A Preliminary Investigation of Human Adaptations for Various Virtual Eyes in Video See-Through HMDs

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ABSTRACT
A video see-through head mounted display (HMD) has a different viewing point than does the real eye, resulting in visual displacement (VD). VD deteriorates visuomotor performance due to sensory conflict. Previous work has investigated this deterioration and human adaptation by comparing fixed VD and real eye conditions. In this study we go a step further to investigate whether any differences in visuomotor and adaptation trends exist across 16 distinct VD conditions. The performance tasks studied were of two types: foot placement and finger touch. In contrast to our initial prediction, the results showed equal task performance levels and adaptation within about 5 minutes regardless of VD conditions. We found that human adaptation covered a variety of VDs — up to 55 mm in the *X, Y* direction; up to 125mm in the *Z* direction; and up to 140mm of interocular distance (IOD). In addition, we found that partial adaptation gave participants the interesting experience of a sense of body structure distortion for a few minutes.

Author Keywords
video see-through; HMD; immersive reality; adaptation; visual displacement; visuomotor; task performance.

ACM Classification Keywords
H.5.1. Information interfaces and presentation (e.g., HCI): Multimedia Information Systems.

General Terms
Human Factors; Design; Measurement.

INTRODUCTION

What would happen if one's eyes were in front of one's face? Video see-through HMDs raise this problem. A demand is emerging for a portable display that supports fully immersive information services. To meet the needs posed by that trend, it is essential to supply HMDs having a wearable design and offering high levels of immersion.

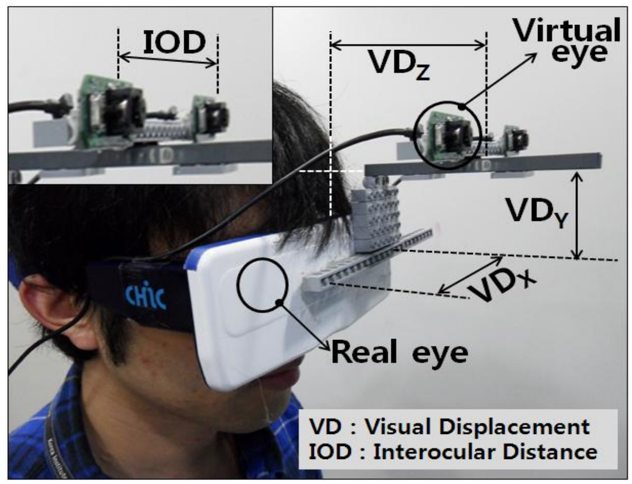

Figure 1. Our developing video see-through HMD provides various VD setups, including X, Y, and Z directional VD and IOD. Human task performance and adaptation were investigated under 16 VD conditions.

See-through HMDs have been studied [10] with those purposes in mind. In video see-through HMDs, the conversion of one's perspective into video clips through digital photography offers an advantage in allowing your real view to be naturally mixed with virtual information in real time. However, in comparison to optical see-through, video see-through indirectly displays the real world so that sensory conflict due to visual displacement (VD) is unavoidable, given that VD is induced by a mismatch between the position of the real eye and the location of the cameras (i.e., virtual eyes), as shown in Figure 1. The VD has been found to induce feelings of discomfort and dizziness and to decrease visuomotor performance [3, 11]. However, Biocca and Rolland [2] showed that human adaptation rearranges these sensory conflicts in a short period of time. A prism adaptation study similarly found that the adaptation process is affected by coordination between the visual system and the motor system when participants wear prisms [7]. Such studies have indicated the presence of adaptation aftereffects once prisms are removed. However, there has thus far been no comparison of various levels of HMD VD. We progressively investigate adaptation trends and performance variance across 16 VD conditions. We firstly expected that adaptation and task performance patterns would emerge with increased VD. Task performance was measured in two ways: foot placement, which requires human balance, and finger touch.

Foot placement task

Foot placement has been used to test balance associated with postural behavior [8]. The study of prism adaptation related to walking and stepping tasks has shown typical visuomotor mismatch adaptation and aftereffects [1]. Morton and Bastian demonstrated prism adaptation associated with whole body movement during a walking task [9]. Along the same lines, we studied foot placement adaptation among VDs, including IODs.

