It's Not Always the Same Eye That Dominates: Effects of Viewing Angle, Handedness and Eye Movement in 3D

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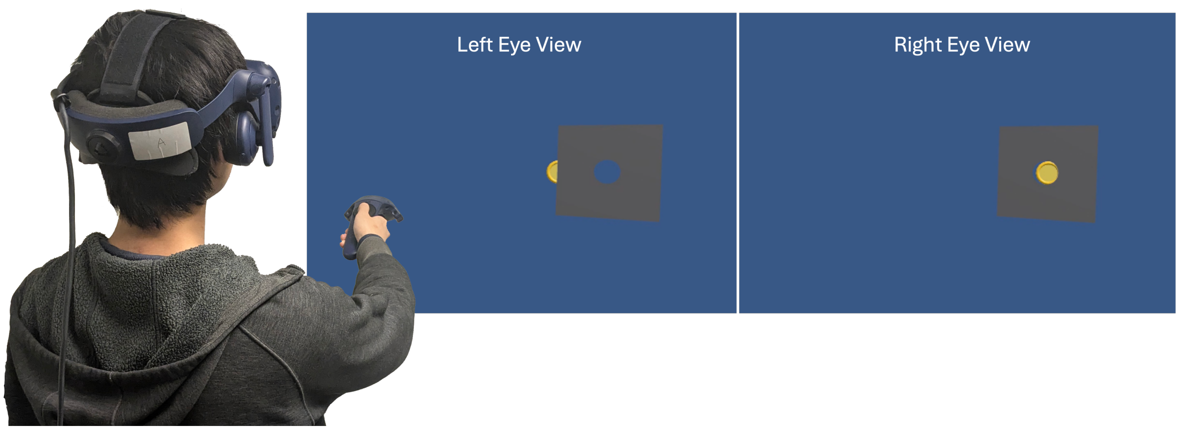


Figure 1: The experimental setup for investigating eye dominance in virtual reality (VR). A participant, wearing a VR headset, aligns a virtual cursor with a distant target using a controller. The two insets display the rendering for the left and right eye views, demonstrating target-controller alignment with the right eye only. In this trial, the participant is right-eye dominant.

Abstract

Understanding eye dominance, the subconscious preference for one eye, has significant implications for 3D user interfaces in VR and AR, particularly in interface design and rendering. Although HCI recognizes eye dominance, little is known about what causes it to switch from one eye to another. To explore this, we studied eye dominance in VR, where 28 participants manually aligned a cursor with a distant target across three tasks. We manipulated the horizontal viewing angle, the hand used for alignment, and eye movement induced by target behaviour. Our results confirm the dynamic nature of eye dominance, though with fewer switches than expected and varying influences across tasks. This highlights the need for adaptive HCI techniques, which account for shifts in eye dominance in system design, such as gaze-based interaction, visual design, or rendering, and can improve accuracy, usability, and experience.

CHI '25, Yokohama, Japan

ACM ISBN 979-8-4007-1394-1/25/04
https://doi.org/10.1145/3706598.3713992

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; **Empirical studies in HCI**.

Keywords

Dominant Eye, Virtual Reality, Eye Movements

ACM Reference Format:
Franziska Prummer, Mohamed Shereef Abdelwahab, Florian Weidner, Yasmeen Abdrabou, and Hans Gellersen. 2025. It's Not Always the Same Eye That Dominates: Effects of Viewing Angle, Handedness and Eye Movement in 3D. In *CHI Conference on Human Factors in Computing Systems (CHI*

'25), *April 26–May 01, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3706598.3713992

1 Introduction

Eye dominance is the subconscious preference for one eye over the other [25], often noticeable during tasks like distance pointing, where individuals align the target and finger with their dominant eye [12]. While well-established in vision science and psychology, eye dominance remains underexplored in Human-Computer Interaction (HCI) despite its relevance to 3D interaction design.

With the rise of virtual and augmented reality (VR/AR), understanding eye dominance has become crucial. These technologies demand precise, naturalistic interactions, where alignment is often critical, e.g., during pointing. Insights into eye dominance can enhance immersive systems, improving usability and accuracy. For example, aligning virtual objects with the dominant eye rather than the cyclopean eye may offer more intuitive depth perception [31]. Similarly, prioritizing the dominant eye in tasks such as foveated rendering could improve performance and battery life [17].

HCI research often oversimplifies eye dominance as a static trait like handedness, underestimating its dynamic nature. Vision science and psychology, however, suggest that eye dominance can be more fluid or fluctuating, influenced by factors such as handedness [11] or the angle of the visual simulation [12, 26]. A deeper understanding of eye dominance and its influencing factors could enable HCI systems, especially for VR and AR, to adapt visual experiences in real time, enhancing usability and interaction quality.

This work investigates eye dominance dynamics when interacting in VR and examines the factors that influence it. In a lab study ($N = 28$), participants aligned a virtual cursor with a distant target while we measured eye dominance. We examined the impact of viewing angle, handedness, and eye movements (random saccades, sequenced saccades, and smooth pursuits). This strengthens previous findings in static scenarios and extends them to dynamic settings — essential for leveraging eye dominance in HCI and AR/VR.

Our results demonstrate that, while eye dominance isn't entirely fixed, its variability is limited to specific conditions, such as sequenced eye movements or smooth pursuits. These findings underscore the importance of considering personal factors such as handedness and static and dynamic aspects (hand used during the interaction, target behaviour) when designing VR/AR systems. Consequentally, this work lays the foundation for more personalized, adaptive interaction paradigms that optimize user experiences by leveraging individual visual behaviours.

