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Are we ready for Haptic Interactivity in VR? An Experimental Comparison of Different Interaction Methods in Virtual Reality Training

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***Abstract*—In recent years, Virtual Reality (VR) has gained attention as a tool for a plethora of applications such as first-aid, firefighting and in the automotive industry. End-user immersion is a key factor in these applications to make the experience representative for its real-life counterpart. By enhancing the traditional audiovisual cues with additional sensory inputs in terms of haptic vibro-tactile and kinesthetic feedback, this immersion can be improved. But are current haptic implementations sufficient to provide the required added value? And how do they compare to other types of VR interaction? In this paper, we present a multimodal VR training framework able to provide subjective and objective comparisons among three different interaction options: (i) haptic gloves, (ii) traditional VR controllers, and (iii) non-haptic handtracking. We performed a user test where the different interactivity flavours were compared in terms of their influence on both subjective perception and objective performance of the end-user by means of three VR training scenarios. The subjective results show an aversion towards non-haptic handtracking for constrained, cognitively light tasks while a preference towards controllers exist for more cognitively heavy multi-tasking. This is however not reflected in objective results, where differences between interaction methods are far less pronounced.**

***Index Terms*—Haptic Feedback, Virtual Reality (VR), User Perception, User Performance, VR Training**

I. Introduction

VR is an important aspect of future of human-computer and even human-human interaction. As a result, it is gaining attention in multiple fields of society such as gaming and entertainment (*e.g.*, *Playstation VR*, *Netflix VR*), Industry [1], [2], mental healthcare [3]–[5] and VR training [6]–[9].

VR training is typically applied in sectors where real-life hands-on training is either too dangerous, too expensive, too time-consuming or too difficult. VR training sessions are typically conducted by providing the trainee with an Head-Mounted Display (HMD) and a pair of headphones (if not integrated) to block out any visual and auditory stimulus from the real world. In the virtual environment, a predetermined set of tasks are to be performed to acquire certain skills, similar to real-world training. In fact, VR training has shown to have the potential to result in the same level of post-session performance as a traditional training setting [7]. However, multiple parameters (*e.g.*, remote vs. local learning, rendering quality [10]...) and their influence on the effectiveness of VR training still remain largely unexplored [11]. One fundamental factor is the influence of the type of interaction method on the user's performance and perception [12].

Currently, interactions with the VR system are either very specifically tailored towards the application at hand (*e.g.*, medical, pilot training, Formula 1...) or relying on the traditional VR controllers for easy plug-and-play in more generic or low-leveled applications. Recently released immersive systems also include handtracking, in which a virtual twin of the real-life hands is created in the virtual environment, into their HMDs (*e.g.*, the *Meta Quest 2*). An interesting alternative is the use of general-purpose haptic gloves, which can provide fine-grained, per-finger vibro-tactile and kinesthetic feedback. However, these are rarely used for VR training applications. As such, the influence on end-user perception and performance of the more accessible, "plug-and-play" interaction methods for VR training fall in a somewhat under-explored part of literature, especially when it comes to comparing them to one another. Furthermore, vibro-tactile and kinesthetic feedback methods are still rarely explored in literature.

The purpose of this work is therefore to explore the influence of different immersive interaction methods (*i.e.*, controllers, handtracking, vibro-tactile and kinesthetic haptic feedback) on both the subjective perception (questionnaires) and objective performance (accuracy) of users. To this end, a testbed including vibro-tactile and kinesthetic feedback, next to traditional controllers and non-haptic handtracking, was created. Furthermore, three different VR scenarios were selected, and a user study was performed. Results show that a subjective aversion towards handtracking exists for constrained tasks such as throwing and stacking, while a preference towards controllers is observed for more cognitively heavy multi-tasking. However, this is not reflected in the objective measurements, where the differences between the interaction alternatives are less pronounced.

The remainder of this paper is organized as follows. Section II gives a brief overview of the current state of the art related to the (comparison of) different interaction methods in VR training. Section III describes the experimental method including the technical setup, the game characteristics and the evaluation methodology. In Section IV, the most prominent

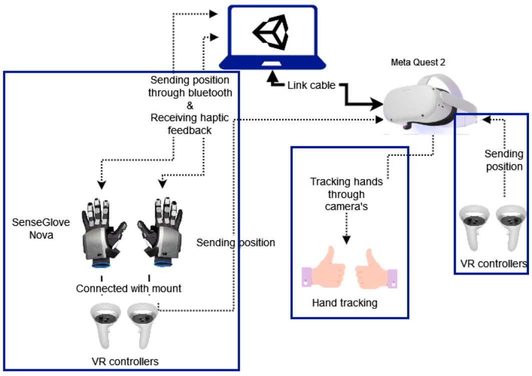


Fig. 1: Schematic overview of the setup created for this study.

findings of this work are presented. Section V, at last, summarizes this work by listing the most important conclusions.

