The Virtual Treadmill: A Naturalistic Metaphor for Navigation in Immersive Virtual Environments

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ABSTRACT

This paper describes a metaphor that allows people to move around an immersive virtual environment by "walking on the spot". Positional data of participants' head motions are obtained from a tracking sensor on a head-mounted display during a training session, where they alternate between walking on the spot and a range of other activities. The data is used to train a feed-forward neural network that learns to recognise the person's walking on the spot behaviour. This is used in a virtual reality system to allow people to move through the virtual environment by simulating the kinds of kinesthetic actions and sensory perceptions involved in walking. An experiment was carried out to compare this method of navigation with the familiar alternative that involves using a hand-held pointing device, such as 3D mouse. The experiment, still continuing, suggests that the walking on the spot method may enhance the participant's sense of presence, but there is not sufficient evidence to suggest that it is advantageous with respect to the efficiency of navigation.

Keywords

Immersive virtual environments, virtual reality, navigation, 3D mouse, neural network.

1. Introduction

In Immersive Virtual Environments (IVEs), commonly called "virtual reality", participants operate in an extended virtual space, created by the interaction between the human perceptual system, and computer generated displays. The displays provide sensory information in the visual, auditory and tactual modalities. In *immersive* VEs (IVEs) sensory input to the human from the external world is, ideally, wholly provided by the computer generated displays. This affords the possibility of participants maintaining a *sense of presence* in the VE, that is the (suspension of dis-) belief that they are in a world other than where their real bodies are located [ELLI 91; HELD 92; LOOM 92a; SHER 92; HEET 92]. Presence is the unique possibility that IVEs offer: just as computers are general purpose machines, IVEs may be considered as general purpose presence-transforming machines. We take the same standpoint as Steur, in regarding presence as the central issue in "virtual reality": "A virtual reality is defined as a real or simulated environment in which a perceiver experiences telepresence" [STEU 92].

A major feature of IVEs is that this form of human-computer interaction can be "naturalistic", with the participant carrying out activities in a manner much as in everyday life. Indeed, where the IVE is used in a training context, such a naturalistic form of interaction is an absolute requirement: for, in this case, operations within the IVE must be similar enough to the real world so that the learning in the virtual environment can transfer to the real world. On this point, Loomis has suggested that the degree of presence and distal attribution[1] might be assessed according to the degree of accuracy that observers can perform visually directed tasks, requiring the perception of distance, in virtual environments as compared to real environments [LOOM 92b].

In practice naturalistic interaction is made difficult by the typically limited tracking information possible with today's equipment - usually only from the head and the dominant hand. Electro-magnetic sensors operate within a small field, so that it is not possible for participants to wander around a large VE by physically walking, unless there are systems specifically designed for that purpose alone, such as roller skates [IWAT 92] or a treadmill [BROO 92]. In general, the gap between actions that are required (such as navigation over large distances) and the sensor information available, means that just as in 2D interfaces, metaphors are required.

Mackinlay et. al. [MACK 90] pointed out that there are four requirements that need to be considered for navigation in virtual spaces:

(a) General - for example exploring a building interior;
(b) Targeted - that is, aiming at a particular visible point;
(c) Specified coordinate - that is, moving to a point specified relative to a coordinate system;
(d) Specified trajectory - that is, moving along a position and orientation trajectory, as with a movie camera.

In this paper we consider mainly case (a) - that is, a metaphor for navigating through an environment, without any specific target or location in mind, but according to the temporary and changing whims of the navigator. Our work is a contribution to a project involved in constructing a system for architectural walkthrough, where architects and their clients are able to navigate through and effect changes to a virtual building interior.

Previous investigations have concentrated on metaphors in the context of navigation in 3D VEs viewed through a 2D display using 2D input devices or six degrees of freedom input devices such as the Flying Mouse [WARE 90]. Three metaphors for navigation were introduced by Ware et. al.:

(1) eyeball in hand - where the viewpoint is directly controlled by the movements and orientation of the input device;

(2) scene in hand - where the viewpoint is stationary and movements of the scene are controlled by the movements and orientation of the input device;

(3) flying vehicle control - where the user flies in a virtual vehicle and the input device is the vehicle control mechanism, for example, controlling acceleration and velocity, but not directly absolute positioning.

