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# THE EFFECT OF LOCOMOTION TECHNIQUE ON PRESENCE, FEAR AND USABILITY IN A VIRTUAL ENVIRONMENT

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## KEYWORDS

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## ABSTRACT

In this study the effects of locomotion techniques were investigated in virtual worlds made for phobia treatment. Three locomotion techniques walk-in-place, hand-controlled viewing and gaze-directed steering were systematically varied for several taks in different virtual worlds. A series of variables were measured to show the effects on presence, fear, avoidance, and simulator sickness. In the experiment was found that more natural locomotion techniques contribute to higher levels of presence and fear. This researh provides guidelines to improve the usability of systems for virtual reality exposure therapy.

## INTRODUCTION

An important, and perhaps the defining aspect of presence is how people react to virtual stimuli. Do they react to a situation as if it is real, or as if they are just looking at pictures of that situation? One example of reactions that people have been known to show is fear of certain objects or situations in Virtual Environments (VE). When confronted with for instance a virtual height, most people with fear of heights will report anxiety and show behavior that is associated with fear towards a height situation. This fact has led to Virtual Reality (VR) being used effectively in treatment of amongst others fear of height (e.g. Hodges et al. 1994), fear of enclosed spaces (Alcaniz et al. 1998) and fear of flying (Krijn et al., 2004).

The relationship between presence as measured using questionnaires and fear was first investigated by (Regenbrecht et al. 1998). In an experiment with 37 non-phobic subjects they did not find a significant correlation ($r = 0.251$, $p>.10$) between presence and fear. A regression analysis did show that presence was the best predictor of fear. (Schuemie et al. 2000), in an explorative study with ten subjects being treated for fear of heights, did find a significant correlation between fear and presence reported on questionnaires. It is unclear however whether a higher sense of presence led to more fear or whether people with a higher fear of heights, because of their higher fear in the VE, report higher levels of presence. In fact, a small study performed by (Krijn 2002) indicated that people diagnosed as having fear of heights indeed report higher presence levels in VE depicting height situations when compared to neutral VEs, while non-phobics reported equal presence levels in both types of VEs. In the same study the level of presence was manipulated by increasing the level of interactivity of the VE. Higher levels of interactivity did lead to a higher level of presence but not to a higher level of fear. The most probable explanation for this outcome is the fact that the higher interactivity allowed subjects to avoid fearfull situations, which they did.

In phobia treatment a patient is confronted with situations that generate fear in the patient, while allowing the fear to attenuate through habituation (Bijl et al. 1998). It therefore seems likely that, for the treatment to be effective, it is essential that the patient experiences at least some level of fear. For effective Virtual Reality Exposure Therapy (VRET) of phobias, we should therefore design our VR setup to optimize this fear. In this paper we will investigate whether increasing the sense of presence will increase the fear a subject is experiencing.

### Interaction and presence

Already some research has shown how aspects of the VE can influence the level of presence (see for instance the survey in Schuemie et al. 2001), and these aspects could thus possible also influence the level of fear a patient experiences. One aspect of the VE that can determine the level of presence is the type and level of interaction possible in the VE. Several studies have investigates the relationship between interaction and presence (Welch et al. 1996) showed that interaction, when compared to no interaction, increases the sense of presence and that longer delay between action and feedback has a negative effect on presence. (Barfield et al. 1998) showed the type of input device to have no significant effect on presence, when comparing a 3 Degrees o Freedom (DoF) joystick with a 3 DoF space mouse. Both (Hendrix & Barfield, 1996) and (Schubert et al. 2000) found a significant positive effect for including headtracking. (Slater et al., 1998) showed that more body movement can lead to a higher sense of presence. (Slater et al. 1993).