II. Related work

Only a limited number of studies that compare different interaction methods for immersive multimedia include haptic gloves into their studies, especially when limited to VR training scenarios. In this Section, we provide a brief overview of the ones we assess to be the most prominent in the field.

Kreimeier et al. [12] made a comparison between visual, vibro-tactile and kinesthetic haptic feedback in terms of their influence on presence and performance regarding manual tasks in VR (*i.e.*, ball throwing, cube stacking and object identification). Their results showed that vibro-tactile feedback outperforms both the kinesthetic and visual feedback regarding subjective perception of presence while kinesthetic feedback significantly lowered the time for throwing and stacking.

Funk et al. [13] explored the differences between visual, auditory and tactile feedback at a manual assembly workplace. Their results show that auditory feedback is perceived as most distracting, while combined visual and tactile cues show the highest potential for improving error notification speed.

Pezent et al. [14] explored whether haptic feedback on the wrist for interacting with virtual objects improved non-haptic hand-based interactions. Based on their findings, wrist-based haptics do substantially improve virtual hand-based interactions in AR/VR compared to no haptic feedback.

The *Ministry of Defence Simulation Centre of The Netherlands* presented a case-study and prototype on multiplayer VR training with inclusion of haptic vibro-tactile and kinesthetic feedback from the *Senseglove Nova* [15], and compared it to an implementation with traditional VR controllers. The first preliminary results suggest that the addition of haptic feedback into a VR training scenario helps to develop muscle memory, contrary to standard controller interaction.

Kangas et al. [16] investigated the difference between three different interaction methods (mouse + 2D screen, VR + controller, VR + haptic pen) in terms of user performance and experience for a 3D manipulation task. To this end, six medical experts were recruited. No significant differences in terms of both subjective experience and objective task duration and accuracy were found. Free feedback did reveal satisfaction with haptic feedback and kinesthetic feedback in particular.

Greinacher et al. [17] compared the influence of visual, verbal, and haptic feedback in an indoor rowing use case in order for athletes to maintain a correct, efficient, and healthy breathing-movement synchronicity (BMS). In addition, user experience and acceptance are measured. The results show a positively significant impact of both purely verbal and purely haptic feedback on BMS, while no significant impact of visuals is observed. Subjective ratings show a strong preference towards visual feedback and even an aversion towards haptics, while the opposite is true in terms of objective performance.

Vermeulen et al. [18] compared three different interaction methods for two Augmented Reality (AR) tasks (stacking cubes and typing) in the *Microsoft HoloLens*: the predefined *Air Tap*, handtracking and haptic feedback. Results showed that handtracking and haptics were clearly outperforming the Air Tap both subjectively and objectively. Furthermore, they observed a slight subjective preference for handtracking for the cube assignment, while a clear preference towards haptics exist in the typing task. Objectively speaking, haptic feedback showed the best results for both tasks.

Van Damme et al. [19], at last, compare the presence and absence of vibrational feedback in a projected AR setup. To this end, participants were asked to complete three different tasks based on fingertracking. In addition, visual latency was introduced. Their results show that, while haptic feedback does not enhance the performance for simple tasks, it substantially improves it for more complex ones. Furthermore, this effect shows to be enhanced with increasing latency. Subjectively speaking, however, participants showed a general skepticism towards the potential of haptic feedback.

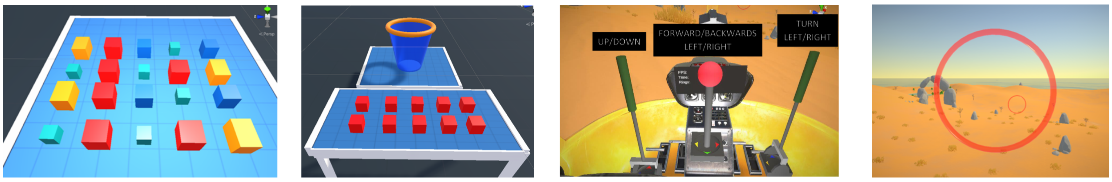
As can be seen from this literature overview, most of the literature is mainly focusing on vibrational/vibro-tactile feedback rather than kinesthetic feedback (or the combination of both). In addition, studies towards the interaction methods currently included in most VR systems, *i.e.*, controllers and handtracking, compared to possible alternatives are almost non-existent. As such, we believe this work provides a valuable addition towards the understanding of interaction methods in VR training scenarios.