Here we are interested in "naturalistic" interaction, so we rule out (2): our requirement is that participants are able to wander around the VE, seeing through their "virtual eyes" which are located in more or less the normal place in their heads. By "naturalistic" in this context, we mean that participants can move through the virtual space in a manner that is similar to how they would do so in everyday reality.

In Section 2 we briefly discuss various methods previously adopted, in Section 3 we outline the new approach, in Section 4 a discussion of some experimental results, and conclusions in Section 5.

2. Navigating in IVEs

[1] Attribution of the objects of our sense perceptions to the external world, or non-self.

A standard solution for navigation in IVEs is to make use of the hand-held pointing device.

VPL used the DataGlove [FOLE 87]: a hand gesture would initiate movement, and the direction of movement would be controlled by the pointing direction. Velocity was controlled as part of the gesture: for example the smaller the angle between thumb and first finger the greater the velocity.

DIVISION's ProVision system typically employs a 3D mouse (though it supports gloves as well). Here the direction of movement is determined by gaze, and movement is caused when the user presses a button on the mouse. There are two speeds of travel controlled by a combination of button presses.

In a previous experiment [SLAT 93a; SLAT 93b] we adjusted the ProVision's standard interface, and based direction of movement on the pointing direction of the 3D Mouse. This disassociation of gaze and direction of movement gives the participant an extra degree of freedom in exploring the VE. However, we still had no direct control over velocity; this makes accurate navigation quite difficult, people frequently overshooting or under-reaching targets.

In our earlier studies we found that although people did quickly get used to using the 3D Mouse as a navigation device, it was far from ideal. We found that this use of the mouse introduced a "mixed metaphor" - subjects in the experiments moved partially by using their bodies in the normal way, and partially by use of the pointing device. Two of the subjects wrote:

> "Sometimes [I had] a desperate need to actually walk when virtually walking, there does seem to be a conflict between what the eyes see and the body feels - eg, my feet appear to be floating but I can feel my feet on the ground."

> "Trying to separate virtual and physical movement: constantly being aware - my initial response was to make the physical move then forcing myself to use the mouse instead... The amount of concentration I had to use was something I remember particularly. Moving around with the mouse, forwards and backwards - and with the helmet turning around - it was difficult to reconcile the two ways of moving."

There are important problems here:

- sensory dissonance - a contradiction between different modes of sensory data (visual and kinesthetic);

- the participants moving in two quite different ways: by actually moving their bodies as they would in real life - for example, to move over short distances - or alternatively by pressing a button, with direction controlled by pointing.

In each of the methods discussed above, there is no explicit metaphor that is given to the participant. Many years of research in human-computer interaction in the context of point-and-click interfaces on workstations have made it clear that such metaphors are invaluable [SHNE 87].

There is some anecdotal evidence that navigation by pointing and button pressing might reduce participant's sense of presence in the IVE. For example, in one of our experiments, subjects stood at the edge of a precipice. Some of them noted that they were unable to physically move themselves forwards by actually taking a step, owing to their fear of heights. However, they were able to move forward by pressing the mouse button. Another subject noted that he was not disturbed by moving into and through walls if this was caused by use of the 3D mouse. However, he was disturbed when he pressed the button to move forward while simultaneously using his legs as if he were actually walking. In this case, he found walking into walls "scary". Generally, analysis of our earlier experimental results suggests that the sense of presence is reduced when actions are not carried out realistically - at least in the context of architectural walkthrough [SLAT 93a]. In the next section we introduce a metaphor that attempts to resolve these problems.

3. A Metaphor for Navigation

Brooks [BROO 92] noted that "Physical motion powerfully aids the illusion of presence, and actual walking enables one to feel kinesthetically how large spaces are..." As part of the Building Walkthrough project at the University of North Carolina, a steerable treadmill was constructed, that allowed users to actually experience walking through virtual buildings and building sites. Here we explore a similar idea, implemented in software rather than a real physical treadmill.

