Buttons and Feedback in Virtual Reality: Effects on Shooting Accuracy

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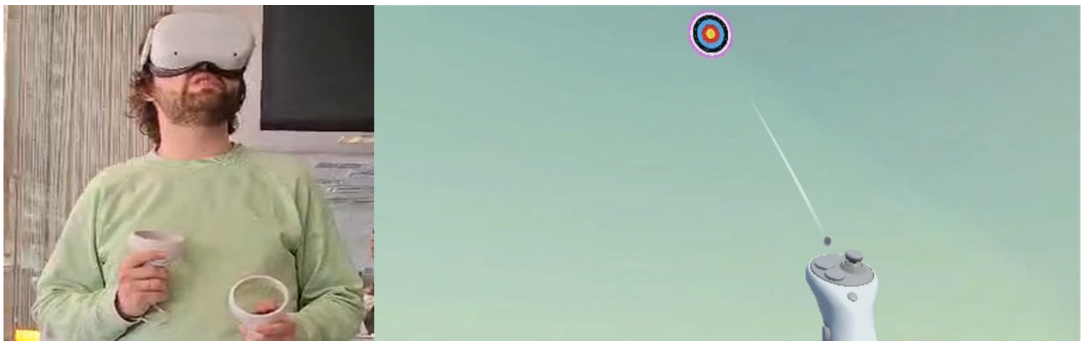

Figure 1: Participant using the VR headset with a screenshot of the VR application displaying visual feedback

Abstract

Virtual reality is increasingly used across various fields that require user interaction, often involving shooting tasks, which play a key role in navigating menus and user interfaces. Thus, there is a need for understanding how different button configurations and feedback modalities influence performance in shooting tasks. This study investigates the impact of different button configurations (same-hand vs. different-hand trigger) on shooting accuracy and response time in Virtual Reality. We also examine the effects of visual, haptic, and auditory feedback. Our results did not show a significant improvement in accuracy or response time with combined feedback modalities. Using the same hand for aiming and shooting decreased accuracy, but did not affect response time. However, user preferences differed from actual performance outcomes. The findings suggest that, while multimodal feedback may not improve performance, user preferences for such combinations highlight the importance of considering subjective experiences in interface design, prompting further exploration of feedback and button configurations.

CCS Concepts

• **Human-centered computing → Virtual reality**; *User studies.*

Keywords

Virtual Reality, Human Factors in VR, Shooting Accuracy

1 Introduction

Virtual reality (VR) has become a widely used tool not only in entertainment and gaming [7, 13], where it enhances user experiences through interactive and immersive environments, but also in various other fields, including healthcare [9].

In VR applications, user interaction often relies on physical controllers, where button presses serve as the primary means of initiating actions. These buttons, such as the trigger button, are essential in tasks that require precision and speed, such as VR-based shooting tasks. While buttons are integral to user interaction, the type and combination of feedback provided during these tasks can also influence performance.

Different feedback modalities—visual, haptic, and auditory—are commonly employed to guide user actions [4]. However, there is limited research on how these feedback modalities specifically affect performance in VR-based shooting tasks, as well as on the interaction between button presses and feedback types.

This study aims to address the gap in understanding how different feedback modalities, both individually and in combination, influence shooting accuracy and response times in VR. Furthermore, we aim to explore the effects of using buttons on the same hand as aiming versus the other hand on performance, particularly in terms of accuracy and response time. The following research question arises: How do different feedback modalities—visual, haptic, auditory, and their combinations—affect shooting accuracy and response time in virtual environments? To explore this question, the following hypotheses will be tested:

(1) Feedback modalities combining multiple types of feedback result in higher shooting accuracy and faster response times compared to single-modality feedback.
(2) Feedback modalities with haptic feedback result in lower accuracy.
(3) Using the same hand for shooting results in faster response times.
(4) Using the same hand for shooting results in lower accuracy.

The remainder of this paper is structured as follows: Section 2 presents the related work. Subsequently, Section 3 outlines the technical implementation and methods used, followed by the description of our user study in Section 4. Finally, the results are presented in Section 5, and a conclusion is drawn in Section 6.

2 Related Work

In previous research, a variety of factors have been shown to influence task performance in virtual environments. Mayer et al. [11] investigated the effect of offset correction and visual feedback in the form of a cursor on mid-air pointing in both real and virtual environments. Their results show that the accuracy when selecting targets increases when a cursor is displayed. However, they also found that the display of a cursor increased selection time. In contrast, our study employs controllers, which may lead to different dynamics in target selection and task performance.

