A Breeze Enhances Presence in a Virtual Environment

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Abstract

Typically virtual environments are created with visual and auditory stimuli. Less often, haptic stimulation is included as well, usually in the form of force-feedback and tactile manipulators. Another possible source of haptic stimulation is moving air. In order to generate a breeze in a virtual environment, we created a breeze cannon from readily-available components. We compared four conditions: no breeze, self-generated breeze, object-generated breeze and nature-generated breeze. Participants reported feeling more immersed in the virtual environment when the breeze was caused by their own movement. Anecdotal results also suggest that moving air may help decrease simulator sickness.

1. Introduction

Typically, virtual environments (VEs) are created with visual and auditory stimuli. Less often haptic stimulation is included as well, in the form of force-feedback and tactile manipulators such as gloves or joysticks. Some VEs include moving air to simulate a breeze, but little research has been done to study the impact this type of haptic feedback could have on users. In this paper, we examine what sources for moving air could be used to increase users' feeling of presence within a virtual world.

1.1 Presence

The psychological perception of being inside a virtual world is known as *presence* [20]. A user's feeling of presence can be affected by several factors, one of which is the content of the virtual environment [10].

Research suggests that realistic information can increase users' sense of presence. For example, Hoffman et al. [8] had participants look at virtual displays of chess pieces that were either placed in a realistic pattern (taken from an actual chess game) or placed in a random pattern on the chessboard. The task consisted of remembering the position of the pieces. The participants were classified into four levels of chess expertise, ranging from naïve (does not know the rules of chess) to expert (tournament-level players). Apart from the naïve group, all participants reported a higher feeling of presence when the pattern was realistic than when it was random.

1.2 Haptic feedback

Haptic feedback is usually defined as incorporating both kinesthetic (coming from muscles, joints and tendons) and tactile (coming from nerve receptors in the skin) information [3,5,8].

Haptic feedback can improve task performance. Teleoperators benefit from haptic feedback when manipulating remote objects [4,14]. People working together on a task within a VE can also benefit from haptic feedback. Sallnäs and her colleagues [17,18] found that when one person was asked to hand an object to another person within a collaborative virtual environment (CVE), the participants completed the task faster and thought that their performance was superior when haptic feedback was used. In another study using a CVE [1,2,7], two people had to collaborate to move a virtual ring along a virtual wire without touching the wire. Again, participants performed significantly better in the haptic than in the non-haptic condition.

Haptic feedback can also increase people's sense of presence within a VE. In the CVE-based studies mentioned previously (where participants either passed an object or moved a ring over a wire) [1,2,7,17,18], participants reported having a higher sense of presence in the haptic condition than in the non-haptic condition. In another study within a CVE [11], participants who got haptic feedback while lifting a virtual box together felt a greater sense of co-presence (being with someone else in the VE) than when they received no haptic feedback during the task. Hoffman et al. [9] also found that haptic feedback increased the sense of presence within VEs. Their participants' task was to handle a virtual ball either with or without haptic feedback (working at a time when digital gloves were still primitive, they used real balls for the haptic feedback).

1.3 Air as haptic feedback

A few simulators already incorporate air as a source of haptic feedback. For example, the flying simulator "Soarin' over California" in Disney's "California Adventure" theme park includes moving air to simulate the sensation of wind. Other examples of commercial applications that incorporate air in their feedback include the virtual reality games *Dream Glider*, a hang glider replicator, and *Sky Explorer*, an ultralight plane replicator.

Very little research appears to have been done on the subject of incorporating moving air into a virtual world. We could find only one report (in Korean) that studied the impact of moving air, and which reported that the feeling of presence can be increased by adding moving air to a VE.

In the real world, there are three main sources for air movement: when a person moves through space (self-generated), when an object passes close to a person (object-generated) and when the wind blows (nature-generated)[1]. This study compared people's sense of presence using each of these three sources to investigate whether people find one more realistic within the context of a virtual world. We also expected people to report a greater sense of presence no matter what the source of the breeze when compared to a neutral condition in which there is no moving air.

2. Description of the experiment

2.1 Participants

Eight participants (five women and three men) were recruited during a one-week period from within the Communications Research Centre. Average participant age was 35 (standard deviation of 7.4) and ranged from a minimum of 26 to a maximum of 48. The majority of participants answered the English version of the questionnaires, although two answered the French version.

Previous exposure to VEs ranged from none to several hours, with six participants having had at least some previous exposure (minimum of five minutes).

