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► **To cite this version:**

Intissar Cherif, Amine Chellali, Mohamed Chaouki Babahenini, Cassandre Simon, Samir Otmame. The Role of Haptic Feedback in Enhancing Basic Technical Skills Acquisition and Transfer in an Immersive Simulator: A User Study. 31st IEEE Conference On Virtual Reality And 3d User Interfaces (VR 2024), Mar 2024, Orlando, FL, United States. hal-04505898

HAL Id: hal-04505898

<https://univ-evry.hal.science/hal-04505898>

Submitted on 25 Mar 2024

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The Role of Haptic Feedback in Enhancing Basic Technical Skills Acquisition and Transfer in an Immersive Simulator: A User Study

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ABSTRACT

We study the impact of haptic feedback on basic technical skills transfer from VR to the real world. Twenty-four volunteers were divided into two training groups (haptic and no-haptic groups) and a control group. The training groups learned to perform a "Ring Transfer" task in a VR simulator, and all participants performed pre-, post-, and retention tests on a similar physical setup. Results show that skill transfer is observed for both training groups and not for the control group. The haptic group participants also improved their performance compared to the no-haptic group, but the difference was not significant.

Keywords: Immersive VR, Haptic feedback, Skills transfer.

Index Terms: Human-centered computing Virtual reality—Human-centered computing User studies—Human-centered computing Haptic devices—;

1 INTRODUCTION

With technological advancements and evolving surgical techniques, virtual reality (VR) simulators have become a fundamental element in the training curriculum for novice and experienced surgeons [2]. Over the past two decades, these systems have provided a safe and controlled setting for repetitive skill practice, eliminating the risks associated with real-world surgical errors on humans and animals. Concurrently, research has focused on enhancing these simulators' fidelity and performance metrics, aiming for the effective transfer of knowledge and skills from the virtual environment to actual operating rooms [3, 8]. However, most efforts in surgical simulation have prioritized graphical fidelity over tactile and force feedback, commonly known as haptic feedback [7]. While graphically intensive systems may have advantages such as lower computational requirements and cost-effectiveness, empirical studies highlight the significant impact of haptic feedback on consistent and accelerated skill acquisition among trainees [1, 5, 6]. On the other hand, counterarguments arise from research [4, 9] that questions the overall efficacy of haptic feedback, positing that visual cues alone may suffice or even exceed haptic feedback in specific scenarios.

Our study aims to examine the effect of haptic feedback on the transfer and retention of basic technical skills from an immersive simulator to the real-world context. Through the outcomes of this study, we aim to offer guidance on effectively integrating haptic feedback in immersive systems tailored for surgical skill training.

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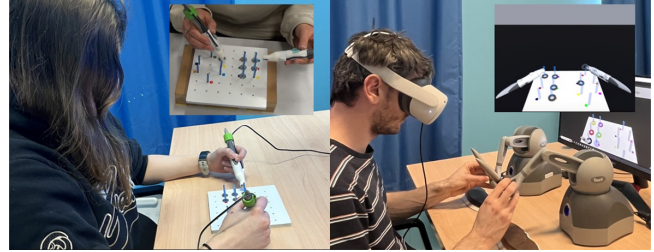


Figure 1: (Left) Physical prototype including two electromagnetic tools and a wooden support with 12 pegs and metal washers. (Right) The virtual prototype includes a VR HMD, two haptic devices, and a virtual environment replicating the physical setup.

2 USER STUDY

The study used a VR simulator and a similar physical simulator for a bi-manual "Ring Transfer" task, with and without haptic feedback. It included 24 volunteers randomly divided into haptic feedback (HC), no-haptic feedback (NC), and control groups (CC). The VR setup included two Geomagic Touch devices, Oculus Quest 2, and a desktop computer (Fig. 1). The physical system had two electromagnetic tools and a prototype platform for object manipulation (Fig. 1). The participants used electromagnetic tools to move washers onto pegs following a specific color pattern to perform the task in the physical setup. The same task was replicated in the VR simulator using haptic devices, with the HC group receiving haptic feedback and the NC group performing the task without it.

This task is crucial for learning basic technical skills such as eye-hand coordination and bi-manual dexterity, fundamental for surgical proficiency. It is usually used as an initial step in a progressive training curriculum, focusing on basic skill acquisition in a controlled environment. The task's complexity in our simulator is increased by the small size of the washers, requiring precise manipulation.

The procedure consisted of a baseline skill assessment, a VR familiarization session, nine VR training sessions of 10 minutes each, and post-training tests in the physical setup to assess skill transfer and retention. Notably, the control group only participated in the pre-test, post-test, and retention test without VR training. The institutional ethics committee validated the study.

Performance was measured in terms of time to complete the task and the number of errors (rings not correctly transferred). We expected the training groups (both with and without haptic feedback) to surpass the control group in both the post-test and retention test, showcasing the effectiveness of VR training in skill acquisition and long-term retention. We also expect that the haptic feedback group will outperform the no-haptic feedback group in both the post-test and retention test, indicating that haptic feedback contributes to superior skill maintenance and learning retention in VR-based training.

