Feel to Aim: Haptic Assistance for Enhanced Targeting in Virtual Reality

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Figure 1: User with VR equipment engaging in a simulated archery experience, shown as a physical-virtual composite.

ABSTRACT

Haptic technology has the potential to substantially support users in mastering complex activities and improving their performance. This paper presents a haptic assistance system for targeting in virtual reality (VR), designed to enhance accuracy and user confidence during aiming tasks by enabling users to sense proximity to and guiding their motion toward a target. To evaluate its effectiveness, we conducted a user study ($N = 28$) using a custom VR archery simulation, assessing both quantitative performance metrics and qualitative user feedback. With haptic guidance, participants achieved significantly higher targeting accuracy and reported increased spatial awareness, although some also noted a reduced sense of agency. These results suggest that, while haptic assistance offers clear benefits, careful design is essential to avoid overreliance or interference with user autonomy in contexts such as accessibility, gaming, and broader human-computer interaction.

CCS CONCEPTS

• **Human-centered computing** → *Human computer interaction (HCI)*; **Haptic devices**; **User studies**; • **Computing methodologies** → **Virtual reality**.

KEYWORDS

Virtual Reality, Haptic Feedback, Aiming, Assistance, Accessibility

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1 INTRODUCTION

Haptic technology holds notable promise in virtual reality (VR) applications and beyond. By introducing tactile feedback, it can enhance user immersion and interaction by providing a sense of touch, but also offer supplementary, pertinent information without disrupting the visual and auditory sensory channels. As a core part of the human sensory system, haptic feedback constitutes an important channel capable of delivering rich cues without significant cognitive interference with other senses [Ernst and Bülthoff 2004; Prewett et al. 2006]. This is particularly attractive for scenarios requiring spatial awareness, fine motor control, or rapid corrective action. Prior research has shown that in VR settings, where sensory grounding is often limited, well-designed haptic interfaces

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can enhance task performance, user engagement, and spatial understanding [Botev et al. 2024; Frisoli and Leonardis 2024; Wang et al. 2024]. However, the design of effective haptic guidance is non-trivial since overly intrusive cues can diminish the user's sense of agency or cause overreliance on assistive feedback [Schneider et al. 2017].

Targeting tasks, such as pointing, aiming, or aligning toward a distant object, are particularly relevant for evaluating haptic support since they require both spatial judgment and precise motor control. In this paper, we examine such targeting in a VR context, using an archery simulation as an example, which requires continuous depth estimation, direction correction, and stable control. Our proposed system provides dynamic haptic guidance by conveying proximity and direction to a target, aiming to improve accuracy and user confidence without compromising autonomy.

The implementation draws inspiration from related efforts in adaptive feedback for accessible sports, particularly para-biathlon, where blind or visually impaired athletes rely on sonification to align with a target via pitch- or volume-based auditory cues translating spatial information into sound to support alignment and shooting [Kuriakose et al. 2022]. While sonification has proven successful in real-world training and competition settings, its effectiveness can vary depending on auditory load and environmental noise. Haptic feedback offers a promising alternative or complement in such contexts, providing non-intrusive spatial cues that are immune to auditory interference. In broader human-computer interaction contexts, such as entertainment and gaming, haptic support may even constitute the only viable way to provide this kind of information without interfering with the experience or other important audio-visual elements.

Informed by these principles, we present a haptic assistance system for targeting in VR. The system delivers tactile cues that dynamically guide users toward a virtual target, allowing them to "feel" directional alignment and accuracy. To evaluate its effectiveness, we conducted a user study ($N = 28$) using a custom VR archery simulation. Our evaluation includes both quantitative performance metrics (e.g., achieved scores, shot accuracy, target time) and qualitative feedback on user experience, perceived spatial awareness, and control.

Results show that participants using haptic assistance exhibited improved targeting accuracy by 13.5% and reported increased confidence in their aim. However, several participants noted a diminished sense of control, reinforcing concerns about balancing guidance with autonomy. These findings suggest that haptic assistance can enhance performance and awareness in targeting tasks, with implications for a range of domains, including VR sports training, accessible interactive systems, and rehabilitation. In particular, our results echo challenges observed in para-sport feedback systems, underscoring the need for careful calibration of assistive cues to support, rather than override, the user's sense of agency.

Before outlining the details of our system setup and study methodology in Section 3, we first provide relevant background and review related work in Section 2. The results of our user study are presented and discussed in Sections 4 and 5, respectively. We conclude with a summary of our findings and an outlook on the future development and application areas of haptic assistance in Section 6.

2 BACKGROUND AND RELATED WORK

Haptic feedback has gained increasing attention as a means of enhancing interaction, immersion, and performance in virtual environments. Both assistive and immersive technologies have explored non-visual feedback mechanisms to support users in carrying out tasks that require spatial awareness, precision, or real-time decision-making. This section reviews prior work relevant to our study, beginning with broader efforts in accessible interaction and feedback in sports and VR, followed by a focus on sonification approaches in targeting tasks which inspired this work, and concluding with research on haptic guidance for pointing and aiming.

