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Comparing Manual Manipulation Task performance among corresponding "real", "tele-matic" and "virtual" environments.

T.Y. Ng and R. H. Y. So

Department of Industrial Engineering and Engineering Management, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

This paper reports the effects of four experimental environments on the performance of manual manipulation task. The four environments were (i) Real Environment (RE), (ii) Restricted-view Real Environment (RRE), (iii) Tele-matic Environment (TE), and (iv) Virtual Environment. All four environments presented the view and sound of the same room, apparatus, and tasks to the participants. While the essentials content of the environments were the same, the presentation ranged from a computer-generated visual environment (i.e., the VE) to a physical environment (i.e. the RE). In between the two extremes, there was the TE – a visual environment made up of camera-captured scene. The task completion time, head and hand displacements were measured and 48 participants took part in the study. Initial results showed that RE had the best performance and followed by RRE, TE and VE. Further analyses indicated that the degraded performance was mainly due to the lack of tactile sensitivity and the presence of image lag. Without the tactile sensitivity, the task completion time was longer ($p<0.01$) and with longer image lag (130 ms), the task completion time was also significantly longer ($p<0.05$).

1. Introduction

Studies have shown that human will have degraded performance in a virtual environment (VE) if the sensory interfaces in the VE are poor (e.g. visual lag: So and Griffin, 1995; System Responsiveness: Watson *et al*., 1998; Stereoscopic/Monoscopic: Greon, 1998; Field-of-View: Barfield *et al*., 1995). However, most of the studies only conduct the experiments in a VE (e.g., So and Griffin, 1995) or in both a VE and RE (e.g., Kenyon and Afenya, 1995; Barfield *et al*., 1995). Therefore in this experiment we would investigate the effects of the experimental environments on Discrete Manual Manipulation Task from a completely computer-generated environment (i.e. Virtual Environment, VE), to a completely physical and natural environment (i.e. Real Environment, RE). Between the VE and RE, we would introduce two intermediate environments which were the Restricted-view Real Environment (RRE) and Tele-matic Environment (TE). The aim was to systematically degrade the sensory environments from RE to RRE to TE to VE, and measure the performance of discrete manual manipulation task along the way. Discrete manual tasks we chose because they were commonly found in VR simulation.

2. Method

2.1 Experimental Design and Approach

For this preliminary experiment, it was a full factorial design with 12 replications. The independent variable is the Experimental Environment which had 4 levels: RE,

RRE, TE and VE. Each experimental environment had 12 participants. They were randomly assigned to the experimental environment.

2.2. Participants and Apparatus

All the participants were Chinese university male students without colorblindness, were right-handed and with normal or corrected eyesight.

For each experimental environment, a Polhemus 3SPACE® tracker system was used to track the position of the head and hand movements. A SGI Onyxll was used to generate the graphics for the VE condition and a CyberGlove™ was used in VE to measure the right hand gesture. In both the VE and TE environments, participants viewed the environment via the VR4 head-mounted display (HMD). In VE, scene presented on the HMD was generated by the Onyxll computer. In TE, scene was captured by a camera. A special headset of the same weight as the VR4 HMD was made for both RE and RRE. The participants in the RE, RRE and TE wore a softball glove with a tracker located on the wrist so as to simulate the wearing of the CyberGlove™ in VE. Figure 1 illustrates the participants of the four experimental environments.

