SPECIAL SECTION

The Influence of Body Movement on Subjective Presence in Virtual Environments

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We describe an experiment to assess the influence of body movements on presence in a virtual environment. In the experiment 20 participants were to walk through a virtual field of trees and count the trees with diseased leaves. A 2 × 2 between-subjects design was used to assess the influence of two factors on presence: tree height variation and task complexity. The field with greater variation in tree height required participants to bend down and look up more than in the lower variation tree height field. In the higher complexity task participants were told to remember the distribution of diseased trees in the field as well as to count them. The results showed a significant positive association between reported presence and the amount of body movement – in particular, head yaw – and the extent to which participants bent down and stood up. There was also a strong interaction effect between task complexity and gender: Women in the more-complex task reported a much lower sense of presence than in the simpler task. For applications in which presence is an important requirement, the research in this paper suggests that presence will be increased when interaction techniques are employed that permit the user to engage in whole-body movement.

INTRODUCTION

When people are given information about an environment, they may have a sense of being present in that environment to a greater or lesser extent. In particular, when people receive sensory data from one environment (e.g., kinesthetic and tactile information from the real world) and different, perhaps contradictory, data from a competing environment (e.g., visual and auditory data from a computer-generated virtual environment), they may be more or less present in each environment. *Presence* refers to the sense of "being in" an environment and makes sense only when speaking about the degree of presence in one environment relative to another (Slater, Usoh, & Steed, 1994). This is because a conscious individual receiving sensory stimuli from only one environment is, by definition, present there. When competing stimuli are simultaneously received from multiple environments, there arises the issue of which environment, if any, comes to dominate and why. The main hypothesis of the experiment carried out in this paper is that the environment relative to which major body movements are made has a higher probability of being the dominant presence environment, other things being equal.

Presence may be subjective or behavioral. *Subjective presence* refers to what an individual will express in response to questions about "being there." Behavioral presence refers to observable responses to stimuli. Although related in practice, there is no necessary logical connection between these two – we think of subjective presence as being a verbal and necessarily conscious articulation of a state of mind, whereas we think of behavioral presence as being automatic, unplanned, nonconscious

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bodily responses. Both types are important: Subjective presence is essentially an evaluation of an experience, whereas behavioral presence concerns responses to events in the environment in question – clearly important in applications such as training and psychotherapy (Hodges, Rothbaum, Watson, Kessler, & Opdyke, 1996). Likewise, presence may be measured by subjective means, such as questionnaires, or through observation of behavior.

Presence research has focused on definition and ideas for measurement (Ellis, 1996; Heeter, 1992; Held & Durlach, 1992; Loomis, 1992; Sheridan, 1992, 1996; Slater & Wilbur, 1997; Steuer, 1992; Zeltzer, 1992), and there have been several empirical studies of contributing factors (Barfield & Weghorst, 1993; Barfield & Hendrix, 1995; Hendrix & Barfield, 1996a, 1996b; Slater, Usoh, & Steed, 1995; Welch, Blackman, Liu, Mellers, & Stark, 1996). Some of the factors studied are the effect of visual display update rate, characteristics of the visual display system, the influence of spatialized sound, head tracking, and interaction.

This paper describes an experiment that examines the influence of two factors on subjective presence in virtual environments: the extent of body movement and the complexity of a task undertaken in the environment. The major focus is on body movement, which has important practical consequences for the design of interactive paradigms in virtual environments (VEs).

This study is motivated by two considerations. The first is anecdotal: We have observed hundreds of participants in head-mounted-display-based "virtual reality" over the past six years. When people first don the head-mounted display (HMD), they frequently treat it as they would a computer screen and just stand rigidly looking ahead. When they are told to move – for instance, to turn their head, bend down, reach up, or look under – they frequently have an observable "aha!" type of experience indicating a transition from low to high presence. It is this effect of body movements on presence that is explored via the experiment reported in this paper.

The second motivation is a practical one. The goal is to construct interactive techniques that exploit the idea of whole-body gestures, in order to maximize presence. An assumption underlying previous work on body-centered interaction (Slater & Usoh, 1994) is that whole-body movement semantically appropriate to the task will enhance presence. This has been experimentally tested in the context of ground-based locomotion (Slater et al., 1995) but not in a more general setting. This is the major purpose of the work described here.

