The Virtual Ante-Room:

Assessing Presence through Expectation and Surprise

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Abstract

We describe an experiment where subjects entered a virtual replica of the laboratory in which the experiment was taking place. They then moved through a door to a new virtual location and carried out the main experimental task, and then returned to the virtual lab. In the real lab they had learned to search for box-shaped objects and point at a telephone whenever it rang. In the virtual lab, additional colouredboxes were introduced, and although the virtual phone position was not moved, the real phone of which it was a replica was moved. On exit from the virtual to the real laboratory, subjects were asked about their degree of surprise that the additional coloured boxes were not there and that the phone had been moved. This was in the context of an experiment to assess the influence of body movement on presence. This paper reportson the relationship between this surprise factor and the presence reported for the main part of the experiment. It was found that the surprise factor and reported presence were significantly positively correlated, suggesting a new approach towards a behavioural measure of presence.

Keywords: Virtual reality, virtual environments, presence.

1. Introduction

Suppose an individual receives sensory data simultaneously from two different environments E_R and E_V. For example, the individual is in a virtual reality laboratory and coupled to a computer system which through a head-tracked head-mounted display depicts an alternative environment to the laboratory. Suppose that E_R represents the (real) environment of the laboratory and E_V represents the virtual environment. Then the individual receives some sensory information from E_R and some from E_V. We can refer to $p(E_V \mid E_R)$ as the degree of 'presence' of the individual in environment E_V relative to E_R, and study the properties of the system that delivers E_V in terms of its effect on p. In previous work (Slater, Usoh, Steed, 1995) we have used the term 'immersion' to describe those objective factors that characterise a system and which can influence p:

- *Inclusive* The extent to which sensory data from the real world is shut out.
- *Surrounding* The extent to which sensory data can be delivered from any direction.
- *Extensive* The range of sensory modalities accommodated.
- *Vivid* The resolution, bandwidth and 'realism' of the displays.
- *Matching* The degree of temporal and semantic correlation between changes to sensory data and kinesthetic proprioception.
- *Eventful* The extent to which there are events in the VE that are independent of the volition of the participants, the extent to which the VE portrays a meaningful scenario.

An understanding of the relationship between these relatively complex factors and presence, would constitute a theory of VEs, affording the construction of systems that offer trade-offs between the various factors in order to achieve high presence, and this has been the goal of many researchers in recent years (Heeter, 1992; Held and Durlach, 1992; Loomis, 1992; Sheridan, 1992, 1996; Steur, 1992; Ellis, 1996; Zeltzer, 1992) and there have been several empirical studies of contributing factors (Barfield and Weghorst, 1993; Barfield et. al., 1995; Hendrix and Barfield, 1996a, 1996b; Welsh et. al., 1996). A practical question of interest would be precise understanding of whether it would be possible to trade the total system lag (part of 'matching') against realism (part of ‘vividness’) while maintaining a constant level of presence (Ellis, 1996).

This begs the question as to why ‘presence’ should play such a central role. We would argue that presence is the special affordance of virtual reality systems - if presence is not required (and, of course, the vast majority of computer applications do not require presence in a VE) then there is no point in using an immersive VE system. For example, if the issue is only one of effective visualisation of a complex 3D object, then a high resolution desktop stereo display may be far more effective than a fully immersive VE. On the other hand if it were crucial to the application that participants exhibit behaviours ideally the same as those that would have been induced by comparable circumstances in everyday reality, then presence is essential. An ideal example of this is the use of immersive VEs for the treatment of various phobias (for example, Hodges, et. al., 1996).

In order to construct a predictive theory of presence, there must be an agreed operational definition that can lead to measurement. In practice the definition is implicit in the form of measurement, and the degree of presence is constructed from a questionnaire administered after a VE experience. Other methods attempt to measure some behavioural correlate of presence - observable and measureable actions by the subjects in the experiment that can *a priori* be assumed to be signs of presence.

