Effects of Vibrotactile Feedback in Commercial Virtual Reality Systems

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Abstract. This study investigates the effects of vibrotactile feedback by motion controllers of a commercial virtual reality (VR) system on immersion, actual and perceived user performance, and perceived difficulty of specific tasks in VR.

To this end, we developed two different tasks in VR with different types of interactions: entering numbers by rotating a number dial and stirring a pot. In a within-subject experiment, 14 participants completed the two tasks with and without vibrotactile feedback.

The results showed that for both tasks self-reported immersion was significantly improved by vibrotactile feedback, while perceived difficulty was significantly reduced for one task, and perceived performance was significantly increased for the other task. These results show that even the limited vibrotactile feedback by motion controllers of commercial VR systems is capable of significantly changing VR experiences.

Keywords: Virtual Reality · Vibrotactile feedback

1 Introduction

Virtual Reality (VR) is a popular platform for emulating reality and creating immersion [5,6]. One of the immersion-enhancing technologies is haptic feedback, which has been used for VR and other platforms for many years [7].

However, the use of vibrotactile feedback in motion controllers of commercial VR systems for haptic rendering has received relatively little attention by the research community. On the other hand, commercial VR games (e.g., Rec Room [1]) provide vibrotactile feedback in many situations, for example, when pulling the (virtual) string of a bow. In this case, the frequency of the vibrotactile feedback is usually scaled with the velocity of the motion controller, which creates an effect that is very similar to haptic rendering.

In this work, we explore the potential of vibrotactile feedback in commercial motion controllers for haptic rendering by adjusting the frequency and amplitude of vibrotactile feedback to the position and velocity of motion controllers. To determine the benefits of this kind of haptic rendering, we implemented a dialing and a stirring task in VR and compared self-reported immersion, actual

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and perceived performance, and perceived difficulty for each task with and without vibrotactile feedback. (Two additional tasks received relatively low presence scores for both conditions—presumably because they both involved virtually touching a virtual wall. Therefore, we are not discussing these two additional tasks.) The dialing and stirring tasks both showed significantly improved immersion with vibrotactile feedback. Furthermore, the stirring task showed significantly improved perceived performance and the dialing task showed significantly reduced perceived difficulty with vibrotactile feedback.

2 Previous Work

A common goal for the use of haptic devices in VR systems is to increase immersion. Similarly to many other haptic devices, the PHANToM Haptic Interface [4] made it possible for users to interact and feel a variety of different virtual objects. To this end, users inserted the tip of an index finger into a thimble. The position of this thimble was measured and a force was applied to it based on collisions with virtual objects. This allowed users to feel virtual surfaces, i.e., it made haptic rendering of virtual surfaces possible. The PHANToM Haptic Interface demonstrated that a low-cost system can provide convincing haptic feedback for interactions with virtual objects, and it showed that users learn to interpret this haptic feedback with relative ease.

More recently, vibrotactile feedback in positionally tracked controllers was used to create the experience of haptic textures. Examples include a vibrating slider by Strohmeier and Hornbæk [8] and the CLAW controller by Choi et al. [2].

Wu et al. [9] used vibrotactile feedback in positionally tracked data gloves to create haptic feedback for a virtual keyboard in VR. A user experiment showed that the virtual keyboard with vibrotactile feedback was considered more realistic by test participants and allowed for faster typing than a virtual keyboard without vibrotactile feedback.

The work by Wu et al. showed that vibrotactile feedback in data gloves has the potential to increase not only immersion of users but also their performance in a specific task. This motivated our study, which investigated whether vibrotactile feedback in commercial motion controllers has a similar potential to increase immersion and task performance.

3 Experiment

Our experiment tried to determine the effect of vibrotactile feedback on immersion, task performance as measured by completion time and amount of errors, as well as perceived performance and difficulty for specific tasks in a VR environment using commercial off-the-shelf components.

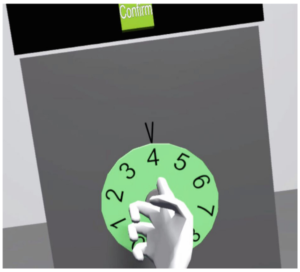

Fig. 1. Dialing task.

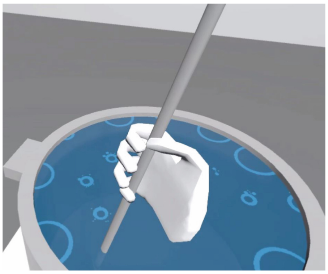

Fig. 2. Stirring task.

3.1 Materials

For the experiment, we developed a VR application with the Unity game engine for the HTC Vive VR system. The VR application includes a dialing task and a stirring task to provide different forms of vibrotactile feedback. Each participant performed each of the tasks (in a fixed order) with and without vibrotactile feedback (in randomized order), thus, each of the tasks could be considered a separate experiment.

The first task was a dialing task (Fig. 1). Participants were shown a number and were asked to turn a numerated dial to this number by virtually touching the dial with their finger. They had to confirm each number by pressing a button. Each time the dial passed a number, the participant received vibrotactile feedback. After the participant had entered all four numbers, the first task was completed.

The second task required the participants to stir a virtual pot (Fig. 2). The participants were prompted to pick up a large spoon and stir the pot placed right in front of them. When a participant stirred the pot, vibrotactile feedback was provided dependent on the velocity of the spoon. Once the required amount of rotations was met, the task was completed.

