Determining the Impact of Haptic Feedback on the Speed and Accuracy of Target Selection in Virtual Reality Environments

Nilay Shah
University of Toronto
Toronto, Canada
nilayp.shah@mail.utoronto.ca

Gilberto Aristizabal
University of Toronto
Toronto, Canada
gilberto.aristizabal@mail.utoronto.ca

Hilal Dib
University of Toronto
Toronto, Canada
hilal.dib@mail.utoronto.ca

Tooba Ahmed
University of Toronto
Toronto, Canada
tooba.ahmadsheikh@mail.utoronto.ca

Hao (Steven) Cheng
University of Toronto
Toronto, Canada
haohao.cheng@mail.utoronto.ca

ABSTRACT

As virtual reality (VR) becomes a more mainstream platform, the feedback given to the user is almost exclusively visual and auditory. An experiment was conducted in order to incorporate the sensation of touch. The hypothesis was that with the addition of haptic feedback, target selection would become quicker and more accurate in a virtual environment. The experiment consisted of two tasks: one to measure speed and another to measure accuracy. Both were conducted with and without the use of haptic feedback. An analysis of variance was conducted to test the correlation between the presence of haptics and speed and accuracy of target selection in VR space. A p-value of 0.0509 was found for accuracy, suggesting correlation. A p-value of 0.2539 was found for speed, suggesting no correlation. The study results showed that vibro haptic feedback, improved the accuracy in target selection, but the speed was not improved.

Author Keywords

Virtual reality, haptic feedback.

ACM Classification Keywords

I.3.7. Computer Graphics: Three-Dimensional Graphics and Realism, Virtual Reality.

INTRODUCTION

The development of Virtual Reality (VR) intends to improve the generation of realistic images, sounds and other sensations to replicate a real environment or an imaginary setting. The current advancements in VR technologies have led to more immersive systems. The goal of VR is to mirror reality as closely as possible. For this to happen, it has to account for more than visual and audible feedback [3]. Current systems like Microsoft Hololens, Google Cardboard, and the Samsung VR Gear, are best at displaying visual and auditory information [3]. Even though the sense of reality in our brain mostly comes from visual input from the world, our sense of reality and feeling of presence is validated through tactual contact [8]. For example, a dream is not reality and one is able to become aware of this 'illusion' due to the lack of tactual feedback. Thus, in order for an individual to truly feel in reality, their sense of presence, the individual must be able to validate their sense of reality tactually [8]. Our hands are our favorite tool to sense tangible objects, as they perform many different tasks including gestures and grasping [5]. The addition of vibro-haptic feedback to the hands would provide VR users with a quick way to verify their perceived reality, via tactile feedback vibrations provided when interacting with virtual objects. Even though there are complex solutions that explore multiple ways to deliver the sensation of touch in a virtual environment, they lack to show that simple vibrations improve basic tasks like target selection. Vibrations improve target selection by providing quick tactual feedback that allow users to verify their perceived reality, when interacting with a virtual object.

RELATED WORKS

There have been several proposals on generating haptic feedback, each with their benefits and limitations [9]. Webster III et. al [10] used devices to render tactile slip and kinesthetic haptic sensations. They showed increased accuracy of motor tasks with haptic feedback. Regenbrecht, H. et al [9] analysed the use of handheld directional vibrotactile feedback to aid usability. Aoki, T et al [10] used a haptic interface, consisting of a small motor which receives input from position sensors placed on top of the finger, actuating three thin wires to introduce force on the tip of the finger, creating a touch sensation. Through modulation of force, it is possible to represent the sense of contact, and there are commercial devices (i.e. PHANToM, SPIDAR-G, DELTA-4) which exhibit various axial and rotational forces [6]. Outputted force is created through real force offered by a base object and simulated force generated through the haptic device. However, these systems are constrained by the intensity and duration of vibrations to produce feedback, and their applications extend primarily to notify the user of some event [4].