In this paper we introduce the beginnings a new method that attempts to assess presence in the VE experience through observations on the behaviour of participants in E_R *after they have exited* the VE. The new method arose in the context of an experimental study designed for another purpose, to be discussed in the next section. In this paper we examine the relationship between the traditional questionnaire based measure of presence and the new approach, and assess the implications of the relationship. The method also offers a useful practical procedure for initiating someone into a VE experience, offering an elegant transition from everyday reality, into the VE, and out again, including the opportunity for adaptation and training in a ‘natural setting’.

In the next section we briefly describe the overall experiment in which these observations arose, and describe the details of the experiment itself in Section 3. The results are given in Section 4, and discussion of the implications in Section 5. Conclusions including the future work on this idea are presented in Section 6.

2. Description

2.1 Overall Experiment

The work described in this paper is based on our recent experiment (Slater, et. al., 1997) to assess the impact of the extent of body movement on presence (this is under the heading of ‘matching’ in the dimensions of immersion). The major hypothesis of that study was that the greater degree of body movement carried out by participants (head rotations and also bending down and looking up) the greater the degree of presence, other things being equal. A secondary factor was the influence of task complexity on presence - the hypothesis being that greater complexity would also lead to higher presence (this is under the heading of ‘eventful’).

The scenario consisted of a field of trees (also referred to as plants) with large leaves, scattered at random through the field. Half the subjects were put into a field where the heights of the trees varied considerably, some being much below head height and some very much taller. This is subsequently referred to as the High variation field. The other subjects, were put into a field where the tree heights were all above normal standing eye level (the Low variation field). Healthy plants had green leaves and diseased plants could be distinguished from healthy ones because the *underneath* of their leaves were shown as discoloured (brown). Moreover, for the trees in the High variation field the leaves were folded inwards in such a way that it would only be possible to see their underneath by looking upwards while underneath the tree. For the Low variation field the leaves were arranged in such a way that it was possible to see their underneaths by looking approximately at eye height in a standing position.

All subjects were asked to move through the field in any direction they preferred, and to count the number of diseased plants. A more complex task was also given to some subjects, not only to count the number of diseased plants but *also to remember* where they were in order to later draw a map showing their distribution throughout the field (Task R). The purpose here was to examine whether the more complex task would affect presence. The factorial design for the experiment was 2×2, there being 20 subjects in total, 5 for each cell of the design.

The subjects were recruited by the Department of Psychology and paid £5 each for completion of the full experiment and all questionnaires. Most of the subjects were students (3 undergraduate, 8 Masters, 4 PhD), and there were 3 Research Assistants, 1 member of the administration and 1 journalist. There were 13 male subjects.

There were 150 trees in each scene, randomly distributed in a garden of dimension 90m×75m. Each tree is 2.4m across, and has 16 leaves. There are three classes of tree in equal proportions (50 each), one healthy, one with 1 bad leaf, one with 4 bad leaves. For the Low variation scene the distribution of heights was 1.7m ± 0.1m, and 2.35m ± 1.9 for the High variation field.

2.2 Measuring Presence

We measured presence in two ways - a subjective self-reporting questionnaire based measure that we have used in several experiments before, and also a behavioural measure. We call the first 'subjective presence' and the second 'behavioural presence'.

Subjective Presence

We have developed a questionnaire-based measure of subjective presence based on the following attributes:

1. *there* - the sense of 'being there' in the virtual field as compared to being in a place in the real world;
2. *real* - the extent to which there were times when the virtual field became the presenting reality - to the extent that the subject 'forgot' that they were standing in a laboratory wearing a head-mounted display;
3. *visit* - the extent to which the virtual field is remembered more as images that were seen, or more as somewhere that was visited;
4. *lab* - the strongest on the whole, the sense of being in the virtual field, or of being in the real world of the laboratory;
5. *struct* - the similarity in terms of the structure of the memory of the virtual field to the structure of the memory of other places;
6. *whelm* - the extent to which the experience was one of standing in an office wearing a helmet or whether the virtual field became overwhelming.

The full set of questions is shown in Appendix A. These are presented on a 1 to 7 scale where the higher score always means higher reported presence. We then construct a conservative measure as the number of high responses (scores of 6 or 7) in the answers to the six questions. We prefer this method on statistical grounds because it does not involve treating the ordinal response data in any way as if it were interval data, and a binomial logistic regression can be used for analysis.

