Patterns in Motion: On Head- and Non-Head Movers in VR during Viewport Control

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ABSTRACT

This paper explores user behavior in virtual reality (VR) environments, emphasizing the integration of idiosyncratic eye and head gaze for optimal user experience. Analyzing a gaze-based viewport control study dataset, we categorize users as head movers and non-head movers. In the study, participants were asked to align the viewport in VR so that a target is in the center. We tested three techniques: Controller Snap, Dwell Snap, and Gaze Pursuit, all using head and eye movement and showcasing particular behavioral patterns where some users prefer head movements, while others refrain from using head rotations for VR viewport control By that, our results point towards distinctive patterns of head- and non-head movers. The study highlights the need for personalized VR interfaces by considering these nuanced behavioral differences.

Index Terms: Human-centered computing—Human-Computer-Interaction—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Human-Computer-Interaction—Interaction paradigms—Virtual reality; Human-centered computing—Human-Computer-Interaction—HCI design and evaluation methods—User models;

1 INTRODUCTION

Understanding how users engage with virtual reality (VR) environments is imperative for optimizing the overall user experience (UX). Behavioral insights derived from user interactions can guide the refinement, adaptation, and design of user interfaces and interaction techniques in VR settings. Recent advancements in gaze-based interaction techniques have underscored the significance of integrating eye and head gaze, for enhanced user engagement (e.g., Sidenmark et al. [19]). Thus, It is relevant to understand specific user characteristics to design these techniques optimally.

Emerging evidence suggests that users exhibit varying preferences in utilizing their heads (and eyes) during VR interactions [18]. For example, while most users predominantly employ both head and eye movements during VR interactions, at times, the eyes would contribute >90% of the movement and would move ahead of the head, requiring the eye to wait for the head to catch up [18]. Meanwhile, some users rely heavily on head movements and show aversion to using a wider eye motion range, instead preferring to use head movements significantly more [18]. This observation motivates further exploration into user preferences.

Following up on this, we present the outcomes of a secondary analysis performed on a dataset gathered in a study that explored gaze-based viewport control. In the original study, participants had to align the viewport so that the center aligns with a target. They used three techniques for viewport control: Controller Snap, Dwell Snap, and Gaze Pursuit. All of the techniques require some amount of head and eye movement to complete the task, but can significantly reduce the amount of head movement. The techniques are further explained in Sect. 3.1. With the secondary data analysis, we aim to highlight nuanced behavioral patterns exhibited by users that we categorize as head movers and non-head movers.

Our results highlight the fact that there are distinctive patterns characterizing users: First, during VR viewport control, those who barely use their head for viewport control but instead rely on the interaction techniques: non-head movers. Second, those who do apply head rotations during viewport control in addition to the interaction techniques, but rely on head rotations significantly more than the rest: head movers.

By delving into these user-centric distinctions, we contribute valuable insights that can inform the design and implementation of personalized and user-friendly VR interfaces and foster research into behavioral idiosyncrasies in VR.

2 RELATED WORK

2.1 Viewport Control

Viewport control techniques were initially devised to address the limited field of view (FOV) in early head-mounted displays [9]. Early methods employing controllers allowed easy viewport adjustment with minimal head movement [11], remaining popular today for their efficiency in navigation [16]. Hands-free approaches, particularly *head amplification*, amplify head movements, enabling users to reach beyond physical limits [22, 15, 14, 9, 20, 10]. Other research about viewport control explored systems automatically controlling the user's viewport in storytelling settings [8]. Additionally, techniques expanding the user's field of view with a 360° camera [2] or overlapping multiple views [17] have been proposed.

Generally, gaze has received little attention for viewport control. Some previous work utilized gaze for locomotion direction (e.g., Pai et al. [12]). We studied gaze-based viewport control techniques and, in this paper, present the results of a secondary analysis investigating head movers and non-head movers.

2.2 Non-head vs. Head movers

Many prior works have shown that there exists a large variance in the tendencies of individuals to move or rotate their heads during gaze shifts [5, 6, 7, 13], A distinction between "head movers" and "non-head movers" has also been proposed in several prior works [1, 3, 6], with "head movers" being individuals that have a larger tendency to move their heads during gaze shifts, and "non-head movers" being individuals that have a lower tendency to move their heads during gaze shifts. These different head movement tendencies have also been observed to carry over from controlled to real-world settings [21].