SUBJECTIVE PRESENCE

The vast majority of studies measure presence through questionnaire and are thus eliciting subjective presence. Witmer and Singer (1998) have developed an extensive presence questionnaire. However, their approach mixes what we have called *immersion* (the objective factors such as field of view, display resolution, and degree of interactivity possible) and the psychological and behavioral response to these factors that we term as *presence* (Slater & Wilbur, 1997). For example, their first question asks, "How much were you able to control events?" We see this as eliciting the participant's view of one of the aspects of immersion rather than being directly concerned with presence. Therefore, for this study, we preferred to use a questionnaire and methodology that we have used for several previous experiments (e.g., Slater et al., 1995).

Our questionnaire included six questions to be rated on a scale of 1 to 7, for which the higher score indicates higher reported presence. A conservative measure of subjective presence is then constructed as the number of high responses (scores of 6 or 7) in the answers to the six questions. Under the null hypothesis that scores are attributed randomly and independently, this results in a binomially distributed count (number of high responses out of 6) as the response variable, and logistic regression (McCullagh & Nelder, 1983, chapter 4) can then be used to analyze the responses. This method is preferred on statistical grounds because it does not involve treating the ordinal response data in any way as if it were interval data, and because it is appropriately conservative in measuring subjective phenomena.

The particular questions used in the current study, scattered throughout a larger questionnaire, were as follows:

1. Please rate *your sense of being in the field among 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 color, 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 realized I was in the lab . . . 7. Never because the virtual field overwhelmed me.

METHOD

Factorial Design

The overall purpose of the experiment was to assess the extent to which body movement – in particular bending down and turning the head around and up and down – influences presence. A scenario was devised that naturally would induce some participants to use bending and head movements more than others.

The scenario consisted of a field of unusual plants or trees with large leaves, distributed at random through the field (Figures 1 and 2).

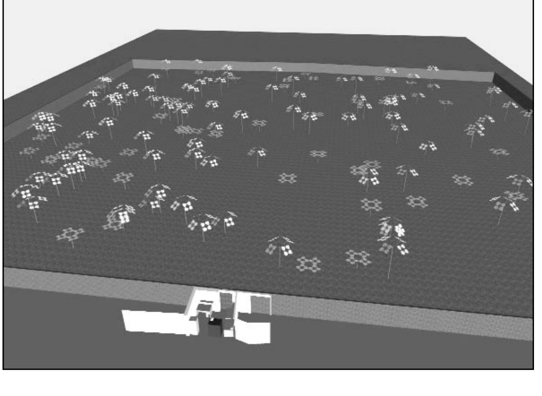

Figure 1. An overview of the scenario showing the virtual lab and the field of trees.

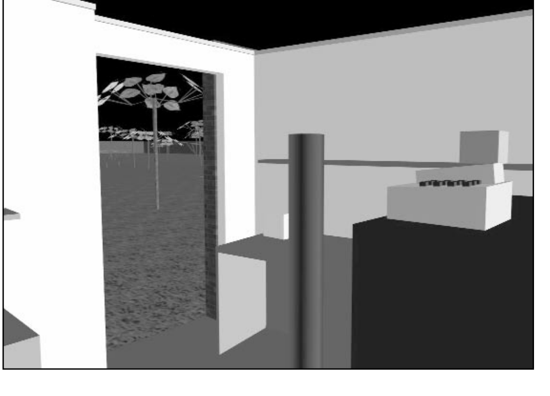

Figure 2. A view from within the virtual lab to the field outside.

Half the participants were put into a field where the height of the trees varied considerably, some being much below head height and some much taller. The other participants were put into a field where the tree heights were all above normal standing eye level. Healthy plants had green leaves; diseased plants could be distinguished from healthy ones because the undersides of their leaves were discolored (brown). Moreover, for the trees in the high-variation field the leaves were folded inward in such a way that it would be possible to see their underside only by looking upward while underneath the tree. For the low-variation field the leaves were arranged in such a way that it was possible to see their underside by looking approximately at eye height in a standing position.

All the participants were asked to move through the field in any direction they preferred and to count the number of diseased plants. Some participants were given a more complex task: 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. The purpose was to examine whether the more-complex task would affect presence.