2 Related Work

The concept of eye dominance suggests that the eye providing the most precise view of the desired target (the relative size of the image) tends to dominate during vision [1].

Porac and Coren classified eye dominance into three types — viewing-, sighting- and sensory dominance — each dependent on the testing method [2]. This paper focuses on sighting dominance, a "behavioural preference", which refers to the eye an individual favours for tasks like looking through a telescope. Furthermore, sighting dominance is the most frequently and reliably tested eye dominance type across disciplines [16, 25]. It operates subconsciously, measured via various sighting tasks [24].

2.1 Eye Dominance in HCI

HCI has considered eye dominance in some domains, for example investigation of binocular rivalry [29, 32], eye-hand coordination when pointing in 3D [13, 20], and for the development of new interaction techniques that use cursors on stereoscopic displays [14, 30]. Other work leveraged eye dominance to optimize rendering, coding, and streaming by showing lower-quality images to the non-dominant eye [10, 17, 33].

In the existing work, it is assumed that the dominant eye is static and does not change. This contrasts vision science, showing that eye dominance is dynamic and dependent on contextual factors [11]. Ignoring the dynamics potentially limits the effectiveness of techniques designed to adapt to eye dominance [13, 14, 17]. With this work, we provide insights on additional factors influencing eye dominance (viewing angle, hand used during interaction, and gaze behaviour) to provide means to further strengthen eye-dominance-based work in HCI.

2.2 Eye Dominance and its Dynamic Nature

Studies on eye dominance stem primarily from psychology and optometry, with its presence also acknowledged in other fields. However, far more depth surrounds the dominant eye than previously assumed. Research has demonstrated dynamic shifts in eye dominance based on viewing angles, which also apply within a VR environment [11, 26]. In these studies, participants switched their dominant eye on average at 15.5° off-centre. Furthermore, the hand used during an alignment task may bias which eye dominates [11].

In addition, studies have shown that monocular deprivation (patching of one eye) temporarily shifts eye dominance to the deprived eye. However, this effect fades after a few minutes of normal binocular vision [15, 19, 27]. Eye dominance also affects behaviours, such as head tilt [5], horizontal saccades [21], and performance during search tasks [28]. These studies indicate several differences in the behaviour and performance of the dominant eye compared to the non-dominant eye.

Previous work involving static targets must be extended toward dynamic settings to leverage eye dominance in AR/VR, where users interact with static and dynamic targets that elicit different eye movements. Thus, this work studies target behaviours by eliciting different eye movements: random saccades, sequenced saccades, and smooth pursuit movements.

2.3 Testing Sighting Dominance

No objective testing method exists for sighting dominance that does not involve participant self-reporting. This is problematic as it can induce bias due to awareness of what is tested [25]. The "hole-in-card" test, commonly used to determine sighting dominance, does not quantitatively measure eye dominance [7] and only considers targets in front of the user. Other tests such as Dolman-Test [3], Near-Far-Alignment test [6], and the Miles-Test [18] similarly rely on participant reporting. Some methods rely on the experimenter determining the dominant eye [23]. Handa et al. made the first step in creating a quantitative approach to measuring eye dominance. However, even their method involved self-reporting of subjects [7].

In a previous study, Prummer et al. [26] determined eye dominance in VR using distance calculations. In their work, eye dominance was determined by measuring and comparing the distances of a virtual cursor with each eye. Participants first aligned a virtual ring-shaped cursor with a static target, then moved this towards their face while maintaining fixation on the target through the ring. At the movement's end, the cursor is closer to one eye, revealing the dominant eye. The shorter distance between eye position and cursor indicated alignment with that respective eye. However, this method is unsuitable for detecting eye dominance while fixating on moving targets. We adapted their method to accommodate moving targets and still do not rely on participant reporting.

3 Study

This study explores eye dominance by examining how target and gaze behaviour influence eye dominance in alignment tasks. Participants completed three VR alignment tasks. In each task, participants aligned a virtual cursor and target with their line of sight, requiring the choice of one eye, defined as the dominant eye, based on sighting dominance. The tasks are:

Task 1: Alignment of the cursor with the target at pseudo-random horizontal positions, inducing random saccades.

Task 2: Alignment of the cursor with targets presented sequentially, inducing sequenced saccades.

Task 3: Alignment of the cursor with dynamic horizontally moving targets, inducing pursuit movements.

3.1 Task

3.1.1 Task 1: Random Saccades. This task explored eye dominance behaviours across various horizontal viewing angles, focusing on which eye participants use for alignment. Figure 2 shows the setup: a virtual round target and a rectangular card (10×10cm) with a dynamic 3.2423° sized central hole, attached to the controller. This design mimicked the traditional hole-in-card method. Participants viewed the target through the hole while aligning the target, cursor, and one eye (e.g., right eye in Figure 2). The card forces people to precisely align one eye with the target, mitigating parallax issues.

Khan and Crawford placed targets with a diameter of 3cm at a 0.53cm distance from participants. We placed targets at 2m to ensure a parallax effect and out-of-reach placement. The targets' 3.2423° size was perceived as 3cm in the visual field.

Alignment was confirmed automatically after 100 consecutive frames of successful alignment. If participants broke alignment, the counter restarted. After confirmation, the target disappeared and reappeared at a new location. The locations of targets were repeated twice and presented randomly at angles from -30° to 30° at 2.5° increments along the horizon

Targets remained anchored to the head-mounted display (HMD) to ensure stable viewing angles, countering participants' head movements without requiring a chin rest. Participants were asked to remain seated and face forward. This procedure was repeated for both dominant and non-dominant hand alignment.