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We need to determine which locomotion gives the highest sense of presenceand fear and is this best suited for VRET. Given the large number of locomotion techniques available to us it is infeasible to test all of them. Fortunately, especially the previous research by (Bowman 1999) has already investigated the accuracy and speed with which users can move through the virtual world with most of the techniques. However, it is still not very clear if a more natural technique will lead to higher presence and a higher fear. To investigate this, we compared the least natural technique to the most natural one. Although of course chosen subjectively, we would like to argue that hand-controlled viewing is the least natural interaction method, because here users have to move a device to rotate the viewpoint and press a button to move forward, which is not at all similar to the way we move in the real world. One of the most natural locomotion technique today that allows the user to move larger distances in the VE than by simple headtracking alone is walk-in-place (Slater et al. 1998). Here the user can rotate the viewpoint by rotating his or her head and can move forward by making a walking motion. An advantage of this technique is that is doesn't require an extra tracking device and is therefore relatively inexpensive.

To determine the separate effects of the headtracking and the walking motion detection, we can add a third locomotion technique: gaze directed steering, where rotation is controlled by headtracking and the user can move forward by pressing a button.

## METHOD

### Design

The experiment consisted of three conditions:

- *Walk-in-place*
- *Trackball* (hand controlled viewing using a handheld trackball device)
- *Headtracking (gaze-directed steering)*

The walk-in-place technique was implemented by feeding the coordinates obtained from the tracking device into a multi-layered perceptron (Herz et al. 1993) that was trained to distinguish between walking and non-walking behavior.

Subjects were required to complete a course through a VE. Each subject was exposed to only one condition.

### Virtual Environment

To generate the images a PC was used equiped with a 3D-Labs Oxygen G420 graphical card and a Visette Pro Head Mounted Display (HMD). This HMD has a Field Of View (FOV) of 70 degrees diagonally and a resolution of 640*480 color elements. The position of the HMD was tracked using an Ascension Technology Flock of Birds. For a full description of the system, see (Schuemie & van der Mast 2001).

The VE used in this experiment consisted of three parts that were connected, forming a single VE: a small training space, where subjects could familiarize themselves with the interaction technique, a room designed to determine the controllability of the interaction technique and a part containing height situations aimed at determining the effect of the locomotion technique on the fear of the subjects.

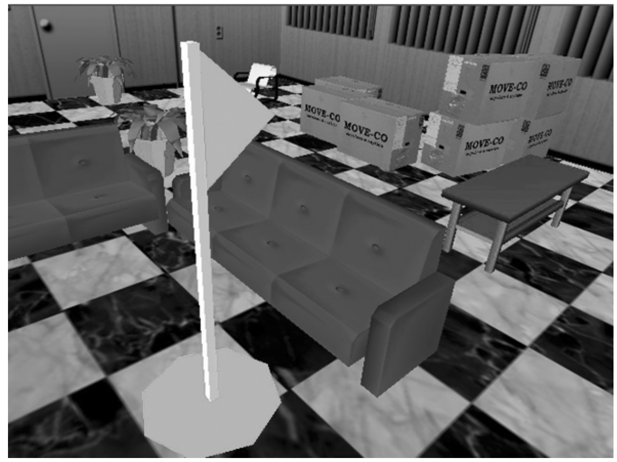


*Figure 1: First part of the VE, with a flag as target for the subject to move to and obstacles such as plants and couches.*

The room designed for determining the controllability of the technique contained several objects such as couches and plants. A specific location in the room was marked with a flag and a spot on the ground as depicted in *figure 1*. The subject was instructed to move to this marker and press a button to indicate that he or she had reached it. After this the marker would disappear and another would appear somewhere else in the room. All the markers were easy to find, but differed in difficulty to reach. This way we prevented the subjects from losing their orientation in the VE. Subjects were also instructed to try to avoid collisions with the objects in the room. By instructing the subjects to avoid collision instead of telling them to complete the task as quick as possible, the emphasis of the test was put on controllability instead of speed.

