The Effect of Haptic Cues on Working Memory in 3D Menu Selection

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Abstract. We investigated the effect of haptic cues on working memory in 3D menu selection. We conducted a 3D menu selection task in two different conditions: visual only and visual with haptic. For the visual condition, participants were instructed to select 3D menu items and memorize the order of selection. For the visual with haptic condition, we used magnetic haptic effect on each 3D menu item. Results showed that participants needed less number of trials for memorizing the selection sequence in visual with haptic condition than in visual only condition. Subjective data, collected from a questionnaire, indicated that visual with haptic condition was more suitable for selection and memorization.

Keywords: Virtual reality, haptic interaction, 3D menu, selection, learning.

1 Introduction

Humans acquire new motor skills through a multi-stage learning process, central to which is of course practice. Through the process of trial and error, we continually refine our motor skills achieving more consistent performance. In this context, feedback is of paramount importance and can take many different forms including verbal communication, visual and auditory signals, and vibrotactile stimulation. Although different in sensory modality, these examples all share the common trait of being indirect forms of feedback. That is, the information that they provide about performance must be translated into the proprioceptive coordinate system. For simple tasks, this translation may not be a significant difficulty, but for more complex tasks it may be overwhelming, particularly in the early stages of learning. More direct forms of feedback are physical guidance where the learner is physically moved all along a trajectory or where the learner is closed to the target.

Current technology makes use of motion based interfaces such as Wiimote™ or Kinect™ . This trend indicates that next generation of human interfaces will involve 3D interactions and complex tasks such as 3D menu selection that require efficient learning and memorization. 3D space is recognized in obtaining information from a variety of visual depth. However, it is difficult to select the 3D menu items in 3D virtual space with only visual information so that other modality information such as haptic or audio cue has been used to improve selectability of the 3D menu items.

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Generally, an application interface has a well-categorized menu structure. When a user calls an integrated function on the application, a couple of menu items are needed to select. In the meantime, the sequence of the selection process should be memorized to learn about how to use the application. Since these processes: selection and memorization are usually carried out at the same time, we could expect that the operability of the selection affects the memorization of the menu selection process. In fact, it is important to investigate the effect of the selectability to address workload of the memorization. However most of studies have focused on operation performance.

In this study, we investigated the effect of haptic cues on working memory in 3D menu selection. We conducted a 3D menu selection task in two different conditions: visual only and visual with haptic. For the visual condition, participants were instructed to select 3D menu items and memorize the order of selection. For the visual with haptic condition, we used magnetic haptic effect on each 3D menu item. In the next section, we present some previous works. In section 3, we describe our system. Section 4 is dedicated to the experiment. The paper ends by a conclusion that provides some tracks for future work.

2 Background

A number of studies have shown that haptic feedback can improve user performance in various tasks involving cursor control [1-4]. In particular, force feedback gravity wells, i.e. attractive basins that pull the mouse and cursor to the center of a target, have been shown to improve performance in "point-and-click" tasks. Hasser et al [5] found that this type of force feedback, provided by a FEELit mouse, could improve targeting time and decrease errors. Oakley et al [6] reported a reduction in errors with the use of gravity wells implemented on a Phantom. Keates et al [7] found that for motion-impaired users, gravity wells could improve the time required to complete a "point-and-click" task by as much as 50%. In these studies, however, force feedback was enabled on a single target only. For the successful implementation of force feedback in a realistic interface, issues surrounding haptic effects for multiple on-screen targets must be addressed. With more than one gravity well enabled, a user's cursor may be captured by the gravity wells of undesired distractors as it travels toward a desired target.

This has the potential to cancel out the benefits of the force feedback, possibly yielding poorer performance than in its complete absence. There have been few studies investigating performance in the presence of multiple haptic targets. Dennerlein and Yang [8] found that even with multiple haptic distracters along the cursor trajectory, performance in "point-and-click" tasks was greatly improved over a condition with only visual feedback. Study participants most often just plowed through the distractors, but at a cost of increased user frustration and effort. In contrast, Oakley et al [9] reported an increase in time when static attractive forces were enabled on multiple targets. This condition was, at best, not optimal, and at worst, detrimental to performance and subjective satisfaction when compared to the purely visual condition. Langdon et al [10] reported a performance improvement for motion-impaired users that was similar across four sizes of gravity wells on adjacent targets.