High-fidelity rendering systems have been proposed in order to address the shortcomings of vibrotactile devices. These studies have explored the usage of gloves, exoskeletons, and skin stretchers, among other methods, in order to create meaningful haptic sensations [8]. Generally, these devices have major limitations on mobility as the user is confined to a specific area and/or has to wear a large device.

High fidelity haptics offer greater textural stimuli; Benko, H .et al [9], discuss two different methods to enhance haptic feedback: NormalTouch and TextureTouch. NormalTouch renders the 3D surface whereas TextureTouch uses 16 individual pins to render a fine-grained surface. These are both high-fidelity haptics. Although regular vibration feedback allowed users to complete their tasks in less time, accuracy was sacrificed.

There has also been research into the use of multiple haptic contact points. Jeon, S .et al [4] devised two haptic interfaces, used to generate taclite output at two contact points on a finger on either hand. Through two interface points, it is possible to grasp an object and better sense its stiffness through squeezing. The stiffness of two real objects with noticeable difference in stiffness appeared more indistinguishable when stiffness augmentation was used. Whether an object was made stiffer or softer had little effect. Similarly Kry and Pihuit [5] created the HandNavigator, and interaction system, where instead of capturing real hand positions and postures, the HandNavigator device used forces exerted on pressure sensors by the user's palm and fingers to control the action of a virtual hand.

An entirely different approach was taken by Cheng and Roumen to provide haptic feedback [3]. They created the TurkDeck system which is a physical representations of the virtual environments and virtual 'props' in them. Then a group of human workers, human actuators, interact and enhance the user's VR experience by presenting and operating the props only when and where the user can actually reach them. Consequently, Mahdi Azmandian and Mark Hancock introduced Haptic Retargeting [8]. Haptic Retargeting consists of three approaches for dynamically aligning physical and virtual objects to improve the sense of touch in VR: world manipulation, body manipulation and the combination of both world and body manipulation. The user's virtual world was manipulated by moving the virtual surroundings to better align with a passive haptic prop, and physical props were placed around the real environment to match their virtual counterparts. The user's body was manipulated through their distorted virtual representation, the distortion was manipulated to better simulate the sense of touch with the passive haptic prop.

While all of these studies provide great insight for immersive VR systems, and have used and created advanced methods to improve these systems. They have not yet study how only vibro-haptic feedback improves one of the most basic tasks: target selection.

Design Concept

The goal of introducing a vibrotactile feedback device is to determine whether if vibrations could enhance user experience, particularly with target selection. For our experiment we decided to place the haptic feedback on the index finger of the participant's dominant hand. We chose a finger because fingers are the universal tool for touch-sensing, and using a finger could also introduce familiarity with other devices like a touchscreen phone. We decided to use the user's dominant hand to send the haptic vibrations, because it is the hand the participants were most comfortable with. We also contemplated on having haptic feedback on multiple fingers but ultimately decided that it would be a factor to test in future studies. In regards to the properties of the vibration, we felt that the tasks we have designed were simple enough, so that different duration or intensity of the vibration feedback was not necessary for the purpose of our study. So the vibration duration and intensity were kept the same throughout the study. An idea which would require change in such parameters could be something like 'proximity sensing', in which case, the haptic feedback could become stronger as the user approaches the target.

Hypothesis

Our hypothesis centers on the belief that when interacting with virtual objects in virtual reality environments, and the interaction requires target selection, the user's sensation of presence vanishes when the objects does not provide tactile feedback.

> *Hypothesis: User's target selection speed and accuracy will improve with the addition of haptic feedback when manipulating virtual objects in virtual environments.*

For discussion purposes.

> *Null hypothesis: The presence of haptic feedback will not improve the speed or accuracy of target selection.*

Methodology

Apparatus

The apparatus' included a *OnePlus 1* smartphone which was placed inside a generic headset (see Figure 1), and plugged into a laptop running *Windows 7*. An *Arduino Uno* was also connected to the laptop. The *Arduino Uno* was then connected to the vibration motor via two wires. The vibration motor had an actuator soldered onto it. Finally, a *Leap Motion* device was placed in front of the laptop to sense hands.