When the subjects reached all seven markers, they were instructed to move into an elevator, which led to the final part of the VE. The subjects were told that the accuracy test was over and were now instructed to locate boxes in the VE. These boxes were placed in the last part of the VE to stimulate the subject to look around. The top side of these boxes was open and on the inside a figure was depicted. Subjects were instructed to tell the experiment leader which figures they saw. *Figure 2* shows the firestairs found at the beginning of this part, along with a box.

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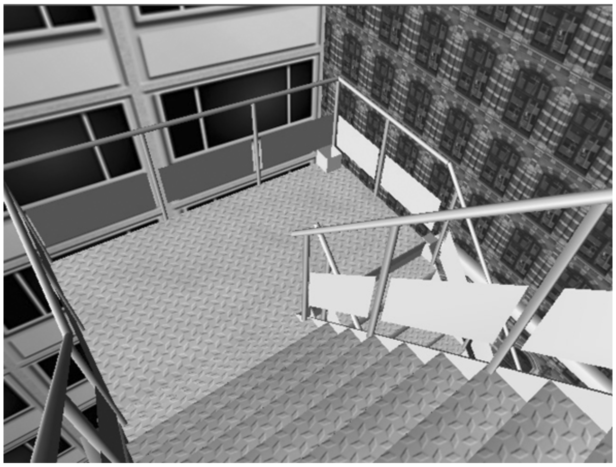

*Figure 2: Firestair with a box placed in the far corner, aimed at stimulating the subjects to look in certain directions.*

The top section of the VE was specifically designed to measure the avoidance behavior of the subjects. *Figure 3* shows an overview of this section. In the first half of the section (Situation 1), subjects could avoid the great depth by keeping to the right. In the second half (Situation 2), an obstacle prevented them from doing this. Situation 1 and 2 are shown in *figures 4 and 5* respectively.

To avoid any unwanted effects caused by differences in framerate between different parts of the VE and between conditions, the framerate was fixed at 15 frames per second.

**Measures**

Prior to the experiment itself, the subjects were required to fill in the following questionnaires:

- Acrophobia Questionnaire (AQ): This questionnaire, developed by (Cohen 1977), consists of 40 items and can be divided into a fear and an avoidance subscale.
- Motion Sickness Tendency questionnaire (MST): A short questionnaire to measure the subject's tendency to suffer from motion sickness.
- Computer Experience questionnaire (CE): 5-item questionnaire regarding the subject's experience with computers and 3D programs
- Tellegen Absorption Scale (TAS): Developed by (Tellegen & Atkinson 1974), this questionnaire aims to measure the subject's openness to absorbing and self-altering experiences.
- Simulator Sickness Questionnaire (SSQ): This questionnaire, designed by (Kennedy et al. 1993), is aimed at measuring the simulator sickness experienced by the subject. The questionnaire was filled in just prior to the experiment to acquire a base-rate.

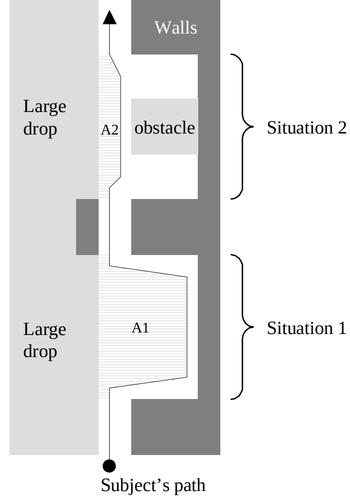


*Figure 3: Overview of the top section of the VE, showing a typical subject's path and the extent of the avoidance behaviour in situation 1 (A1) and in situation 2 (A2).*

*Figure 4: Situation 1, where subjects could avoid the depth by keeping to the right.*