3.1 Doing the Impossible

In a sense what we are trying to do is really impossible. We have the following information: at any moment in time the position (x,y,z) of the head-mounted sensor relative to a coordinate system with origin at the receiver, and the direction vector (dx,dy,dz) of gaze. With these two pieces of information we are trying to construct a navigation system that:

- allows the navigator to go anywhere (at ground level) in the VE (for the moment we rule out flying);

- is consistent across senses - so that what the navigator sees does not contradict other sensory input (of course, this is not completely possible with today's IVE systems);

- is integrated - does not require switching between different metaphors.

3.2 Let Them Walk

If we want people to be able to navigate the environment - let them walk. Here the metaphor is walking - appropriate to an architectural walkthrough application. However, they cannot literally walk, because this would lead them outside of sensor range. Instead, let them "walk on the spot". So the metaphor is: for the participants to go somewhere, they would stay on the spot but carry out actions that for them mean walking - eg, lift one leg, and then the other, reminiscent of walking, but not actually covering distance in the real world. The direction of walking may be a function of direction of gaze. To stop walking - just stop walking on the spot. Velocity could be controlled by the frequency of oscillations in the tracking data.

The advantages of this metaphor are:-

(a) Our system presents participants with a virtual body. While they are walking we also show their legs moving up and down. Hence the problem of sensory dissonance could be reduced.

(b) Virtual ground is covered in this metaphor by almost really walking, or by taking one or two actual physical steps: each case involving whole body movements similar to those of walking in everyday reality. Contrast this with the usual method, which is sometimes moving by actually walking, and other times using a mouse or glove.

(c) There is no use at all for a hand-held pointing device such as mouse or glove in this method of navigation. It therefore is less a "computer interface" metaphor.

It does not rule out other metaphors that do rely on the pointing device (such as flying vehicle control).

The disadvantage - as usual - is that the relative sophistication of the metaphor is at the cost of extra computation, and it could increase the lag time slightly. However, in our current implementation on the equipment that we are using this has not been noticeable at all. In fact, in walking in everyday reality, there is a lag time between the intention to walk, the act of first moving ones legs, and the viewpoint actually changing.

3.3 Neural Net Implementation

The method requires the detection of specific behavioural activity of participants - that is, whether they are walking on the spot or doing something else. An obvious solution to this problem is to use more trackers, at least one on each leg. However, this is not usually feasible for several reasons:

• cost in terms of the additional trackers required;

• cost in terms of two extra streams of data to process, which also slows down the overall system network speed;

• the extra burden to participants of "suiting up" before entering the IVE.

If it is possible to efficiently determine this behavioural activity without extra trackers, then this must surely be preferable.

We have used a feed-forward neural net [HERT 91] to implement a pattern recogniser that detects whether participants are "walking on the spot" or doing something else. The HMD tracker delivers a stream of position values (x_i, y_i, z_i) from which we compute first differences $(\Delta x_i, \Delta y_i, \Delta z_i)$. We choose a fixed sample of data $i = 1,2,...,n$, and the corresponding delta-coordinates are inputs to the bottom layer of the net, so that there are 3n units at the bottom layer. There are two intermediate layers of m_1 and m_2 hidden units ($m_1 \leq m_2$), and the top layer consists of a single unit, which outputs either 1 corresponding to "walking on the spot" or 0 for anything else. We obtain training data from a person, which is used to compute the weights for the net. The network is then executed on the ProVision200 machine that we are using for all of our experiments.

After experimenting with a number of nets, we have found that a value of $n = 20$, $m_1 = 5$ and $m_2 = 10$ gives good results. We have never obtained 100% accuracy from any network, and this would not be expected. There are two possible kinds of error, equivalent to Type I and Type II errors of statistical testing, where the null hypothesis is taken as "the person is not walking on the spot". The net may predict that the person is walking when they are not (Type I error) or may predict that the person is not walking when they are (Type II error). The Type I error is the one that causes the most confusion to people, and is also the one that is most difficult to rectify - in the sense that once they have been involuntarily moved from where they want to be, it is almost impossible to "undo" this. Hence our efforts have concentrated on reducing this kind of error. We do not use the output of the net directly, but only change from not moving to moving if a sequence of p 1s is observed, and from moving to not moving if a sequence of q 0s is observed ($q < p$). In practise we have used $p = 4$ and $q = 2$. The best result we have obtained is a correct prediction 97% of the time. The Type I error is typically around 4% and the Type II error around 5%. However, in the context of the experiment to be described, where we spent less time gathering data, and less time training the net, we did not achieve such good results. It is likely that with further investigation of the Neural Net training method, results will improve.