Physical guidance refers to the process of physically moving a learner's body through an example of a motion to be learned. Haptically enhanced interaction for guidance mainly relies on "snap-to" effects. They can be local magnetic effects around a target that actively captures the pointer if it enters a specific area, or can behave as a gradient force all over the environment to draw the pointer towards points of interest. For object selection, magnetic targets can help by reducing selection times and error rates. However some studies report benefits from magnetic widgets to precision but not to selection times [12]. Moreover, these techniques seem to lead to higher selection times and to a significantly higher overall cognitive load when multi-target selection is considered. Capobianco and Essert [13] proposed a technique able to reduce these drawbacks, and apply it in the context of item selection in 3D menus. Their approach called "haptic walls" consists in haptically rendering solid walls shaped like a funnel, leading to a target located at the intersection of the two walls. The walls act as virtual fixtures: the targets are accessible while slipping along the interior faces and edges of the convex polyhedron that connects them. This approach differs from a magnetic grid since the edges of the haptic shape are not attracting the pointer towards them. This technique can be adapted to any configuration of targets able to be represented as a convex polyhedron. Yamaguchi et al [14]., investigated the usability of haptic interface features to support future development of haptically enhanced science learning applications for students with visual impairments. Three features have been proposed in this study: Haptic Boundary, Menu Selection, and Object Recognition. Results gave insights to the needs of the visually impaired community in regard to haptic applications.

As described above, most of study has focused on investigating capability of haptic cues, especially for task performance which enables to improve completion time or decrease error rate, and so on. Han et al [11]., reported the design and results of an experiment that evaluated the effects of enactment and haptic guidance on building a memory of a sequence of 2D selections, with learning only with visual information as a baseline condition. As an initial study, they focused on the role of the working memory rather than that of the long term memory, since the working memory chunking takes precedence over building the long term memory. For a training system, a large manipulator-type haptic interface was combined with a large LCD visual display to cover the whole arm workspace involved in the task, realizing a collocated visuo-haptic training system. To test the effects of the kinesthetic information, they compared the learning performances of three training methods: visual display only, visual display with enactment, and visual display with haptic guidance. The learning performances were measured in terms of the number of repetitions required for memorizing, along with subjective ratings. However, they has not investigated the effect of haptic cues on menu item selection task in 3D virtual environment.

3 System Overview

The system we use for the study consists of a visual display, a 6 DOF haptic display called SPIDAR-GCC [15], and a Desktop computer. Fig.1 shows the hardware configuration of the system. SPIDAR-GCC is connected to the Desktop PC through USB 2.0 communication. The grip of SPIDAR-GCC is associated with virtual pointer which is a visual pointer displayed in the visual display for operation. Since the workspace of the grip of the SPIDAR-GCC is limited in the frame and does not have clutch function to put a grip position into neutral, the grip position is controlled with velocity control. As for the display, we use a WSXGA LCD monitor with resolution of 1680x1050 pixels.

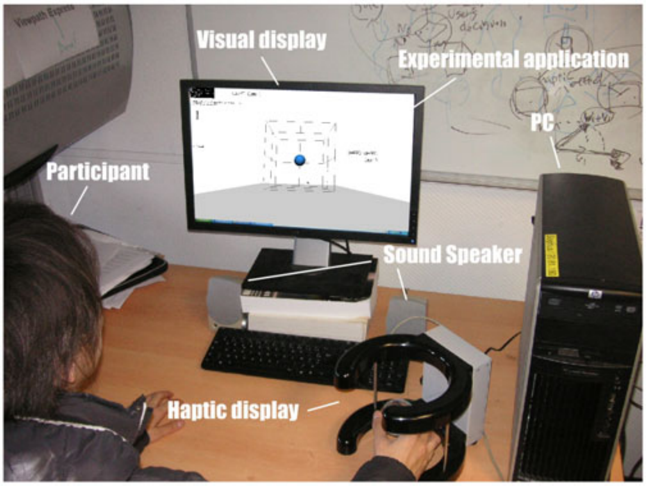


Fig. 1. Hardware configuration of the system - As for the haptic display SPIDAR-GCC, there is a grip which is connected in center of frame using 8 strings. This grip enables to input 6DOF information and represent 6DOF force feedback.

4 Method

In this study, we tested 3D menu selection task with two different conditions: visual condition, and visual with haptic condition to investigate whether difficulty of selection affects memorization of the selection order. In this task, cube type of menu is displayed on 3D grid (Fig.2). The participant selects the displayed menu one by one, and at the same time the participant has to memorize the order of selected cubes. We expected that the number of trial which is spent to memorize the order depends on the difficulty of selection. So, we expected if there is no stress on the selection, the number of trial is reduced.

4.1 Participants

Twenty-four university students from 20 to 24 years old participated in the experiment as participants. All of participants were male and were undergraduate students in author’s university.

4.2 Stimuli

Visual condition (V). In total 9 blue cubes out of 12 cubes are randomly displayed on gray 3D grid one by one every 2 seconds as shown in Fig.2. The number in Fig.2 illustrates display order of each blue cube. Every time the total number of the displayed cubes is three, the displayed cubes are erased to refresh the screen. When touching the displayed cube with 3D pointer, sound effect is played as a notification for touching.