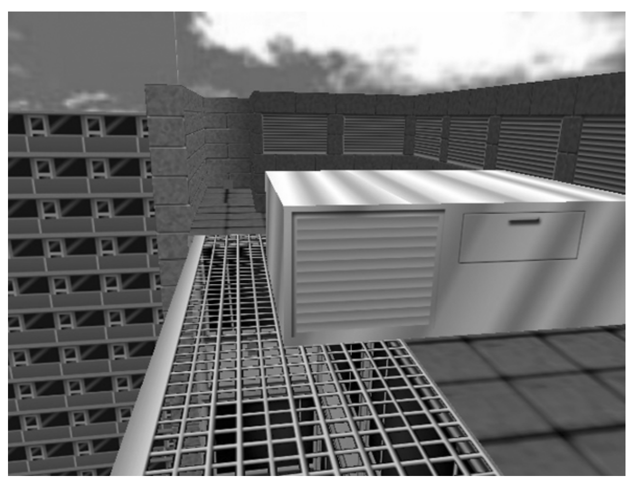

*Figure 5: Situation 2, where avoidance was hindered by introducing an obstacle.*

During the first part of the experiment, where the controllability of the interaction technique was tested, the following data was automatically recorded:

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- *Number of collisions*: The number of times the subject collided with objects in the virtual world, and the magnitude of the collision, where a head-on collision resulted in the highest score.
- *Accuracy*: The accuracy with which subjects positioned themselves near the flags in the first part of the experiment, measured in cm.

In the second part of the experiment aimed at determining the control of fear the interaction technique provided, the following measures were recorded:

- *Heartrate:* With a five second interval, the heartrate of the subjects was recorded with an external device.
- *SUDs:* At certain predefined locations in the VE, the subjects were requested to rate their fear on a scale of 0 to 10. At the beginning of the second part of the experiment, a base-rate measure was taken to compensate for any general anxiety that the subjects might be experiencing.
- *Head-Down Rotation* (HDR)*:* Average number of degrees of downward rotation of the subject's head, used as an indication of whether subjects were looking down into the depth in height situations.
- *Avoidance (AV)*: Extend to which the subject avoided the edge of the large drop in Situation 1 and Situation two, measured as the integral of the distance in cm from the edge.

After the experiment the subjects were instructed to fill in the following questionnaires:

- *Simulator Sickness Questionnaire (SSQ):* Similar to the base-rate measured just prior to the experiment. The final score of the SSQ is calculated by subtracting the base-rate score from this score.
- *Igroup Presence Questionnaire (IPQ):* The questionnaire developed by (Schubert et al. 1999) to measure the subject's sense of presence.
- *Usability Questionnaire (USA):* Small questionnaire aimed at measuring the subject's subjective evaluation of the interaction technique. (see appendix A)

### Subjects

To acquire a wide variety of subjects in terms of age, gender and computer experience, representative of the typical user population for VRET, subjects were recruited through two radio programs on Radio West, advertisement in local newspapers and in the news bulletin of the Fobievrienden Nederland foundation, posters on the campus of Delft University of Technology and email newsflashes at the Hogeschool voor de Kunsten Utrecht. Subjects were excluded from the experiment if they were suffering from epilepsy, had eyesight with deficiency greater than ± 2 dioptres (and did not wear contact lenses) , or were wearing a pacemaker.
42 subjects qualified for these criteria, 23 women and 19 men. These subjects were randomly distributed over the three conditions and received €10 upon completion of the experiment.

## RESULTS

### Subjects

Of the 42 subjects, three were not able to complete the experiment due to extreme fear, resulting in some missing data in the fear section of the experiment. One of these subjects was removed from the experiment altogether because of too extreme values on several scores. *Table 1* shows the some descriptive statistics of the remaining 41 subjects.

| | Min | Max. | Mean (SD) | Max. Score* |
|---|---|---|---|---|
| AQ-fear | 15 | 77 | 44.85 (16.07) | 120 |
| Computer Experience | 8 | 20 | 13.66 (2.67) | 25 |
| Age | 18 | 62 | 30.41 (12.42) | |

* Max. score = highest possible score on the questionnaire.
*Table 1: Descriptive statistics of the subjects*

To test the distribution across the groups an ANOVA with condition as dependent variable was performed for AQ (F=2.309, p=.113). Age (F=1.351, p=.271), Gender (F=.233, p=.801), CE (F=.188, p=.830), MSQ (F=1.439, p=.250) and TAS (F=1.808, p=.178), indicating that the subjects were evenly distributed over the three conditions.