2.2 Material

The virtual world was created using VRML97 markup (ISO/IEC 14772-1:1997) and rendered using the FreeWRL VRML browser (www.crc.ca/FreeWRL). The computer used to render the world was a Pentium III with dual 1Ghz processors and an NVIDIA GeForce III video card. The framerate achieved during the experiment was approximately 25 frames per second. The environment was displayed using a Virtual Research V8 head mounted display (HMD) and head movements were tracked using a Polhemus 6DOF motion tracker mounted on a chair [16]. A generic computer joystick was used to move the person's avatar around the world. Pulling the joystick trigger moved the avatar forward, while tilting the joystick left or right changed its orientation. When the participant pulled the trigger, the avatar would begin to move forward at a slow pace that would accelerate to a set maximum speed (three units per second) in seven to eight seconds. The speed at which the participant was moving was sent via a socket connection to a separate computer where it was displayed in a GUI interface.An audio clip of 'forest sounds' (including bird songs) was played in a continual loop at a low level so as to block background noise.

In order to generate a breeze, we constructed a *breeze cannon* from readily-available components (see figure 1). A bathroom ventilation fan blew 110 cubic feet of air per minute through a 3 inch (7.6 cm) diameter nozzle via flexible ductwork. The fan ran continuously and air flow was controlled by a manually operated valve to ensure that there was no change in fan noise to cue the person experiencing the breeze. This valve could be set at three levels (no breeze, weak breeze, strong breeze). The nozzle was placed 60 cm from the person's face. As people were wearing a head-mounted display, they only felt the breeze on the lower half of their face and neck. The subjective impression was that of a noticeable cool breeze.

[1] There is also a fourth, mechanical source in the form of fans.

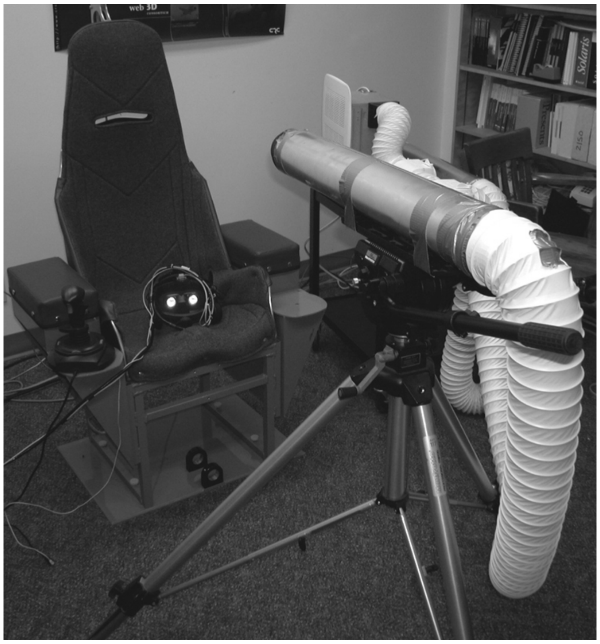

Figure 1. Breeze cannon directed toward the VR chair.

Three questionnaires were filled out by participants, one on presence, one on simulator sickness, and one concerning the haptic feedback.

There have been several questionnaires developed to measure presence [13]. However, we required a short questionnaire that could be administered quickly between conditions. We adapted the five-item questionnaire used by Prothero [15], which was based on the one developed by Usoh and colleagues [19]. Our version has four items, each with a seven-point scale with semantic anchors at both ends. Each question probes for a different aspect of presence within the virtual world. The first question (*lab vs. VE*) asks whether people felt like they were in the lab or in the park (1=lab, 7=park). The second question (*realism*) asks how realistic the world felt like (1=as real as an imagined world, 7=indistinguishable from the real world). The third question (*exclusivity*) asks to what extent the virtual world became the person's reality (1=never, 7=all the time). The fourth question (*insertion*) asks if the VE felt more like something people were looking at or an actual place they visited (1=something they saw, 7=a place they visited).

We used the Simulator Sickness Questionnaire (SSQ) [12] to verify the physical impact that the experiment had on our participants. Finally, we created a short questionnaire to check whether people were aware of the breeze and to measure their feelings about this type of haptic feedback. All three questionnaires were translated by the first author into French.

2.3 Stimuli

The virtual environment used was that of an 'urban park' consisting of approximately 300 widely spaced simple pine trees made up of truncated cones and of five differently colored houses. The size of the environment was set to 1,000 units long by 1,000 units wide. By comparison, the user's avatar was approximately two units in height, while the houses were 6 units wide by 6 units deep by 10 units high. To help participants orient themselves within the environment, the four quadrants had different backdrops: an urban skyline, a mountain chain, a wheat field and a moor.

