in the simulating brain are summarized in Section 4.

3.3 The Simulating Brain

The idea that the brain is essentially about predicting the future is becoming increasingly popular (Clark, 2013; Friston, 2009b, 2010; Hawkins, 2005; Schacter, Addis, & Buckner, 2007). The basic function of the brain is, it is suggested, to use information from the past to make predictions about what is likely to happen in the future. The concept of mental simulations is helpful to focus on these predictions as running, continuously updating expectations. In much the same way as remembering the past seems to involve "a constructive process of piecing together bits and pieces" (Schacter et al., 2007, p. 659), partial simulations based on previous experience are continuously pieced together to simulate future states and guide action.

Partial simulations are stored in brain areas related to the corresponding modalities, providing a basis for higher-level aspects of simulations. For example, the higher-level concept of "colour" is related to simulations of seeing colour, stored in the areas of the brain related to the actual perception of colour; and the concept of "up" is related to simulations of looking up, stored in motor areas. Cognition is further described as having a hierarchical structure where concepts and phenomena at higher levels are grounded in lower levels. High-level predictions correspond to contexts for low-level predictions. For example, a high-level expectation of walking on a flat surface triggers lower-level predictions of your foot hitting the ground at a certain moment. Higher-level contexts only need to change when predictions fail at lower levels, highlighting the importance of prediction errors and feedback in the brain. As long as the foot hits the ground as predicted one does not need to reconsider the walking context. Simulations pieced together throughout a hierarchy, based on current percepts (bottom-up) and current context (top-down), enable efficient interaction by continually preparing for what is likely to happen next.

Particularly interesting for this chapter is how this framework suggests that the brain essentially contains a model of reality, and that brain activity in large part corresponds to experiences that are unexpected or surprising; that is, experiences that were not correctly predicted. Poor predictions can be caused either by an incomplete knowledge of the phenomenon, or by fundamental unpredictability. If the stimuli are fundamentally predictable however, the brain is excellent at detecting and adapting to these stimuli, integrating them into mental simulations and expectations. This effect can be recognized in many well-known phenomena, such as repetition suppression, habituation, and odd-ball paradigms, commonly employed as reliable effects in cognitive neuroscience studies.

The proponents of these theories are not shy about their potential. Karl Friston writes that "one can see easily how constructs like memory, attention, value, reinforcement and salience might disclose their simple relationships within this framework" (Friston, 2009b, p. 293), and in a somewhat more nuanced target paper Andy Clark writes that "what is on offer is a multilevel account of some of the deepest natural principles underlying learning and inference, and one that may be capable of bringing perception, action, and attention under a single umbrella" (Clark, 2013, p. 20).

It may be illustrative to reflect on why humans perceive some things as more "real" than others. To quote Hawkins, "predictability is the very definition of reality" (Hawkins, 2005, p. 128). Consider the opposite of reality: the unreal. If something is unreal it means that it does not fit into one's current understanding of the world, it is inconsistent with the patterns one has learned to recognize, and there is no basis for making predictions about this phenomenon, or running matching simulations. Depending upon how large the deviation from the familiar is, this may lead to confusion, and/or adaptation of the models for what is familiar: that is, learning.

Many aspects of the theories presented above are still debated. Including enough arguments to convince sceptics is outside the scope of this chapter. For an introduction to the discussion surrounding these theories the recent target paper by Andy Clark is recommended (Clark, 2013).

3.4 Presence in the Simulating Brain

The simulating brain suggests possible explanations of phenomena generally associated with presence. The basic reasoning is based on a view of the human brain as continually running a simulation of the surrounding environment, trying to match and anticipate the future as well as possible. Such simulations have reached the brain through experience with reality, through prediction errors that force refinements of the dynamic models. The (hypothesized) fact that these mental simulations originate in (interaction with) the real environment leads to an expectation of similarities between actual reality and the simulation in the brain, both in behaviour and in structure. When the world the brain currently inhabits is a computer-generated virtual reality, this perspective constitutes the foundation for an interpretation of brain function and brain measurements as tightly related to phenomena in and aspects of this virtual reality.

Within the simulating brain, information that reaches any higher levels of the brain is related to internal expectations of the brain to an extremely high degree, rather than being anything like direct information from the external environment. One way to think of such expectations is as mental simulations that together create a subjective mental reality. This subjective mental reality may be more or less influenced by the current external environment, but it does run on its own, as “a generative model of the world it inhabits” (Friston, 2010, p. 135), to a large degree. Since most areas of the brain primarily operate in relation to the rest of the brain, it is reasonable to say that the brain is present in the subjective mental reality that is simulated in the brain. Within this perspective, the degree of presence in a certain environment may be considered to be the degree of synchronization between this environment and your (simulated) subjective mental reality (Sjölie, 2012). In an office: to what degrees are you currently simulating surrounding desks, chairs, pens, etc.?

