Experience with head-mounted virtual reality (HMD-VR) predicts transfer of HMD-VR motor skills

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***Abstract*— Immersive, head-mounted virtual reality (HMD-VR) has the potential to be a useful tool for motor rehabilitation. However, when developing tools for rehabilitation, it is essential to design interventions that will be most effective for generalizing to the real world. Therefore, it is important to understand what factors facilitate transfer from HMD-VR to non-HMD-VR environments. Here we used a well-established test of skilled motor learning, the Sequential Visual Isometric Pinch Task (SVIPT), to train healthy individuals in an HMD-VR environment. We examined whether learned motor skills transferred to a more conventional (non-HMD-VR) environment and what factors facilitated transfer. Our results suggest that on average, learned motor skills from this task transfer from an immersive virtual environment to a conventional environment; however, some individuals did not transfer the learned motor skills. We then examined individual differences between those that did show transfer and those that did not. We found that individuals who had previous exposure to HMD-VR were more likely to transfer their learned motor skills than those who did not. We also found that individuals who reported lower realism on a presence questionnaire had more skilled transfer than those who reported higher levels of realism. Individual differences in previous exposure to HMD-VR environments or levels of presence during training may serve as a predictor to whether learned motor skills will transfer out of HMD-VR.**

***Keywords*— head-mounted virtual reality, skilled motor learning, transfer**

I. Introduction

Virtual reality (VR) has been shown to be a useful tool for motor learning and rehabilitation. A number of previous studies examining VR transfer have found that learned skills have the potential to transfer from virtual to real world tasks [1, 2]. However, a large proportion of these studies used screens as the virtual medium. Furthermore, many of tasks examined in these studies were focused on locomotion (i.e., walking) or surgical skills training (i.e., laparoscopic surgery).

Head-mounted virtual reality (HMD-VR), which is thought to be more immersive than screens, has recently become affordable and portable, making it a desirable medium for motor skill training and rehabilitation. Conflicting research shows that motor skills learned in an HMD-VR environment may [3] or may not [4], [5] transfer from the virtual environment to the real world.

The variability of results across these studies suggests that there may be individual factors or characteristics of tasks that facilitate transfer and generalization. However, there is no clear explanation or potential mechanism for why transfer occurs sometimes but not other times. In order to use HMD-VR effectively in motor rehabilitation, it is important to understand what factors facilitate transfer, which was the focus of the current study.

II. Methods

Thirty-six participants were recruited and participated in this experiment (26 females/10 males, aged: $M = 25.31$, $SD = 3.79$). Twelve participants were enrolled in our initial pilot experiment [5] and twenty-four participants were enrolled in a similar follow-up experiment. Data from all subjects was combined for this analysis. Eligibility criteria included healthy, right-handed individuals who were naïve to the task. The experimental protocol was approved by the USC Health Sciences Campus Institutional Review Board and performed in accordance with the 1964 Declaration of Helsinki.

A. *Experimental Apparatus*

We used a modified version of SVIPT [6], a well-studied skilled motor learning paradigm in which participants applied varying degrees of force between their thumb and index finger to a small pinch force sensor (Futek Pinch Sensor FSH01465; Futek IPM FSH03633) to move a cursor towards numbered targets. The environment was designed using the game engine development tool, Unity® (Version 5.6.6). During training, participants performed the task in a head-mounted VR display (Oculus Rift DK2). During a portion of the testing condition, participants performed the task on a 17.3 inch, 1920x1080 pixel resolution computer laptop (ASUS ROG G751JY-DH71).

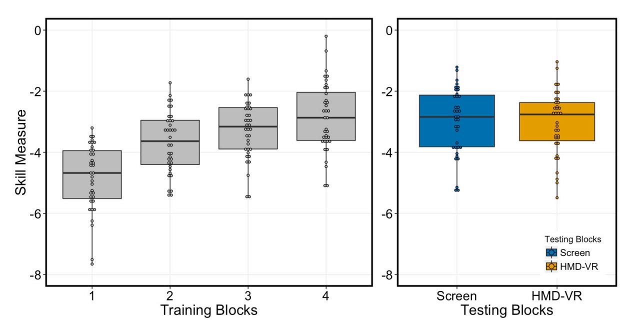

Fig. 1. Skill measure across training blocks in HMD-VR (left) and testing blocks in both CE and HMD-VR (right). Individual participant data shown in circles with the median, minimum, maximum, first quartile and third quartile.