2.1 Assistive Feedback in Sport and VR

VR has emerged as a valuable platform for physical training and rehabilitation. It provides an immersive and controlled environment in which real-world scenarios can be simulated. In sports contexts, feedback delivered via haptics, audio, or visual cues, has been shown to support motor skill learning and improve performance, physiological, and psychological outcomes [Geisen and Klatt 2024; Neumann et al. 2018; Ren et al. 2025]. For individuals with disabilities, VR enables accessible interaction and skill development by supplementing or substituting impaired modalities. This is particularly relevant in adaptive sports such as para-biathlon, where athletes rely on non-visual cues for precision tasks such as targeting. Incorporating such feedback in VR settings allows researchers to safely and repeatedly prototype and evaluate new feedback strategies. Previous work has explored multisensory feedback in VR for rehabilitation and training [Jung et al. 2020], specifically emphasizing the potential of wearable devices to enhance spatial awareness, engagement, and agency [Schneider et al. 2017].

2.2 Sonification and Non-Visual Targeting

Sonification, i.e., mapping task-relevant variables to sound, has been widely used to support non-visual interaction in both real-world and virtual contexts. In sports, for example, it is often employed to assist blind or visually impaired athletes in performing precision tasks such as aiming or navigation [Kuriakose et al. 2022; van Rheden et al. 2020]. A prominent and notable example of this in practice is para-biathlon,[1] in which acoustic feedback (e.g., pitch modulation) helps athletes to align their aim with a target. To this end, athletes use special optical, camera-based rifles developed by the Finnish company Ecoaims.[2] These rifles translate target alignment into changing pitch and tone to enable auditory targeting. Similar assistive sonification systems have also been adopted in disciplines such as shooting, where standard equipment is fitted with dedicated aiming devices.[3]

Beyond sports, sonification is generally designed for and often used in the context of virtual navigation, spatial orientation, and object selection particularly in accessibility research and VR environments [Mendes et al. 2025; Walker and Kramer 2005]. Such systems enable users to interact with digital spaces when vision is limited or overloaded by providing real-time auditory cues about location,

[1] https://www.biathlonworld.com/inside-ibu/para-biathlon
[2] https://www.ecoaims.com/products/category/para-sport/blind-shooting-systems/
[3] https://www.britishblindsport.org.uk/az/shooting

proximity, or direction. A functional classification of core sonification methods specific to targeting has been proposed in [Apavou et al. 2024]. These include single-dimensional approaches, such as pitch-only sonification, and multidimensional schemes combining tempo and pitch, tempo and binary pitch cues, as well as more complex acoustic features, such as chroma, beats and roughness.

While sonification has proven effective across a range of applications, it can compete with other auditory stimuli or impose cognitive load, particularly in complex or immersive environments. These limitations motivate the exploration of alternative or complementary feedback modalities, such as haptic guidance, which can deliver directional or proximity information without overloading the auditory system.

2.3 Haptic Guidance for Pointing and Aiming

Haptic guidance has been investigated as a means of enhancing performance in precision-based activities, such as pointing, aiming, or reaching. Unlike sonification, which is often continuous and ambient, haptic feedback can also be delivered more discreetly and in a spatially localized manner by mapping vibrotactile or force-based actuators. Previous studies have shown the effectiveness of haptic cues in improving target acquisition time and accuracy in both 2D and 3D contexts [Lee et al. 2016; Lindeman et al. 2005].

In immersive VR, wearable haptic systems, such as vibrating vests, belts, sleeves, and gloves, have been employed to guide users toward spatial targets or provide directional assistance [Azmandian et al. 2016; Botev et al. 2024]. These systems are particularly useful in scenarios where visual guidance is constrained [Monica and Aleotti 2023] or where it is critical to preserve users' visual attention [Louison et al. 2018]. To enhance interpretability and reduce cognitive load, spatial separation of feedback channels (e.g., by assigning different types of feedback to distinct body parts like the wrists or ankles) has been proposed [van Erp 2005].

Despite these advancements, haptic guidance or assistance for fine-motor tasks such as precise pointing or subtle adjustments remains relatively underexplored compared to auditory approaches (see Section 2.2). Moreover, designing wearable haptic systems that provide effective guidance while preserving a user's sense of autonomy continues to pose a significant challenge.

3 MATERIALS AND METHODS

This section provides an overview of the hardware and software components of the system, as well as the experimental design. It outlines the VR equipment, the virtual environment, and how haptic feedback is implemented, followed by describing the different conditions used to evaluate its effectiveness.