Behavioural Presence

Behavioural presence may be observed when subjects respond to events in the VE as if they were equivalent events in a real-world context (for example, exhibiting behaviour associated with vertigo in response to a virtual precipice). A correlate of this is that if conflicting information about an event or object in the VE is simultaneously presented to a subject, some data originating from the real world, and other data originating from the VE, then high behavioural presence should result in the subject responding to the virtual rather than the real information.

We have used this idea to construct a behavioural presence measure. We keep an object invariant between E_R and E_V - in other words, before entering the VE the subject is made aware of an object in the real world of the laboratory, and made to carry out some action in relation to that object in response to a stimulus - for example pointing it in response to a sound. When they don the head-mounted display, they see a virtual representation of that object at the same position in the visual field as in the laboratory, and again are asked to respond to the stimulus in the same way. During the course of the VE experience, the real object is moved so that the stimulus may be heard to come from a direction incompatible with the visual location in the VE. When the subject points at the object, the more behaviourally present they are the smaller the pointing angle to the virtual position of the object - they are responding to the virtual visual information rather than to the real auditory information.

This argument is only valid if sensory dominance is factored out - i.e., the pointing behaviour should be associated purely with the degree of presence, and not the degree of sensory preference for visual or auditory information. We therefore also take independent measurements that relate to sensory dominance, and use this in analysis to factor out its influence.

We first used this procedure in an attempt to examine the effect of dynamic shadows on presence (Slater, Usoh, Chrysanthou, 1995). In that case subjects were asked to point to a radio whenever it emitted a certain sound. In the VE the radio was located in the same place with respect to the subject as in the real world, and at moments throughout the experiment the subject was required to point at 'the radio' - except that the real sound source had been moved relative to the (virtual) visual location. The angle between pointing direction and position of the virtual radio was found to be correlated with the questionnaire based subjective presence score, after factoring out sensory dominance. In the current experiment a modified form of the same idea was used, described in the next section.

3. Methods

3.1 Experimental Procedures

Before the subject donned the HMD they were shown a telephone in the *real laboratory* of the experiment. They were trained as follows: first they were asked to look for any box-like shape in the laboratory and remember its colour. When the phone rang they were asked to point at the phone, say "Stop!" and then call out the colour of the box that they had seen. They repeated this procedure several times until they could do this task with ease. One purpose of the search for the box was to simply distract the subject between phone rings - another purpose is described later. When they donned the HMD they were placed in a virtual environment that was a rendition of the *same laboratory in which they were actually standing* with the phone registered in the same position. The experimentor continued to refer to what they were experiencing as "being in the lab", and asked them to repeat the same task with the virtual phone (referred to as "the phone" as if it were the real phone). Now, however, additional virtual coloured boxes were placed into the environment that were not in the real lab. Once again the subjects were trained to point at the phone whenever it started to ring, and in between phone rings look around for coloured boxes.

After this short training session with the phone, the subjects were asked to look around "the lab", and instructed to turn their head, bend down, stand up, so that they realised that these actions were possible. Then they were asked to turn around 180 degrees, and locate the door to the lab. They were told that when the door opened they should go through it, and they would enter the field of plants. The field was located beyond the door, and from any position in the field it was possible to see the door back to the lab. The subjects then went into the field and carried out their task. This continued for about 3 minutes. They were told beforehand that they were to begin to make their way back to the lab, though still continuing with their task, once the sky became brighter (the sky started off as black, but after 3 minutes it became light blue).

During the time that they were in the virtual field, the experimentor said nothing. On returning back to the 'lab', the experimentor said "Welcome back! Well done!" and continued to talk as if they were back in "the lab". The subjects were positioned both virtually and really in the same relationship to the phone as they had been originally.

Now five times they repeated the task of searching for a coloured box and pointing at the phone whenever it started to ring, as before. This time the real phone was moved to five preset random positions, so that the real sound direction would be conflicting with the visual place of the virtual phone. (One subject asked to which direction should he be pointing.The experimentor replied "Just point at the phone."). Each time that they pointed, the pointing angle was stored into a data file.