### Measure reliability

A reliability analysis has been performed for the various questionnaires, using Cronbach's alpha as shown in *table 2*. The heartrate measure was extremely hampered by technical problems such as magnetic interference from the tracking device and was unusable.
The SUD scores were found to correlate significantly with the AQ-fear scores (Pearson correlation=.437, p=.005), confirming that people with a higher fear of heights report higher fear in the VE, suggesting that the SUD measures were reliable.

| Measure | N of cases | N of items | Alpha |
|---|---|---|---|
| IPQ | 41 | 14 | .8308 |
| AQ | 64 | 32 | .9203 |
| MSQ | 42 | 5 | .8380 |
| TAS | 42 | 6 | .6632 |
| USA | 41 | 11 | .6408 |
| SSQ(pre) | 42 | 28 | .8269 |
| SSQ(post) | 42 | 28 | .8572 |
| CE | 64 | 5 | .6148 |

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*Table 2: Chronbach's alpha as calculated for the various questionnaires*

### Accuracy of the locomotion technique

Two measures are related to the accuracy with which subjects can move through the virtual world: the accuracy with which subjects positioned themselves on the markers during the accuracy test and the number of collisions and the magnitude of these collisions with objects in the room. We investigated whether age, gender or computer experience had any influence on these two measures. No correlation was found between these variables.

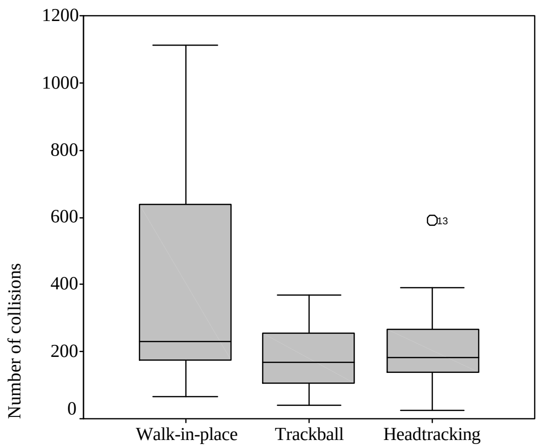


*Figure 6: Boxplot of the number of collisions in the different conditions.*

An ANOVA showed that there was no significant difference in positioning accuracy between conditions (F=2.087, p=.138), but that there was a significant difference in the number of collisions (F=3.273, p = .049). In *figure 6* the boxplot shows that particularly in the walk-in-place condition some people tended to have much higher numbers of collisions.

### Presence

An investigation into what factors could have influenced the presence score revealed that there was no correlation between the IPQ scores and the AQ, gender, computer experience and TAS. This is interesting, since we included the TAS because we expected absorption to be important for presence. Since this did not appear to be the case, the TAS was ignored in the rest of this study.

We did however find a significant positive correlation between age and presence (Pearson correlation =.380, p=.015), indicating that older people tend to score higher on the IPQ. To compensate for this effect in our analysis, age was used as a covariate in an ANCOVA with condition as independent factor and IPQ as dependent factor. Our analysis showed a significant difference in presence between conditions (F=4.722, p =.015). *Figure 7* shows the boxplot of the IPQ scores, showing that presence is highest in the walk-in-place condition.