3.1 Equipment

The VR setup used in this study consisted of a Meta Quest 2 HMD plus Elite Strap with Battery and standard controllers, chosen for their availability, balanced weight distribution, and user-friendly operation. To deliver haptic feedback to the users' extremities, we employed commercially available bHaptics Tactosy wearables. The Tactosy for Arms sleeves, worn on the wrists and forearms, each contain six vibrotactile motors, while the Tactosy for Feet devices, worn over the ankles, incorporate three motors positioned on the top of each foot. These actuators are eccentric rotating mass (ERM) vibration motors, capable of being precisely controlled to produce targeted tactile sensations. Given the relatively small number of motors per device, spatial differentiation is achieved through the distribution of devices across the body, rather than fine-grained localization within individual wearables.

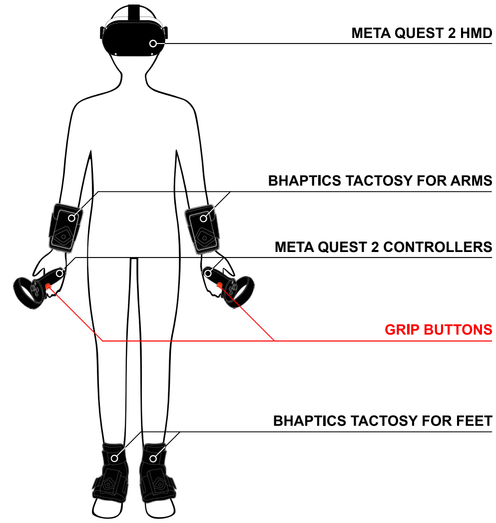

Figure 2: Employed VR hardware and controls.

The HMD and controllers, as well as both wrist-worn tactile sleeves are clearly discernible on the user's arms in Fig. 1, which shows the composite image of the real-world physical space, alongside the corresponding virtual environment. Due to layout constraints, the ankle-worn devices can only be seen as a schematic illustration in the complete setup (see Fig. 2).

3.2 Virtual Environment

The VR experience was developed employing Unity in combination with bHaptics' native SDK plugin to integrate and precisely control the haptic feedback delivered through the Tactosy devices.

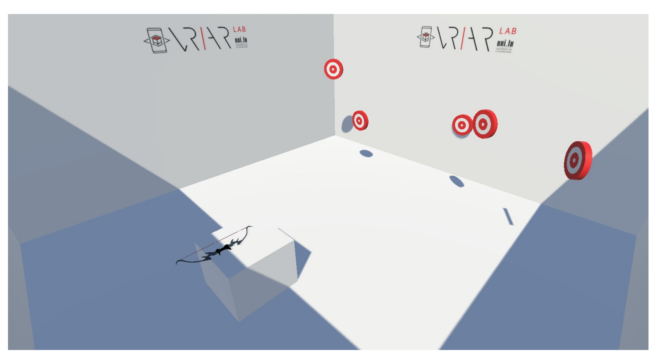

Figure 3: Virtual environment for the archery simulation.

To minimize confounding factors, the virtual environment employed in this study (see Fig. 3) is intentionally kept minimal, featuring low-salience elements and highlighting only task-relevant materials, such as the red target disc and arrow tip. The screenshot shows a static scene with five targets set up for shooting. The bow is positioned on a cube-shaped platform in the lower left of the image, ready for the user to pick up when they spawn in front of it. The bow and the targets are both customised assets that were downloaded from the Unity Asset Store.

In the composite image (see Fig. 1), the semi-transparent blue virtual hands can be seen near the controllers, as the user draws the bow and prepares to shoot. While the bow itself needs to be picked up, for convenience and to avoid repetitive strain or similar, arrows are spawning the moment the empty bow is beginning to be drawn. The user interface is intuitive and also minimalist, with a single trigger-based gesture using the grip buttons to grab and release an object (see Fig. 2). The remaining input, i.e., user orientation, locomotion, and arm movement, is made implicitly through tracking.

3.3 Haptic Feedback

The haptic feedback provided by our system serves two functions, addressing distinct stages of the task via spatially separated actuators. During the aiming phase, directional guidance is delivered to the wrists in the form of continuous tactile cues to help users align their motion toward the target. Once an arrow has been released, feedback relating to success and scoring is conveyed through vibrotactile signalling at the ankles, providing a spatial and temporal separation between guidance and outcome-related feedback. Distributing haptic cues across different body locations has been shown to improve perceptual clarity and reduce cognitive interference between feedback types [Prewett et al. 2012; van Erp 2005]. By decoupling these feedback streams, the system supports more efficient sensorimotor integration, allowing users to maintain focus during aiming while still receiving informative post-action feedback.

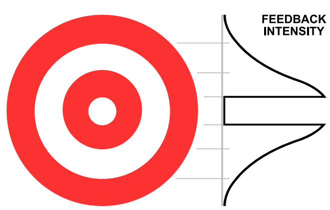

Figure 4: Wrist motor activation and target zone mapping.

Aiming. As illustrated in Figure 4, the continuous haptic feedback's intensity at the wrist increases toward the center of the target, dropping to zero at the bullseye. This is consistent with the sonification behavior described in Section 2.2 in Paralympic biathlon, where the sound frequency increases toward the center of the target disc.