Together, we measured the eye used during alignment and had the following independent variables :

- Target angle: -30° to +30° in 2.5° intervals
- Hand used during alignment: dominant, non-dominant

3.1.2 Task 2: Sequenced Saccade. Task 2 explored whether previous target locations influence a switch in eye dominance by eliciting a sequence of saccades. It has a similar visual layout as task 1 (target size, target distance, card-with-hole, HMD-fixation of targets) but differs in target presentation.

The first target appeared at the outermost angle (-30° or 30°, depending on movement direction) and was termed the *reference target*. The next target appeared 2.5° closer to the opposite side, termed the *intermediate target*. The sequence alternated back to the reference target and continued this pattern, gradually moving to the opposite side while maintaining consistent spacing. This sequence continued until the final target appeared on the opposite side of the reference target. The procedure was repeated twice for each hand (dominant and non-dominant) and movement direction (left, right).

This task examines whether participants switch eye when moving from the reference target to the intermediate target. The independent variables were:

- Target angle: -30° to +30° in 2.5° intervals.
- Hand used during alignment: dominant, non-dominant
- Sequence direction: left-to-right, right-to-left

3.1.3 Task 3: Pursuit Eye Movements. Figure 3 shows the task layout. This task examined dominant eye behaviour during pursuit eye movements and whether participants switched eye dominance. Participants aligned a virtual cursor (white crosshair) with a target (yellow ring, size 3.2423° in visual angle), moving at a constant speed (6.5°/second) across the horizon. The crosshair replaced the hole-in-card because the card obstructed the target if alignment was lost, making realignment difficult. The target movement range started from -30° to +30° and vice versa, depending on movement direction and was HMD-fixed, as in tasks 1 and 2. A trial only began after successful alignment for 100 consecutive frames.

We studied if participants switched the eye used for alignment during the movement with the following independent variables:

- Hand used during alignment: dominant, non-dominant
- Target direction: left-to-right, right-to-left

3.2 Apparatus

The study tasks were presented in VR developed with the SteamVR toolkit in Unity 2022.3.15 on a computer with an Intel Core i7-12700KF CPU, 32 GB RAM, and an NVIDIA GeForce RTX 4070 GPU. We used an HTC VIVE Pro Eye VR headset for the study, with 110° diagonal FOV, 2880×1600 pixels resolution, and 90 Hz refresh rate.

3.3 Determining Eye Dominance

Figure 4 illustrates how eye dominance was determined using a geometric measurement without relying on hand movement after alignment within a trial. The centre of the left and right eyes are represented by *LE* and *RE*, respectively. *C* represents the centre of the cursor in VR (either the cross-hair or the hole-in-card centre, depending on the task), and *T* indicates the centre of the target. We used vectors from each eye's centre through C ($\overrightarrow{RE\,C}$ and $\overrightarrow{LE\,C}$) for

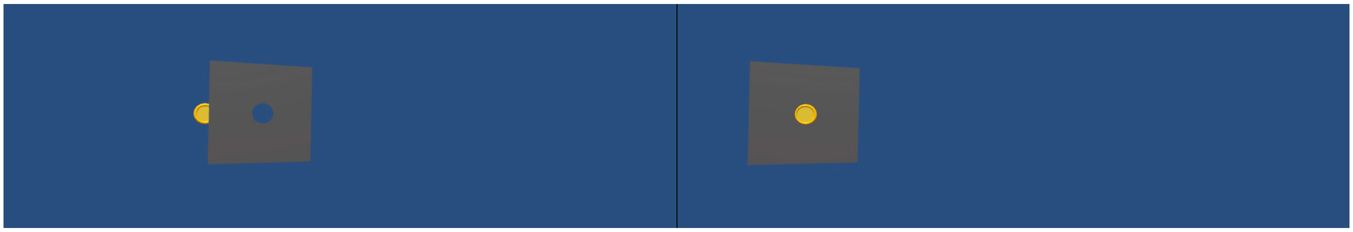


Figure 2: Left and right eye view in Task 1 – Random Saccades. This figure shows the participant's view during the task. The left panel displays the left eye's -, and the right panel shows the right eye's view of the yellow target. The grey card is attached to the cursor held by the participant. In this instance, the participant used their right eye to align the cursor with the target, indicating right-eye dominance during the trial.

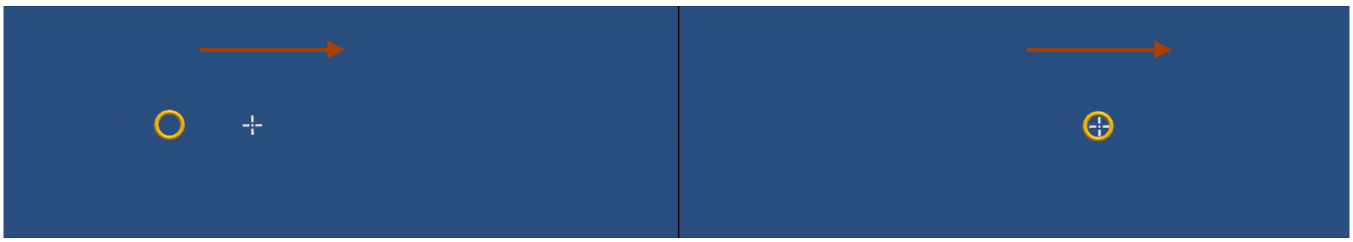


Figure 3: Left and Right Eye View in Task 3 – Pursuit Movement. The left panel displays the left eye's perspective, and the right panel shows the right eye's view. The yellow ring is the moving target, while the arrow indicates the direction of movement from left to right. The crosshair is the cursor controlled by the participant. In this instance, the participant used their right eye to align the cursor with the moving target, indicating right-eye dominance during the task.

