# The Detectability of Saccadic Hand Offset in Virtual Reality

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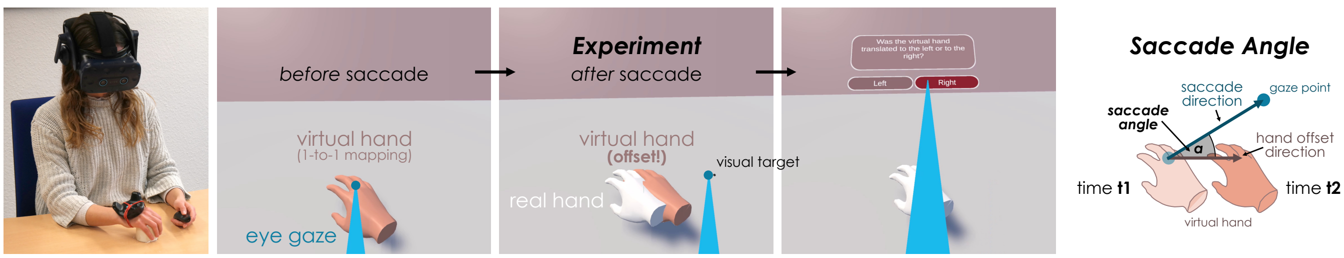


**Figure 1: We conducted a psychophysical experiment measuring the ability of users in detecting virtual hand offsets that are injected during a saccade. The left image depicts the experiment setup and the screenshots show the participant's first-person view (blue eye gaze ray and white real hand added only for illustration). From the results of the experiment we derived detection thresholds (DTs) for saccadic hand jumps. Our findings show that the angle between saccade and hand offset direction, illustrated in the rightmost sketch, significantly impacts the magnitude of offset that can unnoticeably be injected.**

## ABSTRACT

On the way towards novel hand redirection (HR) techniques that make use of change blindness, the next step is to take advantage of saccades for hiding body warping. A prerequisite for saccadic HR algorithms, however, is to know how much the user's virtual hand can unnoticeably be offset during saccadic suppression. We contribute this knowledge by conducting a psychophysical experiment, which lays the ground for upcoming HR techniques by exploring the perceptual detection thresholds (DTs) of hand offset injected during saccades. Our findings highlight the pivotal role of saccade direction for unnoticeable hand jumps, and reveal that most offset goes unnoticed when the saccade and hand move in opposite directions. Based on the gathered perceptual data, we derived a model that considers the angle between saccade and hand offset direction to predict the DTs of saccadic hand jumps.

## CCS CONCEPTS

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

## KEYWORDS

virtual reality, hand redirection, saccades, detection thresholds

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## 1 INTRODUCTION

To advance the field of hand redirection (HR) in virtual reality (VR), recently proposed techniques have started to take advantage of the perceptual phenomenon of change blindness. To do so, modern algorithms like *Blink-Suppressed Hand Redirection* [6] offset the virtual hand when the user is temporarily blinded during a blink, in addition to the traditional approach of gradual hand warping [1, 4, 5]. The next step in this line of HR research is to make use also of saccades, i.e., fast eye movements in between fixations, which occur even more frequently than blinks and are likewise accompanied by change blindness [2]. To meaningfully configure saccadic HR algorithms, however, knowledge is required about how much hand offset can be injected during a saccade without users noticing it. To prepare future HR techniques that take advantage of saccades, this work explores the perceptual detection thresholds (DTs) of saccadic hand jumps (i.e., instantaneous offsets of the virtual hand injected during a saccade), taking into consideration the direction of the saccade relative to the hand offset direction as sketched in Figure 1.


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## 2 EXPERIMENT

The goal of our within-subject study was to investigate whether:

**H1** *The virtual hand can unnoticeably be offset during a saccade.*

**H2** *The angle between saccade and offset direction impacts the magnitude of unnoticeable saccadic hand offset.*

To study both hypotheses we recruited $N = 20$ right-handed volunteers ($9f$, $11m$) between 21 and 69 years of age ($M = 27\ y, SD = 10\ y$) for a psychophysical experiment. Figure 1 illustrates the setup, task, and question. Each trial started with a 1-to-1 hand mapping and the participant looking at the hand. Once a small black dot appeared in the peripheral view, participants looked at it and performed a saccade. After the saccade was detected, the virtual (dominant) hand was offset either towards the left or the right (chosen at random) by a certain magnitude (the stimulus of the current trial). Following this manipulation, participants answered a symmetric one-alternative forced choice (1AFC) question. We applied a weighted 1-up/1-down staircase method[1] targeting the 75%-correct DT (due to the symmetric 1AFC question; dependent variable) with step-sizes of $\Delta_{down} = 1\ mm$ and $\Delta_{up} = 3\ mm$ [3]. Each staircase consisted of an ascending (starting at 0 $cm$) and a descending (starting at 6 $cm$) stimulus sequence and each sequence terminated after 10 reversals. To quickly approach the relevant stimulus range, we used 1 $cm$ steps until 4 reversals had occurred and the last 6 reversals were averaged to compute the DT estimate.

