Influence of Haptic Feedback on a Pointing Task in a Haptically Enhanced 3D Virtual Environment

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Abstract. To gain a better view of the value of haptic feedback, human performance and preference in a pointing style task in a three-dimensional virtual environment was explored. Vibration and haptic attractive force were selected as two simple cases of feedback, each with two levels. These types of feedback were compared to a no-feedback condition to better understand how human performance changes under these conditions. The study included 8 undergraduate students. A Novint Falcon haptic controller was used in a simulated three-dimensional virtual environment. Analysis was conducted on how each type of feedback effects the movement time (MT) of users. The results showed that vibration was perceived negatively and had a slight negative impact on performance. The haptic attractive force significantly improved performance and was strongly preferred by subjects.

Keywords: Haptic, assistive technology, virtual environments, human performance, force feedback, vibration, assistive feedback.

1 Introduction

Haptic feedback is a rapidly growing research emphasis in human computer interaction. The ability to utilize the somatic sense, or sense of touch, can greatly enhance the realism and improve immersion, provide additional awareness through redundancy, or provide assistive support (Robles-De-La-Torre, 2006). Identifying subject preference for types of feedback and performance effects of haptic assistive feedback indicated potential value in functionally similar tasks. For example, a visually impaired person may be able to utilize assistive feedback to better navigate a virtual environment, improving their computer interaction experience. A variety of studies have utilized haptic feedback in medical applications, such as dentist training (Suebnukarn, et al., 2009) and using a Leksell Gamma Knife to neutralize tumors in the brain (Dinka, Nyce, Timpka, & Holmberg, 2006). In these studies, participants' performance and attitudes toward these haptic feedbacks varied. Further research is needed to determine whether haptic feedback improves performance in an objective, general case. To examine the effect of haptic assistive feedback in a simple, performance based Fitts' Law style task was implemented. Fitts (1954) initially

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proposed a one-dimensional tapping task, with subjects alternating the tapping between two targets. This task resulted in the following equation being derived:

$$MT = a + b * \log_2(A/W) \quad (1)$$

Where MT is the movement time from a start point to a target, A is the amplitude of distance from start to the target, and W is the width of the target. The values of a and b are constants calculated from experiment data. The logarithm portion is commonly referred to as the Index of Difficulty (ID). The simple linear relationship between ID and MT has been applied in a wide variety of studies. Furthermore, Fitts identified the Index of Performance (IP) as 1/b in bits/s. This relationship between amplitude and width has been successfully extended into two-dimensional computer environments as well by Accot and Zhai (2003). Further studies have shown results consistent with the original Fitts equation in three dimensions and with different controllers including haptic control devices (Murata, 2001, Mateo et. al., 2005, Campbell et. al., 2008, Margolis et. al, 2011).

To study the effect of haptic assistive feedback on human performance, we had subjects complete a basic Fitts' style task in a three dimensional virtual environment. Subjects would move their cursor from a start point to a target object in the virtual environment, then click to activate it. This would be conducted with no haptic feedback, vibration feedback, and a haptic attractive force feedback.

2 Methods

2.1 Participants

This study included eight undergraduate students as participants, six male and two female, ranging in age from 18 to 20. None of subjects had prior experience with haptic virtual environments.

2.2 System Design

Subjects utilized a Novint Falcon haptic controller to interact with a three dimensional virtual environment. The system was developed based on the Novint Falcon SDK

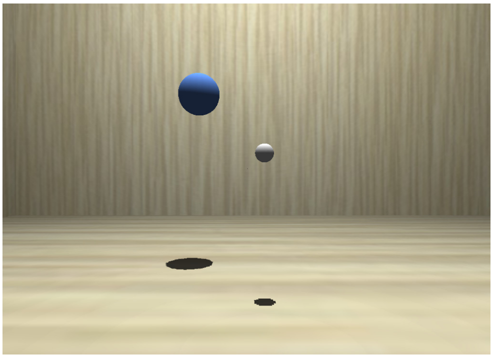

Fig. 1. Subject view of experiment virtual environment

specifically for this study. The subject view of the virtual environment can be seen in Figure 1.

The environment provided a view of looking into a workspace similar to a box. The space was scaled to fit just within the maximum motion range of the Novint Falcon device. Targets would appear in random locations in the workspace. The target size would be sampled from a matrix with three possible sizes. Similarly, the distance to target was sampled from a matrix with three possible distances, and a random location was selected based on the distance vector.

2.3 Feedback

The control condition employed no haptic feedback. Users were simply tasked with moving their cursor as quickly and accurately to the target object, then clicking.