Cockburn et al. [5] conducted a user study with 15 participants investigating mid-air pointing techniques for spatial target acquisition with and without visual feedback in a 2D plane and a 3D volume. Their study found that the feedback modality has an effect on target selection time. In the absence of feedback, the participant's accuracy decreased. Further, the authors found that participants had difficulty acquiring targets in 3D space when there was no stereoscopy, relying instead on the size of the target and cursor for depth perception. Although this visual feedback was found to be better than a separate depth display, the authors noted that it may have been insufficient for accurate target acquisition. This highlights the challenges of visual feedback in 3D environments, which are relevant to our study.

Wingrave et al. [15] conducted a user study with 25 participants to explore selection strategies in VR using Raycasting and Occlusion selection. They found that both methods require aligning a ray with a target, but the performance of these techniques can vary based on the environment and the user's strategy. While Raycasting was generally faster, Occlusion selection was perceived as more accurate, though it also led to more fatigue [14]. Their study also highlighted that users developed strategies to improve accuracy, such as the "sweeping strategy" in Raycasting, where users aligned the ray with a row of objects to increase precision. Raycasting was found to be faster than Occlusion selection in simpler environments without occlusion.

Yu et al. [17] investigated which techniques, feedback types, and pointing enhancements work best for users selecting targets in head-mounted display (HMD) VR environments. Based on related work, they discuss two common forms of visual feedback used in target selection: target highlighting and target shadowing. In target highlighting, the target or its bounding box is emphasized, while target shadowing projects both the target and the cursor onto a ground plane. The results of Yu et al.'s study suggest that both RayCasting and the Virtual Hand techniques provide similar performance levels and error rates. They further found that visual feedback is the most natural and effective, leading to better performance and lower error rates. While combining visual feedback with other feedback types did not improve performance, it was found to reduce error rates. Participants preferred pointing facilitators when efficiency and speed were needed; however, these facilitators sometimes led to uncomfortable interactions. Finally, the authors conclude that when users have limited time to familiarize themselves with selection techniques, simple RayCasting with visual feedback is likely the most effective, as it aligns with the standard cursor movement users are familiar with. Pointing facilitators, being unfamiliar to many users, may require additional time for learning.

Oron-Gilad et al. [12] investigated the use of vibrotactile cues for improving target acquisition. Their results show that continuous distance cues and on- vs. off-target vibrotactile stimuli influenced reaction time and accuracy. They also show that visual cues dominate tactile cues in guiding movement when both cues are present. When both visual and tactile cues were used together, they improved initial movement time, allowing users to determine the direction of movement faster and more reliably. However, no significant improvement was observed when tactile cues were used without visual feedback. There was also no significant difference in target selection time between the visual and visual + tactile conditions. In addition, the authors found that tactile off-target guidance cues are not required throughout the entire task, but can be limited to the initial phase and during submovements towards the target without significant loss in performance.

Ariza et al. [1] investigated the effects of unimodal and bimodal feedback (visual, auditory, and tactile) on 3D object selection in virtual environments. Their participants found bimodal feedback more useful than unimodal feedback. In addition, the bimodal feedback showed a reduced error rate. The authors provide several guidelines based on their findings for improving 3D selection tasks in virtual environments. They recommend choosing binary proximity-based feedback over continuous feedback to achieve faster movement times and higher throughput. While bimodal feedback (especially, audio and haptic) is preferred over unimodal feedback to reduce error rates and increase user acceptance, they highlight that binary-unimodal-haptic feedback offers the best balance between throughput, minimizing undershooting/overshooting, and increasing the correction phase. They suggest that haptic feedback (vibrotactile) is preferable over auditory feedback due to potential interference with environmental sounds in immersive virtual environments.

All the papers mentioned above focus on mid-air pointing or object selection in virtual environments, which are closely related to the task of shooting. However, while these studies are relevant to our work, they do not explicitly investigate shooting tasks, which is the specific focus of our research.

3 Methods

This section outlines the technical implementation of the VR application, the experimental setup, and the procedures followed to investigate the effects of button selection and feedback modalities on shooting accuracy.

We developed a VR application using Unity3D and deployed it on the Meta Quest 2 VR headset. The application features circular targets with multiple rings that move along pre-defined paths. The goal is to hit the center of the targets, which move along predefined paths, ensuring consistency across all participants and conditions.