Likewise, in VR, gaze shifts are performed similarly as in reality [18], and these head movement tendencies are likely to persist in VR. As such, these idiosyncratic tendencies will affect the design of any head or gaze-based interactions in VR as the head and eye behavior of head movers and non-head movers would vary. However, little research has been done to investigate (or classify) head movers and non-head movers in VR settings.

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We pick up on this and outline that these "head movers" and "non-head movers" tendencies are indeed present in VR and affect VR head or gaze-based interactions.

3 Study Description

In the original study, participants were required to align the viewport using their gaze (head and eye rotations) horizontally with a target (either precise or coarse).

We utilized an abstract task towards known and unknown directions, varying by possible angles (or amplitudes). Inspired by Cao et al. [4], seated participants in VR rotated the viewport to bring a target (a pillar) into view. Coarse alignment required them to align the pillar within 20° of the FOV's center, while precise alignment required them to align it precisely with the viewport's center (details in Sect. 3.2).

In our within-subjects study, we investigated four factors: the viewport-control technique (cf. Sect. 3.1), level of control (precise and coarse), prior knowledge of the target (yes/no), and amplitude between targets (15°, 30°, 45°, 60°, 120°, 180°). Participants underwent sets of trials for each technique, encompassing 12 alignments per set and 10 sets overall, resulting in 120 alignments per block. The entire experiment comprised three blocks, totaling 360 alignments per participant.

3.1 Techniques

In the study, we provide three different techniques to rotate the viewport. The techniques allow participants to look around them without moving their heads. However, head movement was not restricted during the study, allowing participants to use their heads to look around as much as they wished.

3.1.1 Controller Snap

Controller Snap is a commonly available technique in many consumer VR experiences. With this technique, a controller rotates the viewport by a fixed amount, triggered via a button press. We recreated this technique identically to SteamVR[1], where the viewport rotates instantaneously by 45° in the direction of a button press.

3.1.2 Dwell Snap

Dwell Snap is a modified version of Controller Snap. Instead of a button press to trigger a viewport snap, it uses the horizontal eye-gaze angle as a trigger. If the horizontal eye-gaze angle is above 25° for at least 400ms, a viewport snap of 22.5° in the eye-gaze direction is triggered. The viewport will continuously snap in the same direction for each subsequent 200ms where the horizontal eye-gaze angle remains above 25°. This continuous snapping ends when the horizontal eye-gaze angle moves back within the central horizontal angular area of [-25°;25°].

3.1.3 Gaze Pursuit

Gaze Pursuit works by rotating the viewport proportionally to the horizontal eye-gaze angle. When a point of interest comes into view, and the user wants to stop, they naturally fixate on it and smooth pursuit towards the center of the viewport. This causes their horizontal eye-gaze angle to reduce, eventually slowing the viewport rotation to a stop so that the point of interest is in the FOV. To avoid accidental rotations, a deadzone of [-5°;+5°] exists in the center of the FOV.

3.2 Task

1 illustrates a trial for the coarse alignment task. Participants align their torso, head gaze, and eye gaze to a designated target (A) before performing three viewport alignments. In each trial, they search for the initial target, align the viewport within [+20°; -20°] of the FOV center, and confirm with a button press (B, C). Incorrect alignments prompt red highlights, requiring participants to realign.

Subsequently, participants locate a second target without prior knowledge (D) and then return to the initial target's position (E). A button press confirms each alignment. The angular distance between the start and second targets defines amplitude. Targets are 3 meters away, appearing as 2° visual angle cylinders. In the precise alignment task, alignment is correct if the FOV center is over the pillar.

3.3 Procedure

First, the experimenter welcomed participants, explained the study's purpose and procedures, and obtained consent. Participants signed a consent form and completed a demographics questionnaire covering age, gender, vision, video game experience, VR experience, and eye tracking experience (all with never, rarely, monthly, weekly, daily). Next, participants were guided to a stationary seat, adjusted the VR headset, and underwent eye-tracking calibration. Task conditions were performed one technique at a time (Controller Snap, Dwell Snap, Gaze Pursuit) in counterbalanced order using a balanced Latin square. Note, in the original study, two more techniques were part of the experiment, but they were, per design, unsuitable to explore head and non-head movers as they heavily promote the usage of head movement. Before each technique, participants received an explanation and had a chance to practice. Then, they performed a set of alignments. After each set, participants removed the VR headset and completed questionnaires. Participants could take a break whenever they wanted. After completing all sets for each technique, participants shared their opinions, and the study ended (appr. duration was 90 minutes).

