Throwing in Virtual Reality: Performance and Preferences Across Input Device Configurations

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Abstract

An underexplored interaction metaphor in virtual reality (VR) is throwing, with a considerable challenge in achieving accurate and natural results. We conducted a preliminary investigation of participants' VR throwing performance, measuring their accuracy and preferences across various input device configurations and throwable object types. Participants were tasked with throwing different objects toward targets using five input device configurations we developed. Our work is relevant to researchers and developers aiming to improve throwing interactions in VR. We demonstrate that on-body tracking leads to the highest throwing accuracy, whereas most participants preferred a controller-derived configuration.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—Human computer interaction (HCI)—Empirical studies in HCI;

1 Introduction

Virtual Reality (VR) has enabled its users to be immersed in Virtual Environments (VEs), allowing them to interact with different components as they would in real life [2]. Currently, interaction paradigms in VR mostly rely on the use of handheld controllers, used to perform different actions such as object selection, locomotion, and navigation [2]. Some interactions, such as object throwing, feel very different in VR from real life [7]. Given that throwing is a common interaction in sports and games, replicating natural and intuitive throwing dynamics in VEs can enhance the immersive user experience and allow users to rely on throwing as a mechanic for completing tasks in VR. Prior work explored improvement of throwing in VR and its applications, covering topics in tracking accuracy by incorporating aerodynamics, controller-based velocity calculation [4, 5, 7], throwing in sports and rehabilitation training [3], point of release (PoR) prediction [6], and differences between real-life and VR throwing [1, 7]. Our study uses three device categories (*in-hand*, *on-body*, and *external*) with a total of five input configurations varying in sensing capabilities and throwing mechanisms.

We conducted a 5×3 within-subject study, where we varied the input configurations and throwable object types. The input configurations included three in-hand (controller-based), one on-body (threshold-based Vive tracker), and one external (threshold-based Kinect Sensor) throwing configuration. The throwable object types were designed for overarm and underarm throwing, including a baseball, a football, and a bowling ball. A post-study survey asked participants for their most and least favorite device configurations.

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2 Study Design

We used the HTC Vive HMD with its controller. The controller configuration is divided into three sub-categories; first, *Controller Hold (CH)* (Fig. 1-row 1), participants pressed and held the controller to grab the throwable and then released the button to throw it; second, *Controller Press (CP)* (Fig. 1-row 2), participants pressed the controller button to grab the throwable and then pressed it again to throw; third, *Controller Threshold (CT)*, used a threshold mechanism where the throwable was already attached to the controller and participants had to hold the controller next to their head or hip (for over arm and under arm throwing) (Fig. 1-rows 3 and 4) to define the threshold origin, the PoR was triggered automatically when the throwable (bowling, baseball, football) moved a threshold distance (0.38, 0.25, 0.25m) away from the origin. *Vive Tracker (VT)* and *Kinect (K)* used the same threshold mechanic, yet the threshold values used to define the PoR differed (VT= 0.40, 0.30, 0.35m) (K= 0.40, 0.30, 0.25m). During pilot studies, we measured one of the author's arm span (distance from controller to the HMD with the hand fully extended down), we measured the same distance for each participant and then used the pre-defined threshold values (these values worked best for the reference author) to personalize the thresholding for each participant. For all device configurations, we used a sliding window (5 or 10 frames, depending on the device) of the participant's hand movement velocity [7].

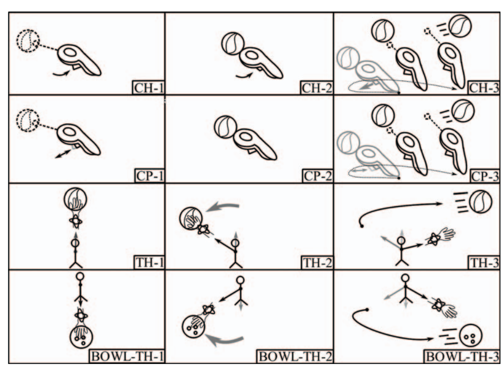

Figure 1: Throwing procedure by device configuration. **CH: (1)** hold trigger, **(2)** move, **(3)** release trigger. **CP: (1)** press trigger, **(2)** move, **(3)** press trigger. **Threshold Overarm: (1)** position near head, **(2)** move, **(3)** cross threshold. **Threshold Underarm: (1)** position near hip, **(2)** move, **(3)** cross threshold.

We used three dissimilar throwable objects from popular sports for overarm and underarm throwing. We applied air friction and physics-based throwing dynamics to make the ball's behavior realistic after throwing. We designed a football stadium as our VE, which was used for both training and actual trials. Each condition had 6 circular targets, with one target randomly assigned per trial. Targets had identical designs, with 4 circular layers: a red central layer (Bullseye) ($r = 0.35m$), a yellow layer ($r = 0.7m$), a green layer ($r = 1.05m$), and a final blue layer ($r = 1.4m$), the distance from the bullseye to

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the target's edge was 1.4m. The targets differed in placement. For bowling, targets were flatly positioned on the ground. For baseball and football, targets were located mid-air. We had 2 groups of targets: 6 mid-air and 6 on-ground targets. In both groups, two targets were to the left, front, and to the right of the participant. For each target group, one was at 5m, and one was at 10m from the participant. The VR task occurred in the middle of the stadium, and targets spawned one at a time based on the participant's position.