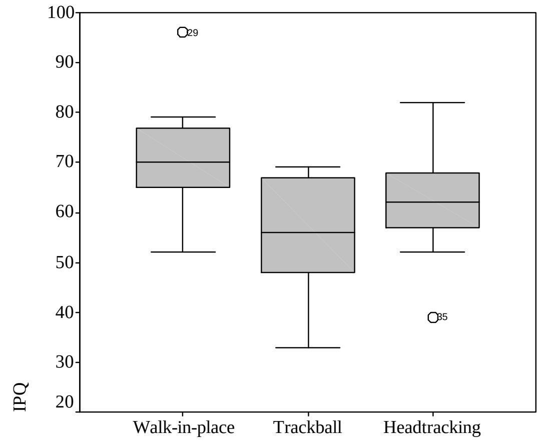


*Figure 7: Boxplot of the IPQ scores.*

### Fear

As stated previously, fear as measured using the SUD scores correlated with the AQ-fear scores. It was therefore used as a covariate in an ANCOVA with condition as independent factor and SUD as dependent variable. For this we used the SUD measure prior to situation 1 and situation 2 (minus the base-rate measure). Other variables were not found to correlate with fear and were therefore not included in this analysis. Results showed a significant difference between conditions (F=4.015, p=.026). The boxplot of the SUD scores in the different conditions in *figure 8* shows that the fear was highest in the walk-in-place condition.

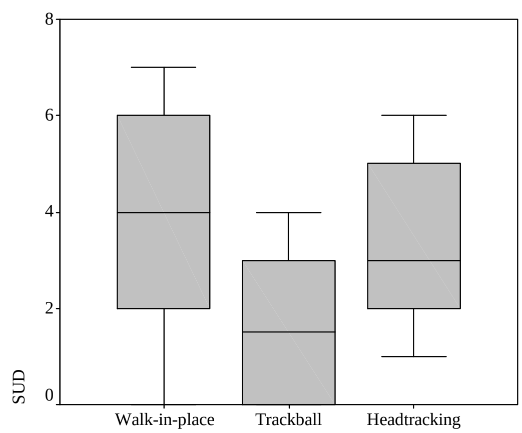


*Figure 8: Boxplot of the SUD scores.*

Furthermore, fear has been found to be significantly higher in situation 2 when compared to situation 1 (F=46.402, p<0.001), indicating that when avoidance is possible, this will reduce the fear a subject experiences. The reduction in SUD scores, resulting from the avoidance behavior, was not significantly different between conditions (F=.599, p=.555), showing that avoidance behavior was just as effective for all locomotion techniques.

**Avoidance**

The subjects could avoid the deep drop in situation 1 and 2 by either looking away as measured using the downward head rotation (please note that only the upward or downward head rotation is relevant here. Because all locomotion techniques steered the subject in the way he or she was looking, sideways head rotation resulted in moving away from the edge as measured by the second avoidance measure.), or by moving away from the edge as measured in the general avoidance measure. An ANOVA for repeated measures showed that for both measures there is a significant difference in avoidance between situation 1 and situation 2. Interestingly, people tended to look down more in situation 2 ($F=5.923$, $p=.020$). The general avoidance measure however was completely in line with our expectations, showing that people moved away much more in situation 1 compared to situation 2 ($F=70.000$, $p<0.001$).
An ANOVA showed that there was no significant difference in either avoidance measure between conditions, indicating that for each locomotion technique, subjects avoided equally.

**Simulator Sickness**

By subtracting the pre-test SSQ score from the post-test score, we obtained a measure of the extent to which the VE experience attributed to the subjects level of feeling sick. Oddly enough, several subjects scored negatively on this cumulative score, indicating that they felt less sick after exposure. Contact with other researchers using the same questionnaire showed that this has indeed occurred in other research as well, for reasons that are yet little understood.

