Working Memory and Presence: Reconsidering the Role of Attention in Presence

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Abstract

This paper presents a working memory based model of attention in presence, in which presence depends on the allocation of cognitive resources to process an environment. In the model, media decoders (cognitive modules specialized in decoding particular media) extract data about the environment in an abstracted form. In order for presence to occur, a certain amount of working memory is required for processing this abstracted data. However, as the extraction process itself requires working memory, the media can have a large impact on the presence experience. To demonstrate its usefulness, the model is used to explain Biocca's book and reality problems. To conclude, a load-based methodology for testing the model is proposed.

1. Introduction

Attention has been recognized as an important variable in presence (for instance in [1]). The importance of attention has been made pre-eminent by Biocca [2] in his posing of the 'reality problem' in presence theory. Briefly put, the 'reality problem' asks how it is possible for a person to be physically in an environment, and yet not experience presence there. This is a problem which affects most current presence theories – partly because they begin with an assumption that virtual environments are approximations to reality (for instance, [3]), and partly because they do not explicitly consider the role that attention plays in the cognitive processes which give rise to presence. This paper proposes that Baddeley's concept of working memory [4], which explicitly deals with the allocation of cognitive resources, can be fruitfully applied in presence research to explain a variety of phenomena such as the reality problem, the book problem, and why text-based virtual environments tend to produce inferior presence experiences to immersive displays.

2. Attention, presence and working memory

Attention as a variable in presence exists in numerous places in the literature. For example, Barfield & Weghorst [5], in proposing a conceptual framework, specifically formulate attention as a resource allocation process which acts as a mediator in presence. Similarly, Wirth *et al* [1] propose that before presence can occur, the media must attract and hold the subject's attention. Empirically, Schubert *et al* [6] in a factor analysis of eight questionnaires found attention as a first order factor.

2.1 Cognitive perspectives on attention

Attention and its relation to various tasks and cognitive processes is a well studied phenomenon in applied psychology. For example, [7] presents evidence of the importance of attention in relation to reading comprehension, and others have studied its role on the task of aviation (cf. [8] for a review). These tasks, like presence, involve inferring an environment from a set of perceptions. A large number of these explanations apply Baddeley's model of working memory [4]. The working memory system is similar to the better known short term memory system in that it has a limited capacity, but unlike short term memory, which is conceived mainly as a system involved in encoding memories and remembering, working memory is seen as a general purpose working space where cognitive processes are applied to data [4]. Working memory is thus not simply related to remembering and encoding memories, but rather as the site where most cognitive processes take place, and where the contents of awareness exist [4].

Working memory is often studied in relation to attention, and it is generally accepted that all stimuli which are attended to equate to the contents of working memory [9]. The relationship between selective attention and working memory is not as clear, although it is thought that working memory space is allocated to new stimuli based partly on the processes currently running in working memory [4]. What is clear, however, is that the amount of working memory resources assigned to a particular task is analogous to the amount of attention which is being focused on that task, and working memory is thus a useful indication of how much attention has been allocated to a task [9].

2.2 The allocation of resources to a task

How working memory is allocated to a task is a complex process. Simply having more information to process does not imply that more working memory will be allocated. Information which is meaningfully related is chunked into more abstract complexes, effectively freeing up working memory space [4]. Thus, a highly immersive display system which renders a large number of correlated variables may require little working memory to process, as the information can be easily chunked; however, if a latency were to develop in the display of one of the variables or channels (for instance, in sound rendering), then the temporal discrepancy would prevent the chunking of sound together with the other variables, and thus more working memory would be required to process the scene. This same mechanism can explain why stimuli which come from 'outside' the virtual environment (as discussed in [10]) can reduce presence – these stimuli will not chunk with the stimuli associated with the virtual environment, and will thus require more working memory to process. If enough of these distractions abound, then they will begin to impinge on the working memory which is necessary for successfully processing the virtual environment, and the subject will begin to become unaware of elements of the environment. This reduction in the amount of attention focused on the virtual environment will lead to a reduction in the sense of presence.

