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Force vs. Illusion: Realism, Cost, and Satisfaction

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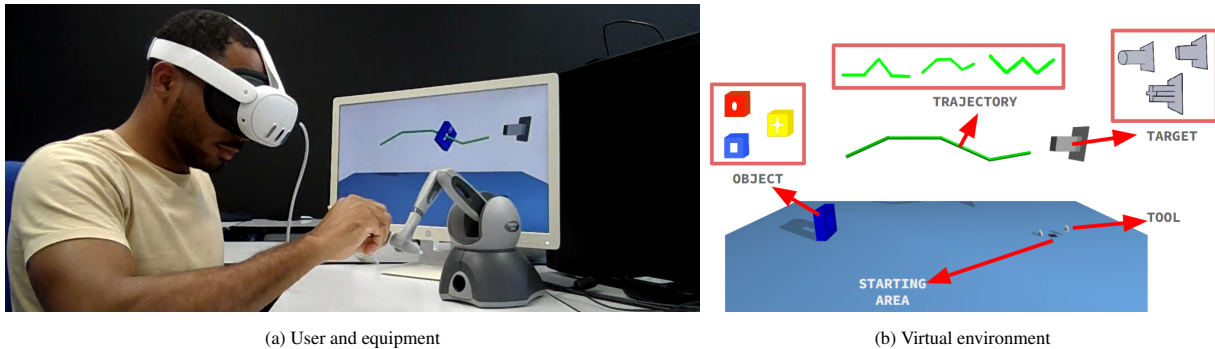


Figure 1: Experimental setup (a) user interacting and visualizing the virtual environment through the haptic device and head-mounted device (b) virtual tool representation, 3D objects, target trajectories, and target placement position and shapes.

ABSTRACT

This research investigates the realism of virtual touch through haptic devices, comparing high-fidelity haptic feedback (force-based) with pseudo-haptics (visual illusions of touch) in the context of training. This preliminary study involves the design and development of a virtual reality (VR) prototype, and an experimental evaluation in which participants performed an object manipulation task under two conditions (force feedback and visuo-haptics feedback) to assess weight estimation and self-performance. Results show that haptic feedback enhances realism and presence in VR, but pseudo-haptic feedback offers a cost-effective alternative for less precision-critical tasks, with potential for refinement.

Index Terms: Virtual Reality, User Experience, Haptic Fidelity, Pseudo-Haptics

1 INTRODUCTION AND BACKGROUND

Highly developed motor skills (i.e., the abilities to control and coordinate movements effectively and efficiently) are essential in various professional and daily activities because they allow individuals to perform tasks that require precise interaction between their muscular system (applied forces) and their sensory perceptions (inputs from the environment). In particular, in the medical domain, surgeons require to master fine motor skills in order to make precise incisions, suture and manipulate instruments and small objects. To face safety and ethical issues, the training of these skills is progressively done through virtual reality (VR) simulators. Force feedback, which simulates physical sensations like weight or stiffness, combined with VR has proven effective in enhancing performance in these tasks [1]. However, the complexity and cost of technologies required for high-fidelity force feedback present limitations [4], such as limited working space, degrees of force feedback (DoFF), and realistic real-time force rendering models.

To address some of these challenges, haptic illusions through different effects might serve as a cost-effective alternative. By exploiting multi sensory cues, these techniques can simulate sensations such as weight or stiffness without the need for complex mechanical systems [2, 6]. For instance, targeted vibrations or visual effects can convince a user that an object is stiffer or heavier than it actually is [3, 8]. These solutions, though less physically accurate than force feedback technology, raise some key questions: (1) in which context or for which tasks could these low-fidelity techniques ensure performance equivalent to that of traditional force feedback devices? (2) could users accept these illusions to achieve comparable performance outcomes and satisfaction for training purposes? Some studies suggest that, in certain contexts, lower-fidelity approaches can match or even surpass classical methods, particularly through enhanced sensory cues [5, 7].

Through the present user study our goal is to contribute to the existent body of knowledge by examining the advantages and limitations of force feedback and visual pseudo haptic illusions in a precise tool-based manipulation task in VR.

2 METHODS

This user study aims to answer (RQ): *how do users perceive haptic illusions compared to force feedback during motor tasks?* We defined two experimental conditions to investigate this RQ: haptic force feedback (**HF**) and pseudo-haptics feedback (**PH**).

2.1 Participants

Twenty four ($N = 24$) participants (18 men, 6 women) enrolled in the study. The average age was 27 years ($SD = 8.45$), they had all used a VR headset before (e.g., for gaming or during demonstrations at exhibitions) but none had previously used a desktop haptic device. All participants provided written informed consent before enrollment and no gratification was given for their participation.

