Effects of assembling virtual fixtures on learning a navigation task

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Abstract: An approach to enhance navigation task performance is to integrate sensory guidance (virtual fixtures) into a virtual training system. To evaluate the effects of adding virtual fixtures to skill acquisition, 32 subjects were required to use a PHANToM input device, to transport a virtual object through a computer generated 3-D graphic maze. Subjects practiced navigation under 4 conditions: the maze was augmented with either a graphic fixture (G), attractive force field (F), both graphic and force field (GF), or no (N) virtual fixture. Fifteen practice trials were given before subjects were transferred to a situation with no virtual fixtures. Results showed that the implementation of the force field assisted task performance during practice; however, it failed to show positive transfer effects. In contrast, adding a graphic fixture to the virtual maze helped subjects to define the optimal pathway throughout navigation, which facilitated skill acquisition.

Keywords: motor learning, virtual fixture, navigation, human-computer interaction, specificity hypothesis

1. Introduction:

Navigation is a common procedure during angiograph, catheterization, endoscopic, and teleoperation. Navigation training using a computer-based simulation, sensory guidance can be implemented with the goal to enhance task performance. Sensory guidance tools, are also called virtual fixtures, can be rendered with either graphics (visual) and/or force (haptic) features. Integration of virtual fixtures with simulation has been documented to improve task performances in navigation by increasing movement speed and accuracy [1-3]. In this study, we are interested in investigating the role of virtual fixtures in skill acquisition. The research question was when subjects are trained in an environment with augmented virtual fixtures, will the skill be transferred to a similar environment without virtual fixtures?

2. Methods:

2.1. Virtual Fixtures and 3-D maze

This study was conducted in the Enhanced Virtual Hand Lab at Simon Fraser University (Figure 1A), with stereoscopic, head coupled graphics 3-D display, or with 2-D display of the maze. In this context, virtual fixtures are computer-generated with haptic, or graphical features or both to provide sensory guidance along a preferred path. We defined a Virtual Fixture Library (Figure 1B) and a set of Virtual Fixture Assembly Languages (Figure 1C), which allowed the virtual fixtures to have different properties and behaviors. The Virtual Fixture Library consisted a set of primitive shapes, including Cone, Sphere, and Cylinder (Figure 1B). With these items, a tunnel was assembled with abilities to display attractive force fields and/or light green color. The tunnel was then built into a 3-D virtual maze (Figure 1D). The maze was constructed using SGI Open Inventor scene graph with two levels, four rooms, and enclosed by transparent glass ceilings and a red floor. The scene graph was then translated into Ghost scene graph to compute the force rendering.