Figure 1. A picture of the headset utilized.

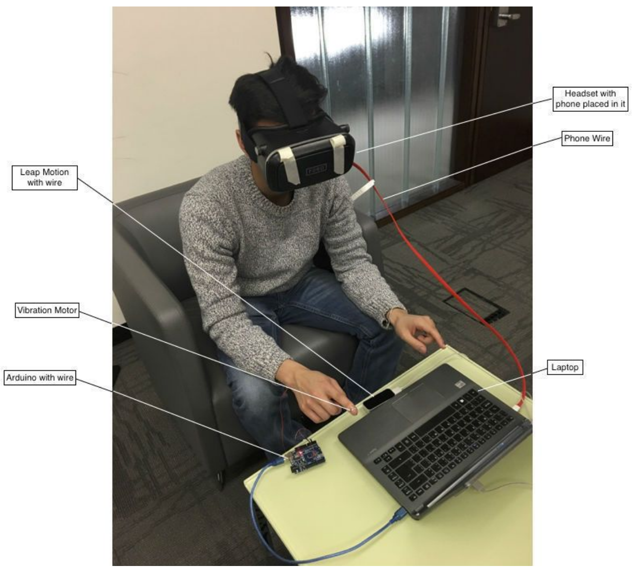

Figure 2. A picture of the full set up, including the phone placed inside the headset.

For the experiments, the laptop contained *Unity* source code which had the virtual environment. Using *Unity Remote 5* mobile app, this was mirrored to the connected *OnePlus 1* smartphone which was then placed inside the headset for users to wear (see Figure 2).

Tasks and Procedures

After participants were briefed on the study, they completed the pre-experiment questionnaire, in which they were asked to provide basic information about them. Then they completed two training sessions without haptic feedback, one for each experimental task without the *VR headset* and using both hands. Participants then began the experiment by performing two tasks. The first task involved stopping five of the cubes coming towards the participant, the participant was instructed to only use his/her dominant hand. The second task involved tapping ten stationary cubes that appeared on screen at different depths, again only using their dominant hand.

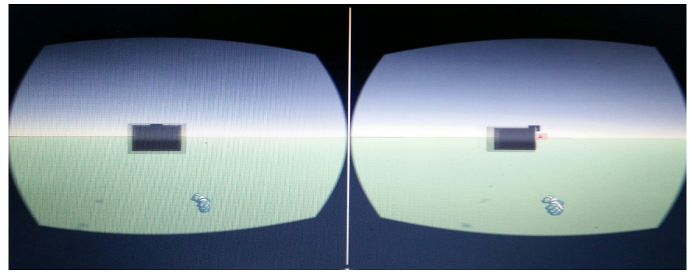

Figure 3. A picture of the first experiment: cubes thrown towards the user.

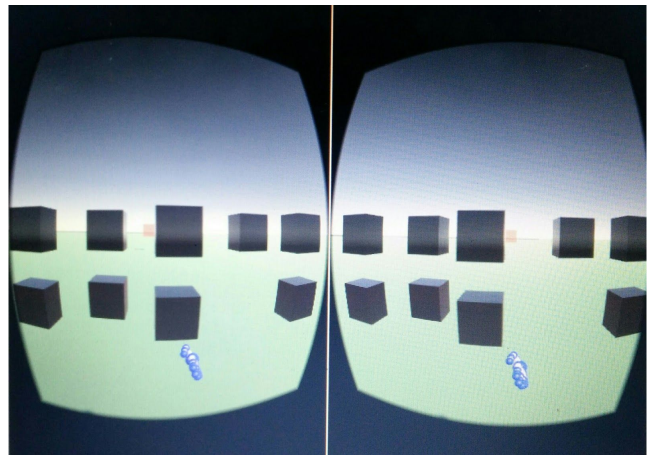

Figure 4. A picture of the second experiment: ten stationary cubes (one cube already selected).

Both tasks were performed two times by each participant, one with haptic feedback and another without haptic feedback. In order to calculate the results for the first task we ended the first level after the user had made contact with five moving cubes (see Figure 3). For the second task, the experiment ended when the user made contact with all ten cubes (see Figure. 4).