3 Procedure

We recruited 30 participants from our university, predominantly right-handed and all over 18 years old, with an average height of $1.72m$ and average age of 21.14. Participants (18 males, 11 females, and 1 non-binary) were able-bodied, had a normal or corrected-to-normal vision, and were compensated $10 for 50 min of their time. Upon arrival at the study location, participants were given a detailed study protocol form, and asked for consent. The study task was then verbally explained, and any questions were answered. Participants wore the HMD and the HTC Vive tracker on the wrist of their dominant hand. The study started with a training phase averaging 10 minutes, where participants practiced with each input configuration, throwable object, and throwing technique. Participants were allowed three throws per condition. Once the training phase was done, we administered the throwing conditions in a counterbalanced order, with each condition consisting of a single input device used to perform six throwing trials with a single throwable object at randomized target locations (90 throws in total). Participants aimed at the current trial's target using the assigned device configuration. The closest distance that the throwable object appeared at, away from the target's bullseye, was recorded as the accuracy metric for the active trial.

4 Results

We recorded throwing accuracy in meters (m) and confirmed the data's normal distribution using Shapiro-Wilk's test ($W = 0.956$, $p < .246$). Using RM-ANOVA, we examined our study factors' main and interaction effects, applying Greenhouse-Geisser correction if Mauchley's test showed sphericity violations. Our post-hoc analysis involved pairwise t-tests with Bonferroni correction. We used Friedman and Wilcoxon's Signed Rank tests to analyze post-study survey. We present bar plots depicting throwing accuracy across device configurations (see Fig. 2-(a)), and scenario (see Fig. 2-(b)).

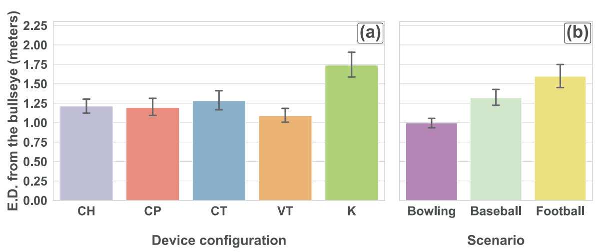

Figure 2: Throwing accuracy for (a) device configuration, (b) scenario. Lower is better, $CI = 95\%$.

We found a significant main effect of input configurations on throwing accuracy ($F_{4,116} = 27.971$, $p < .001$, $\eta_p^2 = .491$). The devices and their respective mean accuracies and standard deviations are as follows: *Controller Hold* (CH) ($\mu = 1.179m$, $SD = 0.877$), *Controller Press* (CP) ($\mu = 1.154m$, $SD = 0.823$), *Controller Threshold* (CT) ($\mu = 1.219m$, $SD = 0.870$), *Vive Tracker* (VT) ($\mu = 1.053m$, $SD = 0.676$), and *Kinect* (K) ($\mu = 1.678m$, $SD = 1.120$). We conducted a post-hoc analysis with pairwise t-test to compare the different input configurations against each other regarding throwing accuracy. We found a significant difference between *controller hold* vs *vive tracker* ($t_{29} = 2.065$, $p < .048$), *controller hold* vs *Kinect* ($t_{29} = -6.444$, $p < .001$), *controller press* vs *Kinect* ($t_{29} = -6.310$, $p < .001$), *controller threshold* vs *vive tracker* ($t_{29} = 3.345$, $p < .002$), *controller threshold* vs *Kinect* ($t_{29} = -7.517$, $p < .001$), and *vive tracker* vs *Kinect* ($t_{29} = -9.187$, $p < .001$). Additionally, we found a significant main effect of throwable object type on throwing accuracy ($F_{1.576,45.711} = 50.263$, $p < .001$, $\eta_p^2 = .634$). We conducted a post-hoc analysis using pairwise t-tests to compare the throwing accuracy between the throwable objects. We found that all throwable object types significantly differed from each other: *baseball* vs *bowling* ($t_{29} = 6.608$, $p < .001$), *baseball* vs *football* ($t_{29} = -5.131$, $p < .001$), and *bowling* vs *football* ($t_{29} = -8.219$, $p < .001$).

Through a post-study survey, we asked participants questions regarding their preferred throwing methods and device configurations. First, participants selected the most preferred device configuration to perform throwing. Participants' choices were as follows: $CH = 16$ (*53.33%*), $CP = 7$ (*23.33%*), $CT = 3$ (*10.00%*), $VT = 3$ (*10.00%*), and $K = 1$ (*3.33%*), with Chi-squared test confirming that these choices were not uniformly distributed (χ^2_4 $(N = 30) = 24$, $p < .001$). For the second question, participants selected the least preferred device configuration to perform throwing. Their choices were: $CH = 1$ (*3.33%*), $CP = 3$ (*10.00%*), $CT = 1$ (*3.33%*), $VT = 11$ (*36.67%*), and $K = 14$ (*46.67%*). Chi-squared test confirmed that the distribution was not uniform (χ^2_4 $(N = 30) = 24.67$, $p < .001$).

5 Conclusion and Future Work

We investigated throwing different virtual objects alongside different input device configurations in VR accompanied by qualitative data across 30 participants. We found that four of five input configurations led to similar performance, with the Vive tracker resulting in the best overall accuracy. Our results indicate that participants were more accurate in the underarm throwing task. Post-study survey results indicate that participants preferred controller hold as they felt more in control of the PoR and overall throwing gesture, even though objectively, this device configuration was not the most accurate. Overall, throwing using the Kinect sensor led to poor results, and it was the least preferred device configuration. Our study showed that when using thresholding properly for the PoR, the results match or outperform the traditional analog input. In the future, we plan to recruit more left-handed participants, incorporate moving targets, explore alternative methods to determine throwing velocity, and conduct similar experiments in augmented reality (AR) and mixed reality (MR).

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