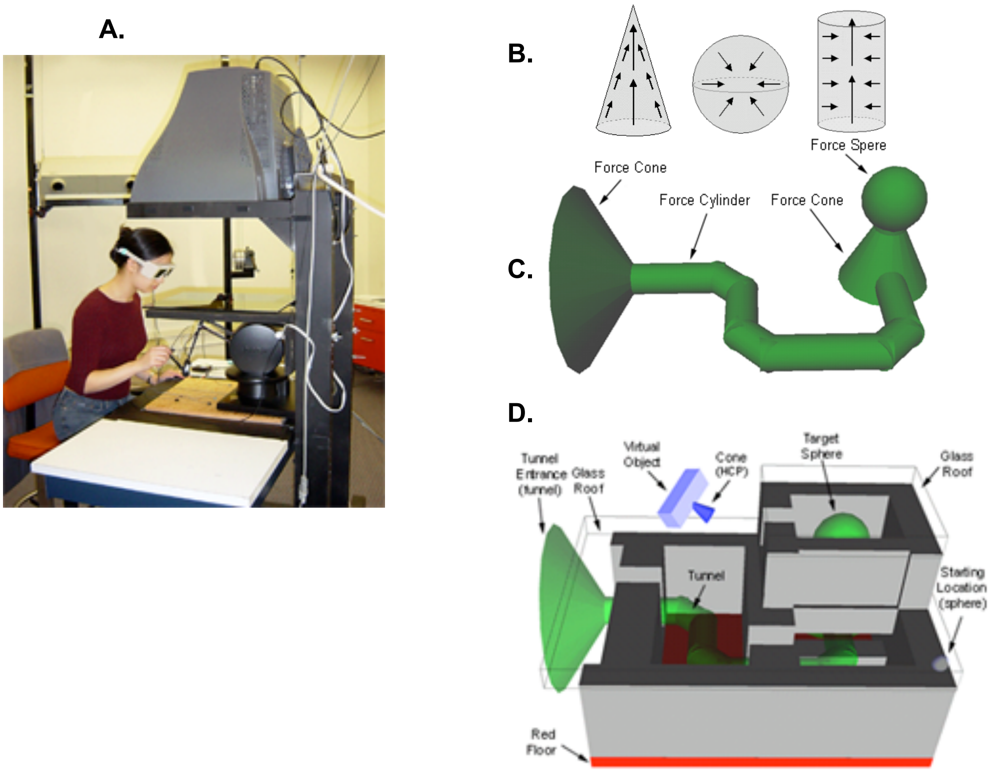

Figure 1. A) Experiment layout. B) Virtual fixture library. C) Assembled virtual tunnel. D) 3-D maze with augmented virtual tunnel.

Since the main focus for this project was to examine the navigation performance of a virtual object through the maze, object-to-object collision detection and force feedback were the major issues for our implementation. We chose an approximation algorithm – voxel sampling [4] – that applies a finite set of points on object's surface and computed the force vector based on collision forces between the object and the components that make up the maze. This force vector was rendered as a point force outputting to the PHANToM stylus. This allowed fast approximation of collision detection and still achieved the haptic rendering rate of 1000Hz.

2.2. Tasks

The task was to grasp a virtual object from its start position outside the maze using a PHANToM, bring the object to the entrance of the maze, navigate it through the rooms inside the maze, and transport the virtual object to the second floor of the maze.

Thirty-two university students (ages 19 to 30 yrs) were recruited and randomly assigned to one of four practice groups, the no graphic and force virtual fixture group (N group), graphic only (G group), force only (F), the graphics and force (GF) group. They performed task for 15 trials then were transferred to a neither graphic nor force virtual fixture condition for 5 more trials. Participants provided Informed Consent, and the protocol was approved by the Simon Fraser University Office of Research Ethics.

2.3. Measures

A navigation trial was divided into 12 phases, corresponding to the transport of the virtual object through different sections of the maze. Movement time and number of collisions were computed for each phase. A summed movement time and number of collisions were computed for each trial.

Collision detection was computed by using voxel sampling [4]. In this experiment, 16 points were equally distributed to the virtual object's surface. When any point touched the maze it would be recorded as a collision. Data were sampled at 100 Hz, while haptic rendering was at 1000 Hz. We sampled one data frame in each 10 haptic frames. In each sampling phrase, we treated the data with all continuous 1's in the data file as one collision, regardless of the duration of each collision.

For example, if a file for collision was recorded as below, 5 collisions were reported.

"1111111111111111000011000000000000000000010101110 0"

Note that we only considered the collision within a sampling phase. If one collision spanned two sampling phases, we consider it as one collision for each phase and sum it as two collisions in total for that trial.

2.4. Data analyses

In order to examine the learning effect, we blocked the 15 practice trials into 3 phases, i.e., the initial phase (trials 1-5), the middle phase (trials 6-10), and the late phase (trials 11-15). We included a transfer phase for trials 16 - 20, with no virtual fixtures added to the maze.

A 4 virtual fixture group (N, G, F, GF) x 4 learning phase (initial, middle, late, transfer) x 2 dimension (2-D vs. 3-D) mixed factorial ANOVA with repeated measure on the last two factors was used for each of temporal and collision measures. Means and standard errors are reported for significant effects, with a priori alpha level of 0.05.

3. Results

Statistical analyses disclosed effects for learning phase and dimensions on several temporal and collision measures. Basically, as practice increased, the movement times and the number of collisions reduced. Also, tasks were performed quicker and less collisions in 3-D than 2-D display environments.