Scoring. Hit or miss status information is conveyed following a shot through individual ankle vibrations, signalling when a target is successfully hit. Intensity and duration of the vibration signal increase in three steps with the precision of the shot, as shown in Table 1. Despite its four-ring design, the target is divided into thirds for discrete scoring, with the center third being worth 3 points, the middle third worth 2 points, and the outer third worth 1 point. Intensity and duration of the signal are doubled at each score level.

Table 1: Ankle motor activation per score level.

Score	Intensity (%)	Duration (*ms*)
1	20	30
2	40	60
3	60	100

3.4 Study Design and Experiment

In order to test the effectiveness of our approach and gain a better understanding of important correlations, we devised a within-subjects experiment in which users were tasked with archery under varying conditions, such as static versus dynamic environments and haptic versus non-haptic modalities (cf. Section 3.4.2).

3.4.1 Participants. For the user study, we recruited $N = 28$ healthy adult participants, mostly from staff and students from the University of Luxembourg, with a female to male ratio of 17.86% – 82.14% and an age range between 24 and 62 years (mean age 31.9 / median 26.5). All participants had normal-to-corrected vision and no known history of neurological abnormality or disease. The majority of the participants (23) were right-handed, while the remaining five were left-handed. Most participants were experienced gamers (89.29%) and familiar with controller use (92.86%). The results were more nuanced for VR and haptic device experiences with more even splits between experienced (intermediate/expert, *VR* 39.29%, *Haptics* 46.43%) and inexperienced (none/beginner, *VR* 60.71%, *Haptics* 53.57%) groups, qualifying these as control variables for our models (see Section 4).

The experiment took place in the VR/AR Lab test space at the University of Luxembourg. After being set up and briefed, the participants provided informed consent and performed the archery tasks in the virtual environment. Each session lasted approximately 15 minutes.

3.4.2 Experimental Procedure. The main experiment follows a 2×2 full factorial design. Fig. 5 shows the experimental procedure and different conditions in the study, wich are triplets constituting of two target-related conditions (motion and visibility), as well the presence (or absence) of haptic support. The small icons indicate the number of targets in a phase (5 training / 3 trial), the vertical line and shuffle icon mark the sequence-randomized conditions.

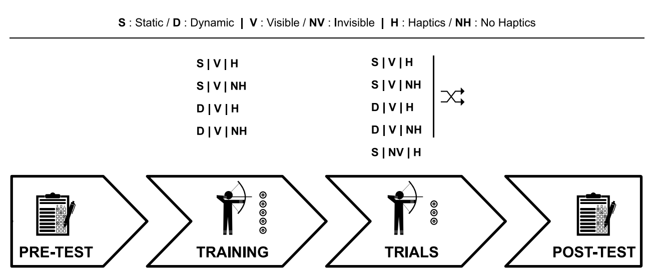

Figure 5: Experimental procedure and conditions.

To simulate blind shooting and gain insights into potential accessibility applications, an additional condition was introduced where the targets were made invisible.

Pre-Test. The pre-test questionnaire collected the demographic and experience data presented in Section 3.4.1. In addition to providing age and gender information, participants indicate whether they have corrected vision or a history of motion sickness, and rate their experience in the four categories VR, gaming, controller use, and haptic devices.

Training. During the training, users become familiar with the various conditions in a virtual environment comprising five targets (see Fig. 3). This allows them to compare aiming with and without haptic feedback, starting with a static setting, and then repeat this exercise with moving targets.

Trials. In the actual trials, each condition comprises three targets to be hit, i.e., two fewer than in the training. The conditions with visible targets correspond to those for the training phase, but are randomized to counterbalance order effects and minimize learning or fatigue confounds. A fifth condition in which the targets are invisible is always added at the end to simulate a blind shooting scenario and to gain insight into potential accessibility applications.

Post-Test. Table 2 shows the 17 post-test questionnaire statements grouped under different variables and evaluated on a 5-point Likert scale. The four groups—confidence, usability, immersion and presence, physical strain and discomfort—aim to assess the qualitative aspects of the haptic support and overall experience.

Table 2: Post-test questionnaire items by evaluated variable.

#	Statement
	Confidence
1	I felt confident using the VR bow and arrows.
2	I felt confident hitting the targets after the initial training.
3	I would be more confident if I redid this.
	Usability
4	I felt the haptic feedback for targeting aid was clear.
5	I felt the haptic feedback for targeting aid was intuitive.
6	I felt that the haptic feedback for targeting was precise.
7	Understanding the haptic feedback was easy.
8	I found the controls intuitive.
	Immersion and Presence
9	I felt immersed in the virtual environment during the experience.
10	I adjusted quickly to the virtual environment experience.
11	The haptic signals distracted me.
12	I was able to focus on the task rather than the haptic feedback.
13	I felt proficient in moving through the virtual environment.
	Physical Strain and Discomfort
14	I found the physical activity involved in the study manageable.
15	I felt physically exhausted after participating in the study.
16	I experienced physical strain (e.g., shoulder, arm, or eye strain).
17	I felt discomfort or motion sickness during the VR session.