To study **H2**, we tested 5 different angles between saccade and hand offset ($\alpha \in \{0°, 45°, 90°, 135°, 180°\}$; independent variable) by controlling the placement of the visual target. The resulting 5 staircases were interleaved.

An HTC Vive Pro Eye with eye tracking was used alongside a spatial boundary technique for saccade onset detection. The dominant hand was tracked using an HTC Vive Tracker and answers were provided with a clicker in the non-dominant hand. The experiment received approval by the Ethical Review Board of the Faculty of Mathematics and Computer Science at Saarland University.

## 3 RESULTS & DISCUSSION

Figure 2 summarizes for each tested saccade angle the amount of hand offset that can unnoticeably be injected during a saccade. Our results support **H1** with Wilcoxon signed-rank tests (using a Bonferroni correction; corrected $p$ values denoted as $p'$) indicating the DTs of saccadic hand jumps for all tested angles to be significantly greater than 0 $mm$ (all $p' < .001$) – hinting towards the practical realizability of saccadic HR independent of saccade direction. Furthermore, our results also support **H2** as we found the DTs for saccadic hand jumps to increase significantly with greater angles between saccade and offset direction. Specifically, we found saccadic hand jumps in the centimeter range to go unnoticed when saccade and hand offset move in opposite directions (i.e., for $\alpha > 90°$). In contrast, the DTs were one order of magnitude smaller, i.e., in the millimeter range, when saccade and hand offset moved in the same direction (i.e., for $\alpha \leq 90°$). A Friedman test confirmed the DTs to differ significantly with $\alpha$ ($\chi^2(4) = 63.06, p < .001$). The effect was found to be large ($W = 0.79$). The results of the corresponding pairwise post-hoc Wilcoxon signed-rank tests (Bonferroni-corrected) are indicated in Figure 2. To make these results accessible for future

[1] *Unity Staircase Procedure Toolkit*: github.com/AndreZenner/staircase-procedure

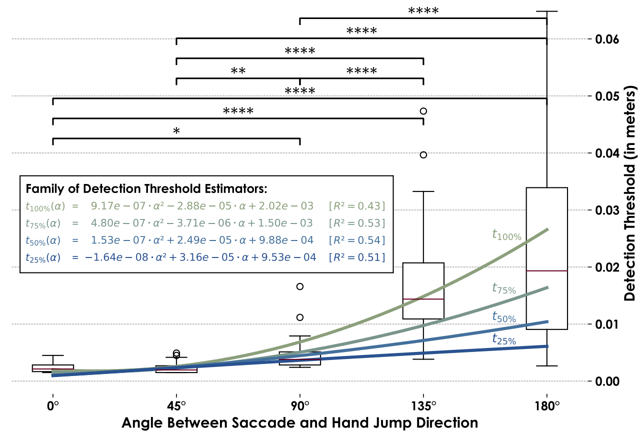


**Figure 2: Box plot of DTs for saccade-injected hand offset and corresponding prediction models. Significant differences are indicated ($p' < .05(*)$, $p' < .01(**)$, $p' < .0001(****)$).**

HR algorithms, we fit four quadratic regression models to the most conservative 25%, 50%, 75%, and 100% of collected DTs, respectively. The resulting functions $t_{25\%}$ to $t_{100\%}$ are presented in Figure 2 and predict DTs for arbitrary angles with decreasing conservativeness.

## 4 CONCLUSION

To lay the grounds for saccadic HR we investigated the detectability of saccade-injected hand offsets in VR. We found that saccades are suitable to hide offsets (**H1**). Furthermore, we found the magnitude of unnoticeable offset to differ with saccade direction (**H2**) and showed that most offset can covertly be injected when saccade and hand offset move in opposite directions. From our results, we derived models predicting the DTs of saccadic hand jumps with different levels of conservativeness to support future HR algorithms.

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