Promoting research and clinical use of haptic feedback in virtual environments

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ABSTRACT

Converging evidence demonstrates the important role played by haptic feedback in virtual reality-based rehabilitation. Unfortunately many of the available haptic systems for research and intervention are rather costly, rendering them inaccessible for use in the typical clinical facility. We present a versatile and easy-to-use software package, based on an off-the-shelf force feedback joystick. We propose that this tool may be used for a wide array of research and clinical applications. Two studies, involving different populations and different applications of the system, are presented in order to demonstrate its usability for haptic research. The first study investigates the role of haptic information in maze solving by intact individuals, while the second study tests the usability of haptic maps as a mobility aid for children who are blind.

1. INTRODUCTION

People perceive their body and the surrounding environment through different sensory modalities. Neuroanatomical and neurophysiological studies suggest that early processing is modality specific, and that later on the unimodal data are integrated into a complete description of the world (e.g., Treisman, 1986). Studies in various disciplines have demonstrated that the modalities may interact. These cross-modal interactions are observed at several processing levels. Different modalities may influence each other even prior to the appearance of stimuli, as manifested in the control of attention. Behavioral studies have shown how shifting attention in one modality caused a shift of attention in another modality. Longer lasting effects appear in cross-modal transfer, where knowledge acquired in one modality, improves performance when employing another modality (e.g., Krekling et al., 1989).

To date, most virtual environments (VE) consist of visual or audio-visual feedback. Adding haptic feedback may have several potential benefits. First, an extra channel of information may produce a more realistic environment and increase the level of presence, which consequently, may enhance the efficiency of Virtual Reality (VR)-based interventions (Durfee, 2001). Second, beyond this general enhancement which applies to any VE, specific populations may find haptic feedback especially beneficial. Many patients with stroke, for example, suffer from both motor and sensory deficits. They may benefit from haptic feedback as a component of their therapy aimed at restoring proprioceptive function. In such cases, it may be argued, that audio-visual non-haptic VR therapy may actually lead to deterioration and "learned non-use" of the affected limb. A similar case, supporting haptic feedback, can be made for interventions directed at children suffering from a high somatosensory threshold. A third, rather obvious, case where haptic feedback is required, includes populations where haptic feedback is the primary means of the intervention. Previous applications of haptic interventions include those targeted at strengthening muscles (e.g., Deutsch et al., 2001), or perceptual training for children who are blind (e.g., Colwell et al., 1998).

These concerns lead us to contend that there is a need to systematically characterize the role of haptic feedback in virtual environments and its potential benefits for virtual rehabilitation. This line of research will help developers and clinicians to decide which types of impairments (motor, cognitive, sensory) merit the hardware and software costs caused by adding the haptic channel. Unfortunately, research of haptic feedback is still rather scarce. To a large extent, this void is due to the high cost and encumbrance of many of the currently available haptic devices.

This paper presents a new low-cost, user-friendly tool, aimed at facilitating multi-modal research and intervention. In order to establish the usability and justify the importance of the proposed tool, two separate studies are presented as well. We have created software which runs on a standard PC desktop and uses an off-the-shelf force feedback joystick. This user-friendly program enables a therapist or researcher to quickly design simple visuo-audio-haptic environments by drawing and encoding basic geometric shapes. Although simple to operate, many sophisticated, game-like tasks may be designed and used for a gamut of research/treatment goals that test and train participant abilities.

It should be noted that such low cost haptic devices have been suggested in the past for intervention purposes (e.g., Reinkensmeyer et al., 2002). The proposed tool, however, offers a unique and valuable feature, namely flexibility. Thus the researcher or therapist may create a wide array of environments and tasks independent of external help from a professional programmer. We believe this easy-to-use interface will make haptic research and therapy accessible to many clinicians in the "trenches". In order to illustrate the feasibility of this tool, as well as to further establish the importance of basic haptic research, we present here two separate studies. The first study investigates the influence of haptic feedback on task performance. The second study examines the ability of haptic feedback to enhance spatial perception of children who are blind via the presentation of virtual environments.

2. THE TOOL

2.1 Hardware

We used the Sidewinder Force feedback 2 joystick manufactured by Microsoft (http://www.microsoft.com/hardware/sidewinder/FFB2.asp). It should be noted that there are other off-the-shelf products which function in similar ways (e.g., the Force 3D joystick by Logitech (http://www.logitech.com/index.cfm/products/details/IL/EN,CRID=12,CONTENTID=5016)).

2.2 Software

The software is composed of three modules. The Editor is used for designing the environments, the Simulator is used for the actual simulations, and the Analyzer serves for post-hoc analyses.