4 RESULTS

In this section, we present both quantitative and qualitative results. The quantitative analyses focus on participants' performance during the experimental tasks. The qualitative results are based on post-experiment questionnaires that assess subjective experiences throughout the tasks. We performed inferential statistics with R (v4.5.1) using the packages lme4 (v1.1-37), ordinal (v2023.12-4.1), glmmTMB (v1.1.11), car (v3.1-3), and emmeans (v1.11.2).

4.1 Quantitative Results

We analyzed four models targeting different aspects of how haptics may meaningfully influence performance. Each model assesses a different outcome variable within the 2×2 factorial design between *haptics* (with vs. without) and *target type* (static vs. dynamic). These variables include scoring performance, distance-based hit accuracy, arrow misses, and time taken to complete each trial. VR experience was included as a control variable in all models. For models only analyzing successful hits, the distance from the user to the target was also included to account for distance-related effects. Distance to target was centered so that model estimates reflect performance at the average shooting distance.

4.1.1 Score. Fig. 6 shows the raw average scores and distribution data across conditions, revealing a decrease in absolute scores from static targets to dynamic targets to invisible static targets.

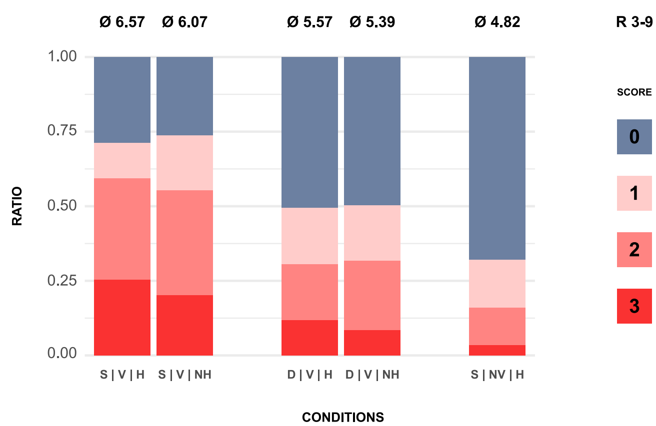

Figure 6: Average score and distribution across conditions.

To examine the effect of haptic feedback on participants' scoring performance (i.e., how close to the center they hit the target), a cumulative link mixed model was fitted using only successful hits which gave a score between 1 and 3. The model included fixed effects of *target type*, *haptics*, their interaction, VR experience level, and the centered target distance. A random intercept for each participant accounted for repeated measures.

A Type III ANOVA revealed a significant main effect of *target type* on score ($\chi^2(1) = 8.19, p = 0.004$), and a strong effect of *target distance* ($\chi^2(1) = 31.09, p < 0.001$), with greater distances associated with lower scoring outcomes. However, there was no significant main effect of *haptics* ($\chi^2(1) = 0.33, p = 0.566$), nor a significant interaction ($\chi^2(1) = 0.40, p = 0.526$).

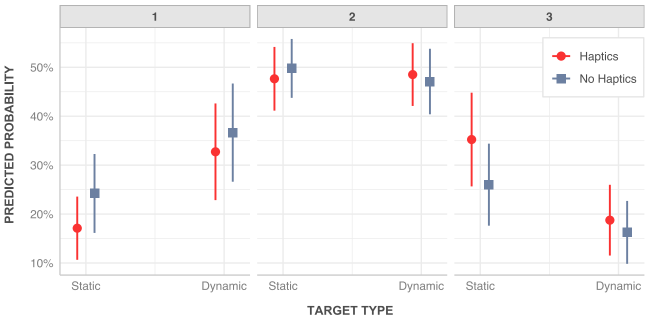

Figure 7: Predicted score outcome probabilities by condition.

Estimated marginal means indicated that using *haptics* had 1.55× greater odds of achieving a higher scoring region compared to those without on static targets ($OR = 1.55, 95\% \, CI[0.88, 2.72], p = 0.129$). With dynamic, i.e., moving, targets, the odds of higher scores were only slightly higher with *haptics*, and not statistically significant ($OR = 1.19, 95\% \, CI[0.66, 2.15], p = 0.566$).

While not statistically significant, the result pattern suggests that using *haptics* may have improved score performance under static conditions, but had little impact when targets were in motion. To better visualize the model's predictions, estimated probabilities were calculated for each score category across haptics conditions and target types, and plotted in Fig. 7. With static targets, haptics increased the probability of higher-scoring outcomes (i.e., a score of 3) and reduced the probability of lower ones. This shift was not observed with dynamic targets, supporting the suggestion that *haptics* may be more effective in simpler, stable targeting environments.