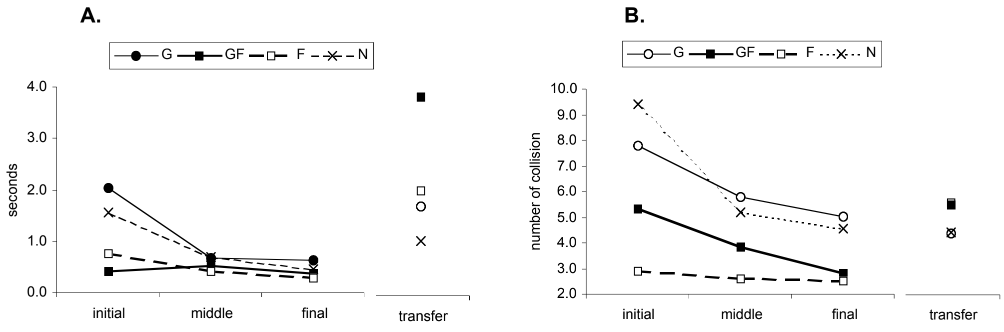

Figure 2. The movement time and number of collisions reduced as practice went on. Interaction between learning phase and virtual guidance was revealed on time12 (A) and number of collision at segment 5 (B).

Interactions between learning phase and virtual fixture group were also revealed for movement times and number of collisions (Figure 2A, 2B). Figure 2A illustrated the phase and guidance interaction found from time 12, where the virtual object was transported out of the maze. With attractive force fields (F and GF groups), subjects transported objects faster during the practice. However, such superior performance could not be carried to the transfer trials, where the force field was not available. In contrast, when practicing in N and G conditions, subjects built skills through practice and carried some of this skill to the transfer trials. Figure 2B illustrated that subjects in F and GF groups transported the object with less collisions during segment 5 of practice. However, when subjects performed in the transfer trials where the force field was not available, the number of collisions increased dramatically compared to the N and G group. In contrast, when practicing in condition with no virtual guidance (N group) and graphic guidance (G group), subjects were able to reduce the number of collisions through practice. Subjects kept a lower rate of collision during the transfer trials. Similar results were found for total time and collisions.

4. Discussion

The primary goal of this study was to investigate the role of virtual fixtures on skill acquisition. Specifically, we examined the effects of implementation of virtual fixtures (either haptic or graphic) on learning a navigation task. We hypothesized that adding virtual fixtures would facilitate task performance and the skills would be transferred to a no-virtual-fixture environment. However, the results from this study demonstrated that adding a force field indeed facilitated the task performance during practice but did not have positive effects on skill acquisition.

Although the result contradicted our expectation, it supports the prediction of the *specificity hypothesis* for motor learning. The specificity hypothesis addresses the skill specific to feedback conditions during which the skill was learned [5]. If a designed task requires subjects to navigate throughout a maze without virtual fixtures, adding extra sensory feedback during the practice phase would not help build specific motor skills.

In this study, subjects trained in the F and GF conditions showed no positive transfer effects to the condition with no virtual fixtures. In contrast, practicing in the N group, subjects positively transferred parts of their skill to the transfer trials because the sensory feedback they experienced was identical. Therefore, an optimal training environment should match the sensory feedback for the designed environment. Skills built in such a training environment would have higher transfer rate to the designed work environment.

Our second comment focuses on the outcome of G group where the virtual fixture was rendered with graphic features. Implementation of graphical guidance (a green tunnel, in this study) did not facilitate task performance (Figure 2A, 2B). This maybe due to the design of graphic guidance itself: the cross-sectional area of the graphic guidance was smaller than the gates and rooms of the maze. Transporting the object into a graphic tunnel in G group was actually more challenging than moving the object throughout the maze itself.

Surprisingly, after being trained with a graphic fixture in the G group, subjects did better in transfer trials than those subjects in F and GF group. It seemed that increasing the task difficulty on practice (i.e., adding visual constraints in this case) might help build specific motor skills. Obviously, the above statement does not agree with the specificity hypothesis; however, earlier research found similar results, indicating skills built in a tough practice environment could be transferred to an amiable environment [6, 7].

Recently, a study on motor learning was conducted by Burdet et al (2001). The task was to move a mechanical lever between the start and end position as quickly and accurately as possible. In one training condition, a divergent force field was applied during the movement. If the lever moved out of an ideal but invisible neutral line, the divergent force field would further deviate the movement trajectory. Being trained in such an unpleasant environment, subjects built better skills compare to subjects trained in a normal environment. Subjects were forced to define the optimal pathway throughout the practice.

In conclusion, adding virtual fixtures has contrasting effects on skill acquisition. Increasing task constraints during the practice such as introducing restricted graphic guidance may not be good for task performance initially, but does help subjects to define the optimal pathway throughout navigation, which subsequently helps with skill acquisition. These results have important implications for the design of an optimal virtual training environment.

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