There were 20 participants (13 men, 7 women), and a between-subjects factorial design was used with 5 participants in each condition. The participants were recruited by the Department of Psychology and paid £5 each (about $9 US) for completion of the full experiment and all questionnaires. Most of the participants were students (3 undergraduates, 8 master's-level, and 4 doctoral students), and there were 3 research assistants, 1 member of the administration, and 1 journalist. None had any involvement in the research or any knowledge of the purpose of the experiment.

There were 150 trees in each scene, randomly distributed in a garden 90 × 75 m. Each tree was 2.4 m across and had 16 leaves. The three classes of trees present (healthy trees, trees with one bad leaf, and trees with four bad leaves) were in equal proportions (50 each). The distribution of heights was 1.7 ± 0.1 m for the low-variation field and 2.35 ± 1.9 m for the high-variation field.

Procedures

When the participants donned the HMD they were placed in a virtual environment that was a rendition of the same laboratory in which they were actually standing. The experimenter continued to refer to what they were experiencing as "being in the lab," where they carried out some initial training tasks.

After this short training session, the participants were asked to look around the virtual lab and instructed to turn their heads, bend down, and stand up, so that they realized these actions were possible. Then they were asked to turn around 180° 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. Hence 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 participants then went into the field and carried out their task. This continued for about 3 min. 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 min it became light blue). From earlier pilot experiments it had been found that after about 3 min participants started to become visibly bored by the task.

During the time that they were in the virtual field, the experimenter said nothing. On their return to the virtual lab, the experimenter said, "Welcome back! Well done!" and continued to talk as if they were back in the lab. After another short set of tasks the participants were asked to look around the lab once again. Then the HMD was removed, and again they were asked to look around the lab. After this the questionnaires were administered.

Explanatory Variables

Information was collected on many explanatory variables, the most relevant for this paper being the following: (a) background information such as gender and occupation; (b) pitch in °/s: the summation (after smoothing for noise) of all vertical (i.e., pitch) angles through which the head moved (i.e., if the head orientation vector is projected onto a vertical plane and the angle between two successive head orientations is measured, pitch is the sum of all such successive angles divided by time); (c) yaw in °/s: a similar measure for yaw angle (the sum of horizontal angles through which the head turned divided by time); (d) roll in °/s: a similar measure for roll angle; and (e) mean and standard deviation of hand height above ground level (m).

Materials

The scenarios were implemented on a Silicon Graphics Onyx with twin 196 MHz R10000, Infinite Reality Graphics, and 64M main memory. The software used was Division's dVS and dVISE 3.1.2. The tracking system has two Polhemus Fastraks, one for the HMD and another for a five-button 3D mouse. The helmet was a Virtual Research VR4, which has a resolution of 742 × 230 pixels for each eye, 170 660 color elements, and a field of view 67° 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 10 Hz in stereo. The display lag was approximately 100 ms.

Participants moved through the environment in gaze direction at constant velocity by pressing a thumb button on the 3D mouse. Participants had a simple inverse kinematic virtual body. Most of the time they remained unaware of their virtual arm and hand because of the relatively limited field of view.

RESULTS

Measuring Body Movement

The fundamental question concerns the relationship between body movement and presence. Body movement in the conditions of this experiment has two components: the degree to which there was variation in whole body height (the extent of bending down and standing up) and the degree of head rotation. As it turned out, the first factor, tree height, was the main source of variation for the first type of movement, and the second factor, task, was the major source of variation for the second.

For the low-variation tree field, although there was no bending down, there was considerable head rotation, for most of the participants did not realize that when approaching the trees from certain directions it was possible to see the undersides of the leaves without having to rotate the head upward. The average head movement (rotation in pitch, yaw, and roll) was not significantly different between the two tree groups; the major difference was the amount of overall body movement.

A measure of how much the body crouched down and stood up (independently of head rotation) was obtained by measuring hand height. The hand was not required to do anything other than hold the 3D mouse and press a button for locomotion. Therefore the changes in height reflected changes in overall body extension. The variable used for this was the ratio of mean to standard deviation in hand height. This would be smaller for participants who tended to bend down and stand up more than those who remained standing (or sitting) throughout. The mean hand ratio was 13.7 ± 12.2 for those in the low-variation tree group and 3.8 ± 2.0 for those in the high-variation group. We therefore used this numerical variable *instead* of the tree factor in the analysis, in order to avoid the problems caused, for example, by the two participants who sat on the floor throughout.