Two buttons were selected: the top-front button on the right controller (trigger button) and the X button on the left controller. The top-front button on the right controller was selected because it serves as the standard button for menu navigation in the Meta

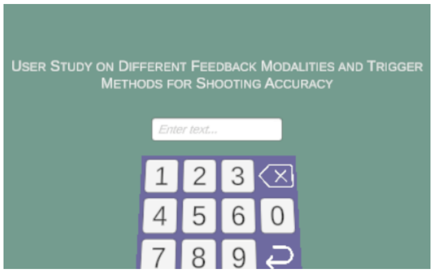

Figure 2: Screen at the Start

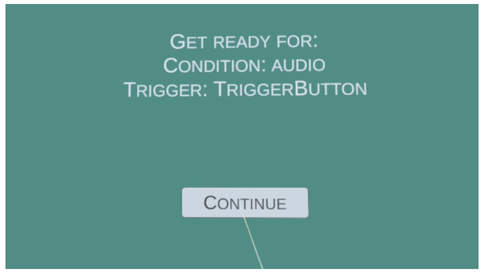

Figure 3: Screen between conditions

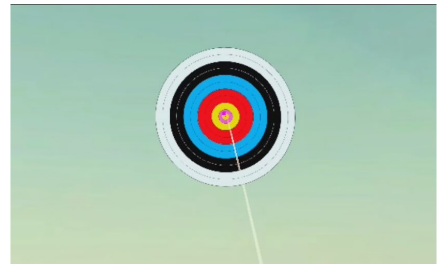

Figure 4: Target shot with visual feedback

Quest 2 interface. This makes it familiar and intuitive for participants. In contrast, the X button on the left controller was chosen to investigate whether shooting accuracy is affected when users use a button on the opposite controller from the one used for aiming. In addition, five feedback modalities were implemented:

- **Visual feedback:** The respective target rings turn purple when the user's controller points at the target's rings.
- **Haptic feedback:** The controller vibrates, with the intensity increasing as the user's aim approaches the center of the target.
- **Auditory feedback:** A sound plays, increasing in pitch as the user's aim gets closer to the target center.
- **Visual + haptic feedback:** A combination of visual and haptic cues.
- **Visual + haptic + auditory feedback:** A combination of the three feedback modalities.

Both vibration and auditory feedback are activated only when users aim at the target. The combination of two button designs and five feedback modalities resulted in ten experimental conditions.

The feedback modalities—visual, haptic, and auditory—are selected to represent distinct sensory channels and explore their individual and combined effects on shooting accuracy. Visual feedback is included as it provides spatial awareness [6] by highlighting the target rings in purple when users aim at the target. Haptic feedback has been shown to improve users' response speed in VR environments by providing additional sensory cues [16]. Building on this, our study examines the role of haptic feedback in enhancing shooting accuracy, where quick and precise responses are essential. Auditory feedback was included because it has been shown to improve accuracy in VR tasks by providing real-time performance cues through sound dynamics [2]. The combination of these sensory modalities allows for the analysis of potential synergies in enhancing user performance.

The VR application was designed to guide the participants through the study autonomously. Upon starting, a welcome screen is displayed where users can enter their participant ID. The screen is shown in Figure 2. Based on the entered ID, the application determines the condition sequence for each participant using a Latin-square design to counterbalance the conditions and assign the starting feedback modality. Additionally, the starting button (either the top-front button on the right or the X button on the left) is assigned based on the participant's ID modulo 2.

Afterwards, a screen announces the start of a practice session. The instructions on the screen ask the participant, to try both buttons for shooting, to familiarize themselves with both buttons. Participants can then press "Continue" to begin the practice session. After the practice session, the application displays a screen indicating the start of the first experimental condition with a "Continue"-button allowing to proceed with the first condition, after which a new screen appears to notify them of the next condition. This cycle of completing a condition followed by a screen indicating the next condition continued until all conditions had been completed. Figure 3 shows an exemplary screen between conditions, and Figure 4 shows a target with visual feedback that is being shot.

Finally, after completing all conditions, the application presents a closing screen thanking the participants and offering a button to return to the start of the application.

4 User Study

The experiment was conducted using a Meta Quest 2 VR headset, with the application developed in Unity3D. Participants interacted with circular targets using the controllers provided with the headset while seated in a chair.