3.4 Apparatus

We used Unity 2021.3.14f1 and the HTC VIVE Pro Eye VR (110° diagonal FOV, 2880×1600@90Hz). The application ran on a desktop PC (Intel Core i7-12700 CPU, 16 GB RAM, and an NVIDIA GeForce RTX 3070 Ti GPU).

3.5 Participant Demographics

We enrolled 20 participants (10 self-identified as male, 10 as female; M_{age}=27.2 years; SD=7.43) from a local university, with one dropout. Participants had diverse vision conditions (10 normal, 2 corrected with lenses, 8 with glasses). Video game habits varied: 9 rarely played, 3 played monthly, and 5 played daily. VR experience ranged from none (2 participants) to rare (15 participants). Regarding eye tracking, 11 had no experience, 7 had rare, and 2 had monthly usage. Compensation was a 10 GBP Amazon voucher. Notably, one participant with slight astigmatism had clear VR vision, and another reported autism. The university's Institutional Review Board approved the study.

3.6 Measures

We measure cumulative eye yaw and cumulative head yaw per alignment. For this, we sum up the inter-frame angular yaw difference from the start of an alignment task to the end of an alignment task.

4 Results and Discussion

While analyzing the original study's data, we discovered some of our participants seemed to have completed the alignment tasks distinctly. Analyzing the data, we detected head-movers and non-head movers. Head movers are participants who are more inclined to rotate their heads to perform viewport alignment. Non-head movers

[1] https://store.steampowered.com/app/250820/SteamVR/, SteamVR (2023-09-04)

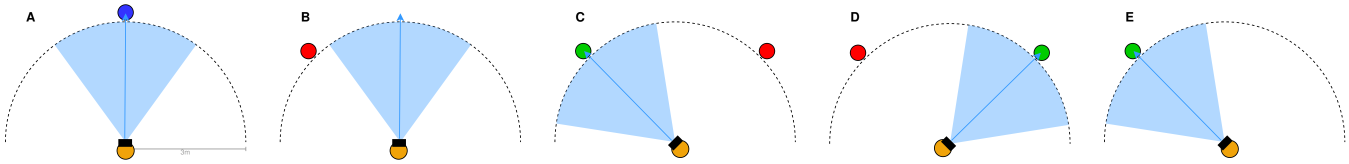


Figure 1: Schematic overview of the alignment task. A: Participants first perform an initial alignment. B: The participant searches for the start target randomly located at their left. C: The participant has aligned the viewport and confirms. D: The participant selects the second target. E: The participant selects the first target again, which ends the task sequence. The target in E is at the same location as the target in C, and the user has to rotate the viewport to select it again.