2.2.1 Editor. The Editor provides a user friendly interface (see Fig. 1) used by the investigator or therapist to place objects of different sizes and shapes on the screen. These objects are assigned various attributes such as colour, sound, movement, and type and intensity of haptic feedback. Juxtaposition of the virtual objects and association of their attributes enables the creation of either simple or complex environments. The Editor also enables the user to define the start and end points of the environment as well as the speed in which it will operate.

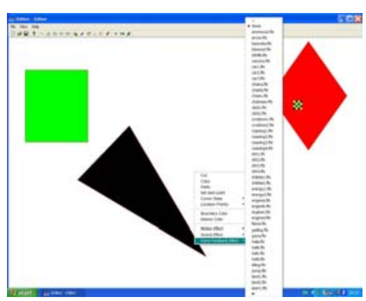


Figure 1. *Example of the Editor interface.*

2.2.2 Simulator. Once the environment is loaded to the software, The Simulator is then employed for running experimental trials or for conducting intervention. The Simulator lets the client interact with the various objects in the virtual environment. The client uses the joystick to control and move the cursor. Whenever the cursor is moved onto an object its sound and force feedback features are activated. Thus a particular sound, which may also be a pre-recorded message, will be heard. For as long as the cursor is on the object, the client will feel the haptic sensation associated with this object (as defined when creating it in the Editor).

The Simulator has several working modes suited for different client populations. The cursor can move in pre-set velocities or allow the client to change speed during the session. It can also present online the current speed and the time that has passed since the start of the session. Finally, the Simulator has a ‘right-angle’ mode where the cursor can be moved only in right angles, i.e. up-down-right-left.

2.2.3 Analyzer. The Analyzer is used by the investigator/therapist to review past sessions and analyze the data collected during these sessions. The Analyzer shows the virtual environment traversed by the client and the path of the cursor movements. The path can be viewed all at once or be animated in order to be viewed together with the client. The Analyzer may also present the temporal information associated with the trace. Thus the user may see where and at what time the cursor was at any point.

3. EXPERIMENT ONE – HAPTIC MAZE

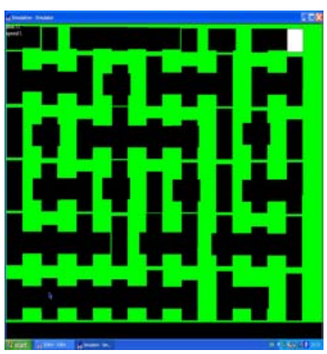
We propose this tool as a versatile system for research of haptic feedback as well as using it for intervention. Hence we decided to use it for two different experiments, each with different goal and target populations. We believe these experiments may assist to evaluate the usability of the system.

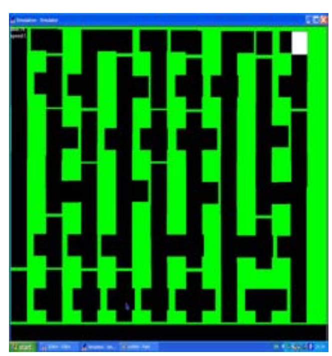
The goal of the first experiment was to test whether haptic information may facilitate performance in a maze task. This task was chosen as mazes involve both lower and higher cognitive and executive functions, and offer a variety of research and intervention paradigms (e.g., Porteus ,1973, Wann, 1997).

We hypothesized that participants may use haptic cues to help them in learning the correct route of the maze. While traversing the haptic maze, the participant constantly feels haptic feedback of many different kinds. The type of feedback is unique to each part of the maze. Our rationale was that while traversing the maze over and over, the subject will associate certain haptic feedback with the correct route, and use these haptic cues, in addition to the visual information, when solving the maze.

Our pilot studies have shown that in the case of simple mazes, the participants tended to solve them rather easily employing mainly their visual sense. They simply looked for a short while at the maze and quickly found the correct route. It seemed that, for these simple mazes, they relied almost solely on the visual information, which was so dominant, that the haptic information was not employed. These findings led us to create a dynamic maze, whose components move constantly. Parts of the maze moved back and forth either on the vertical or the horizontal axes, alternately creating and eliminating possible routes (See Figs. 2 & 3). Since these components moved back and forth repeatedly, there was, in fact, no change in the maze’s solution, and there was only one correct route. The constant motion, however, made it more difficult to detect the correct route by merely looking at the maze. This encouraged the participants to learn the maze while moving in it, thereby enhancing the opportunity to benefit from the haptic information provided to them.

Half of the subjects solved a visual-haptic maze whereas the other half solved a purely visual maze, where no force feedback cues were delivered through the joystick. We hypothesized that the first group would perform better than the latter.





Figures 2 and 3. *Screen captures of the dynamic maze at different times. The participant moves the cursor (too small to be seen in the figures) towards the white square at the top right of screen. Note how the path (black foreground) is in different positions in these two figures.*

3.1 Method

3.1.1 Subjects. Thirty six volunteers, aged 18 to 30 years (mean = 23.9; SD=3.4) participated at the experiment. All were right handed and had normal or corrected to normal vision. The number of females and males was equal. The subjects were randomly assigned to one of two groups. Each group consisted of nine males and nine females.