III. Experimental methodology

This Section presents the followed methodology for evaluating the influence of different interaction methods on VR training. First, Section III-A provides a description of the technical setup. Next, Section III-B introduces the three tasks to be performed by the test subjects. This is followed by a description of the procedure for the subjective and objective user study in Section III-C.

A. Technical setup

Figure 1 shows the setup created for this study. The core consists of a gaming laptop running a game engine. Through a high-throughput cable, this laptop is connected to an immersive HMD. Three different methods are put forward to interact



(a) Cube Stacking (b) Cube Throwing (c) Helicopter (d) The rings in Helicopter

Fig. 2: Visualization of each of the three test scenarios.

with the virtual environment: (i) the traditional VR controllers (vibrational feedback), (ii) handtracking (no feedback) and (iii) haptics (vibro-tactile and kinesthetic feedback). Handtracking is provided through the cameras in the front of the HMD, while wireless position polling is used for the VR controllers. The latter can be mounted on top of the haptic gloves, which send their hand movement data to and receive haptic feedback from the laptop over a Bluetooth connection.

In terms of hardware, we chose the *Dell G Series G5 15 5500* gaming laptop including a *NVIDIA® GeForce® RTX 2060, 6GB GDDR6* for optimal VR performance. As such the minimal framerate of 90 fps for avoiding cybersickness [20] can be maintained. Unity is used as an engine together with the *Meta Integration* and *VR Interaction Framework* packages to allow for a wide range of VR interactions in terms of grabbing and hand positioning and practical implementations for interaction with levers, doors, sliders etc. The laptop is connected to the *Meta Quest 2* HMD through a *Meta Link Cable* to allow for sufficient throughput and to be able to use the better performing computing power of the laptop rather than the integrated CPU and GPU of the HMD. We further make use of the *Senseglove Nova*, as it is currently the only pair of haptic gloves on the market that includes both vibro-tactile and kinesthetic feedback at a semi-reasonable price.

B. Test scenarios

In order to compare the three interaction methods, three VR training scenarios were implemented: *Cube Stacking*, *Cube Throwing* and *Helicopter* (Figure 2). These scenarios were selected to have a broad representation of interactions both in terms of granularity (fine-grained stacking, coarse-grained throwing, and multi-task helicopter) and of cognitive load: one action without time constraints (Cube Throwing), one action with time constraints (Cube Stacking), and an interplay of actions with time constraints (Helicopter).

In *Cube Stacking*, the trainee is presented with a set of 20 cubes differing in size and shape. Their goal is to stack as many cubes as possible within 1 minute. The score is determined by the maximal number of stacked cubes reached during the playthrough of the task.

In *Cube Throwing*, the trainee is given access to 10 cubes, identical in both shape and size. Here, they have to throw as many cubes as possible into a bin from a fixed distance of two meters. There is no constraint in terms of timing, such that the user can pay full attention to accuracy.

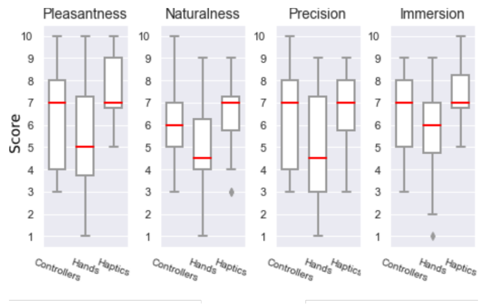
Finally, in *Helicopter*, the trainee follows a helicopter pilot training. Thus, they are asked to steer a helicopter through a predetermined path (marked by a set of 11 red circles, Figure 2d) as accurate as possible. Accuracy is measured as the number of rings correctly flown through. These rings are chosen to have clear differences in height and to follow a curved path towards the destination, such that the user is forced to move the helicopter in all three dimensions and to include rotation while doing so. To this end, the trainee has to combine multiple handles (Figure 2c) to move the helicopter up/down (left handle), move it forward/backward and left/right (middle handle) and to rotate it around the vertical axis (right handle). As such, this task requires the trainee to multi-task and to make a trade-off between speed and accuracy. The control pattern was purposely adapted from the standard control mechanism of a helicopter (which partly uses pedals) to make it suitable for hand-based interaction only.