Visual with Haptic condition (VH). 9 blue cubes are displayed on 3D grid as same as the visual condition. When touching the cube with 3D pointer, magnet force is represented so that the 3D pointer is immediately put on the target cube. The amount of magnet force is calculated for ease of selection and release.

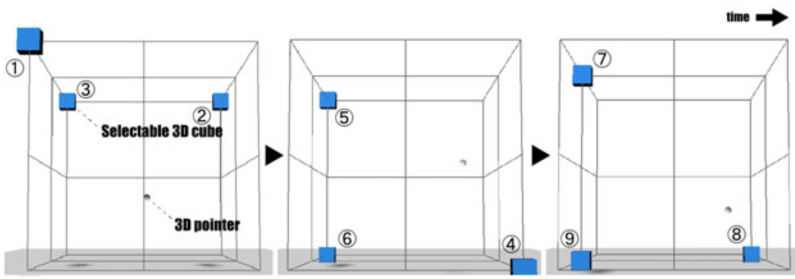


Fig. 2. 9 cubes are randomly displayed one by one in one trial

4.3 Procedure

We tested two conditions as explained in section 4.2. In both condition, same procedure was conducted.

Step1: When the experiment application is launched, the start screen as shown in Fig.3 is displayed. A Participant grabs the grip of SPIDAR-GCC and moves the 3D pointer to the blue sphere which is displayed in center of 3D grid. The position of the 3D pointer is fixed with magnet force.

Step2: The participant pushed the space button on the keyboard to begin a trial. The participant has to select displaying cube on the 3D grid one by one and at the same time, the order of cube has to be memorized correctly. When 9 cubes are displayed in total, the trial is finished.

Step3: If the participant is for sure that the order is perfectly memorized, answering mode is conducted. If not, they could try the trial again up to 20 times. In the answering mode, all 12 cubes are displayed with 10% transparency rate as shown in Fig.4. While touching the cube, the transparency rate is changed to 100%. The participant has to select the cube one by one to recall the memorized order and space button on the keyboard is pushed to verify the order. The limitation time of answering is set up to 90 seconds.

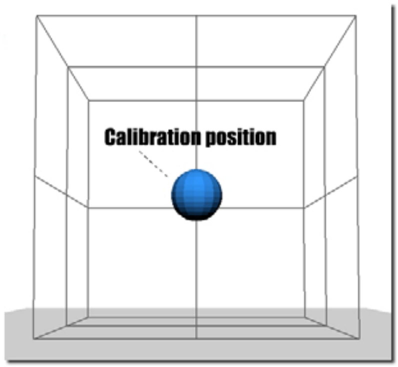


Fig. 3. Start page of experiment application

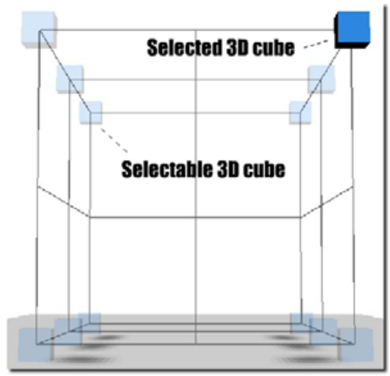


Fig. 4. Answering mode

In this experiment, we use between-subjects design to alleviate the affect of learning effect of each experiment condition. 12 participants were assigned to each condition to make two experiment groups.

5 Results and Discussion

5.1 Repetition Number of Trial

Fig.5 shows the results of average of repetition number of trial. A t-test was performed on the mean number of both conditions. T-test showed that there is significant difference between visual condition and visual with haptic condition (** $p < 0.01$). The result shows that participants were able to memorize menu on visual with haptic condition much more quickly than visual one.

