Interaction of Cursor Warping and View Manipulation in Multi-Display Extended Reality

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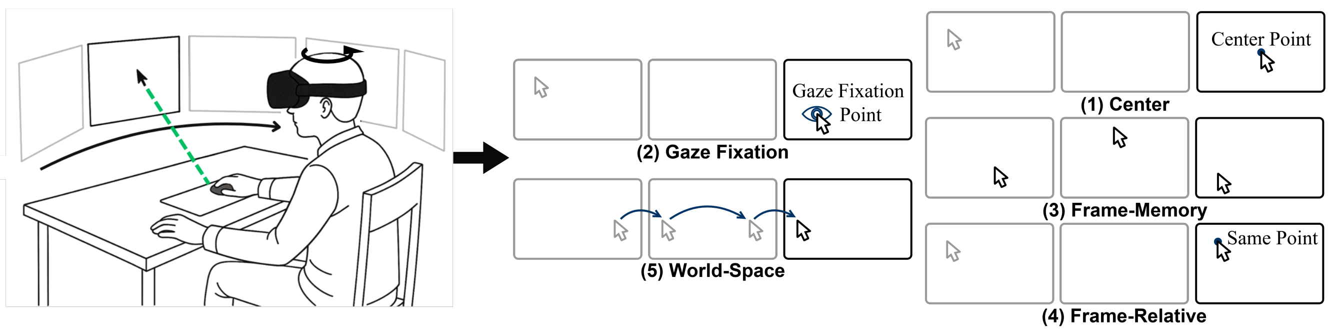

Figure 1: Cursor warping strategies when switching input focus between adjacent displays in XR: (1) Center: the cursor always reappears at the centre of the new display. (2) Gaze-Fixation: the cursor appears at the user's gaze landing point (first fixation) on the target display. (3) Frame-Memory: each display maintains its own cursor, and warping activates the target display by restoring its cursor (i.e., the last remembered position on that display). (4) Frame-Relative: the cursor appears at the same relative position it was in on the previous display. (5) World-Space: the cursor moves continuously across adjacent screens and keeps its current position when switching.

Abstract

Extended Reality (XR) headsets enable large, reconfigurable multi-display workspaces and support view manipulation, allowing the workspace to reposition itself around the user. Cursor warping similarly reduces traversal distance and pointer search by reinitialising the cursor at defined locations. Yet when both mechanisms operate together, the spatial relationship between user, displays, and cursor becomes dynamic, and it remains unclear how cursor repositioning behaves when the workspace itself moves. In a study (N=20) of five cursor-warping strategies with two view manipulations, we show that the benefits of both do not automatically combine: workspace motion can disrupt spatial consistency and alter both performance and movement costs. We show that continuous cursor movement in world space is limited compared to alternative warping techniques, and cursor behaviour and view control are tightly coupled. Hence, cursor initialisation and view manipulation must be co-designed to support efficient and comfortable interaction in XR multi-display environments.

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CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**; *Virtual reality*; *Mixed / augmented reality*.

Keywords

Cursor, Viewport, Desktop, Gaze-based Interaction, Augmented Reality, Virtual Reality, Human-Computer Interaction

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1 Introduction

Extended reality (XR) headsets are increasingly positioned as productivity devices as they provide a large, reconfigurable workspace without the physical constraints of multi-monitor hardware [15, 36, 39]. XR affords portability, privacy, immersion, and focus for knowledge work [16, 42], as well as flexible arrangement of virtual displays in space around the user. Unlike in a physical space, where users must fully turn to a display for interaction, XR also makes it possible to manipulate the user's view, and have the workspace turn toward the user in accordance with their attention [21, 27]. This can reduce users' effort in working across virtual screens and extend the range around themselves that users can leverage for placing comfortably reachable windows, thereby scaffolding multitasking and productivity. However, while this introduces greater flexibility for multi-display work, it is not clear how best to support input across virtual screens in an XR environment.