After this procedure the subjects were asked to look around the lab once again, and then the HMD was removed, and again they were asked to look around the lab. After this the questionnaires were administered.

3.2 Equipment

The scenarios were implemented on a Twin 196 Mhz R10000 Silicon Graphics Infinite Reality system with 64M main memory. The software used was DIVISION's dVS and dVISE 3.1.2. The tracking system was with two Polhemus Fastraks, for the HMD and a 5 button mouse. The helmet was a VR4 which has resolution 742×230 pixels for each eye, 170,660 colour elements and a field-of-view 67 degrees diagonal at 85% overlap.

The total scene consisted of 32,576 triangles (almost all of these accounted for by the 150 trees) which ran at a frame rate of no less than 10Hz in stereo. The display lag was approximately 100ms.

Subjects moved through the environment in gaze direction at constant velocity by pressing a thumb button on the 3D mouse. Subjects had a simple inverse kinematic virtual body. Most of the time subjects only became aware of their virtual arm and hand though because of the relatively limited field of view.

3.3 Response Variables

The main focus of this paper is a score based on two questions administered immediately after the subjects exited the virtual reality laboratory. The questions were premised on the idea that for subjects highly present in the VE, there would be an *expectation* that the real lab would reflect any changes made in the virtual lab. Hence, the two questions were concerned with the extent to which subjects were *surprised* to see that the real telephone had been moved once they had taken off the HMD, and also the extent of surprise that the coloured boxes introduced in the virtual lab were not actually present in the real lab. These questions were the reason why the subjects were asked to look around the virtual and then the real lab at the conclusion of the experiment. These two questions were also measured on a 7-point scale, where the higher score indicated higher degree of surprise (Appendix B).

These two variables were combined into one overall 'surprise' variable (S) by taking the square root of their product (geometric mean). Their product would give a very high value for high surprise scores on each of the responses, a medium value for a high response on one variable, and a low score in the case of a low score on both variables. The square root was used to return to the original units of the 7-point scale.

Although here we are violating our rule of not using ordinal data as if it were interval data, this is justified in a spirit of data exploration rather than hypothesis testing. The experiment was not originally designed for the purposes we describe in this paper; rather the results we achieve here justify further rigorous experimentation with a suitable scoring method, taken up in Section 6.

3.4 Explanatory Variables

Presence

There were two measures of presence - considered as response variables for the main purpose of the study concerned with body movement, but as explanatory variables in this study. The response variable is the number of 'high' scores out of the six questions, as explained earlier. The angle measure, that is the angle between the pointing vector to the phone and the vector to the virtual phone in relation to the subject is the other measure for presence.

Information was collected on many other variables. We mention here only one that proved relevant for this particular study: The extent to which subjects were disturbed by sounds in the real environment of the lab during their VE experience (this was measured on a 7-point scale - Appendix B).

4. Results

4.1 Results of the Main Study on Body Movement

The main study supported the notion that presence is positively associated with body movement. This proved to be the case both for the subjective questionnaire based measure and for the behavioural measure. Moreover, taking into account sensory dominance, the behavioural measure based on pointing angle was correlated with the questionnaire based presence count.

4.2 Results for the Surprise Response

The interest here is whether there is any relationship between the 'surprise' score (S) and the presence scores: between the degree of surprise that that the phone and boxes in the real lab were not the same as in the virtual lab immediately before exit from the VE.

Table 1
Mean and Standard Deviation of Surprise Score by Tree Level

Tree Height Variation	Mean±SD	Min, Max
Low (n=10)	1.50 ± 0.52	1.00, 2.24
High (n=10)	3.20 ± 2.00	1.41, 7.00
Combined (n=20)	2.35 ± 1.66	1.00, 7.00

Table 1 shows the mean S score for the Tree height factor (there were no significant differences for the Task factor). This suggests that there was a higher surprise level for the group that required greater body movement in order to complete their task. The difference is statistically significant (on a two-tailed t-test at the 5% level) but this result should be treated with caution because of the large difference between the two standard deviations.