The Polhemus Isotrak tracking device we are using actually returns data to the application at a rate of 28-30 Hz. The overall error is largely caused by the actual output lagging behind the real output by typically 5 samples, at the end of each sequence of 1s or 0s.

4. Experiments with Participants

4.1 Experimental Procedures

In this section we describe an ongoing experimental case-control study. The experiment has three purposes:

(a) To assess the extent to which the neural network can learn the walking behaviour of individuals;

(b) To assess whether, in the context of the experimental scenario, the walking metaphor is preferred by subjects to the method based on navigation using hand gestures and pointing;

(c) To assess the impact of the walking metaphor on the reported sense of presence of the subjects.

Subjects for the experiment are being recruited mainly through informal contacts, by asking people whether they wish to take part in a "virtual reality" experience. Most of those participating to date are post-graduate students or researchers not in computer science, and all but one have never experienced virtual reality.

The experiments described in this paper were implemented on a DIVISION ProVision200 system. The ProVision system consists of a DIVISION 3D mouse (a hand held input device), and a Virtual Research Flight Helmet™ as the head mounted display (HMD). Polhemus sensors were used for position tracking of the head and the mouse. Scene rendering is performed using an Intel i860 microprocessor (one per eye) to create an RGB RS-170 video signal which is fed to an internal NTSC video encoder and then to the displays of the Flight Helmet™ . These displays (for the left and right eye) are colour LCDs with a 360×240 resolution and the HMD provides a field of view of about 75 degrees along the horizontal with a consequent loss of peripheral vision.

Each person is invited to alternate "walking on the spot" and other activities for a ten minute data gathering process. This data is used to train a neural net to recognise "walking on the spot" behaviour, which does differ from person to person. During walking on the spot, some people move their heads much more than others. Clearly the net requires rather more data for those who move their head slightly compared to those who move their head a lot. The average stride length of subjects in reality is also measured during this period. This is used to adjust the distance they move forward for each step of "walking on the spot". The subjects are invited back for the main part of the experiment a few days later.

Each subject is first given a short description of the procedures, which includes a warning that virtual reality does result in symptoms akin to travel sickness for some people. They are given the opportunity to withdraw prior to the start of the experiment. Of the ten people we have considered at the time of writing, one withdrew because of this warning.[2]

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[2]In past experiments we have not given such a warning, on the grounds that merely alerting people to the possibility may induce the result. However, we have come to believe that it is unethical to subject people to this possibility without prior warning.

The experimental scenario consists of a corridor with a room at either end. The first room contains many blocks laying on the floor, and one distinct small red cube at the end of the room furthest from the doorway. The second room, at the other end of the corridor is on two levels. The main level is at normal floor height, but this ends at an edge to a deep drop to a lower level which contains some tables and chairs. There is, in addition, one single blue chair suspended on a wall at the main floor level, across the chasm of the room. There is a plank leading out from the main floor towards this chair, but the end of the plank is too far away from the suspended blue chair for anyone to reach it.

After entering the IVE, the subjects are placed first in the corridor, and given a brief training session. They are shown how to move through the environment, and how to pick up an object. All subjects hold the DIVISION 3D mouse in their right hand; this is held somewhat like a gun - it has four buttons, of which at most two are used in the experiment. The forefinger button, equivalent to the trigger of a gun, is used to select and lift an object. The thumb button, following the analogy of a gun, is in the position of the hammer. Depressing this thumb button would move participants through the scene at ground level, in the direction in which their hand was pointing. All other buttons are disabled.

All subjects saw a representation of their hand, and their thumb and first finger activation of the buttons would be reflected in movements of their corresponding virtual fingers. The hand was attached to an arm, that could be bent and twisted in response to similar movements of the real arm and wrist. The arm was connected to an entire simple body representation, complete with legs and left arm. The virtual body seems to be an important factor in enhancing the sense of presence [SLAT 93a, 93b] and so was included for all subjects.

