The Influence of Body Movement on Subjective Presence in Virtual Environments

MEL SLATER and ANTHONY STEED
Department of Computer Science

JOHN MCCARTHY and FRANCESCO MARINGELLI
Centre for Economic Learning and Social Evolution
Department of Psychology

University College London
Gower Street
London WC1E 6BT
UK

ABSTRACT

This paper describes an experiment to assess the influence of body movements on presence in a virtual environment. Twenty subjects were required to walk through a virtual field of trees and count the number of trees with diseased leaves. A 2?2 between-subjects design was used to assess the influence of two factors on presence. One factor was tree height variation, and a second factor was the complexity of the task. The field with greater variation in tree height required subjects to bend down and look up more than those in the lower variation tree height field. Those with the higher complexity task 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 subjects bent down and stood up. There was also a strong interaction effect between the task complexity and gender, with females in the group with the more complex task reporting a much lower sense of presence than in the simpler task.

Short title: Body Movement and Presence

KEYWORDS
Virtual Environment, Virtual Reality, presence, immersion, body movement, interactive techniques.

INTRODUCTION

When information about an environment is presented to an individual, that individual may have a sense of being *present* in that environment to a greater or lesser extent. In particular, when someone receives sensory data from one environment (say, kinesthetic and tactile information from the real world) and different, perhaps contradictory, data from a competing environment (say, 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 only really makes sense 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 is the issue of which, 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 behavioural. Subjective presence refers to what an individual will express in response to questions about 'being there'. Behavioural 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, and behavioural presence as being automatic, unplanned non-conscious bodily responses. Both types are important: subjective presence is essentially an evaluation of an experience, whereas behavioural presence is concerned with responses to events in the environment in question - clearly important in applications such as training or psychotherapy (Hodges et. al., 1996). Likewise, presence may be measured by subjective means such as questionnaires, or through observation of behaviour.

Presence research has focused on definition and ideas for measurement (Heeter, 1992; Held and Durlach, 1992; Loomis, 1992; Sheridan, 1992, 1996; Steur, 1992; Ellis, 1996; Slater and Wilbur, 1997; 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; Slater et. al., 1995; Welsh et. al., 1996). Some of the factors studied have included the effect of visual display update rate, characteristics of the visual display system, the influence of spatialised sound, head-tracking, and interaction.

This paper describes an experiment to examine the influence of two factors on subjective presence in virtual environments - the extent of body movement, and also complexity of a task undertaken in the environment. The major interest is on body movement which has important practical consequences for the design of interactive paradigms in VEs.

This study is motivated by two considerations. The first is anecdotal - we have observed hundreds of subjects in head-mounted display based ‘virtual reality’ over the past six years. It is very frequently the case that when a person first dons the head-mounted display (HMD), that they treat it as a ‘computer screen’ and just stand rigidly looking ahead. When they are told to move - turn their head, bend down, reach up, look under, they frequently have an observable ‘aha!’ type 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 maximise presence. An assumption underlying previous work on ‘body centred interaction’ (Slater and Usoh, 1994) has assumed 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, Usoh, Steed, 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, or degree of interactivity possible) and the psychological and behavioural response to these factors that we term as ‘presence’ (Slater and Wilbur, 1997). For example, their first question asks ‘How much were you able to control events?’ We see this as eliciting the subject’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 (for example, Slater, Usoh, Steed, 1995).

There are six questions each on a 1 to 7 scale, where the higher score always means 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 and Nelder, 1983, Chapter 4) can then be used to analyse 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 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 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.

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 subjects 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 (Figure 1). 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. The other subjects, 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 *underneath* of their leaves were 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 underneath by looking approximately at eye height in a standing position.

Figure 1 about here

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. The purpose was to examine whether the more complex task would affect presence.

There were 20 subjects in total, and a between subjects factorial design was used with five subjects in each condition. The subjects were recruited by the Department of

Psychology and paid £5 (about $9 US) 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. No subject 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 of dimension 90m?75m. Each tree was 2.4m across, and had 16 leaves. There were 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 field the distribution of heights was 1.7m ? 0.1m, and 2.35m ? 1.9m for the high variation field.

Procedures

When the subjects 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 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. 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 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). From earlier pilot experiments it had been found that about 3 minutes was the right length of time after which many subjects started to become visibly bored by the task.

During the time that they were in the virtual field, the experimenter said nothing. On returning back to the '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 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.

Explanatory Variables

Information was collected on many explanatory variables, the most relevant for this paper being:

?? background information such as gender and occupation.

?? pitch in degrees/sec. - the summation (after smoothing for noise) of all vertical (i.e., pitch) angles through which the head moved. (i.e., project the head orientation vector onto a vertical plane, and measure the angle between two successive head orientations. pitch is the sum of all such successive angles divided by time).

?? yaw in degrees/sec. - a similar measure for yaw angle - the sum of horizontal angles through which the head turned divided by time.

?? roll in degrees/sec. - a similar measure for roll angle.