The secondary question concerned the relationship between task complexity and presence. There were two levels of the task factor, Level 1 corresponding to the instruction just to count the diseased trees and Level 2 to count and remember to later sketch the distribution of diseased trees. This factor was confounded with head rotation (pitch, yaw, and roll rotation). There are significant differences between the mean head rotations between Task Levels 1 and 2, with the more complex task leading to higher rotation, especially yaw, as shown in Table 1.

Logistic Regression

A binomial logistic regression analysis was used for the presence response, which is the count of high scores out of six questions. Logistic regression is a standard technique for the analysis of binomial data and involves a logistic function transformation in order to ensure that the fitted values are within the

TABLE 1: Means and Standard Deviations of the Head-Movement Variables by Factor

Variable (°/s)	Tree 1 (low)	Tree 2 (high)	Task Level 1 (simple)	Task Level 2 (complex)
Pitch	3.4 ± 1.4	3.3 ± 1.4	3.7 ± 0.9	5.1 ± 1.1
Yaw	12.3 ± 3.7	10.1 ± 3.5	9.4 ± 3.3	13.0 ± 3.1
Roll	13.5 ± 4.1	11.2 ± 3.7	2.6 ± 0.7	4.0 ± 1.7

Note: The differences within each pair of Task means are significant on a *t* test at 5% on 18 *df*).

range of allowable values (between 0 and the maximum possible count – 6 in this case).

Suppose, for example, that there were two factors, A and B, with h_A levels of Factor A and h_B levels of Factor B. In the (i,j)th cell there are n_{ij} responses (y_{ijk}, $k = 1,...,n_{ij}$), and suppose that associated with each are two explanatory variables x_{ijk} and z_{ijk} ($i = 1,...,h_A$; $j = 1,...,h_B$; $k = 1,...,n_{ij}$). Then the linear predictor is of the form

$$\eta_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + b_{ij}x_{ijk} + c_{ij}z_{ijk}, \quad (1)$$

$i = 1,...,h_A$; $j = 1,...,h_B$; $k = 1,...,n_{ij}$, where α_i is the main effect for Factor A, β_j the main effect for Factor B, and γ_{ij} is the interaction effect between A and B. The model also allows the regression slopes (b_{ij} and c_{ij}) to be different across the factor levels. Solution to the least-squares equations requires constraints on the parameters, achieved by setting the first level of each coefficient to zero: $\alpha_1 = \beta_1 = \gamma_{i1} = \gamma_{1j} = b_{1j} = b_{i1} = c_{1j} = c_{i1} = 0$. This is the standard approach for such generalized linear models (McCullagh & Nelder, 1983).

The logistic regression links the expected value of the presence count $E(y_{ijk})$ to the linear predictor as

$$E(y_{ijk}) = \frac{n}{1 + \exp(-\eta_{ijk})} \quad (2)$$

where n (6) is the number of binomial trials per observation (the six presence questions). Maximum likelihood estimation is used to obtain estimates of the coefficients, which is equivalent to iteratively reweighted least squares on the transformed response variate η. The deviance (minus twice the log-likelihood ratio of two models) may be used as a goodness-of-fit significance test, comparing the null model (all coefficients are zero) with any given model. The change in deviance for adding or deleting groups of variables may also be used to test for their significance, and in the following sections all significance tests are at the 5% level. The (change in) deviance has an approximate χ^2 distribution with degrees of freedom dependent on the number of parameters (added or deleted). A good overall fit should result in a low deviance (judged against the corresponding chi-squared value).

The Fitted Model

A number of different models were compared by starting from the baseline model, which included only task and the hand height mean/standard deviation ratio, and then adding and deleting terms. A very good overall fit was obtained with a model that additionally included the interaction between task and gender and the head-rotational yaw variable (Table 2). Note that the range of the yaw variable is from 6.6 to 17.9 °/s, and the range of the hand height ratio is from 0.34 to 33.7.