C. Test procedure and evaluation methodology

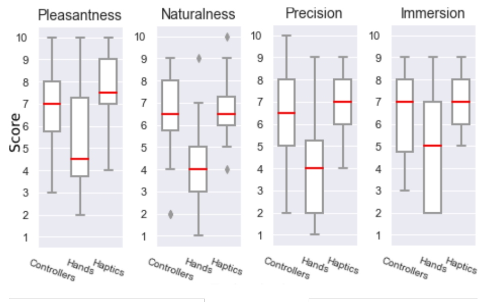
The test procedure consists of three consecutive phases. At the beginning of each phase, one of the three interaction methods (Controllers, Handtracking and Haptics) is randomly selected. Next, the participant plays the three games (*Cube Stacking*, *Cube Throwing* and *Helicopter*) using the selected interaction method. Each game consists of a one minute test-run and an experimental part. In the test-run, the user can get familiar with both the game and the interaction method and no data is recorded. Afterwards, the experimental phase is conducted. These phases are limited to 1 minute (Cube Stacking), 10 cubes (Cube Throwing) and 4 minutes (Helicopter).

During a session, the trainee is evaluated both subjectively and objectively. In subjective terms, a pre-session questionnaire is provided in which users are polled about gender, age and prior experience concerning usage of games, VR and haptics. After each game playthrough, the user is asked to fill in a questionnaire dealing with pleasantness, naturalness, precision, and immersion of the interaction method. After the experiment, users are requested to order the three technologies (Controllers, Handtracking and Haptics) in terms of ease-of-use for each of the three games. All questions, except for the ordering, were asked on a 1-to-10 Likert scale [21].

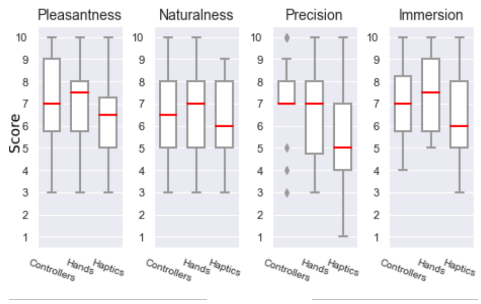
Trainees are also objectively evaluated by monitoring their performance for each of the tasks. For Cube Stacking, this consists of the maximal height of the tower (number of cubes) during the 1 minute playthrough of the game. In Cube Throwing, this is the number of cubes correctly thrown into the bin. For Helicopter, the number of rings correctly flown through is counted.



(a) Cube Stacking



(b) Cube Throwing



(c) Helicopter

Fig. 3: Subjective perception in terms of Pleasantness, Naturalness, Precision and Immersion for each of the three scenarios and per feedback.

IV. Results

This Section presents the results of the study. First, Section IV-A briefly describes the participants taking part in this study. Next, Section IV-B discusses the subjective perception analysis. Furthermore, Section IV-C describes the objective performance results.

A. Participants: description and demographics

16 participants were gathered for user testing. 12 of them identified as male and 4 as female. Their ages were between 20 and 60, with an average of 33.8. 9 of them were between 20 and 30, 3 between 30 and 40, 1 between 40 and 50, and 3 between 50 and 60. Prior to the experiment, participants were instructed both written and orally about the methodology and goal of the experiment. They were also informed that they could still ask for further explanation during the experiment if anything remained unclear. In addition, they were warned about the possible side-effects of cybersickness. Furthermore, participants were explicitly asked for consent to process their anonymized data concerning gender, age and answers to the subjective questionnaires according to the GDPR regulations. Within the same light, they were informed that they could withdraw their consent and stop their participation at any time.