One implication of this perspective on presence is that brain activity associated with a high level of presence should depend strongly on the specifics of the current environment and task. Conversely, a low level of presence should be related to a mismatch between the actual brain activity and the brain activity required to simulate the environment. If being present in an environment means that your brain is simulating aspects of that environment, then your brain activity should reflect this, and being present in different environments should lead to corresponding differences in the patterns of brain activity. In the case of reduced or disrupted presence in relation to a specific environment, the “alternate environment,” representing reduced presence, may be another actual environment, a state of general confusion, or some form of daydreaming.

The simulating brain may be easily related to many previous accounts of presence, such as the importance of avoiding “breaks in presence” (Slater, 2002), the ability to use familiar representations to “do there” (Jäncke et al., 2009), the successful transformation of intentions into actions, or the perceptual illusion of non-mediation (Giuseppe Riva, Waterworth, Waterworth, & Mantovani, 2011). For example, *breaks in presence* (BIPs) correspond to events that destroy the sense of presence through events that go against the expectations that underlie the acceptance of a VE as real, such as hearing a chair move in a forest VE. In relation to the simulating brain, BIPs are prediction errors that are big enough to rise through the hierarchy of predictions and finally invalidate the prediction that one is in a context that can be treated as a real place.

The importance of expectations and their violation for achieving and maintaining presence has been explicitly emphasized several times, for example, in terms of simulations in the brain (Giuseppe Riva et al., 2011; Sjölie, 2012), or the importance of being able to rely on expectations and existing motor schemas to be able to "do there" (Jäncke et al., 2009; Sanchez-Vives & Slater, 2005).

Two key aspects of the conception of presence presented above are:

1. Presence is a general function of cognition, related to your familiarity with and attention to your current environment. It is not specifically related to immersive VR, although VR provides unique opportunities to manipulate and explore all aspects of presence.
2. The brain activity related to presence, and differences in the level of presence, in any specific environment, is tightly related to the actual environment and the current task.

These points should primarily be understood as a delimitation of the conception of presence discussed here, rather than a claim on what presence should be generally.

3.5 Measuring What, How?

The rest of this chapter delves into what one can expect to be able to measure when it comes to presence in the simulating brain. How may measurements be gathered, and how might previous results be integrated? The present section focuses on methodological issues and theoretical background, while the next section delves into previous studies.

Ensuring reliability and validity when estimating presence using brain measurements can be challenging. The primary problem for validity is that there is no obvious or generally agreed upon ground truth to compare measurements against. According to common conceptions of presence, the ideal would be to be able to ask the user a question like "where are you?" while they are immersed and engaged within a VE. In general, this is not possible without disrupting the very experience (of presence) that we wish to measure, although some studies suggest that this disruption may be manageable (Kober & Neuper, 2012). Behavioural and physiological measurements are interesting alternatives that may be recorded during VR interaction (Insko, 2003). Such measurements are related to presence indirectly, for example, by assuming that increased arousal corresponds to increased presence. However, such assumptions are debatable and any practical measure quickly becomes very dependent on specific conceptions of presence. Questionnaires may focus on factors assumed to be related to the sense of presence, such as the sense of control, or variations of whether the environment is experienced as a place (Insko, 2003). Given how tightly measurements are tied to theory in general, new potential measurements should be considered based on whether they are theoretically defendable, rather than on compatibility with previous measures of presence.

The complexity and context sensitivity of human brain function provide challenges to both reliability and validity. Brain measurements are often presented in terms of which areas of the brain "light up." This is particularly common in fMRI studies, where the most common data analysis looks at each point in the brain separately, checking whether the local "activity" is significantly different between some conditions. Interpretation of such activations is usually related to what previous research tells us about the functional role of specific brain areas (functional segregation) (Friston, 2009a). However, such interpretations must be tempered by the fact that activation in any specific brain area can be caused by many different combinations of excitation and inhibition from other brain areas, essentially representing different contexts (Jäncke et al., 2009; Logothetis, 2008). These issues are well known in the brain imaging community in general, but addressing these issues fully requires sophisticated studies that are still relatively rare, and reporting in the popular press is often flawed. The basic message to readers not familiar with brain imaging is: avoid interpretations on the form "the function X is located at position Y in the brain". Brain areas do tend to play specific roles and data about brain area activations is valuable, but interpretations need to acknowledge the importance of context.

Unravelling how local brain activity depends on interactions with the rest of the brain usually requires additional analysis. One approach is to investigate connectivity between specific brain areas explicitly (Baumgartner et al., 2008). Another increasingly popular approach is to compare measured brain activity with models, with explicit expectations (Friston, 2009a). Theoretical frameworks such as the simulating brain provide a valuable basis and starting point for the construction of such models for presence in the brain.

