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An Experiment on the Influence of Haptic Communication on the Sense of Being Together

C. Ho, C. Basdogan, M. Slater*, N. Durlach, M. A. Srinivasan

Laboratory for Human and Machine Haptics and Research Laboratory of Electronics
Massachusetts Institute of Technology, Cambridge, MA 02139

1. Introduction

This paper describes an ongoing experiment to study whether haptic communication through force feedback can facilitate a sense of togetherness between two people at different locations while interacting with the same virtual environment. This is a companion paper to Durlach and Slater (1998) which provides a conceptual framework.

The experiment concerns a scenario where two or more people are at remote sites, but must co-operate to perform a joint task or play a game in a shared VE. In the current experiment, the set-up is an abstraction from a real situation, in order to simplify the interactions that occur in real life and to create a more controlled context suitable for an experimental study in the laboratory. We focus mainly on the impact of haptic display on the perceived quality of the interaction itself.

The sense of *presence* of a person in a VE has been of increasing interest to researchers, as discussed in the companion paper. In addition, there have been several studies on the development of social relations in shared VEs, and also on task performance (Bowers, 1996; Schroeder, 1997). However, there has been little attention paid to co-presence, that is the sense that participants have of being with other people, and to our knowledge, no attention paid at all to what the addition of touch and force-feedback between people would contribute to the shared experience. In this regard, the purpose of the experiment was to assess the impact of force feedback in addition to visual display

- On performance of the task
- On the sense of being together as reported by the participants
- On the extent to which participants could make guesses about the 'personality characteristics' of one another based on what they could see and feel of the behaviour of the other person during the course of the experiment.

2. Haptic Feedback for Shared Virtual Environments and Teleoperators

Haptic display of 3D objects in virtual environments has been a growing research area for scientists and engineers during the last few years. (Refer to Srinivasan, 1995 and Srinivasan and Basdogan, 1997 for a brief review of the current literature and the summary of research status). Analogous to graphical rendering, haptic rendering is concerned with real-time display of the touch and feel of virtual objects to a human operator through a force reflecting device. Our group at MIT has developed efficient haptic rendering methods for displaying the shape and surface details of 3D polygonal objects in VEs (Ho et al., 1997).

Although haptic display of 3D objects is being developed for various applications such as medical simulation and computer-aided design, its applications for shared virtual environments and teleoperators has not been explored previously. It is likely that the addition of haptic modality to shared virtual environments having visual and/or auditory displays may increase the sense of "being together" and the quality of the interactions while performing collaborative tasks.

3. Experiment

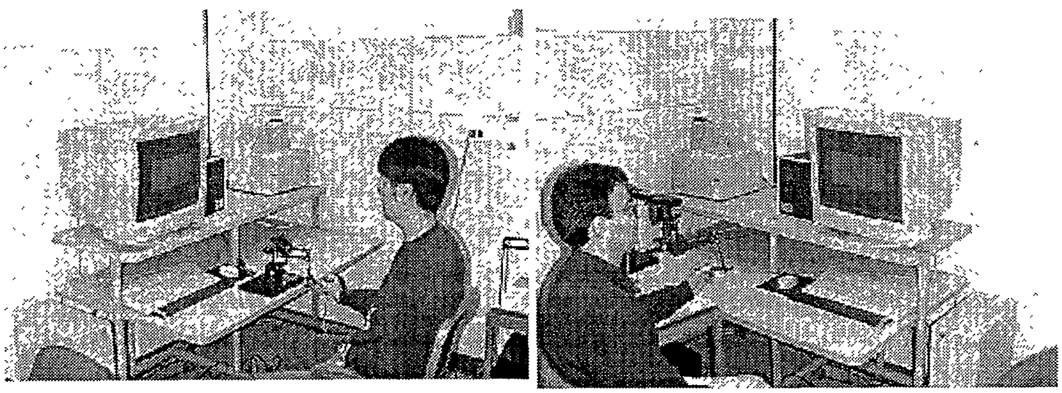
3.1 Components of the Experimental Set-Up

The experimental set-up includes a dual 300 MHz processor IBM compatible personal computer, running Open Inventor to display the graphical model of the 3D virtual environment, and a force feedback device, PHANToM (SensAble Technologies Inc.), to convey to the user a sense of touch and feel of virtual objects.

3.2 Design

During the experiment, subjects were asked to play a collaborative game in virtual environments. They played the game with one of the experimenters who was an "expert" player. The subject was not allowed to know the "expert" player, and had no idea where the "expert" player was located during the experiment. The players were in different locations but saw a common scene and could feel the objects in the scene. The shared visual scene included a ring, a wire, and two cursors (green and blue small spheres that represented the contact points) attached to the ring (Figure 1). They were asked to move a ring on a wire in collaboration with each other such that contact between the wire and the ring was minimised or avoided.

Each subject manipulated his/her own cursor through a stylus attached to the force feedback device placed next to their seat. When the subject manipulated the stylus of the touch device with his/her right hand, the cursor moved in 3-D space, so that the ring could be moved.