3.1.2 Apparatus and Stimuli. The maze was presented on a laptop computer positioned on a desk in front of the subjects, and the joystick was placed next to it. (See Fig. 4). The maze was of two possible types, visual-haptic maze or visual mazes. Otherwise they were identical in all aspects. The auditory features of the software were not employed in this task in order to limit the modalities of feedback.

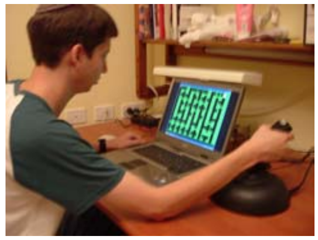


Figure 4. *Positioning of the apparatus.*

3.1.3 Procedure. Participants were first introduced to the joystick and underwent short training in its use. They were then instructed to solve the maze ten times with a short break after each trial. The execution time (ET) as well as the trace of the subject's cursor movement were collected for each trial. This session was followed by another session which took place 24-48 hours after the first one. The second session consisted also of ten trials, solving the same maze as in session one. At the end of each session the participants filled a short feedback questionnaire.

3.2 Results

The results presented here are preliminary and include only the analysis of execution times, but not the analyses of errors and of movement patterns. Generally, as commonly expected in learning tasks (e.g., Karni 1996), a learning curve was produced where execution times were improved until reaching a plateau. When comparing the mean ET of each trial of the first session to the parallel trial of the second session, a significant improvement ($p<0.05$) was achieved for all trials. The improvement of performance between sessions is known in the literature and is accounted for by the consolidation of the learned task (Karni et al., 1994). These learning effects were achieved for both groups, visual only and the visual-haptic.

To test for haptic facilitation we compared the mean ETs of the visual group to the visual haptic group. Fig. 5 describes the two learning curves (as manifested by ETs) of the first session. The differences between the groups were not significant except for the ETs of the second trial, where the visual-haptic group performed significantly faster ($t(34)=1.994$; $p<0.05$) than the visual group.

3.3 Discussion

There are two issues to be learned from this experiment. First, the data suggest that haptic feedback may facilitate learning at a rather early stage, as indicated by the faster times achieved by the haptic group at the second trial. Although this gain disappeared after subsequent trials, the learning curve took a significant 'dive' at the second trial. To further explore these findings, we plan to focus at the performance of the first few trials. This will enable us to run a much shorter experiment consisting of one short session, with many more subjects, which may lead to more decisive conclusions.

A second lesson from this experiment is the ability to use this system for research. As can be seen here, the system can be used to explore haptic feedback in motor and cognitive tasks.

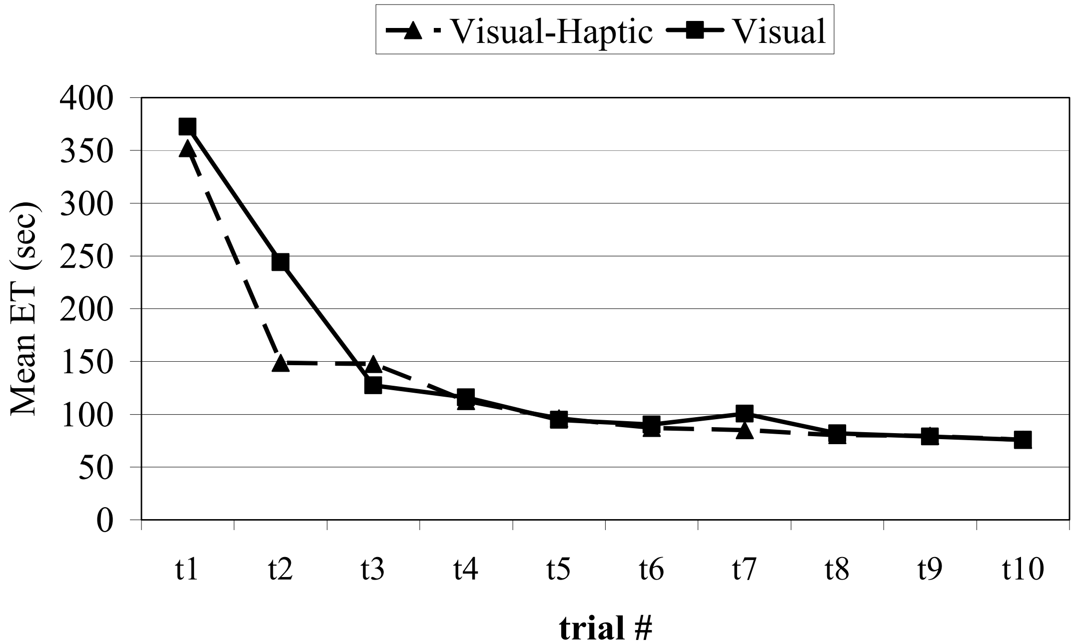


Figure 5. *Learning curves of the first session, comparing the mean ETs of the visual haptic group (dashed) and the visual group (solid).*