If we accept the simulating brain as a working hypothesis: can we expect some areas of the brain to always be associated with increased presence? As suggested above, in a perfect VE, with perfect presence, presence-related brain activity should be dictated by the particular task and context. However, no such perfect environment exists today, and it is debatable if presence is ever perfect for any length of time. Thus, we are primarily dealing with degrees of imperfect presence.

Brain measurements related to imperfect presence should be related to aspects of the current environment and task that fail to synchronize properly with the simulated subjective mental reality. In particular, brain areas that correspond to a (higher-level) context or (lower-level) detail predictions related to a problematic phenomenon can be expected to be activated in an attempt to resolve the prediction error. For example, a troublesome virtual fork may trigger re-evaluation of both lower-level "physical fork handling" simulations and higher-level "eating with a fork" simulations.

Keeping in mind how brain areas correspond to aspects of simulations within a hierarchy may be helpful to get an initial sense of how measured local brain activity fits into the larger context and affects the total sense of presence. For example, significant disruptions in presence should correspond to large prediction errors that rise through the hierarchy, leading to increased activity in more frontal brain regions. Also, brain areas that are consistently implicated in relation to varying presence should be interpreted as corresponding to aspects of the simulated mental reality that are particularly important for the creation and maintenance of a general sense of presence.

One common approach is to compare brain measurements related to different conditions designed to elicit varying levels of presence. Subjective reports of presence may be used to verify a significant difference in reported presence between conditions (Baumgartner et al., 2008; Clemente et al., 2012), but variability in how subjects report presence and biases like the recency effect are an issue, in particular since brain imaging studies often have a relatively small number of subjects. Asserting that measured responses are related to changes in subjective presence more generally, rather than related to specifics of the employed conditions, is also a primary challenge.

The latter problem may be addressed either with variability in the conditions, leaving differences in presence as the primary explanatory variable, or by trying to keep the conditions as similar as possible and still elicit different sensations of presence. Bouchard et al. (2012) demonstrated the second approach by using different narratives to produce differences in presence while keeping the VE itself constant across conditions. Such methods provide a level of confidence that measured activity is related to differences in presence, but it is still unclear how the results depend on particulars of the context.

Another approach is to focus on what happens when presence changes. That is, focusing more on transitory events or short time periods where the sense of presence changes. The great challenge here is that it is difficult to get reliable information on the subjective experience of presence over time without seriously impacting the experience we want to investigate. As remarked above, if we were to ask the subject about their degree of presence at regular intervals this would be very likely to affect their sense of presence. One may design the experiment to introduce events that are expected to lead to differences in experienced presence, for example, by violating expectations and (potentially) triggering BIPs. However, this approach has the same vulnerabilities as the comparison of conditions above, potentially drowning effects of changing presence in effects related to particulars of the designed events.

An alternative to using designed changes to affect presence is to try to piece together when subjects experienced changes in presence through some combination of behavioural data and post-scan reports. Spiers and Maguire have used such a setup in several studies, for example, to investigate the neural correlates of spontaneous mentalizing (Spiers & Maguire, 2006).

3.6 Previous Studies

There are many brain imaging studies with results that can be related to presence, but only a small number that investigate presence explicitly. This chapter cannot begin to give a complete review of relevant studies, but the selection below should provide an introduction to the kind of studies conducted.

VR and brain imaging have been used together in a number of studies over the last decades. A recent review by Maguire (2012) provides a general overview of research using a combination of VR and fMRI (VRfMRI). Early VRfMRI studies by Hoffman et al. (2003) and Lee et al. (2004) include a discussion of presence, but neither present any brain measurements directly related to presence.

Baumgartner et al. (2008) conducted the most comprehensive fMRI study on presence to date. Their study is based on the comparison of two conditions designed to elicit high and low presence, respectively. Both conditions were presented as non-interactive roller-coaster rides in a 3d-environment, with a flat track in the low-presence condition and spectacular slopes and loops in the high-presence condition. Post-scan questionnaires were used to relate differences in reported presence to differences in brain activation, across subjects. Restricting initial analysis to the prefrontal cortex based on an a priori hypothesis, activity in bilateral dorsolateral prefrontal cortex (DLPFC, a "high-level control" area) was reported as negatively correlated with the sense of presence. Subjects who reported a smaller increase in presence between conditions showed a greater BOLD (blood-oxygen-level-dependent) increase in DLPFC. Using connectivity analysis, DLPFC activity was further related to down-regulation of the egocentric dorsal visual processing stream (including parietal areas) and up-regulation of the medial prefrontal cortex (MPFC).