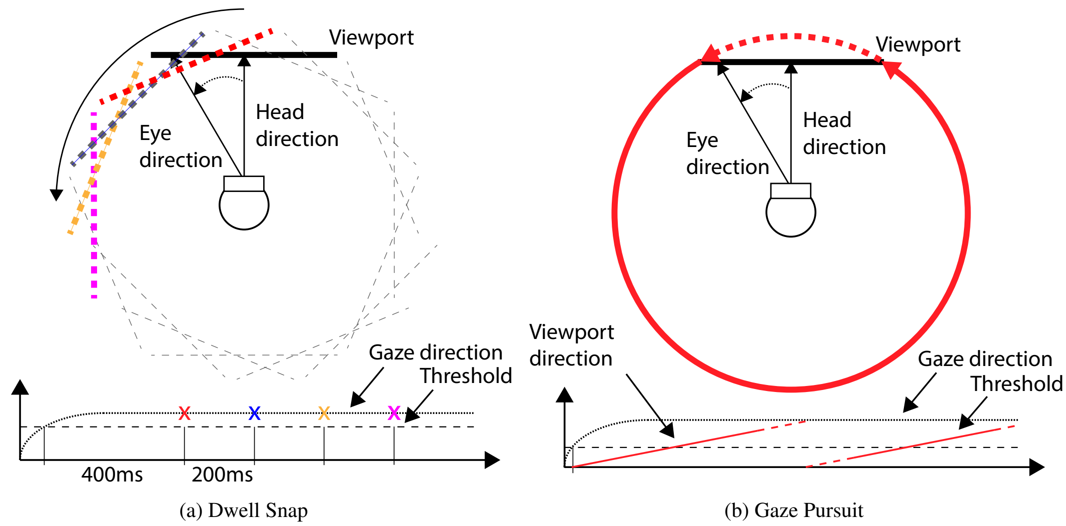


Figure 2: Viewport Control with dwell snap and gaze pursuit. Dwell Snap is illustrated by Figure (a). It shows the top-down view of a user with the head looking forward and the eyes looking to the left. If the eyes' yaw angle crosses a threshold and stays there for 400 ms (see graph at the bottom), the viewport snaps once in this direction (first "x" in the graph). Follow-up snaps take only 200 ms if the eyes stay in this area (second to fourth "x"). Dashed lines indicate viewport positions. Figure (b) shows the working principle of Gaze Pursuit. Here, the user's gaze crosses a threshold, and with that, the viewport starts rotating (red arrow) until the gaze returns to the central field of view. The red lines in the graph correspond to the viewport rotation, whereas the black line corresponds to the eye direction

are participants who are less inclined to rotate their heads to perform viewport alignment, instead opting to utilize the alternate methods provided (Controller Snap, Dwell Snap, Gaze Pursuit) to complete the viewport alignment task. Note it is not possible to sort all 20 participants into either the head mover or non-head mover category. This suggests that head mover and non-head mover do not form two groups or distinctions but exist more as a spectrum. In the following, we describe and characterize our head and non-head movers (potentially the ends of the spectrum).

4.1 Characterising Head and Non-Head Movers

From 20 participants, we found 6 who exhibited clear patterns — 3 head movers and 3 non-head movers. Differences exist for the remaining 14 participants but are less prominent and salient.

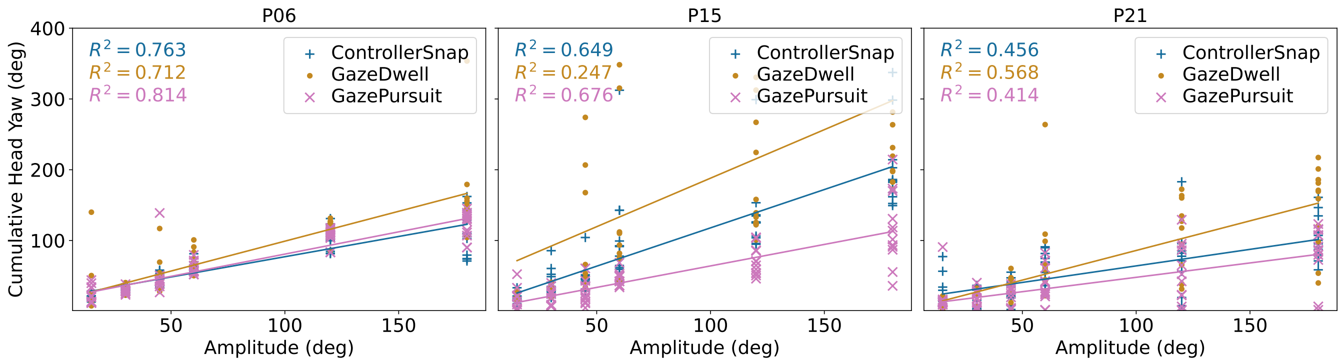
Figure 3 shows the cumulative head yaw angle per selection amplitude (the angle between Figure 1C and Figure 1D) separated by technique for head movers (Fig. 3a) and non-head movers (Fig. 3b). For head movers, the figure shows that head movement increases for larger selection amplitudes (farther away targets). Note participants could have rotated the viewport to those targets with little head movement using Controller Snap, Dwell Snap, or Gaze Pursuit. Still, they chose to use head movements. On the contrary, participants' behavior illustrated by non-head movers shows that P05, P16, and P22 rotate their heads barely, irrespective of selection amplitude. These participants heavily relied on the individual techniques (Controller Snap, Dwell Snap, and Gaze Pursuit) to do significant rotations and only used their heads for minor adjustments.