A regression analysis was carried out with S as the response variable on the independent and explanatory variables of Section 3.4. The main focus was on the relationship between the presence scores and S. There was no significant relation found between S and the behavioural angle measure, although there were significant correlations with the subjective questionnaire based presence scores.

The Overall Presence Count

First we consider the overall presence count (pres) as constructed from the questionnaire responses. The best fitting regression model found that included this presence count is shown in Table 1. The variable 'sound' refers to the extent to which subjects were aware of background sounds from the real laboratory in which the experience was taking place. A higher score indicates greater awareness. This factor proved significant in all the models tested for this study.

Table 2(a)
Regression for S on Presence Count and Tree Height and the Influence of External Sound

$R^2 = 0.74$, $F(1,14) = 4.60$ (5%)

Parameter	Estimate	S.E.	F-Ratio df=1,14
Const.	1.40	0.95	
tree(2)	-2.18	1.28	
pres	0.049	0.16	
sound	-0.027	0.19	
tree(2).pres	0.67	0.25	7.39
tree(2).sound	1.15	0.32	13.23

Table 2(b)
Fitted Regression Models
Non-significant Estimates are in *Italics*

Tree Var.	Fitted Model for S
(1) Low	1.4 + *0.05*pres - 0.03*sound*
(2) High	-0.77 + 0.72*pres + 1.12*sound

In Table 2(a), tree(2) refers to the high tree variation field. The '(2)' indicates that the parameter estimate shown corresponds only to the *change* in coefficient induced by adding in the second level of the tree factor. The significance of tree(2).pres and tree(2).sound shows that the regression models are significantly different for the two levels of tree height. For the lower variation in tree height these coefficients are not significantly different from zero, but are positive for the higher variation in tree height (i.e., where participants were forced to often bend down and look up in order to carry out their task).

The fitted model is shown in Table 2(b), indicating that the degree of 'surprise' increases with an increasing presence count score, and also with the extent to which subjects were disturbed by external sounds from the real environment.

Components of Presence

As well as examining the influence of the overall presence count, we can also consider the individual components contributing to this count. Three of the components were significant, shown in Table 2.

Table 3(a)

Regression for S on Presence Count and Tree Height and the Influence of External Sound

$R^2 = 0.94$, $F(1,11) = 4.84$ (5%)

Parameter	**Estimate**	**S.E.**	**F-Ratio df = 1,11**
Const.	1.62	1.15	
tree(2)	-7.84	1.53	
sound	0.002	0.10	N.S.
visit	0.12	0.11	N.S.
struct	-0.42	0.20	N.S.
whelm	0.33	0.10	10.83
tree(2).sound	1.24	0.17	52.10
tree(2).visit	0.56	0.21	7.38
tree(2).struct	0.97	0.22	18.91

Table 2(b)
Fitted Regression Models
Non-significant Estimates are in *Italics*

Tree Var.	**Fitted Model for S**
(1) Low	1.6 + 0.33*whelm + *0.00*sound + 0.11*visit - 0.42*struct*
(2) High	-6.2 + 0.33*whelm +1.2*sound + 0.68*visit + 0.54*struct

The results suggest that independently of the variation in tree height, the 'whelm' component of presence (the virtual field of plants overwhelming the real lab) is positively associated with S. For the high variation field, there is positive association with awareness of outside sounds, and additionally the presence 'visit' (the virtual field was remembered as somewhere visited rather than just images seen) and 'struct' (the structure of the memory was similar to the structure of the memory of other real places).

5. Discussion

In the experiment described in this paper we placed subjects at the beginning and at the end of their VE experience in an environment which was a replica of the virtual reality laboratory in which the experiment took place. The subjects carried out tasks in that virtual lab, and observed changes to the lab during the course of this (the addition of the coloured boxes). Their task was also concerned with a telephone. On exit from the virtual reality, they could observe that there were no additional boxes in the real laboratory, and also that the phone had been moved. We have focused on whether their degree of surprise at these changes is related to their presence in the virtual field of plants (the major issue of the experiment).