During the training session, the subjects are asked to estimate the distances between each of two pairs of lines, two red lines, and two blue lines. They then move to the doorway leading to the first room, and the task for the remainder of the experiment is explained. This is to go to the small red cube at the far end of the room, pick this up, and take it to the room at the other end of the corridor, and place it on the blue chair. (At this point, the subjects have not seen inside either of the rooms).

Subjects are randomly assigned to one of a control or experimental group. Those in the control group move through the environment by using the mouse tool: that is, they move by pressing the thumb button, and they move in the direction of pointing. Those in the experimental group, move by "walking on the spot". Direction of movement is determined by gaze. (The subjects are not explicitly told that direction is determined by gaze, but all realised this immediately).

Subjects repeat the task twice. Those in the control group first carry out the task using the mouse method of moving. They then exit from the IVE and are given Part I of a questionnaire to answer. They then return after a few minutes and repeat the experiment using the walking on the spot method of moving. They then complete Part II of the questionnaire, which asks them to compare the two experiences on a number of criteria. Those in the experimental group do the same, except that their first experience is by walking on the spot, and the second by using the mouse. They answer exactly the same questionnaires. Note that after their first entry, each subject has only properly experienced one method - the control group using the mouse, and the experimental group walking on the spot.

The main problem with these procedures was that the network performed ineffectively for a proportion of the subjects assigned to the experimental group. There was one fallback for this - we have a "standard" network that many casual visitors to the laboratory are able to use without the necessity of a net trained for their personal style of walking. If their personal network did not work for a subject, then we tried them with the standard network. If this did not work, then they only completed the control half of the experiment.

4.2 Results with the Neural Net

There have been 10 subjects considered at the time of writing. Of these one withdrew before starting the experiment. Five out of the remaining nine were able to move by walking on the spot with their personal nets, and one other was unable to move with the personal net, but used the "standard" net successfully. The remaining three were unable to move at all with their personal or standard net.

Through observation during the experiments we realised that in our initial data gathering procedures we were not asking subjects to walk while gazing at different elevations. This resulted in some of the nets favouring cases for subjects looking in a certain direction only. We are tightening up this data gathering procedure.

One subject was unable to successfully move at all either by walking on the spot or by using the mouse. We have had probably more than 50 people experience our system using the mouse for navigation in the course of the past year, and every one has been able to use the this method of navigation. We therefore decided to eliminate this person from the experiment, she being so unusual in this regard compared to the norm.

Table 1 shows the performance of the personal nets across the subjects based on the training data only.

Table 1

Performance of Personal Net Based on Training Data

Subject ID	Overall Performance %	Type I error %	Type II error %	Personal net could be used?
1	94	6	5	Yes
2	90	10	8	Yes
3	92	11	2	Yes
4	93	9	5	No (standard net used OK)
5	93	11	3	Yes
6	91	15	3	No
7	85	10	12	No
8	87	20	4	No (couldn't use mouse either)
9	94	7	3	withdrew
10	92	7	10	Yes

4.3 Results on Navigation

Part I of the questionnaire contained three questions relating to navigation, scattered throughout the questionnaire. There were 4 control subjects and 4 experimental subjects, and the results are shown in Table 2.

We were interested in three aspects of navigation: the general process of moving around, the task of getting specifically from one place to another, and whether or not the process seemed "natural". Obviously with such a small data set at the time of writing, we cannot do any statistical tests, or come to firm conclusions. Nevertheless, we can observe that on all three criteria, those who moved through the world by walking on the spot found it slightly easier in general, slightly more straightforward to get from place to place, and maybe slightly more "natural". These are the results immediately after the first part of the experiment. There were only six subjects who completed both parts of the experiment. Their part II answers, where they make a direct comparison between the two methods, give the advantage with respect to getting from place to place to the method using the mouse (Table 2). This was to be expected, in comparison with the nets used, navigation could be more easily controlled when using the mouse. Also, use of the mouse is certainly easier in the sense that it requires less energy - pressing a button instead of the whole body activity involved in walking on the spot.