Once the participants were done with both tasks, they were asked to fill out a post-experiment questionnaire, in which they were asked about their experiment experience and for some feedback.

Sessions were designed to be completed in 10-15 minutes. Participants were permitted to take breaks at any point in the experiment, in case they felt dizzy.

Measures

For the first task, participants were asked to select five cubes as the cubes were moving towards them. We measured the time that this took in order to observe the effect of vibro-haptic feedback on the speed of target selection. We then measured the time it took without haptic feedback.

For the second task, participants were asked to select ten cubes that were displayed at different depths. The time it took participants to destroy the ten cubes at varying depth with vibro-haptic feedback and without vibro-haptic feedback was recorded.

The average difference in time between the vibro-haptic feedback and none vibro-haptic feedback results reflect the time 'saved' due to the sense of verification that the vibro-haptic feedback provides people when interacting with the the virtual cubes.

Accuracy was defined as the level of confidence a participant has of making contact with the cube.

As the difference in time between vibro-haptic and no vibro-haptic feedback increases, the level of confidence in the participant decreases; this means accuracy decreases as well.

Data Collection

The *Unity* application automatically measured the time it took for the participant to make contact with the cubes. It did this by adding up Time.deltaTime (provided by Unity), which provides the time between each frame render. The application stored a count of the number of cubes that needed to be hit, subtracting the total number by one each time a collision with a cube was detected (collision was only tracked on the first frame of contact). When the count of cubes needed to be selected hit zero, the application stopped and the time was displayed on to the screen. In task one, this was when five cubes had been selected, in task two this was when all cubes in the Unity environment had been selected. This information was recorded on a Google Drive spreadsheet. This may have resulted in a minor latency in the time between the task completion and the frame to finish rendering, but this was deemed trivial.

Participants

A total of 78 session were run across both form-factors and training (26 sessions used to train the participants on both tasks, 13 on each task, and 52 sessions where the experiments. 26 sessions for the first task, 13 with haptic feedback and 13 without haptic feedback. Another 26 sessions for the second task, 13 sessions with haptic feedback and 13 without haptic feedback). The session were performed by 13 right handed participants (7 female) recruited from the broader university community, within a mean age of 24 (sd = 3.6). None of the participants had any *Virtual Reality* experience. Participants were first trained and then asked to perform two tasks, the first task was to block five incoming cubes and the second task was to tap ten static cubes. All participants were volunteers.

Experimental Design

Each experiment/game employed a 2x2 balanced Latin Square within-subjects design. The independent variables, or factors, were feedback mode and task. The levels for the feedback mode were haptic feedback and no haptic feedback. The levels for task were blocking incoming cubes and tapping still suspended cubes. The experimental conditions were two games: in the first game the participants' speed was tested and recorded, one trial with haptic feedback and another trial without haptic feedback. The second game tested and recorded the participants' accuracy with and without haptic feedback. The control variable for the first experiment was the rate at which the cubes were thrown at the participants, and the control variable for the second experiment was the constant ten cubes presented to the participants. These control variables were introduced to improve the internal validity of the experiments by controlling their variability. The random variable for the first game was the location where the cube was thrown within the participants' reach area, this variable was introduced to improve external validity through situational variability. The second experiment had no random variable. All participants were given a pre-experiment and a post-experiment questionnaire. The pre-experiment questionnaire was used to learn basic demographic information about the participants. And the post-experiment questionnaire was used to get some feedback about the experiment from the participants. The participants were all instructed the same, using a written script, and trained once in each game without the headset; this was done to normalize their task understanding and VR experience. To counterbalance the experiments a 2x2 balanced Latin Square was used. Therefore, the participants were divided into two groups, half of them started the games without haptic feedback and the other half started the games with haptic feedback. These two groups were alternated as seen in *Table 1: Raw data* below. This overall experiment design was selected to minimize any learners bias.