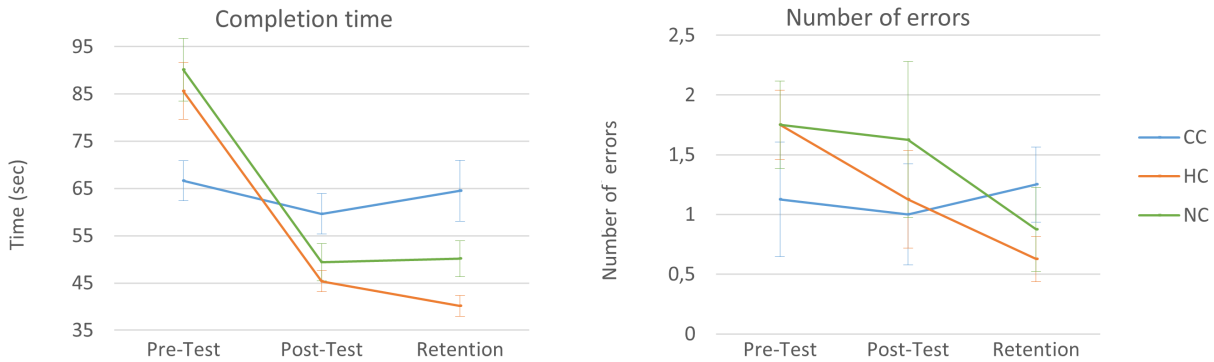


Figure 2: (Left) The mean completion times during the pre-test, post-test, and retention test sessions on the physical setup. (Right) The mean number of errors during the pre-test, post-test, and retention test sessions on the physical setup (error bars represent the standard error)

3 RESULTS

For completion times, a 3x3 two-way mixed design ANOVA revealed a significant interaction between the test session (1-9) and the group ($F_{(3,07,32,25)} = 17.73$, $p < .0001$, partial $\eta^2 = 0.62$), indicating that the change in completion times differs between the groups over the three test sessions. There was a significant main effect of test session on completion times ($F_{(1,53,32,25)} = 95.18$, $p < .0001$, partial $\eta^2 = 0.81$), but no main effect of group ($F_{(2,21)} = 0.83$, $p = .44$, partial $\eta^2 = 0.074$). Nine 2x2 ANOVAs were conducted to test all the possible interactions between the three levels of the two independent variables. The results show that only four interactions were statistically significant, indicating that the effect of training occurred only between the CC group and the two training groups, and this was at the pre-test - post-test and at the pre-test - retention test levels. This suggests that the two training groups improved their completion times significantly better than the control group from the pre-test to the post-test and retained this performance gap at the retention test. In contrast, no significant difference between the two training groups is observed.

For errors, no significant interaction ($F_{(3,03,31,87)} = 1.39$, $p = .36$, partial $\eta^2 = 0.095$) between the test session and the group was found. Additionally, there was no significant main effect of test sessions ($F_{(1,51,31,87)} = 2.43$, $p = .11$, partial $\eta^2 = 0.10$) or the groups ($F_{(2,21)} = 0.28$, $p = .75$, partial $\eta^2 = 0.02$) on errors.

4 CONCLUSION

The role of haptic feedback in learning basic skills in surgery is a subject of increasing importance but remains relatively underexplored, particularly in the context of VR simulators. Existing studies have illuminated various facets of haptic feedback's potential advantages and limitations. However, there is a pressing need for methodologically rigorous research that evaluates its impact on skill acquisition, transfer, and retention in real-world surgical settings. Our study contributes to this discussion by investigating the role of haptic feedback during VR training for a "Ring Transfer" task. This task serves as a fundamental proxy for complex surgical skills. We have constructed a closely matched physical prototype to serve as a benchmark for real-world skill transfer. Participants were divided into groups receiving either haptic or non-haptic feedback alongside a control group with no VR training.

Through multiple test sessions (pre-test, post-test, retention test), we observed that both VR-training groups, irrespective of haptic feedback, demonstrated significant improvement in real-world task performance in terms of task completion time compared to the control group. However, haptic feedback's anticipated distinct advantage in enhancing skills transfer to real-world tasks compared to

non-haptic VR training was not significantly evident. This finding suggests that while VR training is beneficial, the specific role of haptic feedback in skill transfer and retention in real-world scenarios is not as clear-cut as hypothesized, highlighting the complexity of skill acquisition and the multifaceted nature of learning in immersive environments. This suggests further exploration with more complex tasks and extended training duration. Future research should enhance haptic interfaces and incorporate diverse, intricate surgical tasks. These findings lead to other questions about the nuances of haptic feedback in VR training and its real-world applicability, underlining the need for more in-depth research to unravel these complexities.

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