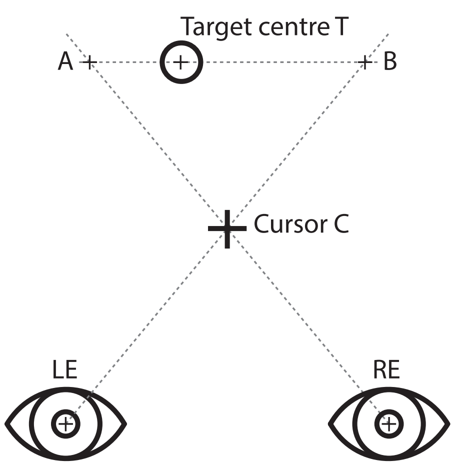


Figure 4: Distance-based measurement for eye dominance classification in VR. The distances from each eye-cursor ray ($\overrightarrow{RE\,C}$ and $\overrightarrow{LE\,C}$) to the centre of the target at target height are compared ($\overrightarrow{A\,T}$ and $\overrightarrow{B\,T}$). Here, $\overrightarrow{A\,T}$ is smaller, indicating right-eye dominance.

the calculation. A reference line parallel to $\overrightarrow{LE\,RE}$, passing through the target centre (T), intersects with these vectors. We then measured the distances between the T and the intersection points A and B. The dominant eye was identified as the one corresponding to the shorter distance, either $\overrightarrow{A\,T}$ or $\overrightarrow{B\,T}$.

We measured the interpupillary distance (IPD) to ensure accurate eye positions by photographing participants holding an 85mm card at eye level. A digital photo-editing tool (GIMP) was used to measure the number of pixels of the card length and of the IPD (from pupil to pupil). Using these values, the IPD was calculated with the formula:

$$IPD = \frac{85mm}{\text{Card } pixels} \times \text{IPD } pixels$$

The IPD and the HMD's position were combined to determine accurate eye positions, counter eye tracking inaccuracies, and ensure stable, consistent calculations during the experiments. Note that this study relies solely on positional data reported from the headset, the IPD, and the controller without the need for eye-tracking.

3.4 Procedure

Before participation, participants signed informed consent and completed a demographics questionnaire. IPD was measured, and tasks were explained. The HMD was adjusted by rotating the IPD knob to match the IPD. The study took on average a total of 45 minutes to complete.

To control for order effects, *task* order was randomized, and a 4 × 4 Latin square design was used for balanced condition presentation. After the experiment, we asked participants to complete the *Edinburgh Handedness Inventory* [22] to assess handedness strength. Sighting eye dominance was then tested using the miles-, hole-in-card-, and point-test.

Miles-Test: Participants overlapped their flat hands before them, forming a hole between thumbs and index fingers, and viewed the experimenter's nose through the hole while keeping both eyes open.

Table 1: Standard Eye Dominance Testing Results. Miles test and Hole-in-card test mostly agree. Point test differs slightly.

Method	Right Eye	Left Eye	Ambiguous or Equal Viewing
Miles Test	21	7	0
Hole-in-card Test	21	6	1
Point Test	14	8	6

The experimenter, standing 3m from the participant, noted with which eye the participant had aligned the hole in their hands.

Hole-in-Card Test: Participants held a 10×10cm card with a 2.5cm diameter hole in the centre with both hands, viewing a 3m distant target through the hole while keeping both eyes open. The participants took turns closing each eye one eye at a time and reported what they observed. Whenever the target was no longer viewed in the hole of the card, the closed eye was noted as dominant.

Point-Test: Participants were instructed to point at a 3m distant target with both hands. Identically to the hole-in-card test, participants had to close one eye and indicate whenever the target was no longer aligned with their pointing index fingers.

3.5 Participants

A total of 28 participants (11 female, 16 male, 1 non-binary, M=29.12 SD=8.02 years, age range: 20-48), recruited from our local university, participated.

Seventeen reported normal vision, and 11 had corrected vision (ensuring participants wore lenses to avoid discomfort in the HMD resulting from large frames). Most participants (26) were right-handed, with one left-handed and one ambidextrous, per the Edinburgh Handedness Inventory. Three eye dominance tests showed inconsistent results (majority right-eye dominant; see Table 1). Participants received £10 compensation. The university's ethics committee approved the study.

4 Results

We did not drop any data due to eye tracking. For tasks 1 and 2, we considered the last 30 out of the 100 frames to determine the eye used for alignment and calculated the mode (majority value). For task 3, no such calculation was possible, but switches in eye dominance were recorded. In tasks 1 and 2, we consider a single trial a saccade between two targets (the reference and intermediate target). A switch occurred if participants used a different eye to align the reference and intermediate target. In task 3, a switch is considered when the eye used for alignment changes during the pursuit movement.

4.1 Task 1: Random Saccades

Task 1 explored if and how the eye used to align depends on different horizontal viewing angles and the hand used for alignment during random saccades. Each of the 15 angles was visited four times, twice for each hand.

4.1.1 Influence of Hand and Target Angle. A binomial logistic regression was performed to determine the effects of hand use and horizontal viewing angle on participants' likelihood of using the right eye. Table 2 shows the results. The logistic regression model was not statistically significant, $\chi^2(2) = 3.518$, $p = .172$. The explained variation in the dependent variable based on our model ranges from 0.1% to 0.2%. The area under the ROC curve was .522 (95% CI, .498 to .546), which is a poor level of discrimination according to Hosmer et al. [9]. The binomial logistic regression model failed to find significant evidence that the predictors (hand used for alignment and horizontal viewing angle) reliably influence which eye a participant would use. This suggests that neither the hand used for alignment nor the horizontal target angle confidently predicted if a participant would use the right eye (or the left eye) in our task with random saccades.