4.4 Results on Presence

All subjects but one carefully avoided colliding with objects distributed over the floor in the first room, on their way to pick up the red cube. There seemed to be no difference between the methods of moving in this regard. However, this may have little to do with the sense of presence. Just as a matter of interest we asked one subject, who had been especially careful not to collide into objects in the first room, to repeat the process of moving through the room (after the final completion of the formal experiment) but this time without immersion - by using the mouse and holding the HMD, while watching the results on the TV monitor. Again, he carefully navigated around the objects. His explanation was that it is "normal" not to go through objects.

Table 2
Moving Through the World: response to questionnaire

General Moving			**Getting from place to place**			**Natural/unnatural**		
Did you find it relatively "simple" or relatively "complicated" to move through the computer generated world?			How difficult or straightforward was it for you to get from place to place?			The act of moving from place to place in the computer generated world can seem to be relatively "natural" or relatively "unnatural". Please rate your experience of this.		
To move through the world was...			*To get from place to place was ...*			*The act of moving from place to place seemed to me to be performed ...*		
1. very complicated			1. very difficult			1. very unnaturally		
2. ...			2. ...			2. ...		
3. ...			3. ...			3. ...		
4. ...			4. ...			4. ...		
5. ...			5. ...			5. ...		
6. ...			6. ...			6. ...		
7. very simple			7. very straightforward			7. very naturally		
Group	**Mean**	**Median**		**Mean**	**Median**		**Mean**	**Median**
Exp.	5	6		5	5		4	4
Control	5	5		6	6		3	2
Part II comparison: **prefer**: walking: 4 same: 1 mouse: 8 TOTAL:13			**Part II comparison:** **prefer**: walking: 1 same: 2 mouse: 10 TOTAL:13			**Part II comparison:** **prefer**: walking: 5 same: 3 mouse: 5 TOTAL:13		

The purpose of the scenario in the second room was to repeat some aspects of the "visual cliff" experiment, in which young children and animals are encouraged to move across a visual chasm to (for example) reach their mother. The chasm in fact is covered by a sheet of glass, so that there would be no real danger to the subject. This famous experiment, concerned with the visual guidance of human actions reported in [GIBS 60], suggested that humans and animals are hard-wired to avoid deep drops - the youngsters could not be goaded into crossing the gap. Our previous informal observations and results of a pilot experiment [SLAT 92] suggested that this phenomenon also operates in IVEs. It may be related to the sense of presence, since subjects who are not present, would be unlikely to experience the sense of danger indicated by the virtual visual chasm.

We found no difference in observed behaviour between those in the experimental or control group as a whole. Most of the subjects hesitated, some for a long time, before venturing out over the chasm (they did not virtually fall!) to place the cube on the chair. Most attempted to reach the chair by stretching out their arms. One subject in the control group never went out to the chair.

Table 3

Subjective willingness to move over the chasm

In the last room you had to place a cube on a chair, over a fairly deep chasm. How willing were you to move off the plank, out over the drop, in order to do this?		
I was ...		
1. very reluctant to move off the plank.		
2. ...		
3. ...		
4. ...		
5. ...		
6. ...		
7. very willing to move off the plank.		
	Mean	**Median**
Exp.	4	3
Control	3	3

Table 3 shows a question asked in Part I of the questionnaire, regarding the subjects' assessment of their willingness to step out over the chasm. This suggests that those who walked on the spot were perhaps slightly more willing to do so than those who used the mouse. This contradicts our earlier informal observations.

Table 4

Subjective Reporting on Presence

Being there			**Real or present**			**Seeing/visiting**		
Please rate your sense of being there in the computer generated world...			To what extent were there times during the experience when the computer generated world became the "reality" for you, and you almost forgot about the "real world" outside?			When you think back about your experience, do you think of the computer generated world more as something that you saw, or more as somewhere that you visited?		
In the computer generated world I had a sense of "being there"...			*There were times during the experience when the computer generated world became more real or present for me compared to the "real world"...*			*The computer generated world seems to me to be more like...*		
1. not at all			1. at no time			1. something that I saw		
2. ...			2. ...			2. ...		
3. ...			3. ...			3. ...		
4. ...			4. ...			4. ...		
5. ...			5. ...			5. ...		
6. ...			6. ...			6. ...		
7. very much			7. almost all of the time			7. somewhere that I visited		
Group	**Mean**	**Median**		**Mean**	**Median**		**Mean**	**Median**
Exp.	6	6		5	5		5	5
Control	5	5		4	3		5	4
Part II comparison: **prefer**: walking: 6 same: 5 mouse: 2 TOTAL:13			**Part II comparison:** **prefer**: walking: 7 same: 5 mouse: 1 TOTAL:13			**Part II comparison:** **prefer**: walking: 7 same: 6 mouse: 0 TOTAL:13		