4.1 Experimental Setup

The study included 10 conditions (2 buttons × 5 feedback modalities), with each condition consisting of 5 targets following predefined paths. To minimize learning effects, rotational counter-balancing was employed as described in section 3. Participants first completed the feedback modalities with one button before switching to the other button. Each participant completed 9 out of the 10 conditions, with all conditions evenly distributed, maintaining a balanced dataset and minimizing order effects.

4.2 Participants

Participants were family members, friends, and classmates enrolled in the course on Virtual Reality. A total of 21 participants completed the study. Most participants (17) were aged 18-29, with 3 participants aged 40-49 and 1 over 60. The sample included 12 males, 8 females, and one participant who preferred not to disclose their gender. Regarding prior VR experience, 6 participants had never used VR before, 9 participants reported using VR for less than 5 hours in the past year, 5 participants had used VR for 5-20 hours, and 1 participant had used VR for more than 20 hours. On a scale from 1 for not confident to 7 for very confident, participants reported varying levels of confidence with new technology, with the majority expressing high confidence: 11 participants rated their confidence as 6, 3 participants as 5, and 3 participants as 7.

Figure 5: A participant engaging in the study

In terms of familiarity with aiming or shooting tasks on electronic displays, 6 participants rated their familiarity as 5, 6 participants as 3, and 4 participants as 4. Regarding sensory impairments, 15 participants reported no issues, while 6 participants mentioned visual impairments. Most participants (19) were right-handed, with only 2 left-handed participants.

Regarding discomfort, 19 participants reported no discomfort (such as headaches, fatigue, or eye strain), while 2 participants indicated they were experiencing mild discomfort. In terms of motion sickness when using VR, 5 participants were unsure or had not used VR enough to provide an answer, 9 participants reported experiencing motion sickness occasionally, and 3 participants frequently experienced it, while 4 participants never experienced motion sickness.

4.3 Procedures

The study began with an explanation of the study's purpose and procedure to give participants a clear understanding of what to expect. Following this, participants were provided with a Consent Form, which they had to sign to indicate their agreement to participate in the study.

The study proceeded with a pre-test questionnaire to collect demographic data. From this point until the post-test questionnaire, the study was fully guided by the VR application, with participants following the on-screen instructions throughout the experiment and removing the headset when the screen for the next condition appeared, to answer the post-task questionnaires.

We can see in Figure 5 the setup of the study, where a participant is engaging with the VR application during the experiment.

First, a practice session followed, where participants could familiarize themselves with the controls by shooting at ten targets. For each condition, participants completed a set of five shooting tasks and then answered a post-task questionnaire containing items from NASA-TLX [8], ASQ [10], SUS [3], and other metrics. Before each condition, a menu indicated the upcoming condition. Participants could proceed with the next condition by pressing the "Continue" button using the top-front button on the right controller, regardless of the current condition. The predefined paths for the targets were identical across participants and conditions but varied within each condition to ensure task variability.

After completing all conditions, a post-test questionnaire gathered feedback on button preferences and the perceived effectiveness of the feedback modalities. At the end of the study, participants had the opportunity to provide direct feedback about their experience.

5 Results

In this section, we present the results of our study. First, we focus on the evaluation of the hypotheses. Afterwards, we analyze the participants' stated preferences from the post-test questionnaire and their comments. Finally, we discuss the results and propose directions for future work.

5.1 Hypotheses

The data analysis was performed using log files created during the study, from which we extracted two primary performance metrics: shooting accuracy and response time.

Shooting accuracy was determined based on how close the participant's shot was to the center of the target, with a score of 100 representing the closest shot. This value was directly extracted from the log files for each shot. To ensure valid comparisons, practice sessions and the first target of each condition were excluded from the analysis.

Response time was calculated by subtracting the time at which the target spawned from the time the button was pressed. This metric reflects how quickly participants shot the targets.

Two participants were excluded from the analysis due to technical difficulties that led to early termination of their participation. The remaining data was used to evaluate the hypotheses.

Before testing the hypotheses, we assessed the distribution of the data for both accuracy and response time using the Shapiro-Wilk test. The results revealed that the data for both metrics were not normally distributed: For accuracy, the p-value was 9.84×10^{-17}. For response time, the p-value was 6.28×10^{-37}.