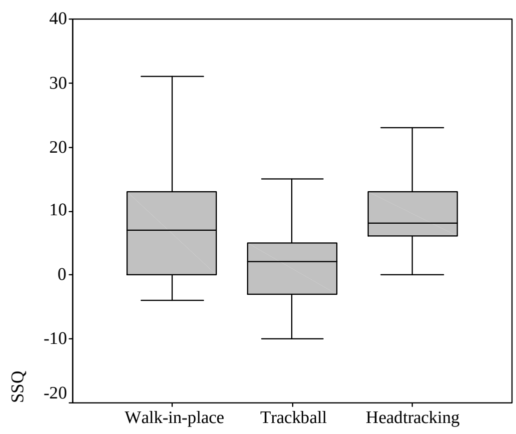


*Figure 9: Boxplot of the SSQ scores*

An investigation into factors contributing to simulator sickness showed no correlation between SSQ and age, gender, computer experience, AQ and MSQ.
An ANOVA showed SSQ scores to be significantly different between conditions ($F=3.257$, $p=.049$). *Figure 9* shows that SSQ is higher in both conditions using headtracking for viewpoint rotation, compared to the trackball condition.

**General usability**

The scores on the usability questionnaire did not correlate with the scores on computer experience, AQ, MSQ, age or gender. There also was no difference between conditions ($F=.705$. $p=0.500$), indicating that subjects rated all locomotion techniques equally.

**DISCUSSION**

The accuracy with which users could move through the VE did not differ greatly. Only the number of collisions was significantly higher in the walk-in-place condition.
As discussed in the previous chapter, the locomotion technique can influence fear in two ways: by changing what the user sees and by changing the user's sense of presence. The results of this experiment show that subjects indeed could use the locomotion technique to lower their fear, resulting in lower fear scores in situation 1 when compared to situation 2. Results also showed that all three locomotion techniques allowed for the same avoidance behavior, since there was no difference in avoidance as measured through the distance from the edge and the downward head rotation between conditions. This provided us with an excellent opportunity to test whether presence does indeed influence fear directly, because what the subjects saw in all three conditions was now the same.
The more natural locomotion techniques resulted both in higher presence scores and in higher fear scores, indicating that presence has a positive effect on fear. The simulator sickness was higher for the more natural locomotion techniques, and the results suggest that this is mainly attributable to the headtracking used to determine the rotation of the viewpoint. These results are in line with previous research, and can be explained by the fact that nobody actually keeps his or her head perfectly still, resulting in continuous movement of the viewpoint, whereas in the trackball condition one simply does not have to touch the trackball to keep still. The continuous movement in the headtracking conditions will confront the user more with the latency of the system and will therefore lead to more sensory conflict and thus to more simulator sickness.
The overall scores of the subjects concerning the usability of the system was not different between the devices, indicating that subjects found all techniques equally easy to use.
This experiment suggests that more natural locomotion techniques can contribute to higher levels of presence and fear in a VE, and that all techniques offer comparable levels of control over what the patient sees and hears in the HMD. The result on simulator sickness suggest that adding headtracking increases simulator sickness, but more natural interaction techniques such as walk-in-place do not add further to simulator sickness. In all, the most natural locomotion technique seems to be the one most suitable for VRET.

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**Conclusions**

This experiment clearly confirms that, when a virtual fearful situation can be avoided, people with fear of heights will indeed show avoidance behavior in a VE, and this avoidance behavior will lead to a significant reduction in that person's fear. This experiment also showed that, when avoidance behavior is equal, presence does correlate with fear and that more natural locomotion techniques not only lead to more presence but also to more fear.

There apparently is very little difference in the general usability of the different locomotion techniques, or even between patient control and therapist control. Also, there does not seem to be much difference in simulator sickness, although headtracking does seem to add to sickness reported by subjects.

It should be noted however that only a limited number of locomotion techniques has been tested in these experiments. Therapist control was only compared to one type of patient control, and our own research has shown there to be differences between different types of patient control (i.e. between different types of locomotion technique). Also, the difference between patient and therapist control was minimized because with either type of control, patients could use headtracking to look around in the VE.

All subjects behaved as if the fearfull situation was real: instead of taking the shortest route, they chose to avoid the height situation and take the long way round.

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