RESULTS

Based on the data we found (see Table 1), to test if the results were statistically significant, singer-factor, within-subject Analysis of Variance (ANOVA) tables were created for both tasks (see Figure 5 and 6). We chose this method of analysis as the ANOVA test provides us with knowledge to tell whether or not the result is significant.

Participant	Task 1	Task 2	Haptic feedback?
1	17.52	65.88	No
1	9.62	12.36	Yes
2	31.40	12.13	Yes
2	15.44	8.23	No
3	41.85	32.51	No
3	29.19	12.68	Yes
4	12.33	12.18	Yes
4	16.91	30.45	No
5	27.8	33.17	No
5	16.72	8.49	Yes
6	11.07	7.23	Yes
6	20.68	9.005	No
7	43.11	28.53	No
7	22.55	32.35	Yes

8	16.42	18.38	Yes
8	24.06	23.64	No
9	13.09	8.91	No
9	12.53	5.23	Yes
10	28.06	4.67	Yes
10	15.51	6.63	No
11	14.06	9.68	No
11	15.47	7.59	Yes
12	15.80	5.76	Yes
12	14.58	6.31	No

Table 1. Raw data of our 12 participants. The experiments were done in the order recorded.

```
ANOVA_table
=========================================================================
Effect              df        SS            MS           F          p
-------------------------------------------------------------------------
Participant         11     1230.090      111.826
F1                   1       79.025       79.025      1.449     0.2539
F1_x_Par            11      599.709       54.519
=========================================================================
```