4.1.2 Accuracy. To assess whether haptic feedback improved accuracy in hitting the target, we modeled the log-transformed distance from the arrow to the target center using a linear mixed-effects model. The model included fixed effects of *target type*, *haptics*, their interaction, *VR experience*, and centered *target distance*, with a random intercept for each participant.

A Type III Satterthwaite ANOVA revealed significant main effects of *haptics* ($F(1, 304) = 4.67, p = 0.032$), *target type* ($F(1, 304) = 16.31, p < 0.001$), and *target distance* ($F(1, 304) = 37.94, p < 0.001$), indicating that both target behavior and proximity influenced shot accuracy.

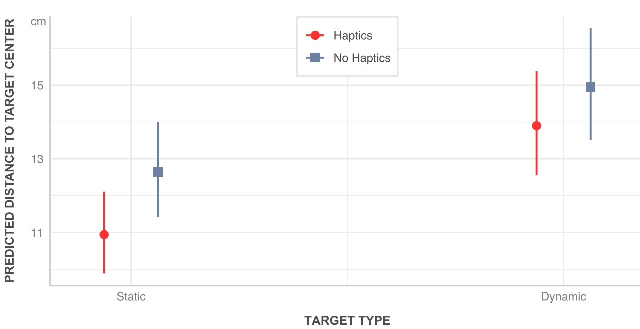

Figure 8: Predicted distance to target center by condition.

Estimated marginal means showed that participants using *haptics* landed arrows 13.5% closer to the center than those without *haptics* (*mean ratio* $= 0.865, 95\% \, CI[0.75, 1.00], p = 0.043$) in the static condition, corresponding to a reduction of approximately 2 cm in mean distance. In the dynamic condition, the effect was smaller and not significant (*mean ratio* $= 0.93, 95\% \, CI[0.81, 1.07], p = 0.306$).

These results suggest that haptic guidance may improve shot accuracy under stable target conditions but offers limited benefit when targets are in motion. Predicted distances from the model are shown in Figure 8, illustrating the difference in average target accuracy across conditions.

4.1.3 Hit Rate. To examine whether haptic feedback affected participants' ability to hit targets efficiently, we modeled the number of arrows missed per target using a zero-inflated Poisson generalized linear mixed model. The model included fixed effects of *motion*, *haptics*, their interaction, and *VR experience* level. A random intercept and random slope for *haptics* were included for each participant to account for individual variability in response to the intervention.

A Type III ANOVA found no significant main effects of *haptics* ($\chi^2(1) = 0.50, p = 0.481$) or *motion* ($\chi^2(1) = 3.24, p = 0.072$), and no significant interaction ($\chi^2(1) = 2.90, p = 0.089$). The only significant predictor was VR experience ($\chi^2(1) = 7.89, p = 0.005$), with more experienced participants missing fewer arrows overall.

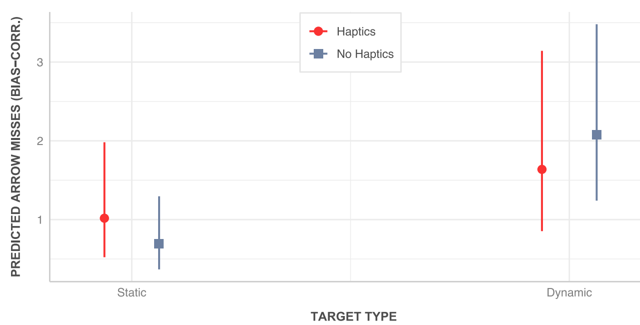

Figure 9: Predicted number of missed arrows by condition.

Estimated marginal means found condition-specific but non-significant trends. In the dynamic condition, participants with haptic feedback missed 21% fewer arrows than those without (*rate ratio* $= 0.79, 95\% \, CI[0.41, 1.53], p = 0.481$). In contrast, participants with haptics missed more arrows on average than those without (*rate ratio* $= 1.47, 95\% \, CI[0.68, 3.19], p = 0.326$) on static targets. While neither difference reached significance, the differing direction of effects may reflect task-specific differences in how participants utilized haptic cues.

Model-predicted arrow miss counts are visualized in Figure 9, illustrating estimated means across *motion* and *haptics* conditions, adjusted for bias introduced by the log-link back-transformation. While participants in the static condition appeared to miss more arrows when haptics were enabled, the absolute difference was small (1.02 vs. 0.69 arrows). Similarly, in the dynamic condition, haptics slightly reduced misses (1.64 vs. 2.08 arrows). These small differences, paired with wide confidence intervals, suggest that even if there are condition-specific trends, the practical impact of haptic feedback on miss rates is likely minimal.

4.1.4 Time. Trial completion time (log-transformed trial duration) was modeled using a linear mixed-effects model. Fixed effects included *motion*, *haptics*, their interaction, and *VR experience* level, with a random intercept for each participant.