With that, we can attempt a definition of head mover and non-head mover as follows:

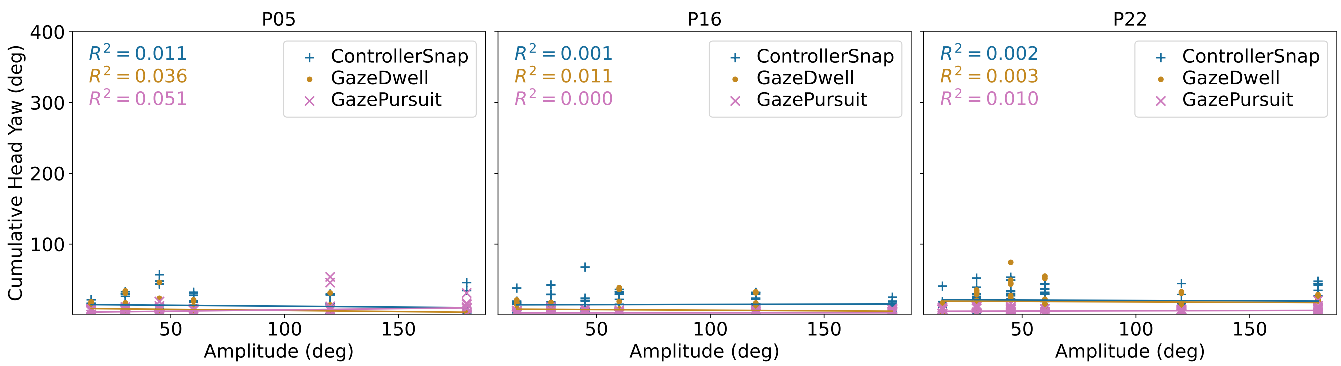
- For **Head Movers**, there is a positive relation between selection amplitude and cumulative head yaw. The relation between both has a relatively high goodness of fit (indicated by R^2 and a Least Square linear regression). In other words, cumulative head movement for a selection is largely predicted by selection amplitude.

- For **Non-Head Movers**, the relation between selection amplitude and cumulative head yaw is weak or non-existent. This means their coefficient of determination (R^2) after a least square linear fit is small. In other words, cumulative head yaw for a selection is barely predicted by selection amplitude.

Following this definition, the different characteristics between the two groups can be seen in Fig. 3a and Fig. 3b. Figure Fig. 3a shows that for the three head movers, regardless of which technique is provided, their trend line has a positive gradient and has a relatively high R^2 value. Meanwhile, Fig. 3b shows that for the three non-head movers, regardless of which technique is provided, their trend line has a very low R^2 value and is almost flat.



(a) Head Movers.



(b) Non-head Movers.

Figure 3: Cumulative **head yaw** per individual selection.

A less salient and prominent but similar difference can be made for eye movement as indicated by Fig. 4a and Fig. 4b. The linear regression shows relatively high goodness of fit for head movers between cumulative eye yaw and selection amplitude, indicated by $0.688 \geq R^2 \geq 0.253$. This suggests an increase in eye movement with selection amplitude (note that for head movers, the head movement also increases with selection amplitude). One reason for this is that increased head movement leads to more stabilizing movements of the eyes, which increases cumulative eye yaw. For non-head movers, the amount of eye movement per selection is barely explained by selection amplitude for controllers snap and Dwell Snap, indicating that participants rely more on the technique. Only for Gaze Pursuit the eye movement increases with the selection amplitude. This is expected as with Gaze Pursuit, the viewport rotation depends heavily on eye movement (confirming that non-head movers would instead use the technique rather than move their head).

These effects could also be seen using least squares polynomial regression.

4.2 The implications of head and eye movers during viewport control

Our findings extend previous work on head movement tendencies and reveal variations in how users explore virtual reality (VR) when exposed to various viewport rotation techniques. These individual idiosyncrasies are independent of techniques for some user groups: the head and non-head movers. Therefore, optimal VR experiences should accommodate these nuances by providing alternate techniques for viewport control.

Based on that, the ability to tailor interaction preferences is crucial. Customizable settings would enable a personalized experience aligned with individual comfort and natural tendencies. This flexibility promises to optimize user satisfaction and overall usability.