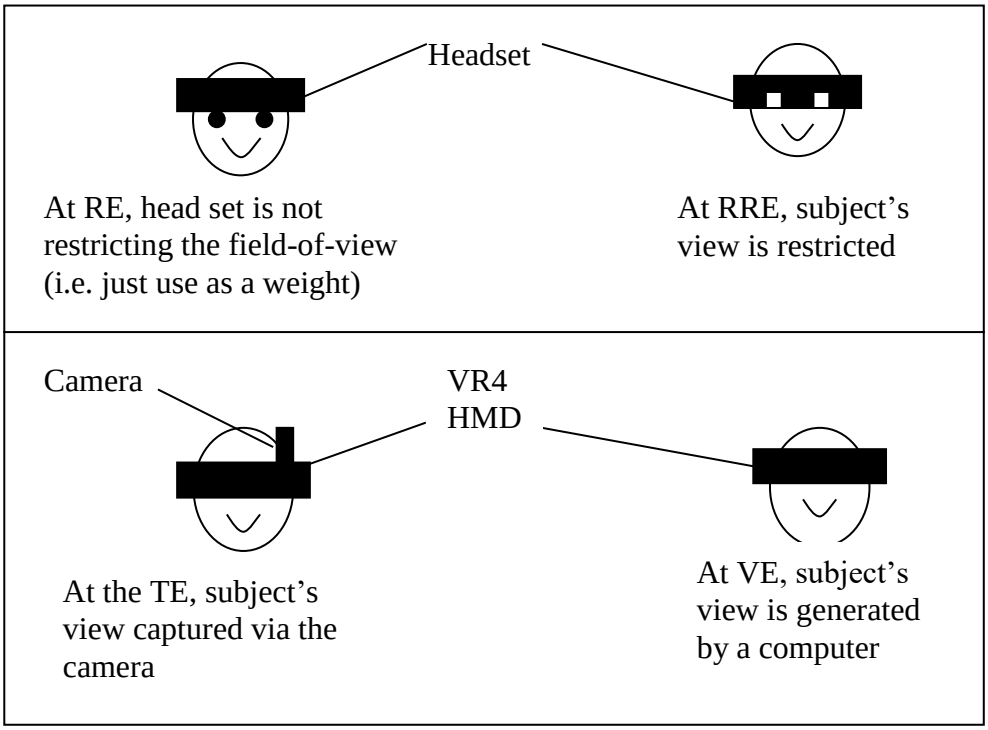

Figure 1. Front view of the subject with head-mounted display (HMD) or headset in the four experimental environments: Real Environment (RE), Restricted-view Real Environment (RRE), Tele-matic Environment (TE) and Virtual Environment (VE).

2.3. Independent variables

As mentioned before that the experimental environment was the independent variable in this experiment. It has 4 levels: RE, RRE, TE and VE. The differences among the 4 experimental environments were classified using the sensory variables (see Table 1).

Table 1
The sensory variables for each experimental environment

Variables	Experimental Environments			
	Real Environment(RE)	Restricted field Real Environment (RRE)	Tele-matic Enviroment(TE)	Virtual Environment(VE)
Field of View	Not Restricted	48x36	45x34	48x36
stereo/mono view	Stero	Stero	Mono	Mono
Image Lag	Without	Without	approx 130ms	approx 60 ms
Image Quality	Real	Real	Digital(capture from a camera)	Digital(SGI generate)
Display's Resolution	High	High	Low	Low
Auditory	Spatial	Spatial	Spatial	Spatial
Tactile	With	With	With	Without

2.4. Task and Dependent Variables

The discrete manual manipulation task required the participant to grasp and pick up a cylinder and moved it from point A to point B (a white box) to and fro. Every 5 times (from A to B and back to A) was called a trial and in this task the participant was required to complete 5 trials which meant the participant needed to move the cylinder 25 times. The horizontal distance between A and B is 72 cm. Within this task, the trial time and the hand and head movement were measured. The trial time (in second) was measured started from the time when the participant grasped the cylinder from A and placed it into a white box B and then took it back to A five times. For the head and hand measurements, only the hand lateral displacement and head yaw angular displacement were concerned here.

2.5. Hypothesis

The task completion time for RE and RRE will be similar and comparatively less than the other three experimental environments, it will increase from RRE to TE and VE. The reasons for this hypothesis are (i) TE and VE both had significant time lag, and (ii) the lack of sense of touch in the VE. According to the research done by Watson *et al*. (1998), the time for grasping and placing the object increased as the frame rate and the system response time increased. Kenyon and Afenya (1995) compared the performance of a " pick -and- place" task in which the VE also did not provide tactile and the result showed that the task completion time in the virtual environment were to be two times greater than those in a real environment.

3. Results

Median trial time data as function of trials and experimental environments are shown in Figure 2. Inspection of Figure 2 shows no observable learning effects occurs in trials. However experimental environments seem to have observable influences on trial time.