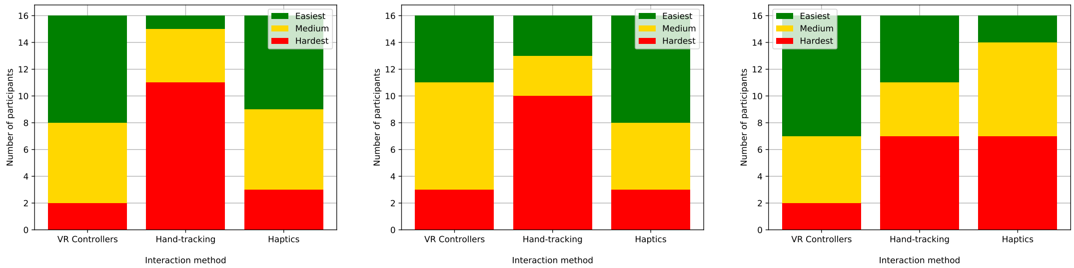
B. Influence on subjective perception

Figure 3 illustrates the results for the subjective evaluation of each *(task, interaction)* - combination in terms of Pleasantness, Naturalness, Precision and Immersion. *Kruskal-Wallis Rank Tests* for ordinal data show significant differences for Immersion in Cube Stacking ($p<0.05$) and for the Pleasantness, Naturalness and Precision of Cube Throwing ($p<0.05$, $p<0.01$ and $p<0.01$, respectively). Post-hoc pairwise *Wilcoxon Signed Rank Tests* with *Bonferroni correction* show a significant difference between the *(Handtracking, Haptics)* pair in the Immersion of Cube Stacking ($p<0.01$) and between both the *(Controller, Handtracking)* and *(Handtracking, Haptics)* pairs in Pleasantness, Naturalness and Precision of Cube Throwing (twice $p<0.05$ for Pleasantness, $p<0.05$ and $p<0.01$ respectively for Naturalness and twice $p<0.01$ for Precision). Overall, this indicates a clear subjective aversion towards handtracking for Cube Throwing. This can be partially explained by the fact that the positioning of this interaction method is camera-based. As such, whenever the hands go out-of-sight for the cameras on the HMD (which is not uncommon while throwing in a natural way), the handtracking is distorted resulting in specific repercussions on the throwing accuracy. This was also orally reported by multiple participants. Moreover, several participants indicated to require some kind of tactile confirmation (either Controllers or Haptics) to confirm grabbing the object, which the Handtracking is unable to do.

For Cube Stacking, we assume that the presence of Handtracking with tactile feedback resembles more closely the real-life analogy than the counterpart without feedback, therefore resulting in a higher perception of Immersion.

For Helicopter, no significant differences between the interaction methods for any of the categories were observed. There can be noticed that there is a much smaller spread in the scores of the Controller regarding Precision compared to Handtracking and Haptics. This could indicate a much larger variation in the participants' level of skill in this interaction methods compared to Controllers. As such, the latter induce more consistent user behaviour in terms of Precision.

Figure 4 shows the results of the post-session questionnaire Users were asked to rank the three interaction methods based on ease-of-use for each particular task. Kruskal-Wallis Rank Tests show significant differences between the interaction methods for each of the tasks ($p<0.001$ for Cube Stacking and $p<0.05$ for the others). Bonferroni-corrected post-hoc pairwise Wilcoxon Signed Rank Tests show significant differences between the *(Controllers, Handtracking)* and *(Haptics, Handtracking)* pairs for both Cube Stacking and Cube Throwing ($p<0.01$ for all). For Helicopter, a significant difference between the *(Controllers, Handtracking)* and *(Controllers, Haptics)* pairs is observed (both $p<0.01$).



(a) Cube Stacking (b) Cube Throwing (c) Helicopter

Fig. 4: Results of the subjective ordering of the interaction methods for each of the tasks.

For Helicopter (Figure 4c), the results imply a preference towards the VR Controllers with 9 out of 16 participants (56.25%) indicating it as their preferred interaction method for operating the helicopter. The Haptics and Handtracking were indicated as first choice by only 2 (12.5%) and 5 (31.25%) out of 16 users, respectively. An equal amount of users (7/16 = 43.75%) selected these methods as the hardest one for this task. On the one hand, based on users' feedback, we assume this to be a result of implementation rather than the intrinsic nature of the Haptics. As the Senseglove Nova are still a proof-of-concept and not yet in mass-production, the possibilities of the API in combination with Unity are still limited. This resulted in some mild issues related to the specific case of interacting with levers, therefore affecting precision. This is not the case for the Controllers and the Handtracking. On the other hand, some users mentioned that the use of VR Controllers allowed for faster switching between levers than the hand-based methods in order to steer the helicopter through the rings in a timely manner.

These results once again reveal a clear aversion towards Handtracking for both Cube Stacking and Cube Throwing, with 11 (68.75%) and 10 (62.5%) out of 16 people indicating it as the hardest interaction method, respectively. Only 1 (6,25%) and 3 (18.75%) out of 16 people indicated it to be the easiest interaction method for this particular tasks, respectively. The lower appreciation for Handtracking can once again be explained by limitations of the implementation at the one hand the need for tactile confirmation on the other.