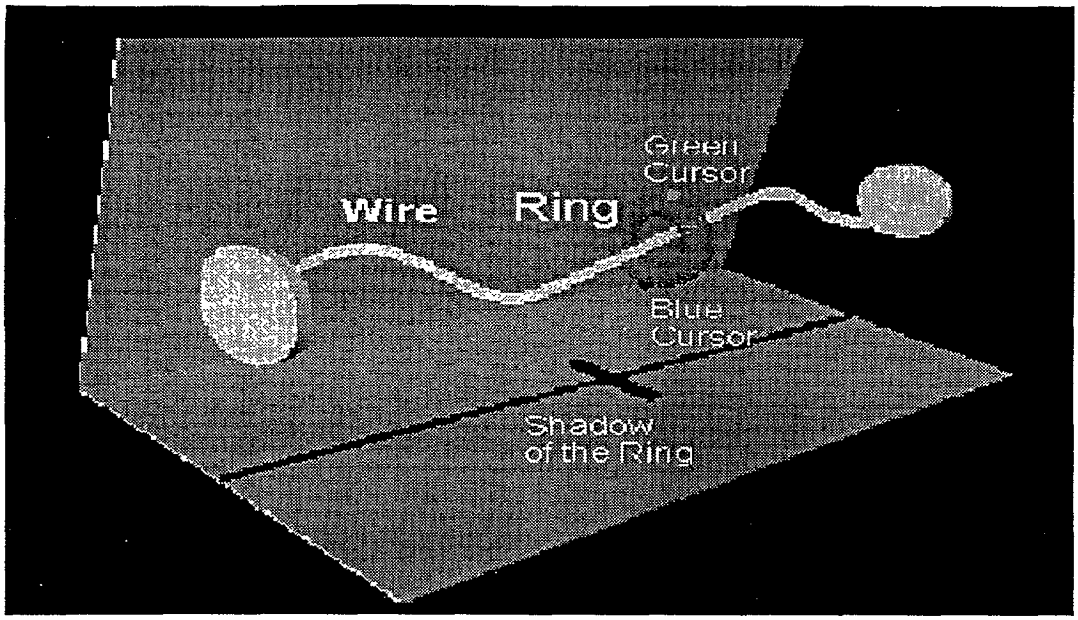


Figure 1. A shared virtual environment was created to play the "*Ring on a Wire*" game. Two subjects, represented by blue and green cursors and physically located in two separate rooms, share the same VE to move the ring in collaboration. Each subject can feel the resistive force through the haptic device when (1) the ring touches the wire (2) he/she pulls or pushes the other person.

The goal of the game was to move the ring with help from the other person without touching the wire. If the ring touched the wire, the colors of the ring and the surrounding walls changed to red to warn the subject of an error. They changed back to their original colors when the subjects corrected the position of the ring. To hold the ring, both subjects needed to press on the ring towards each other above a threshold force. If they did not press on the ring at the same time, the ring did not move and its color changed to gray to warn them. To move the ring along the wire, they each needed to apply an additional lateral force. Moreover, the shadow of the ring was displayed on the ground to give cues to the subject about its position relative to the wire.

The subjects were asked to move the ring back and forth along the wavy wire 3 times per trial. The shape of the wire was changed each time they reached the target end of the wire. The subjects could feel the forces through the haptic display (1) when the ring touched the wire (2) when a movement was induced by the other subject.

At the time of writing, we have tested 10 subjects. Five of these experienced first the haptic and visual condition, and then between 11 and 15 days later, the same scenario but without any haptic feedback at all. The second group of five subjects experienced the visual only condition. It is intended that they will later carry out the tasks again but with the haptic feedback enabled. Each pair participated in at least 10 trials which took about 30 minutes.

3.3 Variables Measured

We aimed to understand the effect of haptic cues on the sense of being together in VEs using *subjective* measures (see the descriptions of these terms in the companion paper by Durlach and Slater, 1998). After the experiment, each subject answered a questionnaire, which supplied basic demographic and background information. Subjective questions were asked in four categories including their (1) performance, (2) their sense of 'being together', (3) emotional reactions, and (4) personality profile.

Performance: Each person made a self-assessment of their own performance and the performance of the other person using the questionnaire. Sample questions in this category include:

Please give your assessment of how well you contributed to the successful performance of the task.

1. Not good at all ... 7. Excellent

Please give your assessment of how well you and the other person together performed the task.

1. Not good at all ... 7. Excellent

Sense of Being Together: Each of the following questions was rated on a 1-7 scale, where 7 meant a greater sense of 'togetherness'. There were seven questions in this category, sample questions include:

To what extent, if at all, did you have a sense of being with the other person?

1. Not at all ... 7. Very much so.

To what extent were there times, if at all, during which the computer interface seemed to vanish, and you were directly working with the other person?

1. At no time ... 7. Almost all the time

Emotional Reaction: To see if the experiment had any emotional impact on each subject, we included a few questions such as:

To what extent did you feel embarrassed, with respect to what you believed the other person might be thinking about you, in the way that you carried out this task?