3.2 Setup

Apart from the HTC Vive VR system, the experimental setup included a facilitator and an observer. The role of the facilitator was to introduce the participants to the test and inform them about their tasks. The observer took notes during the tests both from how the participant acted and what could be seen on the computer screen, which mirrored what the participants saw in the HTC Vive head-mounted display.

3.3 Procedure

The experiment used a within-subject design, which consisted of an introductory questionnaire to assess previous VR experience and demographics, the tasks with and without vibrotactile feedback, questionnaires about presence and a comparison between the versions with and without vibrotactile feedback, as well as an interview.

The presence questionnaire used a 7-point Likert scale to assess the level of presence experienced by the participant while performing each task. The questionnaire was inspired by a similar questionnaire by Witmer and Singer [3]. The participants answered the presence questionnaire after each version of each task. After participants had completed both versions of a task (with and without vibrotactile feedback), they answered a questionnaire to compare the two versions. After all tasks were completed, an interview was conducted to obtain information regarding the participants' experience of immersion, performance, and VR sickness.

4 Results

The demographic of the test consisted of 14 participants (10 male and 4 female) with ages varying from 21 to 29 years.

Using the Wilcoxon signed rank test with significance level of $\alpha = 0.05$, the presence questionnaire's total scores showed no significant difference between the versions of the tasks with and without vibrotactile feedback. ($p = 0.55$ for the dialing task and $p = 0.86$ for the stirring task.)

A Wilcoxon signed rank test was also performed on the results of the questions directly comparing the versions of each task with and without vibrotactile feedback. The questions were:

1. Which task did you perform better in?
2. Which task did you find more difficult?
3. Which task did you find more immersive?
4. Which task felt more real?

Participants answered by naming either the version without vibrotactile feedback, which was coded as -1, the version with vibrotactile feedback, which was coded as $+1$, or they stated that they saw no difference, which was coded as 0. p values were determined by Wilcoxon signed rank tests comparing the answers to the null hypothesis of no difference. Results for the means and p values are summarized in Table 1.

Participants found the dialing task more difficult without vibrotactile feedback. On the other hand, vibrotactile feedback made the task feel more immersive and real to the participants.

For the stirring task, participants felt that their performance increased with vibrotactile feedback. The task also felt more immersive and real with vibrotactile feedback.

To compare the required time for each task, a Student's t-test was performed, which showed that participants required significantly more time for the dialing with vibrotactile feedback.

Table 1. Mean values (positive for vibrotactile feedback) and p values of Wilcoxon signed rank tests for comparison questions. Significant p values are set in **bold**

Question	Dialing	Stirring
1. Better performance?	$M = 0.21; p = 0.39$	$M = 0.5; p = \mathbf{0.01}$
2. More difficult?	$M = -0.43; p = \mathbf{0.02}$	$M = -0.21; p = 0.15$
3. More immersive?	$M = 0.79; p = \mathbf{0.003}$	$M = 0.79; p = \mathbf{0.001}$
4. More real?	$M = 0.71; p = \mathbf{0.004}$	$M = 0.71; p = \mathbf{0.002}$

The number of errors in the dialing task were analysed with a Wilcoxon signed rank test but showed no significant differences.

The intensity of the vibrotactile feedback was experienced differently by participants. The vibrotactile feedback in the stirring task was found to be either too strong or too weak by 8 participants. 3 participants found the feedback in the dialing task to be too weak.

In the questionnaire that was answered before the test, 5 of 14 participants answered that they had experienced VR sickness while using VR. These participants rated their experience of VR sickness appearing from "rarely" to "sometime." After experiencing the test, 1 of 14 participants said that he or she experienced VR sickness.

5 Discussion

The presence questionnaire showed no significant differences between the versions with and without vibrotactile feedback. One reason for this might be that this questionnaire was not specific enough to show any effect of vibrotactile feedback.

On the other hand, the more specific comparison questions showed that the tasks felt more immersive and real with vibrotactile feedback. Thus, we conclude that vibrotactile feedback can in fact increase immersion in virtual reality.

No significant differences were found in performance errors when comparing conditions with and without vibrotactile feedback. It is possible that the dialing task was not sufficiently well designed to utilize vibrotactile feedback for better performance.

The only significant difference in time was found for the dialing task. This difference showed that participants took longer in completing the task with vibrotactile feedback. One possible reason for this result could be that participants took time to explore the vibrotactile feedback and were not aware that their performance was measured.

The data also suggests that despite the participants not feeling an increased performance in the dialing task with vibrotactile feedback, they found it more difficult without vibrotactile feedback. This might suggest that participants felt that without vibrotactile feedback more effort was necessary to reach the same performance.

The answers to the comparison questions for the stirring task suggest that vibrotactile feedback increased perceived performance. According to the participants, it helped them to know that their interaction had an effect, which might have led them to think that they were performing better.

6 Conclusion

This study showed that vibrotactile feedback by commercial motion controllers can result in higher immersion, increased perceived performance, and decreased perceived difficulty. It also suggests that comparison questions might be preferable to general presence questionnaires to identify these effects with statistical significance.

On the other hand, we did not see a significant effect of vibrotactile feedback in two other tasks that we had tested nor an effect on the actual performance in any of the tasks. This indicates that the tasks were not sufficiently well designed to make use of the vibrotactile feedback and/or that the vibrotactile feedback was not sufficiently well designed to a have a significant effect.

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