4. EXPERIMENT TWO – HAPTIC MAP

After using the system for a cognitive study we tested it as an intervention tool. The blind population appears to be a natural candidate who may benefit from a haptic system. Lahav and Mioduser (e.g., 2002) have used a force feedback joystick to help blind persons to get acquainted with a room and the objects within it. We took a different environment, and used our system to help children who are blind navigate in a building using a haptic map. This is an ongoing study and we report here its design as well as some very initial results.

4.1 Method

We used our system to build a haptic map of a segment of a building. In contrast to the previous experiment where the haptic feedback did not have any inherent meaning, here every type of feedback carries particular information. We created a legend of haptic feedbacks for the various classes of obstacles commonly found in buildings corridors (e.g., doors, windows, stairs, benches). Fig. 8 shows a haptic map of the areas depicted in Fig. 6 and Fig. 7. Our hypothesis is that participants who are blind may be able to use this system to learn a new environment prior to encountering it in reality.

Figures 6 and 7. *Environment to be learned by participants who are blind. The two hallways are connected and are perpendicular to each other.*

Figure 8. *Haptic map of the environment appearing in Figures 6-7. The different colours are used to represent different haptic feedbacks.*

4.1.1 Population. This experiment takes place in a school for the blind. Participants are children, aged 8 to 13 years, who are congenitally and totally blind. These children have not learned yet to use canes for mobility, and use primarily their hands.

4.1.2 Apparatus and Stimuli. The children use the system on a desktop in the school's computer room. The stimuli consist of a map, at a scale of about 1:100, as shown in Figure 8. The real world environment studied by the participants is located in a nearby building, where they have never been prior to this experiment. We have found two similar environments in this building so we are able to compare performance with the VR training to a baseline of no training.

4.1.3 Procedure. The participants are initially acquainted with the joystick using a very simple haptic environment. They are introduced then to the haptic map and trained with it by an instructor who verbally helps them at the early stages. As they become more proficient, the instructor gives assignments which require navigation (e.g., 'Go from the main staircase to the bathroom'). Once they perform well within the virtual environment, they are brought to the real environment and asked to perform various navigation tasks within it. They are also brought, on a separate day, to another environment in this building where they are asked to perform similar tasks. They are videotaped and their performance in both environments is compared by an evaluator, who is not aware of which environment is the learned one and which is the novel one. Each of these two environments may serve either as the practice environment or as the novel environment for different participants. The order in which these environments are introduced to the subjects is counterbalanced.

4.2 Results

As indicated above this is an ongoing study. To date we have used this system with one child (and with one adult at the early design stages) for usability testing. The child is a 12 year old girl who became blind at age 8 as a result of a tumour. She underwent a very brief training on the software, which lasted less than an hour, including the introductory session where she used the joystick for the first time ever. Upon arrival to the real environment she was asked to go to different rooms and did so very quickly and confidently, as she attested to in a subsequent interview.

4.3 Discussion

We are encouraged by this pilot result which suggests that this system may aid navigation for children who are blind. This is in line with previous studies (e.g., Lahav & Mioduser, 2002) and will likely extend their findings to the population of children and to environments of larger scale, leading to further participation of this population in everyday life.

5. CONCLUSIONS

The two studies presented here join the growing body of evidence demonstrating the important role of haptic feedback. Since many of the commercially available haptic systems require a significant investment of resources we propose this tool to help in partially filling the research void of this important area. Several studies have already successfully used force feedback joysticks for research and intervention application. This proposed tool, however, aims to be user friendly and not require the support of a programmer, thus offering both flexibility and accessibility to many researchers and therapists who wish to incorporate haptic feedback into their research

Although the tool presented here is simple to operate, many sophisticated, game-like tasks may be designed and used for a gamut of research/treatment goals that test and train participant abilities. These include:

- cognitive deficits (e.g., executive functioning, spatial orientation, attentional disorders, memory)
- motor deficits (e.g., motor planning, motor control)
- sensory deficits (e.g., orientation and navigation skills for people who are visually impaired, proprioceptive deficits for patients following stroke, re-education for peripheral nerve injuries)
- functional skills (e.g., simulator training to learn to operate a powered wheelchair)

In addition to the two example applications presented here, we anticipate that this tool will allow for future studies of cross modal tasks, eventually leading to the development of additional, haptic-based therapeutic interventions.

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