1. Never ... 7. Almost all the time

Personality Profile: This area of study is new, and we wanted to 'push the limit' to examine whether it was possible to guess about the personality of the remote partner from these forms of interaction. We asked each individual to complete a standard personality profile test (Leary, 1983) supplemented by some additional questions particularly relevant to this task. We asked each person to complete this test for him/herself, and also to complete the test guessing the answers for their remote partner. The purpose was to examine whether subjects' assessments of their unknown partner would change under the experimental conditions.

4. Results

At the time of writing we have an unbalanced design: a 'within subjects' experiment of five people (who experienced first visual and haptic, and then later visual only). A second group of five experienced the visual condition only. The analysis below is therefore in two parts - first comparing the within subjects experiment in itself, and second a 'between subjects' analysis comparing the visual plus haptic results of the first group of five, with the visual only results of the second group.

There were seven questions that related to the *sense of togetherness* experienced. A conservative measure of the overall level of togetherness experienced by a player is realised through counting the number of high scores (6 or 7) amongst the seven different questions. This is in line with scores used in previous studies of presence (Slater and Wilbur, 1997). A plot of this sense of togetherness against the maximum score realised in the game is shown in Figure 2 for the visual plus haptic group. The correlation r = 0.98 which is significantly different from zero at the 1% level. If mean game score is used instead of maximum score, then the result is similar, with r = 0.88 which is significant at 5%. While not too much can be made of this result, relating perceived 'togetherness' with task performance, this is at least encouraging.

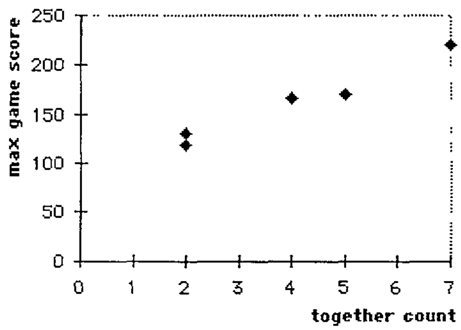


Figure 2. The Y axis shows the maximum score achieved by a player during the trials. The score is based on the number and proportion of contact times between the ring and the wire. The X axis shows the number of high (6,7) scores amongst the seven 'togetherness' questions.

Togetherness

The response variable is the number of high (6 or 7) scores out of the seven 'togetherness' questions. This is treated as a binomial variable (number of 'successes' out of 7 trials), and therefore logistic regression is used to test the influence of a linear model involving the other independent and explanatory variables on the response. All significance tests are carried out in the context of the logistic regression, and no results are reported with significance less than 5%.

For the within subjects design the significant variables are the main condition (whether haptic plus visual or just visual), gender, age, and the subjects' assessments of the social anxiety of their remote partner. The overall chi-squared for goodness of fit of the model (which should be small for a good fit) is 7.5 on 5 d.f. No variable can be deleted from the model without significantly worsening the goodness of fit.

For the between subjects design the results are the same, except that age is not significant.

To summarise, the results from the overall logistic regression are:-

- The haptic plus visual condition results in a higher sense of reported togetherness than the visual only condition.
- Females tend to report a higher sense of togetherness than males.
- Togetherness decreases with age (in the within subjects design only).

- Togetherness is positively associated with the estimated extent of social anxiety of the remote partner.

Task Performance

A performance score was constructed from the proportion of time that the ring was not intersecting the wire. Since there were many attempts for each experimental subject, we take the maximum score achieved as a measure of task performance. The table below shows the mean (standard deviation) of the maximum scores, and the results of t-tests comparing the means for the visual only conditions against the haptic plus visual. As would be expected performance is significantly better with the presence of the haptic feedback.

Treating the maximum score as a dependent variable in an ordinary multiple regression analysis results in an extremely good fit (squared multiple correlation being 97% for the within groups design and 88% for the between groups design). The model includes the basic condition and 'togetherness'. However, 'togetherness' is significantly and positively associated with the score under the haptic plus visual condition only (ie, the regression slope for togetherness is not significant under the visual only conditions).

	Mean (SD) Max Score	**t-test for diff. in means**
Haptic plus visual	161 (39.8)	
Visual only (within design)	67 (13.7)	$P < 0.002$
Visual only (between design)	77 (34.5)	$P < 0.008$

5. Conclusions

This note reports an ongoing experiment to examine the extent to which haptic communication, in addition to the usual visual feedback, influences the sense of togetherness between remote participants in a shared VE. Preliminary results suggest that haptic feedback adds significantly to the sense of togetherness, as does gender (higher for females). Interestingly, togetherness also increases with the degree of 'social anxiety' estimated for the other (unknown, remote) person by the subject. The reason for this is unknown, but it occurred in both experimental conditions.

There is also a clear influence of haptic feedback on the performance of the task, and independently, in the presence of haptic feedback, the degree of togetherness also significantly improves task performance.

The experiment remains to be completed, so the results above are certainly tentative.

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M.Slater, permanent address: Department of Computer Science, University College London.