2.2 Experimental Procedure

A within-subjects design was used, where all participants performed two sessions in the VR simulator (one for each feedback condition: HF and PH). The presentation order of the conditions was counterbalanced to avoid learning effects. Before the experiment, participants were asked to read and sign a consent form and to complete a demographics questionnaire. Then, the experimental instructions were presented (prototype description, devices use

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explanation, and experimental task instructions). They performed a familiarization task before each condition to feel comfortable with the manipulation of the tool and the understanding of the task goal.

The experimental task's goal was for participants to place an object on a target as quickly and accurate while minimizing collision and dropping errors (Fig. 1a). The steps were: (1) Place virtual tool on the designated starting area; (2) pick up the object with it; (3) move the object along the pipes trajectory (trajectories changed between trials); (4) insert the object in the target area; (5) return to the starting area. This procedure was repeated twice for each object (3 virtual objects with different weights were chosen) (Fig. 1b).

Concerning the design and development of the prototype, displacement ratios technique was used for the PH condition and force feedback was provided through the Geomagic Touch haptic device for the HF condition. Development was done on C++ with CHAI3D framework, and displayed in a Meta Quest 3 device.

3 RESULTS

Participants subjective feedback was gathered for each condition concerning their perceived workload (NASA TLX), their feeling of presence (Fig. 2) and performance perception (Fig. 3).

Although the HF condition showed a slightly higher mean score (PH: $\mu = 6.56$, $\sigma = 1.09$; HF: $\mu = 6.65$, $\sigma = 1.40$) indicating an increased perceived workload, a t-test revealed no statistically significant difference between the two conditions ($t = -0.37$; $p = 0.72$).

The Presence Questionnaire, proposed by Witmer and Singer, measures the feeling of presence in virtual environments across several dimensions. In this study, a subset of the questionnaire was used, focusing on subscales for realism, action possibility, interface quality, examination possibility, self-performance evaluation, and haptics. Wilcoxon tests revealed significant differences only for two categories between conditions: Realism ($p < 0.05$): HF scored higher ($\mu = 4.49$, $\sigma = 1.31$) compared to PH ($\mu = 3.99$, $\sigma = 1.27$). Action Possibility ($p < 0.01$): HF also scored higher ($\mu = 5.05$, $\sigma = 1.16$) compared to PH ($\mu = 4.37$, $\sigma = 1.34$).

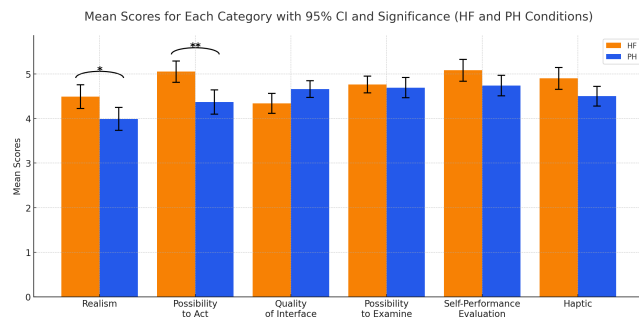


Figure 2: Presence questionnaire (7-point Likert scale) mean results for each questionnaire category for each condition.

Participants were invited to compare the conditions regarding perceived competence, time optimization, and error awareness: 72% felt HF made them more competent; 56% judged HF as faster for task completion; 72% reported HF improved error awareness.

4 DISCUSSION AND CONCLUSIONS

This study provides preliminary insights into the perception of haptic illusions in virtual reality, comparing high-fidelity haptic feedback (HF) and pseudo-haptic feedback (PH) in a tool-based manipulation task. While both conditions enabled participants to complete the task effectively, HF demonstrated higher scores in realism and action possibilities. This suggests that force feedback contributes significantly to the sense of presence and perceived competence in tasks requiring fine motor skills. However, the lack of sig-

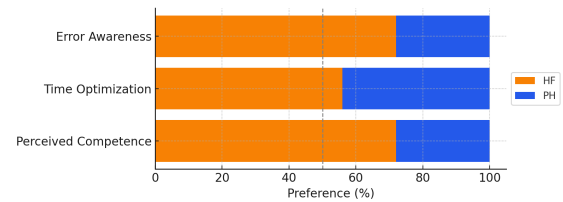


Figure 3: Participants answers to error awareness, time optimization and self-perceived performance for each condition.

nificant differences in workload (NASA TLX) and other presence dimensions highlights the potential of pseudo-haptics as a viable, cost-effective alternative for certain applications and tasks where precision and realism are less critical, which aligns with previous works conclusions [5, 7].

A key limitation of this study is the absence of objective performance metrics, such as error rates and task completion times. These metrics should be incorporated into future studies to provide a more comprehensive evaluation of the effectiveness of haptic modalities. This includes investigating the contexts in which PH can fully substitute HF and identifying the thresholds of fidelity necessary for effective training in VR. Moreover, enhancing pseudo-haptic techniques to close the gap with traditional haptic feedback could expand its applicability to broader use cases, offering cost-effective and scalable solutions for VR training.

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