We also asked three questions relating directly to presence, scattered through the questionnaire. The questions and a summary of the responses are shown in Table 4. These particular questions are derived from our earlier work on presence: Presence concerns the extent of "being there", the extent that the VE becomes more real than everyday reality, and the sense of visiting somewhere rather than seeing something.

All three indicators, in Table 4, suggest that the walking on the spot metaphor may be associated with a higher sense of presence than using the mouse. This is further supported by the comparisons made in Part II of the questionnaire. With respect to the three presence indicators, only two subjects preferred the use of the mouse over walking on the spot.

4.5 Other Issues

Motion sickness and nausea is observed in a minority (about 40%)of all people who have used our system. We have observed that the degree of nausea may be reduced for those walking on the spot compared with those using the mouse. To date, our experimental evidence does not support this subjective impression, there being no reported difference in the level of reported nausea between the two groups. The mean and median level of reported nausea on a 1 to 7 scale (1 = "not at all", 7 = "very much so") were 2 or 3 for both groups.

We asked subjects to estimate the distances between each of the two sets of lines in the corridor, following the possibility that subjects who virtually *walked* over the lines would be in a better position to estimate the distance compared to those who *glided* over the lines by using the mouse. However, we found no difference in the estimates. In fact we have to judge this part of the experiment as a failure, since subjects did not generally notice the lines until we pointed these out to them. This is because of the lack of peripheral vision afforded by the HMD.

When we examine the Type I errors (the net incorrectly concludes that the subject is walking on the spot) of the networks successfully used by the subjects, and compare these with their responses on navigation and presence, the data indicates that the lower the Type I error, the greater the tendency to report a higher sense of presence, and greater ease of navigation. Of course, this is based on a very small amount of data, and might not hold in the subsequent experimental trials. If it is the case, however, it is important especially with regard to navigation. It implies that if we can reduce the Type I error sufficiently, by improving our data gathering and net training methods, then it is possible that the walking on the spot metaphor may be preferable to the use of the mouse, even in the case of navigation.

5. Conclusions

In this paper we have introduced a walking metaphor for navigating through a virtual environment. We have discussed how this can be implemented with a neural net recognising a participant's walking on the spot behaviour pattern, based on data gathered from the tracking system for the HMD. Our provisional results indicate that such a net can be successfully trained, and that this metaphor may enhance the sense of presence, in comparison to the more usual method of navigation using a hand-held pointing device. Of course, this is based on a small amount of data at the time of writing, though our experiments are continuing.

It is less clear whether people prefer this walking method to using the mouse, purely from the point of view of actually getting around the environment. As Brooks (op. cit.) noted in the case of the real treadmill: "The steerable treadmill provided quite a realistic walking experience, and it neatly solved the problem of the limited range of the head sensor on the head-mounted display. Nevertheless, it proved to be too slow a tool for exploring extensive models. The user wore out with the exercise and grew frustrated at the slow pace. The flying metaphors proved more useful for this kind of rapid survey."

The utility of any metaphor depends on the application context. Clearly, just as in real life, walking is not a good method for exploring large spaces. We observed that some of our subjects did become physically tired as a result of walking, and we would not recommend it to be used for a long time. However, it is a cheap additional tool in the range of interface metaphors available in virtual reality, and there are circumstances where the sense of presence would outweigh the costs of relative inefficiency and tiredness. For example, consider an application for training simulation of emergency service personnel in hazardous conditions such as a fire: the fact that users would become tired and frustrated as a result of the additional exercise involved in a whole body movement is realistic. In real life, they would not move around a hazardous environment by using a mouse.

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