2.3. The link between working memory and presence

An important question that remains is how presence is linked to working memory. The working memory model has been used to explain phenomena which, from a micro-cognitive perspective, are similar to presence. These include investigations into working memory in reading comprehension [7], as well as studies on working memory and navigation [11]. These tasks involve the processing of a subset of external stimuli so as to decode some meaning (be it spatial or otherwise) to allow further inferences about the space or behaviour in the space. If one accepts that such a processing task is necessary for presence, and given that all processing requires some working memory, then it follows that for presence to occur, some amount of working memory will be required to process the environment.

Using working memory in this way changes the relationship between presence and attention slightly. Rather than considering attention primarily as a filter or selector for external stimuli, this view considers attention as the allocation of cognitive resources (in the form of working memory) for the processing of particular aspects of the external stimuli or environment. Thus, instead of thinking about presence occurring because the virtual environment is being attended to rather than the real environment, or because the real environment is not providing any distractions [10], one would speak about the amount of working memory allocated to processing the virtual environment. From the working memory perspective, distracters from outside the virtual environment negatively affect presence because they require working memory to process; this in turn must be taken from the limited pool of resources which are also being used to process the virtual environment.

3. Working memory and the processing of media: A two-process model

Central to applying working memory theory to presence research is an idea of the role that working memory plays in the processing of media, given that all virtual environments are encoded in some medium [12]. This is a particularly interesting problem, because presence can arise from a wide variety of sources, from text-based media to highly immersive media such as a cave display. From a cognitive perspective, one might pose the problem thus: How can virtual environments be encoded in a variety of representations while still having the same basic cognitive effects?

One possible solution to this problem comes from separating the act of processing a virtual environment into two sub-processes. In the first process, the medium which encodes the environment is decoded so as to transform the perceptual stimuli into more abstract representations (such as scripts or schemata [13] or spatial situation models [1]). Then, in the second process, these representations are used to draw inferences and make decisions about the virtual environment. It is during this second process, when higher level cognitive processing is occurring about the virtual environment, that presence is most likely to occur [1]. Shifting the 'presence cognitive event' (if one may be so vague) to the second process in this way allows this simple model to predict presence occurring regardless of the medium that the environment was encoded in (as suggested in [14]).

3.1 Media decoders and working memory allocation

The mechanism by which perceptual stimuli are decoded (the first process discussed in section 3 above) is a complex one, because the specific processes applied to the stimuli will vary depending on the way the stimuli are encoded. For example, decoding a photograph of a room requires different cognitive processes to decoding a verbal description of that room, even though the final product of that decoding will be similar in both cases. Also, it is important to consider that media require varying degrees of effort to decode – for instance, decoding a photograph occurs much faster and with less conscious effort than decoding a written text. Finally, one needs to take into account individual differences with regard to the ease with which people are able to decode some media (for instance, reading skill increases with age and with practice [7]).

One can model this process by considering the decoding of each medium as being done by a separate cognitive module whose input is a set of perceptual stimuli, and whose output is a set of abstract representations of the content of the medium (schemata, spatial situation models, etc.). Each of these media decoding modules is a collection of strategies and processes for decoding a particular medium; thus one can think of there being a writing decoder (after evidence from [7]), a film decoder (after evidence from [15]), a diagrammatic decoder (after evidence from [16]), and so on. When a new set of perceptual stimuli are considered for processing, the appropriate media decoder would be selected on the basis of a small set of key features in the stimulus set (for instance, the basic shape of letters in the spatial memory buffer might trigger the writing decoder). Once the media decoder has been activated, it would proceed to decode the stimuli. If a media decoder attempts to decode the wrong type of medium (for instance, in the case of a picture being embedded in text as occurs in a magazine), then the error would signal for the selection of a new decoder.

One can link the notion of media decoders to working memory without much difficulty. Because decoding a stimulus requires cognitive processing, it will therefore require some degree of working memory [4]. How much working memory a particular media decoder will use is, however, a complex question which will require empirical investigation. It seems reasonable to suggest that decoding some media will require more working memory than decoding others. For instance, images and video are relatively easy to decode (partly because there are brain structures which are specialized for this task), whereas writing is harder to decode (as it requires first a visual pass to decode individual letters and words, and a parallel second semantic pass to decode the meaning of the sentences as a whole [7]). It also seems reasonable to suggest that some media decoders become more efficient with use and practice; for instance, reading requires time to learn and generally improves with practice, eventually becoming effortless. Similarly, some film genres make use of conventions which must be learned at first, but are later decoded with little effort [15]. From a working memory perspective, this increase in efficiency of the decoding process and associated subjective sense of effortlessness comes from a decrease in the amount of working memory used by the decoder [4].