Vibration feedback was designed to improve the transition from ballistic to homing motion. Users feel a constant, light vibration in the controller until they are within close proximity to the target. Two levels of vibration feedback were employed.

Attractive haptic force feedback provided a moderate attractive force from the users' cursor to the target, regardless of cursor position. The construct used was similar to a spring, providing a positive addition to user input force in the direction of the target. The feedback itself would not automatically move the cursor to the target, rather it would amplify user-initiated motion. Two levels of attractive haptic force feedback were employed.

2.4 Procedure

Subjects initially completed a brief training session to familiarize them with the virtual environment, the haptic controller, and the types of feedback they would experience. Following the training session, subjects completed the main trials.

Each trial employed the same basic task, based on extending Fitts' Law to three dimensions. At the beginning of each trial, a large white sphere, or start object, was present in the interface. Users would move their cursor to the start object and click. Once they had clicked the object, the start object disappeared and a blue sphere, or target object, would appear. The objective was to move the cursor to the target object as quickly and accurately as possible, then click the center button on the top of the Novint Falcon. The target then disappeared and a new target appeared. Movement time, the primary response measure, was recorded from the time the start object or target was clicked to the time the next target was clicked.

As previously stated, three target widths and three amplitudes of distance to target were used, creating nine unique width-distance pairs. Each pair was replicated three times in a trial, resulting 27 total target objects in each trial. The feedback in each trial was provided in a random order. Aside from feedback, the main trials were identical.

Following the main trials, subjects completed a survey to rank their preference for feedback and assessed their perceived performance under each feedback type.

3 Results and Discussion

The results for Fitts' parameters can be seen in Table 1, grouped by feedback type.

Table 1. Fitts parameters *a*, *b*, and *IP*, by feedback type

	Haptic	Vibration	None
a	0.57	-0.02	0.35
b	0.33	0.56	0.46
IP	3.00	1.77	2.20

The Index of Performance had clear implications about the effect of the feedback on performance. The significantly higher IP of 3.00 bits/s for the haptic attractive force feedback significantly outweighs the IP of 1.77 bits/s for vibration feedback. While the addition of assistive feedback of any time would presumably improve performance, the IP for vibration feedback was actually lower than that of the no feedback trials.

A plot of the average movement time for each given ID provides more insight into the relationship. Figure 2 presents a plot of average MT by ID for each type of feedback.

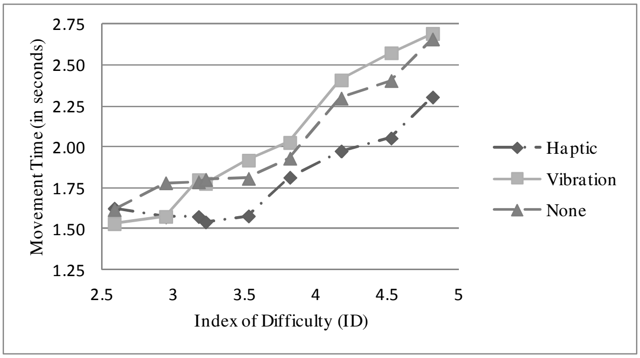

Fig. 2. Plot of average movement time by index of difficulty for each feedback type

Of interest are the data points for lower IDs. The overlap of the three data series implies that the task difficulty at these levels was low enough to not generate different user behavior under the conditions, meaning users could likely complete the task purely with ballistic motion. Furthermore, the coefficients of determination, or r-square values, for the linear regression are 0.976 for vibration, 0.923 for no feedback, but only 0.837 for haptic feedback. To analyze only the data for which the ID is sufficient to require both ballistic and homing motion, the analysis is repeated after removing the lowest 3 IDs. Table 2 contains the adjusted Fitts' parameters a, b, and IP.

Table 2. Adjusted Fitts parameters a, b, and IP, by feedback type for highest 6 IDs

	Haptic	Vibration	None
a	-0.03	-0.23	-0.14
b	0.48	0.61	0.57
IP	2.10	1.63	1.75

The adjusted values show a similar relationship between feedback types. The IP for haptic attractive force feedback still remains the highest at 2.10 bits/s, no feedback at 1.75 bits/s, and vibration indicated performance below the no feedback condition at 1.63 bits/s. The adjust plot can be seen in Figure 3.