Since the data were not normally distributed, we used non-parametric tests for our analysis. Specifically, for the comparison of two independent groups in each of the four hypotheses, we used the Mann-Whitney U test.

Hypothesis 1: Feedback modalities combining multiple types of feedback result in higher shooting accuracy and faster response times compared to single-modality feedback. For the first hypothesis, we divided the analysis into two parts: one focusing on shooting accuracy and the other on response time. We compared the performance of combined feedback modalities (visual, haptic, auditory) with single-modality feedback in both aspects.

1.1 *Shooting Accuracy*: We performed a Mann-Whitney U test to compare shooting accuracy between the combined feedback modalities and the single-modality feedback condition. The results showed that the difference in accuracy was not statistically significant (p-value = 0.094). Therefore, we **failed to reject** the null hypothesis, suggesting that the use of combined feedback modalities did not lead to significantly higher accuracy compared to single-modality feedback.

1.2 *Response Time*: A similar analysis was conducted for response time using the Mann-Whitney U test. The results showed no significant difference in response times between the combined and single-modality feedback conditions (p-value = 0.258). Therefore, we **failed to reject** the null hypothesis, indicating that combining different feedback modalities did not result in faster response times compared to using a single feedback modality.

Hypothesis 2: Feedback modalities with haptic feedback result in lower accuracy. For the comparison of the shooting accuracy between the haptic feedback condition and the other feedback modalities, the results showed no significant difference in accuracy (p-value = 0.385). Therefore, we **failed to reject** the null hypothesis, indicating that haptic feedback did not result in lower accuracy compared to the other feedback modalities.

In Figure 6, we can see the accuracy by feedback modality. The accuracy across the feedback modalities appears similar, further supporting the statistical analysis.

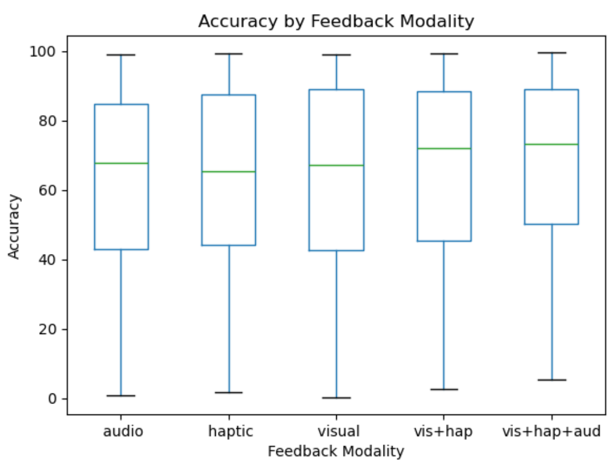

Figure 6: Accuracy by Feedback Modality

Hypothesis 3: Using the same hand for shooting results in faster response times. For the comparison of the response times between the same-hand trigger condition and the different-hand trigger condition, the results showed no significant difference in response times (p-value = 0.137). Thus, we **failed to reject** the null hypothesis, suggesting that using the same hand for the trigger did not result in faster response times.

Hypothesis 4: Using the same hand for shooting results in lower accuracy. For the comparison of shooting accuracy between the same-hand trigger condition and the different-hand trigger condition, the Mann-Whitney U test revealed a significant difference in accuracy (p-value = 0.0046). This result indicates that we **rejected** the null hypothesis, suggesting that using the same hand for the trigger did indeed result in lower accuracy.

We can see in the box plot in Figure 7 that the accuracy is higher for the X button than for the trigger button, supporting the statistical analysis. The mean accuracy for the Trigger button was 5.19 (SD = 6.08), while for the X button, the mean accuracy was 5.43 (SD = 7.10).

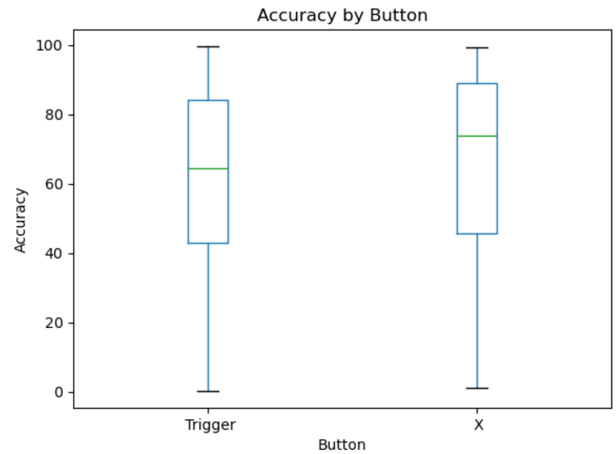

Figure 7: Accuracy by Button

Additionally, we examined whether there was a difference in shooting accuracy between the two buttons by comparing the accuracy shortly before and at the moment the button was pressed. This was done to investigate whether hand instability, which might arise when both hands are used for aiming and shooting, influenced the accuracy. The Kruskal-Wallis test showed no significant difference in accuracy between the two buttons (p-value = 0.317).