Finger touch task

It is well known that the finger touch task is associated with adaptation to limb visuomotor coordination and demands more accuracy than does the foot task [5]. We investigated human performance in touching an exact point on a touch screen. Li [6] described how participants learned motor coordination when undertaking an open-loop (i.e., lacking visual feedback) pointing task wearing prism goggles. In our study, participants were asked to recognize foot and finger positions during a closed-loop process task.

METHOD

We designed 16 combinations of test conditions with 5 factors as shown in Table 1: test order, IOD, and transforming of the cameras in the *X* (right to left), *Y* (upward), and *Z* directions (in front, the minimum possible distance from the real eye for our prototype was 70 mm). This study employed the "Taguchi method," which uses an orthogonal array to minimize the number of tests [12]. Traditionally, to investigate all test conditions, a 4(test order) X 4(IOD) X 4(VDx) X 4(VDy) X 4(VDz) experiments necessitates 1024 tests. However, the orthogonal array allows us to use only 16 sets of test conditions and still effectively represent all combinations based on its unique characteristic of equally and independently separating the effects of each factor on the others.

No. of test Condition	Test order	IOD (mm)	X (mm)	Y (mm)	Z (mm)
1	1	65	0	0	70
2	2	65	25	25	95
3	3	65	40	40	110
4	4	65	55	55	125
5	1	90	25	40	125
6	2	90	0	55	110
7	3	90	55	0	95
8	4	90	40	25	70
9	1	115	40	55	95
10	2	115	55	40	70
11	3	115	0	25	125
12	4	115	25	0	110
13	1	140	55	25	110
14	2	140	40	0	125
15	3	140	25	55	70
16	4	140	0	40	95

Table 1. Experimental test conditions

Participants

Twelve participants undertook this test (age, 28.5 (5.9); 9 men, 3 women). Ten were right handed, all had normal vision, and all had an inter-pupillary distance of 64~66mm. There were no self-reported abnormalities of balance or motion sickness susceptibility. Three participants had had a great deal of experience with 3D or HMD, 6 had had some experience and 3 had had little. All participants gave their informed consent prior to testing and responded to a preliminary questionnaire. We followed Declaration of Helsinki ethical standards and obtained IRB approval.

Apparatus and measures

Video see-through HMD: We developed a video see-through HMD with 2 individual 30mm, 30 fps screens in front of the eyes. This HMD had 2 parallel cameras offering a straightforward install not requiring toe-in setup, and which do not generate vertical parallaxes under conditions of up to 140mm of IOD. During the test, participants had no difficulty with convergence because the HMD provided about 40 cm of convergence distance at 140mm of IOD. The HMD had a 640×480 display resolution and an FOV of 48° in the horizontal and 18° in the vertical.

Foot placement performance measures: To measure foot placement performance, participants were asked to step onto a 150mm-high box placed in front of them and to step down every 5 seconds to a target on the ground indicated by foot markers. A step was counted as a failure when the participant's foot landed 30mm outside the markers. This failure criterion was determined to yield 80 ~ 90% of accuracy on average after adaptation, corresponding to the findings of Rolland and Biocca [2] and Martin [7]. During the test, an experimenter counted the number of successes for each trial and informed participants of each instance. This test was composed of 20 trials.

Finger touch performance measures: Participants were asked to touch a 20mm-diameter red blob that appeared on a monitor screen (285 mm×165 mm) within a given amount of time: The blob appeared for 5 seconds before moving to another position. This task was repeated 20 times for each participant. During the task, a program counted the success of the trial and informed participants in each instance. The distance from the chair to the monitor was 60cm.

Test procedure

After filling out preliminary questionnaires, participants were divided into 4 groups of 3 each. For example, Group 1 performed test conditions 1-2-3-4 in order, and Group 2 performed conditions 5-6-7-8, as shown in Table 1. Before the main test, we made preliminary observations and inquired concerning difficulties participants experienced in controlling their bodies while wearing the video see-through HMD. In the main test, participants performed the foot placement task for 20 trials and the finger touch task for 20 trials in sequence as shown in Figure 2. Paricipants completed a total of 80 trials for each task because each participant repeated each task 4 times.