4. Addressing the book and reality problems with working memory

An important question that one might ask about the use of working memory theory in presence is 'does it work?' Clearly, empirical evidence would be the most satisfactory way of answering such a question (see section 5 below for a discussion of how this evidence could be collected). Given that this idea is still in its preliminary stages, an alternative method of checking its validity can still be applied – by checking if the model is capable of responding to the book and reality problems [2]. These problems were posed as general limitations of current presence theories (particularly those which emphasize the role of immersion and underemphasize the role of attention). Therefore, it seems that any new theory of presence, particularly one dealing explicitly with attention and non-immersive environments, should be able to respond to these two problems.

4.1 The reality problem

The reality problem deals with a common experience – someone who, while physically in the real world, experiences very little presence there (due to the subject being lost in their thoughts or something similar). In this situation, the fact that the subject is completely immersed with 'high-fidelity' sensory stimulation from the environment seems to have little effect on presence. Working memory can be used to explain this by examining the cognitive state of the subject. What are the contents of working memory at the time? If the subject is thinking deeply about something other than the environment they are in, then very little working memory capacity is likely to have been allocated to processing the environment. Thus, very little information exists for the drawing of inferences about the environment or about even forming memories of their experience; indeed, if the environment is not allocated much working memory, the subject will not even be aware of it [4], and so very little presence will result. Applying working memory theory to the reality problem has the further benefit that it allows one to explain this phenomenon in degrees (one could be said to be more or less present in one's environment even if lost in thought). This is explained by stating that the degree of presence in any environment (real or otherwise) is a function of the amount of working memory allocated to processing that environment. Thus, if one is paying a little attention to the environment, only a small amount of working memory will be allocated, and a maximum of only a little presence can be expected. However, if a lot of attention is given to the environment, then a lot of working memory will be allocated, and the maximum amount of presence expected will be large. Note that under this model, the amount of working memory allocated to processing the task does not guarantee an increase in the degree of presence experienced. The amount of working memory allocated only predicts the maximum degree of presence which a subject can experience. If the display system represents low fidelity or low-immersion stimuli, then the presence experience will not be particularly intense, regardless of the amount of working memory allocated to processing the environment [5].

4.2 The book problem

The book problem asks how books, arguably the lowest form of immersive display, can lead to presence experiences. The two-process model described in 3.1 above, together with media decoders and working memory can be used to respond to the book problem. In the two-process model, presence is seen as occurring in the second process and therefore the medium representing the environment is relevant only in terms of how it is decoded by the relevant media decoder. Thus, if a decoder is available for the given medium, and the decoder does not use too much working memory for processing, enough working memory should be available for the second process, and thus presence is a possibility.

If one takes into account that media decoders can account for individual differences in media competency (as discussed in 3.2 above), then it is also possible to explain individual differences in presence experiences (as discussed in [14]).

5. A working memory methodology for presence

As working memory has been well researched by psychologists, it would be sensible to consider their methods and adapt them to presence research. In general, working memory research makes use of a *memory load* paradigm, which is used to investigate to what extent a particular main task (such as navigation or reading) relies on working memory. Subjects are divided into groups, each of which is given a loading task of varying intensity. This loading task (for instance, remembering a list of unrelated items [4]) is used to place a demand on the working memory systems and is performed simultaneously with the main task under investigation. The intensity or load of the loading task is then the independent variable of the study, and performance on the main task is the dependent variable. The degree to which the main task makes use of working memory will be shown by the rate at which its performance declines with increasing working memory load (cf. [4] for numerous examples of this paradigm in use). In a presence study, memory load tasks can be easily integrated into a virtual environment. Integration can prevent confounds related to having a task which is unrelated to the environment and may become a distracter. One might, for instance, create a task where the subject is required to gain and remember passwords (for loading semantic working memory) or button press sequences (for loading spatial working memory) to progress through the virtual environment. Such a task would allow the experimenter to vary the memory load (length of the password, for instance), but because the task is integrated into the virtual environment, it would not act as a reminder that the subject is in an experiment and thus break presence. This ensures that the task serves only to load working memory rather than moving the subject's focus away from the experience of being in a virtual environment to the experience of being in an experiment.

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