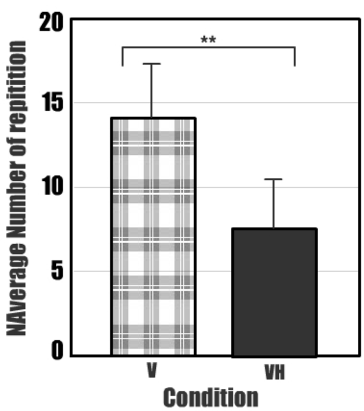


Fig. 5. Average of repetition number of trial

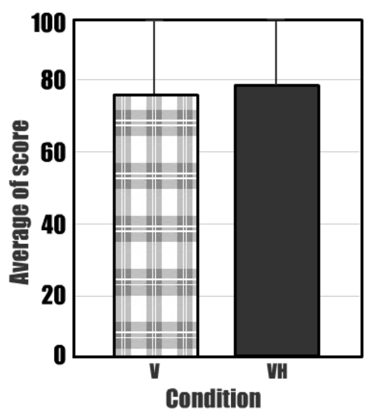
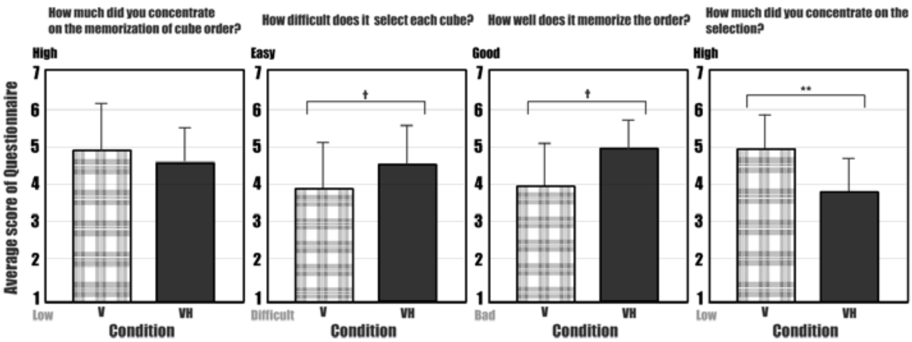


Fig. 6. Average of score of trial

5.2 Score of Trial

Fig.6 shows the results of average of score of trial. A t-test was performed on the mean number of both conditions. T-test showed that there is no significant difference between visual condition and visual with haptic condition. However, the result shows that there is a trend where score on visual with haptic is higher than the one on visual condition since the mean value on visual with haptic condition is higher than the one of visual condition. From this result and the result of repetition number, with the visual with haptic condition, the participants were able to memorize 3D menu order much more correctly and quickly than on the visual one.



(a) (b) (c) (d)

Fig. 7. Average score of questionnaire: (a) – Question 1, (b) – Question 2, (c) – Question 3, and (d) – Question 4

We asked 4 questions in a questionnaire after the trial session: **Question1** - *How much did you concentrate on the memorization of cube order?,* **Question2** - *How difficult does it select each cube?*, **Question3** - *How well does it memorize the order?*, and **Question4** - *How much did you concentrate on the selection?* A t-test was performed on the mean value of score of each question.

5.3 Concentration on the Memorization of Menu Order (Question 1)

The result shows that there is no significant difference and indicated participants were able to concentrate on the memorization on each condition. However, there is a trend where participants were able to concentrate on the memorization on visual condition much better than on the visual with haptic condition. From the result, we expected that visual attention might be on top of haptic attention. In other words, these attention functionalities might be independently working.

5.4 Difficulty on the Selection (Question 2)

The result shows that there is no significant difference, however there is significant trend so that the result indicated participants were able to select 3D menu easily on visual with haptic condition. From the result, we expected if there is no difficulty on selection, participants would be able to concentrate on memorization since selection and memorization were done at the same time.

5.5 Difficulty on the Memorization (Question 3)

The result shows that there is no significant difference. However there is significant trend where participants were able to memorize 3D menu order on visual with haptic condition much better than on visual condition.

5.6 Concentration on the Selection (Question 4)

The result shows that there is significant difference between visual condition and visual with haptic condition (** $p < 0.01$). This result indicated participants had not paid attention to selection on visual with haptic condition. This result implies that participants could concentrate on memorization since the participant's attention was not used a lot for selection.

6 Conclusion

In this paper, we investigated the effects of haptic cues on memorizing the selection sequences in 3D menu. We tested it on two conditions: visual condition, and visual with haptic condition. As for the visual condition, participants selected 3D menu on 3D grid with 3D pointer and at the same time they memorized the order. For the visual with haptic condition, we controlled difficulty of selection by using haptic modality to put a magnetic haptic effect on each 3D menu. As the result of performance data, repetition number of trial where is a number the participants spent to memorize the order on visual with haptic condition is shorter than on visual condition. Moreover there is a trend where the score of trial on visual with haptic condition is better than visual condition. As a result from the subjective data, we expected visual attention is working on top of haptic attention since there is a trend where concentration on memorization on visual condition was higher than visual with haptic condition although they could memorize the order on visual with haptic with more fewer repetition number of trial than on visual condition (Question 1). As for the difficulty of selection, the participants were able to select 3D menu easily on visual with haptic condition (Question 2). For the difficulty of memorization, the participants were able to memorize the order easily on visual with haptic condition (Question 3). Moreover as for the concentration of selection, the participants were able to select easily on visual with haptic condition and this result indicated that they could memorize selection order very well (Question 4). In the future, we plan to investigate the effect of different modality and difficulty condition to address workload of memorization of 3D menu sequence.

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