The results from the study by Baumgartner et al. are further discussed in a paper by Jäncke et al. (2009). Among other things, it is acknowledged that the identified network of brain areas is not exclusively related to modulation of presence, since the areas in question are involved in many other psychological functions. However, the DLPFC is suggested to play a central role in regulating (among other things) the sense of presence, as it serves as an "executive control". The simulating brain suggests an essentially compatible but conceptually different explanation. The DLPFC corresponds to a higher position in the hierarchy of simulations and predictions in the brain. From a bottom-up perspective any failure of lower-level predictions, such as internalized simulations of spatial interaction, is expected to give rise to prediction errors that must be dealt with further up, for example, in the DLPFC. From a top-down perspective, when a situation is familiar and simulations are synchronized with external phenomena, predictions can be pushed down through the hierarchy relatively effortlessly. In essence, lower-level areas can successfully run simulations based on (among other things) predictions from DLPFC and need not bother the DLPFC further. An association between reduced activity in DLPFC and increased presence fits well with both these perspectives.

An interesting alternative to the comparison of different environments has been presented by Bouchard et al. (2012). Their study used narratives to convince some subjects that an immersive VE was real, while others were immersed in the same VE without believing that it was real. Believing that the VE was real was correlated with an increased sense of presence and increased activation in bilateral parahippocampal cortex.

As remarked above, if presence requires a close match between simulations in the brain and phenomena in the interaction environment, brain measurements related to varying presence should be related to important aspects of the environment and task in question. Indeed, in the study by Baumgartner et al. (2008) increased presence while riding a roller-coaster was related to visual and spatial brain regions. Similarly, in the study by Bouchard, increased presence related to believing oneself to be in a real room was related to activations in parahippocampal cortex, a brain region known to be involved in spatial/location processing.

It should be noted that none of the studies above allowed the user to interact with the environment. A recent study by Clemente et al. (2013) compares conditions in a manner similar to Baumgartner et al., but also includes an interactive condition. While this study has a lower number of subjects, making it somewhat harder to interpret with confidence, the primary findings are in line with Baumgartner et al. and other brain imaging studies comparing similar conditions, implicating DLPFC and spatial brain regions, among others.

fMRI may be the brain imaging method with the greatest promise for understanding brain measurements related to presence generally, but other methods may be more suitable for practical measurements. For example, EEG (electroencephalography) can be much cheaper and easier to use, with far fewer restrictions on possible interactions and scenarios. In one recent study, Kober et al. used EEG to compare a highly immersive VR-system with a less immersive VR-system (Kober, Kurzmann, & Neuper, 2012). Both conditions were interactive, differing primarily in visual field and use of stereoscopy. A comparison across subjects, with different groups for each condition, showed that an increased sense of presence in the highly immersive condition was accompanied by EEG measures signifying increased parietal activation, particularly compared to frontal brain areas. These results seem to agree with Baumgartner et al. in implicating parietal and frontal areas in the modulation of presence. It is interesting that the difference between the conditions is relatively small in this study, but given the poor spatial resolution of EEG some caution may be prudent. Additional studies conducted using commercially available and affordable EEG headset (Emotiv EPOC) (Clemente et al., 2012), or transcranial Doppler (TCD) (Rey, Parkhutik, Tembl, & Alcañiz, 2011) exemplify additional work towards practical brain measurements.

Kober and Neuper illustrate the conceptual overlap between behavioural, physiological and brain measurements in a recent study using EEG to measure brain activity triggered by sounds not related to VR (Kober & Neuper, 2012). The response to the external sounds was measured and related to reports of experienced presence. In principle, this type of response could have been detectable with behavioural or physiological measurements, but by using EEG one may be able to detect smaller, hidden, responses, making it possible to use less intrusive triggers (the sounds) and reduce unwanted impact on presence.

3.7 Conclusion to Chapter 3

As with brain imaging in general, "the conceptual challenge ahead may not lie in finessing the techniques at our disposal but informing the models used to explain data" (Friston, 2009a, p. 402). A theoretical understanding of presence in the simulating brain suggests rich explanations that provide a basis for the construction of such models. Previous studies relating brain measurements to the sense of presence provide valuable data for the initial comparison of models as well as for the continued generation of models and hypotheses.

While results based on comparisons of different environments may be influenced by the particular contexts, they provide important pieces to the puzzle. To improve the general understanding of the relation between brain measurements and the sense of presence, additional research investigating a varied set of environments and contexts would be very valuable. Moreover, established associations to brain activity, for example, in the DLPFC and parietal regions, may be further evaluated in relation to practical measurements in contexts and environments matching the corresponding studies. In either case the perspective provided by the simulating brain may be helpful in teasing out and explaining how differences in environments and contexts may impact presence and its neural correlates.

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