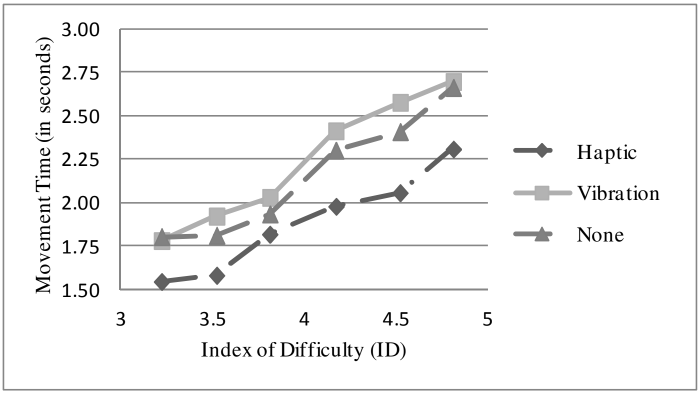

Fig. 3. Adjusted movement time by index of difficulty for each feedback type

The coefficients of determination indicated a much better fit. For haptic attractive force feedback, the value is 0.967, for vibration 0.978, and for no feedback 0.949. The linear regressions were a better fit for this set of IDs. With a sufficiently high ID to require both ballistic and homing motion, human performance in a three dimensional virtual environment conforms to the parameters of Fitts' Law. Furthermore, haptic attractive force indicates an improved performance. Because of the implementation of the attractive force feedback, the constant amplification of motion towards the target should minimize the need for error correction, increasing efficiency in error correction and improving the accuracy of ballistic motion. By improving the alignment and accuracy of ballistic motion, less time should be required for fine homing motion to touch the target, reducing overall movement time.

To complement the performance results, subjects were asked to self-rate their performance by feedback type. Figure 4 shows the results of user self-rating of performance.

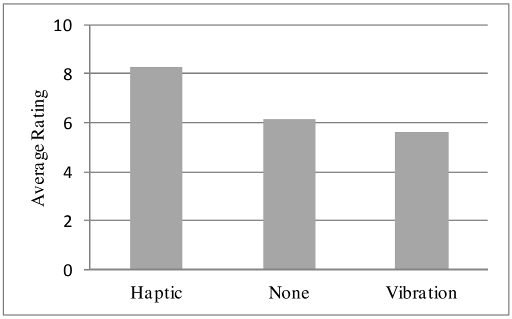

Fig. 4. Self rating of performance by feedback type

These results closely match performance results. Subjects believed their performance to be significantly better with the haptic attractive force. This is the expected outcome for assistive feedback. The goal of providing additional assistive feedback was to both improve performance and improve a user's experience. The vibration results are consistent with previous research on human response to vibration. The sense of urgency is elicited from the feedback. Regardless of whether the vibration conceptually would help, the human reaction is innately negative, possibly influencing the end performance.

Subjects were also asked to rank their preferred feedback, as seen in Figure 5.

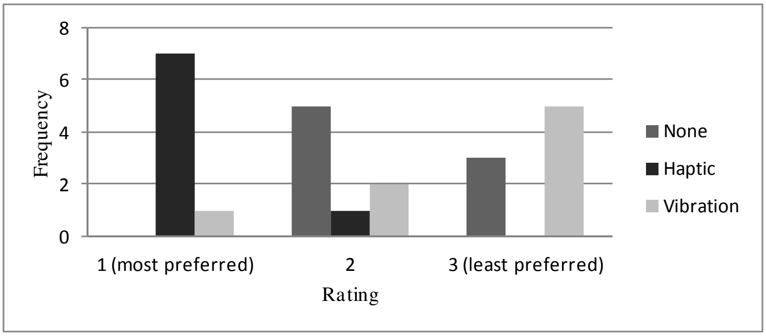

Fig. 5. Frequency count of user preference ranking

The subjective ranking indicates a strong preference for haptic feedback. Similar to performance and self-assessment of performance, subjects showed a lack of interest in vibration feedback, again related to the natural sense of alarm induced by vibration.

4 Conclusion

Subjects completed a pointing task similar to the original Fitts task, in a three dimensional virtual environment with and without haptic feedback. Results indicate that Fitts' Law holds true for this scenario, with a linear relationship between ID and MT. Haptic attractive force feedback elicited the best performance results, along with high user ranking in preference. Vibration feedback resulted in performance similar to no feedback, however user preference was generally low for this feedback. Subject self-assessment of performance was consistent with actual performance results. Ultimately haptic attractive force feedback has a positive effect on performance and users also indicate a preference for the feedback.

Further studies may look at a broader scope of haptic feedback to generate a more clear depiction of human performance. There may be other scenarios or ways to implement vibration feedback that positively influence performance and improve user perception. Haptic feedback may also have more applicability in different virtual environments where the additional multimodal feedback may have a greater effect.

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