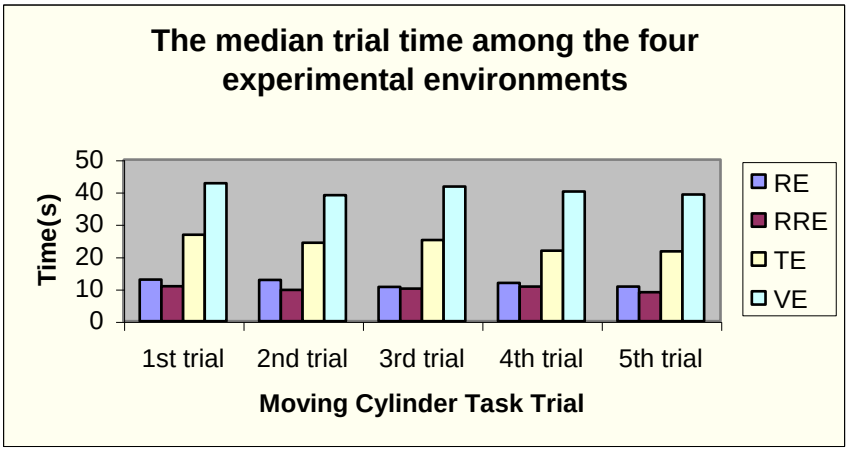

Figure 2. The median trial time among the four experimental environments (data for the first 24 subjects)

As the time data did not follow the normal distribution, log transformation was used so that ANOVA analysis could be conducted (Table 2).

Table 2
ANOVA Table of the trial time data (data from the first 24 participants)

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Experimental Environment (EE)	3	7.19	2.40	120	0.001
No. of Trial	4	0.07	0.02	1	0.25
EE x Trial	12	0.08	0.01	0.5	0.25
Error	100	2.34	0.02		
Corrected Total	119	9.69			

Table 2 shows that Experimental Environment had significant effect on the trial time. However the number of trial had no significant effect on the trial time i.e. the time for trial did not decrease after several “practices”, neither nor the interaction between the Experimental Environment and the number of trial.

Table 3
Grouping of the trial time according to the experimental environment by the SNK method (in ascending order of trial time)

Experimental Environment	Groups		
RRE	A		
RE	A		
TE		B	
VE			C

Subset for alpha = 0.05

In order to investigate the effect of the experimental environment further, the Student-Newman-Keuls (SNK) grouping method was used and the ranking and grouping of the trial time according to the experimental environment are as shown in Table 3.

4. Discussions

4.1. Effects of the Experimental Environment on the task trial time

From the statistical results (see Table 2) showed that Experimental Environment had significant effect on the trial time ($p<0.01$). SNK result (Table 3) showed RE and RRE are in the same group with the shortest time and followed by TE and VE. TE was significantly higher than RE and RRE (see Figure 2). Participants at VE spent the longest time to finish the work. It meant that the poorer the sensory interface (the degradation of the sensory variables from RE to VE), longer the trial time was and we would discuss more in the next subsection. There were no significant differences among the trials ($p>0.05$) which meant that the participants' performances among each experimental environment were very stable and no learning effect was found.

4.2. Further analyses on the effects of the sensory variables on the task trial time

As mentioned above that the poorer the sensory interface, longer the trial time was and in this part we would discuss about it. Shown from the SNK result that RE and RRE were not significant from each other which meant that field-of-view's effect could be excluded from this measurement. As trial time in TE was significantly higher than RE and RRE which meant that stereo/mono view, display resolution, image lag and image quality had significant effect on this measurement. With the combination of the mono view, lower display resolution, longer the image lag and poorer the image quality could delay the task completion time. The results also showed that the time required finishing the task in VE (only experimental environment did not provide the sense of touch) was double from RE (and RRE). This meant that tactile was the main factor in this task confounding with the stereo/mono view, display resolution, image lag and image quality. In addition from the observations during the experiment, nearly two-third of the subjects had the difficulties of holding the cylinder continuously through the whole task.

Analysis on the head and hand movements is still in progress, for further details please refer to the published paper.

Conclusion

Manual manipulation task performance in a corresponding real environment, restricted-view, real environment, tele-matic environment and virtual environment have been found to be less significantly different. Analyses have shown that the tactile sensitivity and the image lag have been the significant factors in affecting the performances. However, these two variables have been confounded with the image quality, stereoscopic/monoscopic view and display resolution. These correlations have been based on the initial results. Analyses are continuing and future studies to investigate the isolated effects of the tactile sensitivity and image lag are in progress.

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