Although the statistical analysis we have used is not ideal (regression analysis using ordinal scales as the response variable), treated as an initial data exploration, the results are nevertheless strong, and suggest the following: Taking into account the experimental conditions (variation in tree height) those subjects in the high variation virtual field, where more body movement was necessary in order to carry out their task, had a greater degree of 'surprise' about the changes from virtual to real the greater their subjectively reported presence. This 'presence' was measured conservatively as the number of high responses out of six questions, and individually for the presence components.

There was also a positive association between the degree of surprise and the extent to which subjects were aware, while in the VE, of sounds from the outside laboratory. It is not clear why there is such a strong correlation in this case. However, the question referred to the virtual reality experience rather than any particular part of it (i.e., did not differentiate between the field of trees and the virtual lab). It could be the case that such people are 'more observant' of their surroundings, and so would tend to be aware of changes in their environment - and be more surprised when those changes are inconsistent.

Although there was no correlation with the behavioural presence score based on the angle between the vector to the virtual phone and the pointing angle, there is a similarity in structure between the two procedures. In the angle pointing method, there is a synchronous anomaly between visual information from the VE and auditory information from the real world. The hypothesis is that the subject selects a response appropriate to the environment in which he or she has the strongest presence. In the new procedure there is an asynchronous visual anomaly (the location of objects) between the real environment and the virtual representation of that environment. The subject would be expected to have a 'surprise' response in conditions of presence in the virtual environment. In this experiment we have noted a correlation between the surprise response and the reported presence in the virtual field of trees - indicating that the 'presence' carried over from one virtual location to the other.

6. Conclusion

The results discussed above are clearly tentative. But they suggest a better procedure for a subsequent purpose-designed study - where the presence measures can be based on behavioural responses rather than reported levels of 'surprise'. Suppose that on entry to the real lab the subject places a number of objects in different concealed places, such as cupboards. Then in the virtual lab, the subject moves these objects to different places. On exit from the VE, the subject is asked to find the objects. Now is the search relative to the original real position of the objects or to the virtual positions? Such a procedure would result in observations that can form a new behavioural measure. The question here would be whether presence in the virtual lab (as indicated by subsequent behaviour in the real lab) indicates also presence in the main part of the VE experience in another virtual location doing different tasks. Our preliminary conclusions are that there would be such a relationship.

As well as basing presence measures on the idea of bracketing VE experiences between time in a virtual lab replica, there is another advantage to this idea. It offers a gentle transition from the real world into the virtual world and out again. It also affords the opportunity for experimentors to train subjects in the VE without introducing yet another virtual location simply for the purposes of training. In itself it may also enhance presence - for it is similar to the idea of 'stacking environments' introduced in (Slater, Usoh, Steed, 1994) where subjects enter a VE and then another one within that up to several layers of VEs within VEs. That procedure in itself was found to increase presence under the appropriate circumstances.

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Appendix A - Presence Questions

These questions were scattered throughout a larger questionnaire.

1. Please rate *your sense of being in the field amongst the plants*, on the following scale from 1 to 7, where 7 represents your *normal experience of being in a place*.
I had a sense of "being there" in the field:
1. Not at all ... 7. Very much.

2. To what extent were there times during the experience when the virtual field of plants 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?
There were times during the experience when the virtual field became more real for me compared to the "real world"...
1. At no time ... 7. Almost all the time.

3. When you think back about your experience, do you think of the virtual field more as images that you saw, or more as somewhere that you visited ? Please answer on the following 1 to 7 scale:
The virtual field seems to me to be more like...
1. images that I saw ...7. somewhere that I visited.

4. During the time of the experience, which was strongest on the whole, your sense of being in the virtual field, or of being in the real world of the laboratory?
I had a stronger sense of being in...
1. the real world of the laboratory ... 7. the virtual reality of the field of plants.

5. Consider your memory of being in the virtual field. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the field, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.
I think of the virtual field as a place in a way similar to other places that I've been today....
1. not at all ...7. very much so.

6. During the time of the experience, did you often think to yourself that you were actually just standing in an office wearing a helmet or did the virtual field of plants overwhelm you?
During the experience I often thought that I was really standing in the lab wearing a helmet....
1. most of the time I realised I was in the lab ... 7. never because the virtual field overwhelmed me.

Appendix B - Some Additional Questions