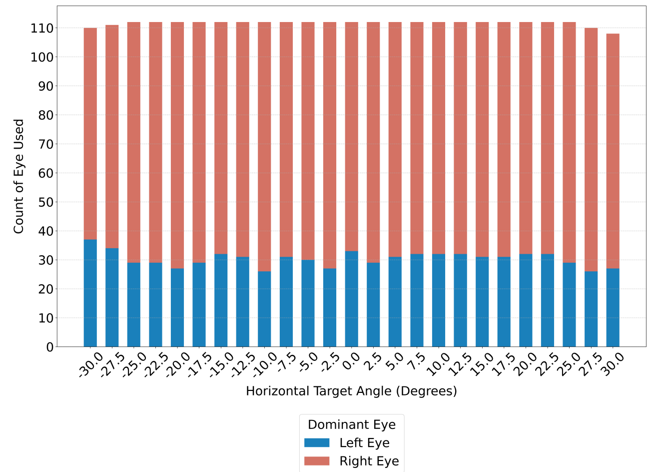


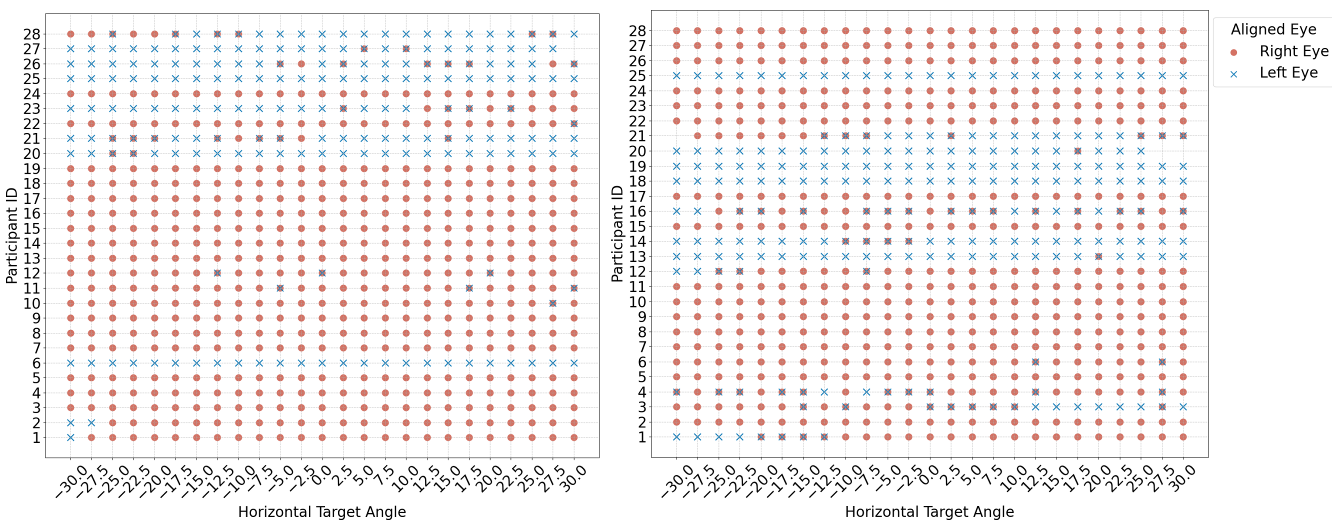
Figure 5: Task 1 – Distribution of left and right eye alignment across horizontal target angles for all participants, aggregated across both hands used. 112 trials were possible at every angle, but fewer trials were conducted at -30°, -27.5°, 27.5°, and 30° due to participants not seeing the target (it was at the edges of the field of view).

4.1.2 Eye used during alignment. Figure 5 illustrates the distribution of left- and right-eye usage during alignment at every horizontal target angle of all participants, irrespective of which hand is used. Across all angles, the right eye is used more often than the left when aligning a virtual card and target, with the right eye being used 72.81% of the time.

4.1.3 Change in Eye Usage per Angle. Each angle was visited four times to examine consistency in eye use for alignment. Figure 6 shows the eye used by participants for each angle, split by hand. Most participants used the right eye, with 89 discrepancies observed across two repetitions: 35 (5.01%) with the dominant hand and 54 (7.76%) with the non-dominant hand. While hand use is not a significant predictor, Figure 6a and 6b show salient differences in which eye participants use for alignment. Some participants consistently use their right eye (e.g., P7) or left eye (P25), and others showed very inconsistent behaviour (P21) or specific patterns (e.g., the influence of angle, P1). Some switched eyes depending on the hand used (P6, P13). Right eye alignment occurred in 74.32% of dominant hand trials and 71.23% of non-dominant hand trials.

Table 2: Task 1 – Binomial Logistic Regression. No independent variable was a significant predictor.

Variables in the Equation	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for Exp(B) Lower	Upper
Hand used for alignment	0.153	0.085	3.246	1	0.072	1.166	0.987	1.378
Horizontal target angle	0.001	0.002	0.269	1	0.604	1.001	0.997	1.006
Constant	0.909	0.059	235.773	1	<.001	2.483		



(a) Dominant Hand Used During Alignment **(b) Non-dominant Hand Used During Alignment**

Figure 6: Task 1 – Eye used for alignment over target angle for all trials per participant. Every icon covers 2 trials. ● shows the right eye has been used in the two trials. × shows the left has been used. ⊗ means there was no consistent usage.