A Type III Satterthwaite ANOVA found significant main effects of *motion* ($F(1, 78) = 4.51, p = 0.037$) and *haptics* ($F(1, 78) = 3.98, p = 0.049$), but no significant interaction between them ($p = 0.182$). VR experience was not a significant predictor of round duration ($p = 0.312$).

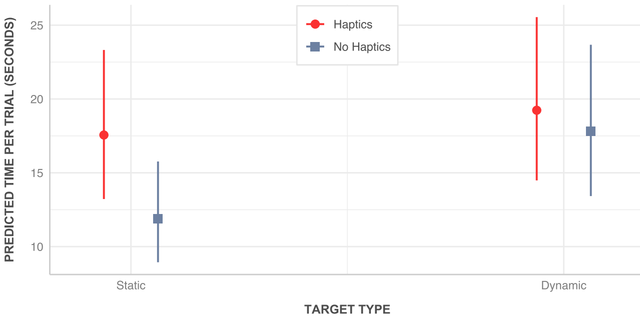

Figure 10: Predicted trial duration by condition.

Estimated marginal means indicated that participants using *haptics* took 48% longer on average to complete the round compared to those without *haptics* (*mean ratio* $= 1.48, 95\% \, CI[1.06, 2.06], p = 0.021$) in the static condition. In contrast, time differences between haptic and non-haptic conditions were small and not statistically significant (*mean ratio* $= 1.08, 95\% \, CI[0.78, 1.50], p = 0.647$) when targets moved dynamically.

These findings suggest that, haptic assistance may also introduce a performance time cost, particularly when targets are static. Model-predicted completion times are shown in Figure 10, illustrating the condition-specific differences in round duration.

4.2 Qualitative Results

In addition to quantitative data, qualitative data related to user experience and haptic feedback were collected after the experiment using a post-test questionnaire (see Section 3.4.2). In the following, we report the questionnaire results by assessed variable, including confidence, usability, immersion and presence, as well as physical strain and discomfort.

4.2.1 Confidence. The results for the confidence variable are shown in Fig. 11, with a strong positive trend of 88% average agreement for confidence-related post-test questionnaire statements #1–#3.

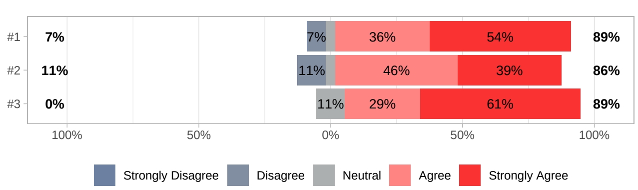

Figure 11: Confidence.

4.2.2 Usability. Fig. 12 shows the post-test questionnaire results for the usability variable with an also very positive trend and average agreement of 78.6% to the usability-related statements #4–#8.

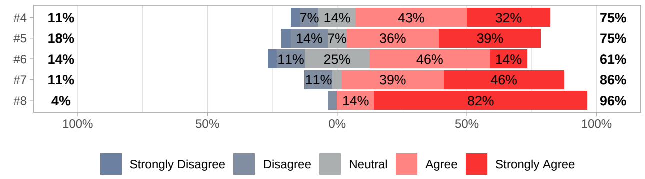

Figure 12: Usability.

4.2.3 Immersion and Presence. As shown in Fig. 13, the post-test questionnaire statements related to the virtual environment (#9,#10, #13) yielded an average agreement score of 89%, indicating that participants generally felt immersed and comfortable in the virtual setting. However, the two statements that specifically addressed the potential distraction caused by haptic guidance (#11,#12) received more varied responses. In particular, these items' lower average agreement scores of 50% indicate a more mixed perception with some participants being able to concentrate on the task without issue, while others experiencing the haptic feedback as partially distracting.

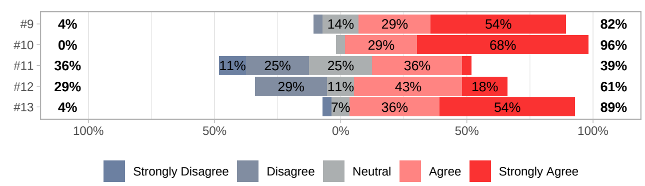

Figure 13: Immersion and presence.

4.2.4 Physical Strain and Discomfort. Figure 14 presents participants' responses to statements related to physical strain and motion sickness. Overall, the task was considered physically manageable by most users with an average agreement of 94.5%, who also reported no issues with motion sickness (#14,#17). However, 53.5% of participants reported experiencing some degree of tiredness or physical strain, such as muscle fatigue (#15,#16).

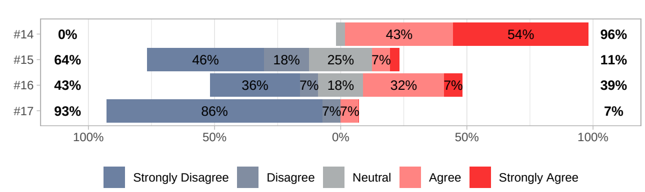

Figure 14: Physical strain and discomfort.