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B. *Sequential Visual Isometric Pinch Task (SVIPT)*

Each trial required participants to apply an isometric force to a small transducer, held in a lateral pinch grip between the thumb and forefinger. The amount of force produced was translated into cursor movement using a logarithmic scale. The goal of the SVIPT is to learn the appropriate force patterns to move a cursor between colored gates in a particular order both as quickly and accurately as possible. In order for the trial to be considered a success, participants needed to move the cursor between each of the gates in the appropriate order. If the cursor fell short of a gate or overshot a gate, the trial was considered unsuccessful. At the end of each trial, participants received auditory feedback (a pleasant "ding" if the cursor correctly entered all the gates or an unpleasant "buzz" if the cursor missed one or more of the gates). All participants first completed 5 familiarization trials to get acquainted with the task. They then completed 4 training blocks of 30 trials each for a total of 120 training trials in the HMD-VR environment. Finally, participants completed 2 different testing blocks of 20 trials each, one in the virtual environment (HMD-VR) and one on a computer screen (CE) (counterbalanced across participants). Performance on the SVIPT for each block was measured using a skill measure, which is calculated as a ratio of speed (time to finish trial) to accuracy (blocks missed) [6].

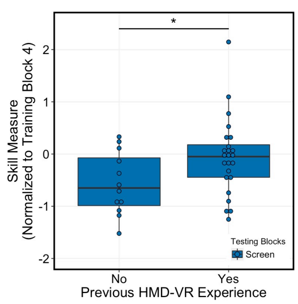

Fig. 2. Individual responses to previous use of HMD-VR correlated with the difference in skill measure between the last block of training (Block 4) and the CE testing block ($t(26.88) = 2.183$, $p = 0.038$).

III. Questionnaires and Statistical Analysis

Questionnaires relating to demographics, previous HMD-VR use, simulator sickness and presence on the training blocks were administered subsequent to completing the experiment. Statistical analyses for questionnaires and performance were conducted using RStudio (Version 1.1.423). Individuals skill measure on Block 1 (baseline) was subtracted from all other blocks in the experiment to obtain individual change from baseline. Paired t-tests and linear models were used for analysis.

IV. Results

A. *Rate of learning and transfer*

The average rate of learning in HMD-VR followed a similar trajectory to that of previous studies using the SVIPT (Fig. 1, left) [6]. To determine whether the learned motor skill transferred from HMD-VR to CE, we compared the skill measure of the transfer block (CE) to the last block of training (Block 4). There was no significant difference in skill measure between Block 4 and the CE block ($t(35) = 1.856$, $p = 0.072$), although there was a trend towads poor transfer. There was no significant difference in skill measure between Block 4 and the HMD-VR block ($t(35) = -0.096$, $p = 0.924$). To examine whether there was a group difference between the two testing blocks, we compared transfer in each of the testing blocks, normalized to performance in Block 4. We did not find a significant difference between the two testing environments ($t(35) = -1.73$, $p = 0.092$).

B. *Predictors of transfer*

In examining individual subject data, it was clear that there was a wide range of transfer across participants (Fig. 1, right). We thus examined whether there were specific factors that could predict transfer. Specifically, we asked whether previous HMD-VR use and presence affected transfer. We found that on average, participants who had not used HMD-VR prior to the experiment performed significantly lower on the transfer block (CE) than participants who had previous exposure to HMD-VR ($t(26.88) = 2.183$, $p = 0.038$; Fig. 2). Additionally, we found that participants who had higher levels of realism on a presence questionnaire had less transfer than participants who reported lower levels of realism ($r^2 = 0.124$; $p = 0.036$).

V. Discussion and Conclusion

The results of this experiment suggest that overall, motor skills learned in HMD-VR transfer to the real world. However, previous exposure to HMD-VR and realism influence transferability. This could be due to the novelty of the environment or enhanced cognitive processes and attention during the training in the HMD-VR environment [7]. Future studies may look at modulating familiarity with HMD-VR and adjusting the realism of the virtual environment to improve transfer.

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