4.2 Task 2: Sequenced Saccades

Task 2 investigated changes in eye alignment across horizontal angles, starting from the outermost angle based on movement direction, and whether the hand used for alignment and target angle predicted eye use during directed saccade sequences, unlike random saccades in task 1.

4.2.1 Influence of Hand, Target Angle, and Movement Direction. We ran a binomial logistic regression to determine the effects of target sequence direction, hand used, and horizontal viewing angle on the likelihood of using the right eye for alignment. Table 3 shows the results. The logistic regression model was statistically significant, $\chi^2(3) = 90.388$, $p < .001$. Movement direction did contribute significantly to the model ($p < .001$). The explained variation in the dependent variable based on our model ranges from 0.8% to 1.2%. The area under the ROC curve was .556, 95% CI (.544, .568), which is a poor level of discrimination, according to Hosmer et al. [9]. These results indicate that a rightward movement direction of the sequence is associated with the likelihood of using the right eye during an alignment task. Still, while rightward movement direction is significantly associated with right-eye usage, the overall predictive capacity of the model is weak.

4.2.2 Eye used during alignment. Figure 7 illustrates which eye participants use during the final alignment at the target. Across all trials, the right eye was used in 70.62% of trials for the left-to-right direction and 78.46% trials for the right-to-left direction. Vice versa, the left eye was used in 29.38% of trials for the left-to-right direction and 21.54% for the right-to-left direction.

4.2.3 Where do people switch eyes? Of all 5341 analyzed trials, 283 trials (5.29%) from 16 participants resulted in a switch. Of those, 130 (45.94%) led to a switch for left-to-right sequences and 153 (54.06%) in right-to-left sequences. Participants switch the eye they use for alignment at an average angle of -7.61° (SD=16.37) for targets starting right and moving left and at an average angle of 7.29° (SD=15.66) for targets starting left and moving right, regardless which hand was used. The average angle across all conditions is -0.77° (SD = 17.66). Table 4 shows these switches' mean horizontal angles by dominant hand and movement direction. Figure 8 illustrates how often and where participants switched eyes over the target angle and movement direction. The farther the target is from the start, the more switches we observe.

Table 3: Task 2 – Binomial Logistic Regression. Movement direction of the sequence predicts if participants use the right eye.

Variables in the Equation	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for Exp(B) Lower	95% C.I. for Exp(B) Upper
Hand used for alignment	-.061	0.043	1.971	1	.160	.941	.865	1.024
Movement Direction	-.336	.053	39.535	1	**<.001**	.714	.643	.793
Horizontal target angle	0.002	.001	3.845	1	0.050	1.002	1.000	1.004
Constant	1.150	.042	761.978	1	<.001	2.483		

Note: Eye dominance is for right-eyed, compared to left.

Figure 7: Task 2 – Distribution of left and right eye alignment by target angles, split by target sequence direction. Each angle and direction had a potential of 104 trials, though fewer trials were conducted at -30° and 30° due to visibility constraints.

Table 4: Task 2 – Average angle at which a switch in eye usage occurred, by hand used for alignment and sequential target movement direction. Rightward movements show larger switch angles than leftward movements.

Hand Used	Movement Direction	Switch Angle M (SD) [°]	N
Dominant	Left	-6.54 (17.00)	73
Dominant	Right	7.21 (15.41)	61
Non-Dominant	Left	-8.59 (15.59)	80
Non-Dominant	Right	7.36 (15.88)	69

4.3 Task 3: Eye Dominance in Pursuit Movements

Task 3 investigated eye dominance and switches during pursuit eye movements. Task 3 modifies task 2 by introducing continuous target movement (left-to-right and right-to-left movement direction), resulting in pursuit eye movements.

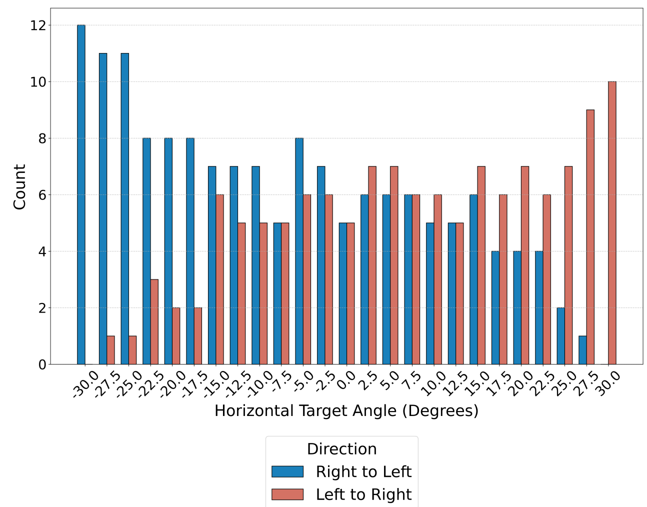


Figure 8: Task 2 – Counts of switches across all participants over a horizontal viewing angle, split by movement direction. The farther away the target angle is from the start angle, the more switches we observe.

4.3.1 Influence of Movement Direction and Hand. A binomial logistic regression determined the effects of hand used for alignment, target movement direction and horizontal target angles on the likelihood of aligning with the right eye, presented in Table 5. The model was statistically significant, $\chi^2(3) = 2656.51, p =< .001$). All independent variables contribute significantly to the model ($p < .001$). The explained variation in the dependent variable based on our model ranges from 1.4% to 2.1 %. The area under the ROC curve was .577, 95% CI (.574, .580), which is a poor level of discrimination, according to Hosmer et al. [9]. Within the context, the hand used during alignment, target movement direction, and horizontal target angle could — albeit poorly — predict whether a participant aligns the target with the right eye.