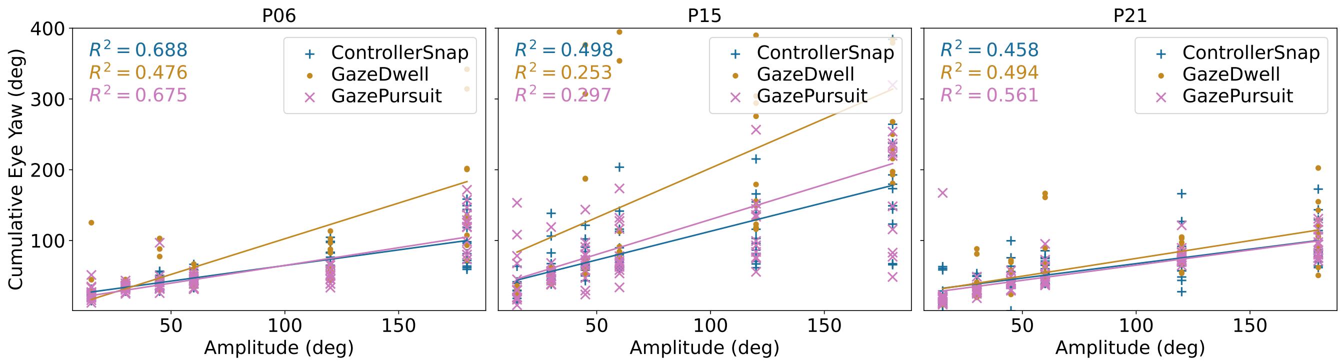
One practical approach involves investigating and incorporating automatic calibration (potentially happening during eye tracking calibration), determining whether users are head movers, and preselecting the most suitable technique. Alternatively (or additionally), users could be offered to manually select their preferred technique through application settings, offering a dual customization option.

Such customization options could enhance the application's ergonomic use, fostering enjoyment and adoption, especially in entertainment applications. They can also potentially improve efficiency in various applications, including productivity and professional experiences.

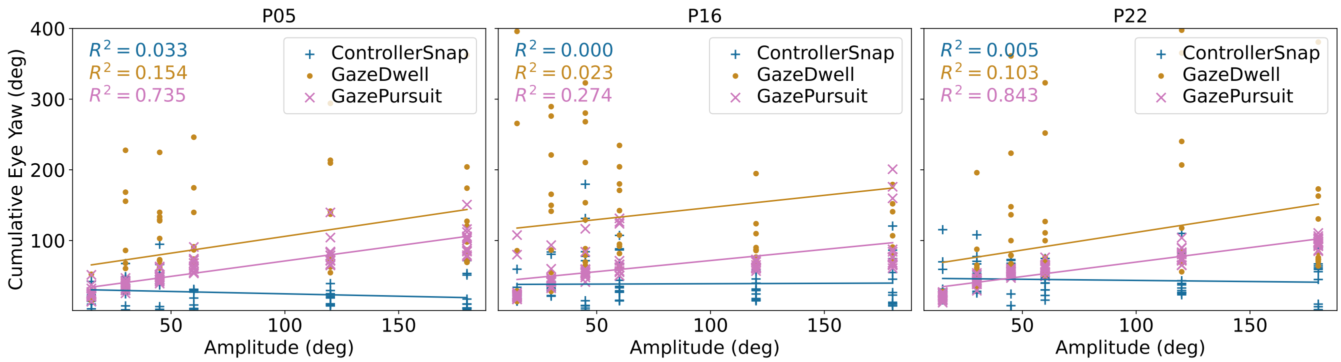
4.3 Selected Research Directions

Acknowledging that head and non-head movers exist on a spectrum raises questions about the applicability of techniques relying solely on eye-angle without considering head movement (not only viewport alignment but also others, such as selection). Conversely, it implies potential for improvement in all head-only techniques by incorporating considerations for eye movement. This challenges traditional assumptions about the dichotomy between head and eye movement, suggesting that a nuanced approach combining both may unlock enhanced user experiences and interaction efficiency.

The characteristics of VR HMDs also introduce additional complexity for other tasks. How much does wearing VR HMDs affect head and non-head movement tendencies, considering factors like HMD weight and limited field of view (FOV)? Does the influence differ between the two groups, with, for example, HMD weight potentially affecting head movers more and limited FOV posing unique challenges for non-head movers? Understanding the intricate relationship between VR technology and user preferences becomes



(a) Head movers.



(b) Non-head movers.

Figure 4: Cumulative eye yaw.

imperative for designing immersive experiences while catering to diverse movement tendencies.

5 Conclusion

This paper explored user behavior in VR, explicitly focusing on gaze-based viewport control. Two user groups — head movers and non-head movers — exhibit distinct patterns in their approach to VR interactions. Head movers show a positive relation between head movement and selection amplitude, while non-head movers rely more on provided techniques than head rotations. Eye movement patterns also differ, with head movers displaying an increase in eye movement with selection amplitude, whereas non-head movers' eye movement is less predictable. These findings contribute to understanding head movement tendencies in VR and emphasize the importance of personalized VR interfaces to cater to diverse user preferences and enhance overall user experience.

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