5 DISCUSSION

This study examined the influence of wearable haptic feedback on targeting performance in a VR archery task under static and dynamic conditions. The results reveal a nuanced picture. While haptic assistance did not significantly improve overall scoring outcomes, it yielded measurable improvements in accuracy and completion time under certain conditions. Participants generally reported positive subjective experiences with haptic assistance. As expected, the system was sufficiently adaptable to different user preferences due to its symmetric nature, and no differences were observed between right- and left-handed participants, suggesting that the dominant hand did not significantly influence outcome metrics such as accuracy or confidence.

5.1 Performance and Scoring

The main performance metric, the scoring outcomes on a 1–3 scale, did not show a significant effect of haptic guidance. However, a closer examination revealed a trend suggesting that participants were more likely to achieve higher scores with haptic feedback in the static target condition. Estimated odds ratios showed a 1.55-fold greater likelihood of scoring higher with haptic feedback in static conditions, although this difference did not reach statistical significance. One possible reason for this could be the coarse nature of the scoring system, which divided the target into three equally spaced radial zones. Improvements in accuracy that do not cross a scoring threshold would not be reflected in this measure, even if precision had objectively increased.

The accuracy model, which is based on continuous distance to the target center, showed a statistically significant effect of haptic feedback, supporting this interpretation. In static conditions, participants using haptics landed arrows an average of 13.5% closer to the target center compared to dynamic conditions, improving by about 2 cm. This effect was not significant in the dynamic condition, suggesting that haptic guidance may be particularly helpful in slower-paced or less visually demanding tasks.

5.2 Misses and Completion Time

Analysis of missed arrows revealed no significant differences between conditions. Although model estimates suggested that participants missed fewer arrows with haptic feedback under dynamic conditions, this trend was not statistically significant and was accompanied by large confidence intervals. Note that absolute miss counts were generally low, which likely limited statistical power and may explain the absence of robust effects.

A more pronounced effect was observed in completion time. In static conditions, participants using haptic feedback took 48% longer to complete each round. This suggests that users may have slowed down to integrate the feedback into their aiming process, an interpretation supported by the accuracy improvements. In contrast, no significant time difference was observed in dynamic conditions, which may indicate that participants were unable to effectively use the haptic cues while tracking moving targets.

5.3 Subjective Experience and Usability

The qualitative responses provide additional context for the quantitative findings. Participants reported high levels of confidence (88%), perceived usability (78.6%), and immersion (89%), indicating that the system was generally well designed and received. However, opinions on distraction from haptic feedback were more ambivalent. Two dedicated questionnaire items received only 50% agreement, indicating that, while some users successfully incorporated the cues, others found them distracting, particularly when competing visual or motor demands were present.

Responses related to physical strain were similarly mixed. While most participants found the task physically manageable and reported no motion sickness (94.5% agreement), just over half of the participants (53.5%) experienced some degree of physical fatigue or discomfort. This may reflect the cumulative effect of repeated aiming and arm movement, especially in the absence of the physical support typically available in real-world archery.

5.4 Implications and Future Directions

Taken together, these results suggest that wearable haptic guidance can enhance targeting accuracy in VR, particularly when targets are static and users can process and apply feedback. However, its effectiveness diminishes under dynamic conditions, where rapid responses may prevent the integration of additional sensory information. These findings echo prior research emphasizing the importance of task timing, feedback modality, and user context when effectively deploying haptic systems.

The lack of significant improvements in discrete scoring outcomes also underscores the importance of feedback-sensitive metrics. Future work could use finer-grained scoring systems or adaptive thresholds to better capture incremental improvements. Additionally, the 3D distance-to-center calculation used here may not align perfectly with user expectations, particularly in tasks dominated by horizontal aiming, suggesting that 2D distance metrics might offer a more intuitive measure in similar setups.

Finally, while subjective responses were mostly positive, the variability in perceived distraction and physical fatigue suggests that user-tailored feedback intensity, adaptive timing, or multimodal feedback alternatives could improve overall effectiveness and comfort. Further research should also investigate how user strategies evolve over time, and whether training or calibration can improve the uptake and utility of haptic cues, especially in complex or time-sensitive tasks.

6 CONCLUSION

This study examined the application of haptic technology to assist users with precision-based tasks in VR. Specifically, we designed a haptic assistance system to improve accuracy and user confidence when aiming by providing proximity feedback and guiding motions toward targets. We evaluated the system through a user study ($N = 28$) involving a custom VR archery simulation that combined quantitative performance measures with qualitative user feedback.

Our findings suggest that haptic guidance can significantly improve targeting precision and spatial perception in immersive VR environments. However, some participants reported diminished control, highlighting the importance of balancing guidance with user autonomy. These results demonstrate the potential applications of haptic assistance in areas such as accessibility, gaming, and interactive training, while underscoring the importance of thoughtful user-centered design to mitigate potential disadvantages, such as overreliance or reduced autonomy.

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