4.3.2 Eye used during alignment. In total, we observed a switch in 47 of 224 trials. These switches, or reversals of eye usage, were either permanent or not. Figure 9 illustrates representative examples of switches during pursuit movements. A *non-permanent* switch occurred in 15 of the 224 trials (6.69%). In these trials, participants switched their eyes temporarily. Six trials happened with the dominant hand and 9 with the non-dominant hand. Figure 9a illustrates

Table 5: Task 3 – Binomial Logistic Regression Task. Hand used for alignment, movement direction and horizontal target angle predicts if participants use the right eye.

Variables in the Equation	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for Exp(B)	
							Lower	Upper
Hand used for alignment	.183	0.011	294.788	1	<**.001**	1.202	1.176	1.226
Target Movement Direction	-.379	.011	1257.230	1	<**.001**	.685	.670	.699
Horizontal Target Angle	.010	.000	1100.705	1	<**.001**	1.010	1.010	1.011
Constant	1.161	.009	125295.081	1	<.001	3.193		

Note: Eye dominance is for right-eyed, compared to left.

Table 6: Task 3 – Average angle at which a switch in eye usage occurred, by hand used for alignment and target movement direction. Right-to-left movements show larger switch angles than left-to-right movements.

Hand Used	Target Movement Direction	Switch Angle M (SD) [°]
Dominant	Left-to-Right	-3.34 (19.22)
Dominant	Right-to-Left	-13.39 (14.76)
Non-Dominant	Left-to-Right	-2.88 (24.73)
Non-Dominant	Right-to-Left	-16.96 (4.11)

such a trial. A *permanent* switch in eye dominance during pursuit alignment tasks occurred in 32 (14.29%) instances across all 224 trials. Figure 9b illustrates a permanent switch in eye dominance. Of these cases, 14 (43.75%) trials were performed with the non-dominant hand. The remaining 177 (79.02%) trials presented consistent eye usage (cf. Figure 9c).

4.3.3 Where do people switch eyes? Of the trials displaying switches, whether temporary or permanent, the average horizontal angle where the switch happened was at -5.77° (SD = 19.77) For permanent switches, the average angle was -7.51° (SD = 18.14). It was -1.05°(SD = 22.75) for non-permanent switches. Table 6 lists the mean horizontal angles at which eye dominance switches occurred, grouped by hand used for alignment and movement direction. Left-to-right switch angles are directed slightly closer toward the centre than right-to-left angles.

5 Discussion

This work advances the fundamental understanding of eye dominance in HCI by examining how target and gaze behaviour influence eye dominance in alignment tasks. We analyzed whether and how the eye used for alignment changes between two consecutive trials. Participants completed three tasks to induce different eye movements — random saccades, sequenced saccades, and smooth pursuits — while we analyzed changes in eye usage across trials, considering factors like horizontal viewing angle, hand used for alignment, and target movement.

Results support the dynamic nature of eye dominance but also draw a more nuanced picture with less pronounced effects than prior research. Overall, we found that, while eye dominance does change for some participants, it is less dynamic than suggested by previous research. Across all tasks, participants exhibited few switches in eye dominance, measured via a change in the eye used during alignment. Regarding influential factors, neither angle nor hand used for alignment significantly affected random saccades. For sequenced saccades, only sequence direction had an effect; the hand used for alignment did not. The hand used for alignment, target movement direction, and target angle showed an effect for pursuit movements.

5.1 Relation to Previous Results

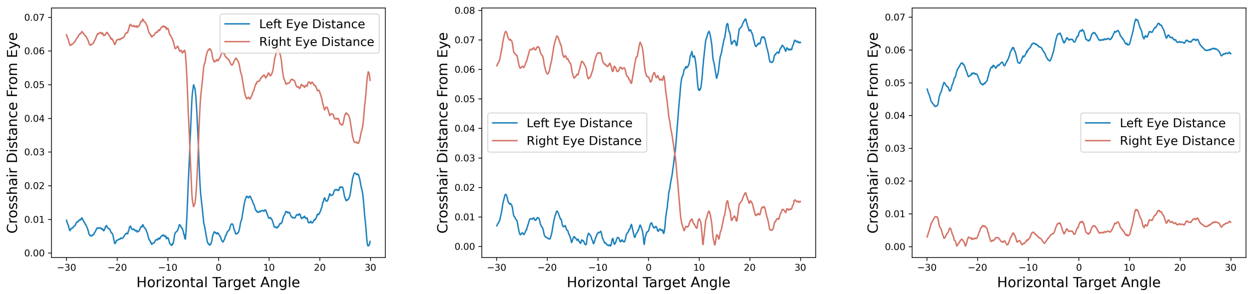
The results of our study conflict with previous findings, where eye dominance (the eye used for alignment) is predicted by horizontal viewing angle [11, 26]. In our work, the target angle does not predict eye dominance for random or sequenced saccades. A core difference between previous studies and ours is the smaller angle range in which we presented targets. When starting trials at the outermost angles, participants were most likely required to choose only one eye, as the other eye is unlikely to view the target. This makes switches in eye dominance throughout tasks more likely, particularly when gaze shifts increase in size (especially with VR-HMDs). In light of this, we assume that viewing angle, especially closer to the periphery, predicts eye dominance. The key takeaway is that eye dominance is dynamic and influenced by horizontal viewing angles, albeit less so when the range for random saccades is small.