Six objects representing radio-controlled airplanes were incorporated into the environment. Five of the planes followed circular trajectories around each house, while the sixth followed a circular trajectory around the user's position.

The houses were randomly placed in the environment such that one house was in each quadrant and the fifth house was in the approximate center of the world. Five different random placements were created for each of the four conditions as well as for a practice condition. This practice condition was the same as the experimental conditions with the exception that, in the experimental conditions, each house was highlighted one at a time by a colored pole that started from the house's roof and went towards the sky. This pole or beacon was wide enough and tall enough to be visible from anywhere within the environment, provided the person was facing the right direction.

2.4 Experimental procedure

The participant was seated in the virtual reality chair and was given a brief explanation of the task by one of the experimenters. The task consisted of visiting each of the five houses in a pre-determined order. The house to visit was indicated by a colored beacon coming out of its roof. When the person got close enough to the house (within 15 units of the house), the house would change color (becoming white) and the next house to be visited would be indicated with a new beacon until the last house had been visited. Participants were encouraged to accomplish this task as quickly as possible.

Once the participant understood the task and was shown how to manipulate the joystick, the HMD was placed on their head and the practice environment was initiated. The participant was encouraged to move around this environment for approximately one minute. After the participant had familiarized themselves with the controls the practice environment was shut down and the first of the four test environments was initiated.

Each participant was exposed to all four conditions (within subject) but in a different order (between subjects), with two people assigned to each order. The order of the conditions was varied in a Latin square as seen in table 1.

Table 1. Latin square order

Session 1	**Session 2**	**Session 3**	**Session 4**
Neutral	Self	Object	Nature
Self	Nature	Neutral	Object
Object	Neutral	Nature	Self
Nature	Object	Self	Neutral

The neutral condition contained no breeze. In the self-generated condition the air cannon was activated whenever the person moved within the environment. If the person was moving slowly (up to half of the maximum speed), the cannon was set to produce a weak breeze. If the person was moving quickly (above half the maximum speed), the cannon was set to produce a strong breeze. In the object-generated breeze condition one of the experimenters handled the breeze cannon to synchronize the movement of air with the motion of the planes in front of the person's avatar. For example, if the planed moved from left to right in front of the avatar the breeze cannon was swept from left to right across the person's face. In the nature-generated breeze condition the breeze cannon was turned towards the participant for approximately ten seconds once every minute that the user was in the environment. For both the object generated breeze and nature generated breeze conditions, the cannon was set to produce a strong breeze.

The time to complete the task was measured from the moment the environment became live (the participant was informed of this by one of the experimenters, and through a visual cue in the environment) to the moment the participant reached the last house.

After the person reached the last house, the environment was shut down and the participant was invited to either shut their eyes or remove the HMD (most people chose to shut their eyes). At this point, the presence questionnaire was read out to them and their answers were recorded on paper. Once the questionnaire was finished, the participant was invited to open their eyes or put the HMD back on and the next environment was initiated. This procedure was completed four times, once for each condition.

After the fourth trial was finished and the last presence questionnaire completed, the experimenter read the SSQ to the participant and recorded the answers on paper. Then the haptic questionnaire was filled out in this same way. Afterwards, the experimenters debriefed the participant and any questions from the participant were answered.

The whole procedure lasted between 20 and 40 minutes.

3. Results

In order to analyze the feeling of presence, Usoh *et al*. [19] counted the total number of times people answered 6 or 7 on their questionnaire. However, we believe that this approach leads to a loss of information. Instead, we have chosen to analyze each question separately. Because of the small number of participants, we collapsed the different orders together and used the non-parametric Friedman two-way analysis of variance by ranks on each of the four presence questions. Table 2 presents the average ratings given by participants for each question according to the four conditions, while Table 3 presents the results from the Friedman analysis of variance. Ratings can vary from 1 to 7, with higher ratings indicating greater feelings of presence.

Table 2. Average rating on presence questions according to the condition

	Conditions			
Question	**Neu-tral**	**Self**	**Object**	**Natu-re**
1. Lab or VE	3.0	4.3	2.5	3.3
2. Realism	2.5	3.1	2.3	2.6
3. Exclusivity	3.3	4.0	2.9	3.6
4. Insertion	3.1	3.8	3.4	3.3

Only the first question reached significance, which means that the participants judged the feeling of presence differently for the four conditions when asked whether they felt as though they were seated in the lab or walking through a park. Although questions 2 and 3 follow a similar pattern of response as that given on question 1 (self condition highest and object condition lowest), neither reaches significance. Question 4 shows a slightly different pattern (neutral condition getting the lowest rating), but again, it does not reach significance. This lack of significance may simply be due to the small number of participants in this experiment.