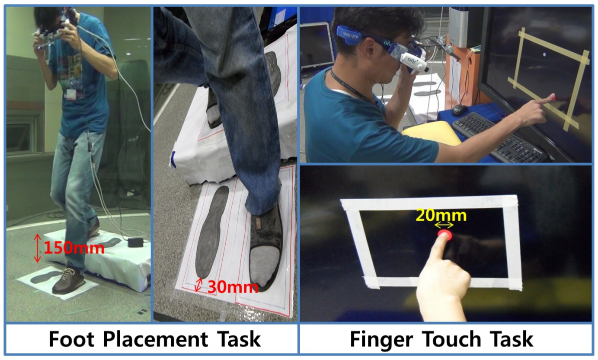

Figure 2. Human task performance measurements consisted of foot placement and finger touch tasks.

RESULTS

We examined whether 4 levels of VD and IOD influenced human task performance variation. However, we found no significant differences, as shown in Figure 3. These results imply that human adaptation occurred for a variety of VDs, up to 55 mm in the *X* and *Y* direction, up to 125mm in the *Z* direction, and up to 140mm of interocular distance (IOD). For example, even with a 55mm disparity in virtual eye position in the *X* direction, participants could rapidly modify their visuomotor performance to suit the new viewing point (by about 78%) as compared to about 76% in the 0mm condition. We investigated these correlations via a T-test (SPSS 18.0), and found no relationship between each VD and IOD and task performance ($P>0.05$).

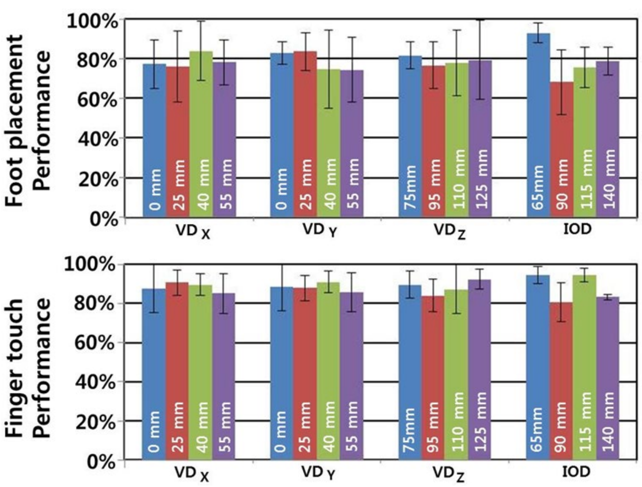

Figure 3. Human task performance under various levels of VD and IOD.

We also analyzed the correlation among test time, task performance and task type. Figure 4 (covering the entire test period) and Figure 5 (covering each test session) show the average of all tasks to illustrate overall adaptation trends. In the foot task, a significant adaptation pattern (r=0.844, $P<0.01$) emerged, while the pattern was not as significant for the finger task (r=0.762, $P<0.1$). After 5 minutes of engaging in the foot task, participants performed correctly around 80% of the time, 60% higher than the initial state.

Most participants remarked that the foot task was harder than the finger task due to the difficulty of balancing one's entire body. A few participants staggered when trying to control their body movements in the beginning. However, by the end of the test, almost all participants showed 90% accuracy in performance on both the foot and finger tasks.

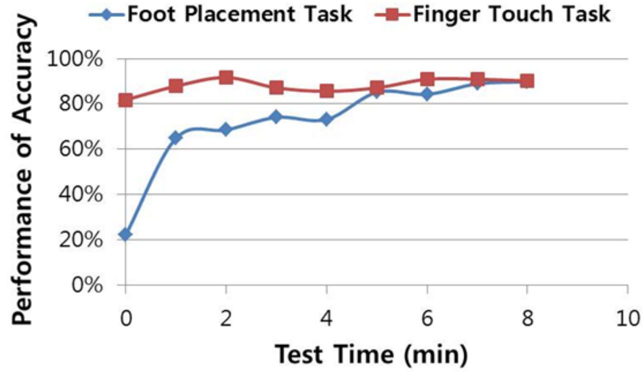

Figure 4. Overall adaptation effects

Figure 5 shows the short adaptation period for each test session. Each participant repeated the task 4 times under various test conditions. Obvious adaptation trends also emerged in the foot task (r=0.586, $P<0.01$) while only vague adaptation trends emerged for the finger task.