?? 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 5 button 3D mouse. The helmet was a Virtual Research VR4 which has a resolution of 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 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 the whole body height (the extent of bending down and standing up), and also 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 subjects did not realise that when approaching the trees from certain directions that it was possible to see the underneath of the leaves without having to rotate the head upwards. The average head movement (rotation in pitch, yaw and roll) was not significantly different between the two tree groups - the major difference being 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 subjects 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. This numerical variable was therefore used *instead* of the 'tree' factor itself in the analysis, in order to avoid the problems caused, for example, by (the two) subjects who sat on the floor throughout.

The secondary question concerned the relationship between task complexity and presence. There were two levels of the factor 'task', 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.

Table 1 about here.

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

Suppose, for example, that there were two factors, A and B with h_A levels of factor A and 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:

$$?_{ijk} = ? + ?_i + ?_j + ?_{ij} + b_{ij} x_{ijk} + c_{ij} z_{ijk} \qquad \text{.......................................(1)}$$

$$i = 1,...,h_A;$$

$$j = 1,...,h_B;$$

$$k = 1,...,n_{ij}$$

where $?_i$ is the main effect for factor A, $?_j$ the main effect for factor B, and $?_{ij}$ 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: $?_1 = ?_1 = ?_{i1} = ?_{1j} = b_{1j} = b_{i1} = c_{1j} = c_{i1} = 0$. This is the standard approach for such generalised linear models (McCullagh and Nelder, 1983).

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

$$E(y_{ijk}) ? \frac{n}{1 ? \exp(??_{ijk})}$$

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 ?. 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 $?^{??}$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 that 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 deg./sec., and the range of the hand height ratio is from 0.34 to 33.7.

Table 2 about here.

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 (?) is shown in Table 3.

Table 3 about here.

Analysis

Task by itself is not significant. However, there is a very significant interaction effect between gender and task. For males the mean presence count is 2.2 ? 2.1 for the simpler task (1), and 3.4 ? 1.6 for the more complex task (2). For females the means are 5.2 ? 0.5 (task 1) and 0.7 ? 0.6 (task 2).

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 hand height mean to standard deviation ratio). 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 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; i.e., 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 is really that of the existence of the phenomenon of ‘presence’ at all. 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 behaviour 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 since 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 idea of a 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 subjects into the virtual environment. The virtual lab may be thought of as a sort of ‘presence ante-room’. It could be used to prepare the subjects 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 subjects even after they have entered the VE. It provides the opportunity for pre-and post-experimental measurements to be taken while in the VE. There is a lot more data that was collected that is relevant to this issue, which 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 and looking 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 behavioural presence.

Acknowledgements

The experiment described in this paper was first discussed with Professor W. Barfield during a short stay by M. Slater at the University of Washington in the summer of 1996. The work is supported through the European ACTS project, Collaborative Virtual Environments (COVEN - AC040). It is also partially supported through EPSRC equipment research grant GR/K99244 Equipment for Networked Multimedia and Virtual

Reality. We thank Division for the dVS/dVISE software license. We thank Amela Sadagic for bringing the researchers in Psychology and Computer Science together. Thanks to Martin Usoh, Michael Bell, Pip Bull and Saeed Massumi for helping with the experiment in various ways. We thank Dr. Tom Fearn of the Department of Statistical Science at UCL for some helpful comments on multicollinearity. This paper was revised by M. Slater while on sabbatical leave at M.I.T.'s Research Laboratory of Electronics; thanks to Nat Durlach for making this visit possible and fruitful. Finally, thanks to the editors Dr R. Williges, and Prof. W. Barfield for their comments and guidance in the production of the final revision of this paper.

References

Barfield, W. Sheridan, T., Zeltzer, D. and Slater, M. (1995) Presence and Performance Within Virtual Environments, in W. Barfield and T. Furness (eds) Virtual Environments and Advanced Interface Design, Oxford University Press.

Barfield, W. and S. Weghorst (1993) The Sense of Presence Within Virtual Environments: A Conceptual Framework, in Human-Computer Interaction: Software and Hardware Interfaces, Vol B, edited by G. Salvendy and M. Smith, ElsevierPublisher, 699-704, 1993.

Barfield, W. and Hendrix, C. (1995) The Effect of Update Rate on the Sense of Presence within Virtual Environments, Virtual Reality: The Journal of the Virtual Reality Society, 1(1) 3-16.

Ellis, S.R. (1996) Presence of Mind: A Reaction to Thomas Sheridan's "Further Musings on the Psychophysics of Presence", Presence: Teleoperators and Virtual Environments, MIT Press, 5(2),

Hendrix, C. and Barfield, W. (1996a) Presence within Virtual Environments as a Function of Visual Display Parameters, Presence: Teleoperators and Virtual Environments, MIT Press, 5(3), 274-289.

Hendrix, C. and Barfield, W. (1996b) The Sense of Presence within Auditory Environments, Presence: Teleoperators and Virtual Environments, MIT Press, 5(3), 290-301.

Heeter, C. (1992) Being There: The Subjective Experience of Presence, Presence: Teleoperators and Virtual Environments, 1(2), spring 1992, MIT Press, 262-271.