Figure 5. One-Way ANOVA results for task 1. Note that $F_{1,11}$ =1.449 and p = 0.2539.

```
ANOVA_table
=========================================================================
Effect              df        SS            MS           F          p
-------------------------------------------------------------------------
Participant         11     2620.668      238.243
F1                   1      667.752      667.752      4.798     0.0509
F1_x_Par            11     1531.029      139.184
=========================================================================
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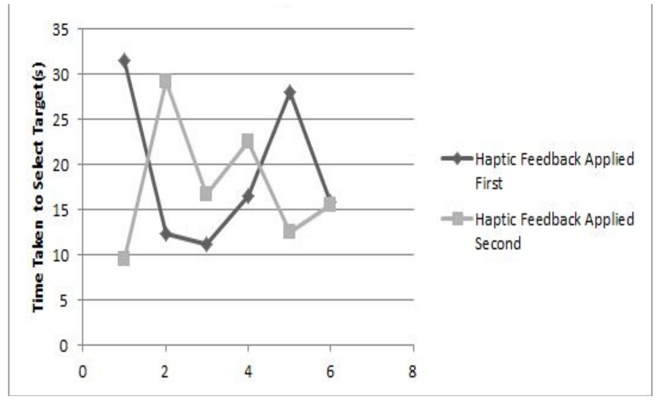
Figure 6. One-WayANOVA results for task 1. Note that $F_{1,11}$ = 4.798 and p = 0.0509.

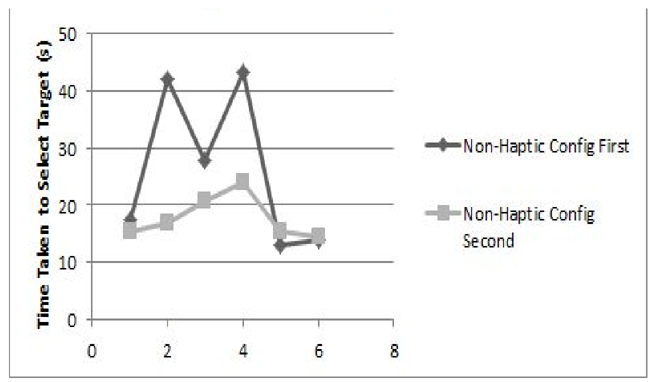
Discussion

For the first task, when looking at the ANOVA results, since $p > 0.05$, this result is not statistically significant. The null hypothesis could not be rejected; the presence of haptic feedback did not improve the speed of target selection. On the contrary, for the second task, since $0.1 < p > 0.05$, the p value is trending. The p value was very close to 0.05 so the null hypothesis can be rejected; the presence of haptic feedback improved the accuracy of target selection. These results are partially in-line with the results of the literature review conducted; studies found in the literature review section suggested that the VR experience was improved with the presence of haptic feedback, implying that the speed and accuracy of target selection should improve with the introduction of haptic feedback.

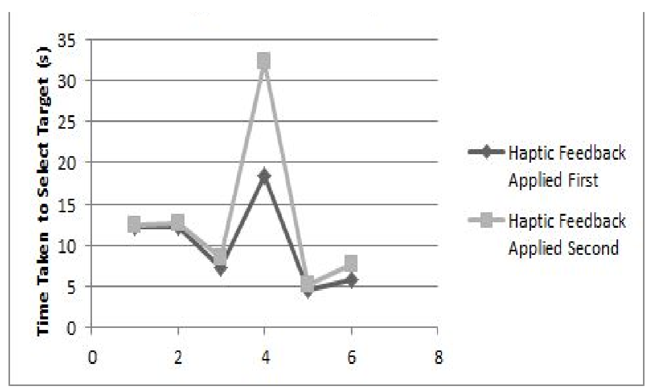
As this experiment was conducted in a within-subjects configurations, we were aware of the possibility that learning effects could alter the results; even though counterbalancing was used to offset learning effects. To better understand if learning effects took place, an analysis was conducted. For both tasks, the difference between time taken to select targets when a particular configuration (vibro-haptic or non vibro-haptic) was used first as opposed to after the non vibro-haptic configuration (See Graphs 1-4).



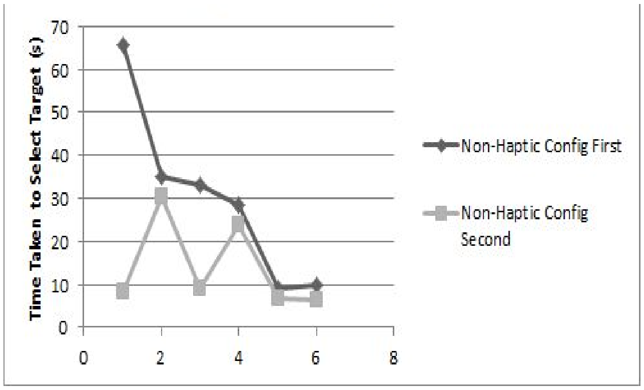
Graph 1. Learning effects for vibro-haptic configuration in Task 1. The average time to select a target was 19.18 seconds when the vibro-haptic configuration was used before the non vibro-haptic configuration and 17.66 seconds for the opposite.



Graph 2. Learning effects for non vibro-haptic configuration in task 1. The average time to select a target was 17.86 seconds when the vibro-haptic configuration was used before the non vibro-haptic configuration and 26.23 seconds for the opposite.



Graph 3. Learning effect for viro-haptic configuration in task 2. The average time to select a target was 10.06 seconds when the vibro-haptic configuration was used before the non vibro-haptic configuration and 13.12 seconds for the opposite.



Graph 4. Learning effect for non vibro-haptic configuration in task 2. The average time to select a target was 14.04 seconds when the vibro-haptic configuration was used before the non vibro-haptic configuration and 30.23 seconds for the opposite.

Conclusion

In conclusion, it would not be determined through this experiment that the presence of haptic feedback impacted the speed to target selection in VR environments. However, vibro-haptic feedback did improve the accuracy of target selection. Though there was counterbalancing present in this experimental setup, it may be beneficial to conduct this experiment using a between-subjects configuration to determine the impact of learning effects. As there was variation among the data points, it will be beneficial to conduct the same experiment with a larger number of participants. Furthermore, in addition to counterbalancing the experiment, another way to reduce a learner's bias should be incorporated into the study.

There is definitely somewhere to move forward to with this experiment. An interesting research question moving forward could be the use of vibro-haptic feedback to give participants a sense of gravity. This would require participants to be in motion, so a much more immersive and complete VR environment has to be implemented.

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