The coefficients shown for main and interaction effects are the *changes* to the constant induced by introduction of the corresponding term. The overall fitted model, expressed as a linear model for the predictor (η), is η = *Constant* + 0.24 yaw – 0.06 × height, where the constants are –2.66 and –2.20 for men and 0.52 and –5.10 for women, in Task Levels 1 and 2, respectively.

Analysis

Task by itself is not significant. However, there is a very significant interaction effect between gender and task. For men the mean presence count is 2.2 ± 2.1 for the simpler task (Task Level 1) and 3.4 ± 1.6 for the more

TABLE 2: Logistic Regression for Subjective Presence

Parameter	Symbol	Estimate	*SE*	Δdev
Constant	μ	–2.66	0.82	
Main effects				
Task	α_2	0.47	0.54	
Gender female	β_2	3.19	0.77	
Interaction effects				
Task and gender	γ_{22}	–6.09	1.18	37.5
Slopes				
Yaw	b	0.24	0.074	12.1
Hand height ratio	c	–0.056	0.026	4.9

Notes: Overall deviance = 21.600, $df = 14$, $\chi^2 = 23.685$ at 5%; Δdev is the change in deviance caused by deletion of the corresponding term, and has a chi-squared distribution with 1 *df* in each case. $\chi^2 = 3.841$ on 1 *df* at 5%. The symbol column shows the corresponding term in the model from Equation 1.

complex task (Task Level 2). For women the means are 5.2 ± 0.5 and 0.7 ± 0.6, respectively.

The results do show a significant relationship between presence and the body movement variables. It is positively associated with yaw and negatively associated with the amount of vertical variation (as measured by the ratio of hand height mean to standard deviation). In other words, those who had a lower mean hand height and greater variation reported higher presence than those with a higher mean and lower variation, other things being equal.

The result for yaw can be queried on the grounds of the confounding between yaw and the task factor. However, the inclusion of an additional interaction term between yaw and task is just above the 5% significance borderline, and shows that for those in the more-complex task (Task Level 2) group there is a positive association between yaw and the presence count. Inspection of these results yielded two outliers, and when removed the inclusion of a yaw/task interaction term was not significant. It is safe to conclude that the impact of head turns holds independently of the task effect. Finally, either roll or pitch head movements could be included (significantly) instead of yaw, but not in addition to yaw; that is, only one of these three variables could be included, and yaw was the most significant by far.

CONCLUSION

In this paper we have considered an issue of theoretical and practical importance. The theoretical issue concerns the existence of the phenomenon of presence. Some researchers in virtual reality have taken presence as a central issue, essentially as a guide as to what constitutes a "good" virtual reality system (within a particular application context). A good system is, in this view, one that delivers greater presence, not only because of the evaluative aspects but also because higher presence should lead to behavior in the VE being similar to what it would be in everyday reality in comparable circumstances.

The practical importance of the results of this experiment is that because there does seem to be a relationship between body movement and presence, it is a reasonable goal to design interactive paradigms that are based on semantically appropriate whole-body gestures. These will not only seem more natural but may also increase presence. We further believe that the increase in presence in itself will engender more body movement, which in turn will generate higher presence, and so on.

The transition from the real lab, to a virtual lab, to the experimental scenario, back to the virtual lab, and then to the real lab may prove a useful means for easing participants into the virtual environment. The virtual lab may be thought of as a sort of "presence anteroom." It could be used to prepare the participants for the experiment and then as a "place" in which to measure presence when they return. It provides experimenters with a way of continuing to talk to the participants even after they have entered the VE. It provides the opportunity for pre- and postexperimental measurements to be taken while in the VE. A lot more data were collected that are relevant to this issue and will be presented in further reports.

The conclusions of this paper are that the reported presence of a participant in an immersive VE is likely to be positively associated with the amount of whole-body movement (such as crouching down and standing up) and head movements (looking around, up, and down) appropriate to the context offered by the VE. The experiment also considered the impact of a certain type of task complexity on presence, but the results in this case were inconclusive because of a confounding of the task with head rotation and a strong interaction effect between task and gender. This paper has concentrated only on subjectively reported presence; further work should examine whether the results extend to behavioral presence.

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