From the above discussion, it looks like the perception of users towards different interaction methods is heavily entangled with the task under scrutiny. Single, constrained tasks such as Cube Stacking and Cube Throwing induce a preference towards tactile feedback in the form of either Haptics or Controllers rather than Handtracking. Furthermore, the manner in which the interaction with the virtual world is implemented as well as the required speed of interaction play a crucial role in the users' preferences, which results in a subjective tendency towards the Controllers for Helicopter. The level to which this is an intrinsic characteristic of the particular task rather than a result of glove-based haptic feedback implementations being still in their infancy, is a question still open for further research. Furthermore, it is important to indicate that Handtracking never showed to be the preferred method. This shows the potential of tactile feedback, in the form of either the vibro-tactile and kinesthetic feedback from the Haptics or the vibrational feedback from the Controllers, to improve end-user perception in VR tasks.

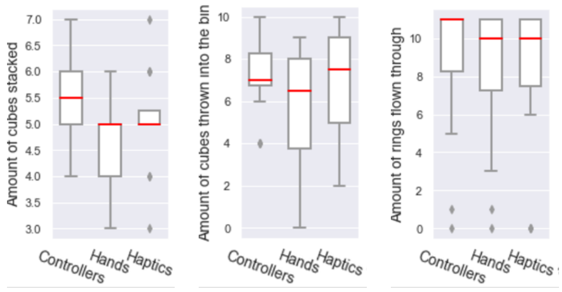
C. *Influence on objective performance*

Figure 5 shows the objective results in terms of the number of cubes stacked, the number of cubes thrown into the bin and the number of rings flown through. A *one-way analysis of variance (ANOVA)* was performed between the three interaction methods for each task. This resulted in statistically significant differences for Cube Stacking and Cube Throwing (both $p<0.05$). A *pairwise post-hoc Tukey Test* only shows a significant difference for the *(Controllers, Handtracking)* pair of Cube Stacking ($p<0.05$). As such, it is remarkable that the clear subjective aversion towards Handtracking for Cube Stacking and Cube Throwing and the preference towards Controllers for Helicopter (as discussed in Section IV-B) are not reflected in the objective results. Therefore, these are indicating a discrepancy between perception and performance. For Cube Throwing, we do notice a much smaller spread of the performance distribution of the Controllers compared to both the Handtracking and the Haptics (standard deviations of 1.94, 2.80 and 2.43 respectively). This could indicate that only part of the users learned to overcome eventual drawbacks of the Handtracking and Haptics while others could not find their way around it. The Controllers, in comparison, lead to more consistent and more predictable end-user behaviour.

From this objective analysis, we can conclude that while participants are showing clear preferences towards interaction methods in subjective manners, these are not reflected in objective performance. Nevertheless, it could be argued that a Controller-based interaction is preferred for throwing if consistent and predictable user behaviour is required. Moreover, additional experimentation increasing the variety of tasks is needed to draw more specific conclusions.

V. Conclusion

This paper has presented a comparative study of different interaction methods for VR training. Therefore, we created a testbed that includes both vibro-tactile and kinesthetic feedback, and presented three different VR scenarios. These were used to perform a user study that compares the influence



(a) Cube Stacking (b) Cube Throwing (c) Helicopter

Fig. 5: Objective performance for each of the three scenarios and per feedback type.

of three different interaction methods on the user perception and performance in a VR environment. These include Haptic vibro-tactile and kinesthetic feedback, traditional VR Controllers and Handtracking. By means of three different VR tasks (Cube Stacking, Cube Throwing and Helicopter), users were evaluated both objectively (accuracy) and subjectively (questionnaires). The subjective results show an aversion towards the handtracking method for constrained and cognitively light tasks. With cognitively heavy multi-tasking, a preference towards Controllers is observed. This is, however, not reflected in objective performance metrics, where differences between interaction methods are far less pronounced.

From our results it turns out that the acceptance of haptic interaction was lower than originally expected. Although current implementations of haptic gloves are already providing satisfactory results, further innovations in haptic feedback technology could have an impact on the observations made in this work. As such, timely repetition of user studies is advisable to keep up with the technological advancements in the field. In addition, further research towards identifying the root causes of disparity between subjective perception and objective performance would be an interesting addition to the current state-of-the-art.

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