Table 3. Results of Friedman analysis

Question	χ^2	**dl**	**p**
1. Lab vs. VE	11.87	3	.008
2. Realism	5.75	3	.125
3. Exclusivity	4.62	3	.202
4. Insertion	3.71	3	.295

Pairwise comparisons were done on the answers for question 1 and significant differences were found between self and neutral ($p<0.01$), self and object

($p<0.001$) and self and nature ($p<0.05$). In other words, our participants felt more as though they were inside the park than in the lab when the breeze was associated with their own movement than when it was associated with any other condition or when there was no breeze.

In order to see whether adding air would have an impact on task, we measured the time spent to complete the task. A measurement error occurred in one case (participant #3, condition B), when the experimenter did not notice that the last house had been reached, thus causing this time to be inflated (over six minutes). However, this error does not seem to have had much consequence. Table 4 presents the average time taken to complete the task for each of the four conditions. A Friedman two-way analysis of variance by ranks on the time taken was not significant ($\chi2_{(3)} = 0.75$).

Table 4. Average time to complete task according to the condition

Condition	Neutral	Self	Object	Nature
Time	3m16s	3m55s	3m3s	3m42s

General SSQ ratings ranged from 0 to 60, with an average of 35. Compared to the base scores established by Kennedy et al. [12], these results are relatively high. This may be because of the task, which required participants to orient themselves frequently within the VE. The common strategy used by participants to discover the next house was to spin themselves around until they had established visual contact with the beacon. There were some instances in which participants had trouble finding the beacon (either not recognizing it or having a house blocking their view), causing them to spin frequently, which may have increased feelings of illness.

All participants reported being aware of the breeze. They were asked to judge its pleasantness on a seven-point scale where 1 represented very unpleasant and 7 very pleasant. On average, people reported that the breeze was pleasant, giving it an average score of 5.5 (minimum score of 3, maximum of 7). When asked whether they associated the breeze with anything in the virtual world, answers varied. Two people did not think it was correlated with anything, while one person reported that she stopped noticing the breeze after a while. Of those who did associate it with something, four people mentioned that it seemed caused by their movement, while two people thought it was the wind. When probed further, one person thought the other conditions were random, one person noticed that the planes produced breezes, and two people thought the air was meant to help them (either to reduce their nausea or to help them breathe). During the debriefing, several participants reported that the breeze did help improve their feeling of presence.

4. Discussion

Participants reported an increased sense of presence during trials with a self-generated breeze as compared to all other conditions, but only in response to the question asking whether they felt as though they were in a lab or in the virtual world. We had expected that all the experimental conditions would produce higher ratings than the neutral condition, but this was not the case. There are several possible explanations for this. For one thing, the object-generated breeze condition did not produce as many encounters with planes as we had anticipated. The plane circling the avatar could not keep up with the rapid pace of movement through the environment and, as a result, rarely circled the person unless their avatar was standing still (which people did infrequently since the instructions asked them to accomplish the task as quickly as possible). Furthermore, people spent very little time next to any one house (just enough time to reorient themselves), so there were also very few encounters with the planes anchored to the house locations. This resulted in very few breezes produced in this condition (less than three in most cases, and more often than not only one). Although the nature-generated condition produced slightly more breezes than the object-generated condition, these breezes were still not frequent when compared to the self-generated condition. A person in the nature condition would have typically been exposed to three or four breezes (30 or 40 seconds of air), whereas in the self condition, the person would have been almost constantly exposed to air (several minutes worth). It may be then that it is not the apparent source of the breeze that increases the feeling of presence so much as the amount of breeze that the person felt during their visit to the virtual world. Further experimentation would help clarify this issue.

There is another difference between the three experimental conditions that could potentially have an impact on people's feeling of presence. Depending on the condition, the breeze was either in movement or stable. That is, the breeze was either swept across the person's face (object-generated condition) or it was pointed straight at the person over a shorter or longer period of time (nature- and self-generated conditions). Although the object condition was not significantly different from the nature condition in this study, a larger sample size might reveal a difference between these two ways of blowing air towards people in a VE.

Surprisingly, some people reported a small decrease in the feeling of sickness when exposed to a breeze. Unfortunately this experiment was not set up to explore the impact of moving air on people's simulator sickness symptoms. However if moving air can be proved to help alleviate people's symptoms, it would warrant incorporating this source of haptic feedback more frequently into VEs.

5. References

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