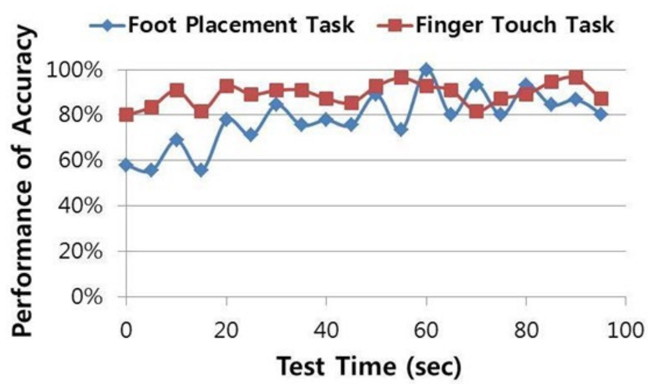

Figure 5. Adaptation effects per test session

DISCUSSION

Adaptation to VD: In the first 10 minutes of a test process, participants tended to rapidly adapt to the new visual sense regardless of the degree and style of VD. Consequently we are cautiously optimistic about the possibility of using a video see-through HMD with wide VDs in practical applications. Our results would help video see-through HMD designers determine a rough range for workable camera positions. A certain amount of deviation in camera position does not seriously deteriorate task performance thanks to the human capacity for visual adaptation. However, VD may pose long-term safety or health risks; we hope to assess that possibility in a subsequent study.

Viewing distance: We considered that viewing distance could have influenced the difficulty of the task types. In the foot placement task, participants stepped down and onto the target over a longer distance as compared to that required for the finger touch task. This difference may have given rise to the difference in adaptation patterns. In the case of the finger task, a more precise task would likely have shown a more distinct adaptation pattern; we will consider this likelihood in designing future tests.

Partial body adaptation: Harris [4] found the presence of an illusion of limbs during visuomotor coordination for a finger-pointing task while participants were wearing a wedge prism. We found the same phenomenon when using the video see-through HMD. During the test, partial body adaptation gave participants a feeling of body structure distortion, including a sense of linkage between their left arm and their chest, and their head being on their right shoulder. This phenomenon was most distinct with the VDx. About 50% of participants mentioned this experience, which occurred as they shifted their attention to a new body part. Even though one may adapt the left hand, one's right hand can remain unadapted, resulting in poor cognition of body structure consistency. For example, when one first looks at an unadapted arm, it appears in an unexpected position, and one then tries to adjust for the perceived positions of the adapted and unadapted arm by reconstructing a sense of linkage. During that time, partial body adaptation occurs. In fact, after the foot test, all participants were asked to remove the HMD for several minutes. During this period, unexpected adaptation to the real view could have occurred. We predict that if participants were to continue to wear the HMD as they changed from the foot task to the finger task, more would have reported this phenomenon more intensely.

CONCLUSION

We suggest that there were no significant differences in task performance using a video see-through HMD despite variations amounting to dozens of millimeters in VD and IOD conditions. This result supports allowance of a wide range of HMD camera positions. In line with the results of previous studies, we found adaptation patterns for the foot and finger tasks with more distinct adaptations emerging in the foot placement task. The foot task was much more influenced by VDs, but the human capacity for adaptation allowed participants to recover successfully from any sensory conflicts in both tasks in a short time.

FUTURE WORK

We are designing the next test procedure to employ a wider VD range, of up to 500mm. We are also considering assessing additional VD factors, such as visual angle and video streaming speed. We also intend to conduct an in-depth investigation of long-term adaptation. A longer period wearing the HMD during normal daily activities should yield interesting results. We will also undertake studies in the future to assess safety and health risks associated with VD and HMD use.

ACKNOWLEDGMENTS

This work was supported by the Global Frontier R&D Program on <Human-centered Interaction for Coexistence> funded by the National Research Foundation of Korea grant funded by the Korean Government (MEST) (NRF-M1AXA003-2012M3A6A3055691)

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