5.2 Participants' Preferences and Feedback

The post-test questionnaire revealed that the majority of participants preferred using the Trigger button, with 13 participants selecting it as their preferred button compared to 7 who preferred the X button.

Regarding the perceived effectiveness for the feedback modalities, we can see the results in Figure 8. The red dot represents the mean value. Participants rated the feedback modalities on a scale from 1 (least effective) to 5 (most effective). As shown in the boxplot, the visual feedback modality has a mean rating of 3.20 (SD = 1.06), with scores ranging from 1 to 5. For haptic the mean is 2.30 (SD = 1.17), with scores ranging from 1 to 4. The rating was 2.05 (SD = 1.10) for audio, with scores ranging from 1 to 4. Audio feedback also received lower effectiveness ratings, similar to haptic feedback. Visual + Haptic feedback has a mean rating of 3.90 (SD = 1.07), with scores ranging from 2 to 5. Finally, for Visual + Haptic + Audio feedback mean rating is 4.25 (SD = 1.12), with scores ranging from 2 to 5.

Since the data were not normally distributed, we used the non-parametric Kruskal-Wallis test to compare the effectiveness of different feedback modalities. The results showed a significant difference in effectiveness ratings between the feedback modalities (H-statistic = 38.49, p-value = 8.87e-08). Additionally, we compared the ratings of all single feedback modalities with combinations of feedback modalities using the Mann-Whitney U test. The results indicated a