Another difference is that the method used to determine eye dominance might influence the results. In prior work, participants had to move a controller and cursor [26] or their hand [11] along their line of sight from the target to the eye they had used for alignment. This motion might have additional unknown influences on eye dominance that are not part of our metric, which is purely based on geometry during alignment.

5.2 Eye Used During Alignment and Switch Location

Approximately two-third of trials showed participants using their right eye for alignment, consistent with our sample (two-third reporting right-eye dominance). Despite all but one participant being right-handed, handedness had little influence on tasks 1 and 2. Only in the more complex task 3, involving continuous motor tracking, did the aligning hand weakly predict eye usage.

Temporary switching in task 3 may result from parallax, leading to double vision for some participants and follow-up realignment. Overall, results suggest that assuming a static dominant eye (e.g.,



(a) (b) (c)

Figure 9: Task 3 – Single Trial Pursuit Data. a) Changes of eye usage between -10 and 0°, yet trial starts and ends with left eye usage. b) Trial starts with left eye usage and changes to right between 0 and 10°. c) A single trial with consistent right-eye usage.

post-calibration) is generally reliable. However, even strongly right-eye dominant participants occasionally switched to using the left eye and reverted. Such inconsistencies pose challenges for applications relying on stable eye dominance, potentially degrading user experience (e.g., by users detecting the lowered image quality in eye-dominance-based foveated rendering).

Similarly, the location of these switches varies greatly. For task 1, previous research suggests crossovers at around 3° for the left hand and -7° – -10° for the right hand for random target angles (although with different target distances) [26], aligning with results from task 2 but with less symmetry. In task 2 (sequenced saccades), the average switch angles are relatively symmetrical for movement directions (appr. ±7.5° from centre). Notably, the type of eye movement seems to be especially important. In task 3 (pursuit), a pronounced leftwards bias emerged, especially for targets moving from right to left (appr. -15° vs. appr. -3°). Neglecting such dynamics risks degraded user experiences, for example, in applications like VR games that rely on eye dominance for accuracy. First-person shooters, for instance, may benefit from accommodating eye dominance switches by relaxing assumptions of static eye dominance or symmetrical zones, especially in central and left-field regions.

5.3 Applications and Implications for HCI

Eye dominance has previously shown to enhance interaction techniques [8, 31] and rendering in HCI [4, 17]. Our results suggest further optimization potential. Although eye dominance exhibits general behavioural patterns, such as a shift to the left in switch location and a tendency to favour the right eye, several other factors influence which eye is dominant at any given moment, and this problem is multivariate. Therefore, we recommend avoiding reliance on fixed eye dominance or simple left/right switches. Instead, it is essential to consider factors such as target behaviour, eye movement, visual field angles, and potentially the hand used for interaction. This applies to a variety of applications:

Foveated rendering, a technique that prioritizes rendering resolution based on gaze direction, may face challenges due to this erratic and dynamic nature of eye dominance. A sudden shift in eye dominance can make a subsampling more noticeable, potentially disrupting the user experience. To address these issues, adaptive solutions are necessary to accommodate fluctuations.

Alignment-based interaction techniques, such as image-plane pointing and perspective pointing, might achieve better accuracy, usability, and comfort when considering the user's dominant eye and switches. With that, they can resolve pointing and selection actions better, leading to an overall improvement in user experience.

Similarly, content placement in occluded or crowded environments can be optimized to ensure that the currently dominant eye perceives critical elements more clearly or sees them first. Adapting these approaches dynamically in response to shifts in eye dominance can enhance interaction quality and may even prevent usability issues associated with mismatched visual alignment.

While more complex heuristics based on our findings are possible, developing a calibration procedure seems necessary.

5.4 Limitations and Future Work

This study faced limitations that inform future research. Hand tremors during alignment tasks may have impacted eye dominance accuracy, highlighting the need for hands-free or more robust methods. Additionally, task repetition might have led participants to rely less on eye dominance and more on behavioural cues like parallax and double vision. This suggests varied and sensitive task designs to capture eye behaviour nuances. Furthermore, only using horizontal viewing angles may limit the generalizability of our findings. Future research could benefit from larger sample sizes and incorporating factors like visual acuity to account for variability.

For future work, a potential direction could be developing a structural equation model (SEM) to assess the multivariate nature of the problem. This would provide a deeper understanding of the relationships between factors influencing eye dominance, such as target angle, hand used, movement direction, target size, target depth, and cognitive load. By modeling these factors within a unified framework, SEM could reveal their interactions, enabling more targeted and practical understanding and personalized user interface adaptations.

6 Conclusion

This work investigated factors influencing eye dominance switches in HCI and VR, studying the influence of horizontal viewing angle, hand used for alignment, and target-induced eye movements in three alignment tasks. Our findings confirm the dynamic nature of eye dominance but reveal fewer switches than previously suggested, with key influencing factors varying across tasks and target behaviour. Understanding the dynamic nature of eye dominance is crucial for optimizing user interface design, interaction and rendering, particularly in AR/VR environments. Our study challenges the notion of eye dominance as a static, predictable trait, demonstrating its variability. These findings underscore the need for adaptive HCI systems that account for eye dominance fluctuations and incorporate calibration, improving accuracy and user experience in VR and AR environments. This work opens pathways for developing adaptive HCI systems that personalize interactions based on individual behaviours. Key takeaways include integrating dynamic eye dominance into real-time designs, considering task-specific shifts for out-of-reach selection or foveated rendering, and further exploring how task complexity and eye movement patterns can optimize immersive system designs.

Acknowledgments

This work was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant No. 101021229, GEMINI: Gaze and Eye Movement in Interaction).

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