Held, R.M. and N.I. Durlach (1992) Telepresence, Presence: Teleoperators and Virtual Environments, 1, winter 1992, MIT Press, 109-112.

Hodges, L.F., Rothbaum, B.O., Watson, B., Kessler, G.D., Opdyke, D. (1996) A Virtual Airplane for Fear of Flying Therapy, IEEE 1996 Virtual Reality Annual International Symposium, 86-94.

Loomis, J.M. (1992) Presence and Distal Attribution: Phenomenology, determinants, and assessment, SPIE 1666 Human Vision, Visual Processing and Digital Display III, 590-594.

McCullagh, P. and Nelder, J.A. (1983) Generalised Linear Models, Chapman and Hall.

Sheridan, T.B. (1992) Musings on Telepresence and Virtual Presence, Presence: Teleoperators and Virtual Environments, 1, winter 1992, MIT Press, 120-126.

Sheridan, T.B. (1996) Further Musings on the Psychophysics of Presence, Presence: Teleoperators and Virtual Environments, MIT Press, 5(2), 241-246.

Slater, M., M. Usoh (1994) Body Centred Interaction in Immersive Virtual Environments, in N. Magnenat Thalmann and D. Thalmann (eds.) Artificial Life and Virtual Reality, John Wiley and Sons, 125-148.

Slater, M., M. Usoh, A. Steed (1994) Depth of Presence in Immersive Virtual Environments, Presence: Teleoperators and Virtual Environments, MIT Press 3(2), 130-144.

Slater, M. Usoh, M., Steed, A. (1995) Taking Steps: The Influence of a Walking Metaphor on Presence in Virtual Reality, ACM Transactions on Computer-Human Interaction (TOCHI) 2(3) September, 201-219.

Slater, M., Wilbur S. (1997) A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments, Presence: Teleoperators and Virtual Environments, 6(6) 603-616, MIT Press.

Steuer, J. (1992) Defining Virtual Reality: Dimensions Determining Telepresence, Journal of Communication 42(4), 73-93.

Welsh, R.B., Blackman, T.T., Liu, A., Mellers, B.A., Stark, L.W. (1996) The Effects of Pictorial Realism, Delay of Visual Feedback, and Observer Interactivity on the Subjective Sense of Presence, Presence: Teleoperators and Virtual Environments, MIT Press, 5(3), 263-273.

Witmer, B.G., Singer, M.J. (1998) Measuring Presence in Virtual Environments: a Presence Questionnaire, Presence: Teleoperators and Virtual Environments, 7(3), June 1998, in press.

Zeltzer, D. (1992) Autonomy, Interaction and Presence, Telepresence, Presence: Teleoperators and Virtual Environments, 1, winter 1992, MIT Press, 127-132.

TABLE 1

Means and Standard Deviations of the Head-movement Variables by Factor

(Differences between each pair of Task means are significant on a t-test at 5% on 18 df).

Variable	**Tree 1 (low)**	**Tree 2 (high)**	**Task 1 (simple)**	**Task 2 (complex)**
pitch deg./sec.	3.4 ? 1.4	3.3 ?1.4	3.7 ? 0.9	5.1 ? 1.1
yaw deg./sec.	12.3 ? 3.7	10.1 ? 3.5	9.4 ? 3.3	13.0 ? 3.1
roll deg./sec.	13.5 ? 4.1	11.2 ? 3.7	2.6 ? 0.7	4.0 ? 1.7

TABLE 2

Logistic Regression for Subjective Presence

Overall deviance = 21.600, df =14, $?^2$ = 23.685 at 5%

? dev is the change in deviance caused by deletion of the corresponding term, and has a Chi-Squared distribution with 1df in each case.

$?^2$ = 3.841 on 1df at 5%.

The Symbol column shows the corresponding term in the model from Eq.(1).

Parameter	**Symbol**	**Estimate**	**S.E.**	? **dev**
Constant	?	-2.66	0.82	
Main Effects:				
Task	$?_2$	0.47	0.54	
Gender female	$?_2$	3.19	0.77	
Interaction Effects:				
Task and Gender	$?_{22}$	-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

TABLE 3

Overall Logistic Regression Model

Linear Predictor ? = Const. + 0.24 yaw - 0.06 height

where the constant is given below:

Male		Female	
Task 1	**Task 2**	**Task 1**	**Task 2**
-2.66	-2.20	0.52	-5.10

Biographies

Mel Slater is Professor of Virtual Environments in the Department of Computer Science, University College London, and has been Visiting Professor in Computer Science Division at UC Berkeley 1991,1992, and Visiting Scientist at the M.I.T. Research Laboratory of Electronics Spring Semester 1998. He holds an MSc from London University and MA from the University of Essex.

Anthony Steed is a Research Fellow in the Department of Computer Science, University College London. He obtained his PhD from Queen Mary and Westfield College, University of London.

John McCarthy, PhD, is a Research Fellow in the Centre for Economic Learning and Social Evolution, Department of Psychology, University College London.

Francesco Maringelli, PhD, is a Research Fellow in the Centre for Economic Learning and Social Evolution, Department of Psychology, University College London.