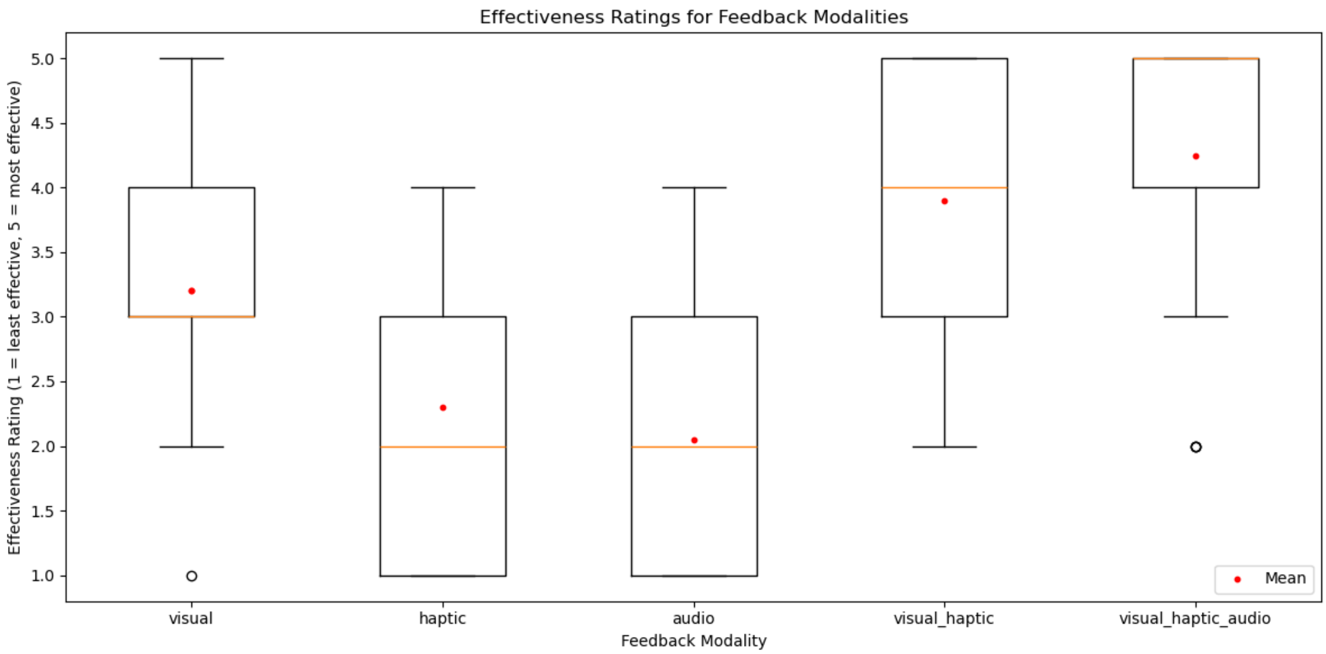

Figure 8: Feedback Popularity

significant difference in the effectiveness ratings between single-modality and multimodal feedback (p-value = 1.95e-06).

Neither button preferences nor feedback modality effectiveness ratings showed significant differences based on gender, as indicated by the Chi-squared tests for both button preferences (p-value = 0.338) and feedback modality preferences (p-value = 0.735).

Some participants provided feedback regarding their experience with the different feedback modalities and the system as a whole. Several participants mentioned the challenges of aiming with the displayed ray. One participant suggested the use of different colors for the rings to enhance clarity. Another participant recommended replacing the white aiming ray with a crosshair, as they found the ray led to errors. One participant reported that they mistakenly shot when it appeared to be aligned with the target, rather than relying on the audio or haptic feedback.

A few participants did not like how the auditory feedback sounded. One participant suggested replacing the sound with, e.g., a shooting sound. Some participants also expressed difficulty with the moving targets. For example, one participant suggested that the targets should be positioned closer and lower to make it easier to hit the center. Another participant mentioned that they had to aim slightly off-center when using the moving targets.

5.3 Discussion and Future Work

Our results showed that combined feedback modalities did not result in significantly higher accuracy or faster response times compared to single-modality feedback. Similarly, we found that haptic feedback did not decrease accuracy as expected, and the use of the same hand for shooting did not improve response time. However, we did observe a significant decrease in accuracy when using the same hand for both aiming and shooting, which is consistent with our hypothesis.

While our findings suggest that the addition of more feedback modalities does not necessarily improve performance, previous research has shown that multimodal feedback can be more effective [12]. Furthermore, we observed that participants preferred the combination of feedback modalities over single-modality feedback. This aligns with the research by Canales and Jörg [4], which found that participants' preferences for feedback modalities may differ from their actual performance with those modalities.

The subjective feedback provided by participants highlights some interesting challenges. For example, many participants expressed confusion with the white aiming ray, indicating that it was not precise. Several participants also suggested alternative feedback cues, such as using a crosshair instead of the ray or replacing the audio feedback with a different sound. Future work could focus on adapting the system to incorporate these suggestions. It could also compare different forms and implementations of, e.g., audio and visual feedback, to better understand users' preferences regarding how exactly the modalities should be realized. Additionally, future work could explore alternative button modalities. For example, future work could be comparing different buttons on the same hand for shooting, or comparing buttons on the opposite hand with each other. This could help to better understand the impact of button configurations within the same hand, as opposed to comparing buttons on different hands.

One limitation of this study is the relatively small sample size, which may affect the generalizability of the findings. Additionally, most participants were relatively young, and the majority were right-handed, which could limit the applicability of the results to other demographic groups.

In conclusion, while the results of this study provide valuable insights into the role of feedback modalities and button configurations, further research is needed to refine the design and explore other potential factors that may affect performance in VR tasks.

6 Conclusion

This study investigated the impact of various feedback modalities—visual, haptic, auditory, and their combinations—on shooting accuracy and response time in virtual reality. Additionally, we examined the influence of using the same hand for aiming and shooting. Our findings show that combining different feedback modalities did not significantly improve accuracy or response times compared to single-modality feedback. However, we observed a significant decrease in accuracy when the same hand was used for both aiming and shooting, confirming our hypothesis.

Despite the lack of performance improvement with combined feedback modalities, participants preferred multimodal feedback, highlighting a discrepancy between subjective preferences and objective performance. These results contribute to our understanding of how feedback types influence user performance and preferences in VR shooting tasks.

The limitations of this study include a small sample size and a predominantly young, right-handed participant pool, which may affect the generalizability of the findings. Future research could focus on refining feedback systems based on user preferences and exploring additional configurations.

In conclusion, this work provides insights into the design of feedback systems for VR shooting tasks and suggests areas for future improvement in both system design and user interaction.

Acknowledgment

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