In this work, we investigate cursor input across virtual screens and how cursor strategies interact with view manipulation. In XR, it is possible to have a cursor in *world space* for continuous movement from screen to screen, or alternatively a *screen-based* cursor that is warped from one screen to the next in accordance with the user's attention [44]. Before XR, cursor warping has been studied extensively in physical multi-monitor environments. Benko et al.'s Multi-Monitor Mouse (M3), for example, showed that performance is strongly influenced by how and where the cursor re-enters the target display [6]. Their techniques operate with a screen-based cursor, where the pointer is defined in the 2D coordinate frame of each physical monitor rather than a single global workspace. When users move to another display, the cursor is re-initialised at a defined location on that screen (e.g., its center, last remembered position, or a frame-relative location), reducing search effort and long cross-display traversals. Beyond these screen-based techniques, MAGIC pointing and related works [1, 50] introduced *gaze-based* cursors that have shown that gaze or head direction can inform cursor repositioning and help reduce search effort. Together, this line of work established cursor warping as a key factor in efficient cross-display interaction on the desktop.

XR brings these ideas into a different setting, where virtual displays can be arranged freely in 3D and span much wider fields of view than traditional monitor arrays. This flexibility comes with challenges not present in physical setups: display borders can be discontinuous or non-planar, cursor travel distances can be substantially larger, and cursor initialisation during display switching becomes less predictable [4, 37]. In addition, the position of displays can change dynamically as a result of view manipulation. Techniques such as Boundary-Switching, introduced by McGill et al., rotate the virtual display array opposite to head yaw, to keep more content in view and reduce neck rotation [27]. Because the workspace can move relative to the user, the spatial relationship between head movement, visual frames, and cursor position can shift dynamically, making traditional cursor mappings potentially more fragile; a cursor strategy that might be efficient with screens fixed in the user's space might not be as efficient when used in conjunction with view manipulation.

The main contribution of this work is a study of cursor warping strategies for cross-display work in XR, and their interaction with view manipulation. We compare five cursor warping techniques: World-Space (continuous movement), Center, Frame-Memory, Frame-Relative, and a gaze-initialised technique, Gaze-Fixation (inspired by MAGIC [50], and evaluate each technique under two view conditions: a standard 1:1 view in which displays are fixed in world space and Boundary-Switching, where displays counter-rotate with head-yaw. We provide open-source code, a demo Unity project, a video figure, and the raw data for further experimentation.[1] Our results show that these mechanisms are interdependent in XR multi-display workspaces and lead to key novel insights:

- There is a fundamental trade-off between task time and movement cost, shaped by view manipulation and cursor warping.
- World-Space warping is limited compared to screen-based and gaze-based warping techniques.
- Cursor behaviour and view control are tightly coupled and should be designed jointly for efficient and comfortable interaction in XR workspaces.

2 Related Work

2.1 Pointing in Multi-Monitor Workspaces

A consistent finding across research on physical multi-monitor setups is that cross-display pointing performance is largely determined by how the cursor is re-initialised when users move between displays. Early work showed that long pointer trajectories across bezels or heterogeneous resolutions often cause users to lose track of the cursor and spend extra time recovering it [4, 5]. Subsequent studies on tiled and large display environments further reported that discontinuities at screen borders, unexpected pointer jumps, or occlusion can increase search effort and degrade selection accuracy [13, 30, 47]. Even locating the pointer can become a task in itself when transitions involve peripheral or distant screens [12], and cross-display navigation often induces additional head and body rotation [2, 22, 41]. These challenges motivate techniques that reduce traversal distance and make the cursor's entry position more predictable.

To address this, perspective-aware systems, such as E-Conic, have shown that correcting for the user's viewpoint improves interaction across heterogeneous displays [31]. Benko's Multi-Monitor Mouse (M3) further introduced screen-based cursor warping, demonstrating that performance strongly depends on where the cursor appears on the next display [5, 6]. Their evaluation compared three families of placement strategies that directly inform the Center, Frame-Memory, and Frame-Relative techniques used in our study [5, 6]. These strategies substantially reduce search effort and cross-display travel compared to World-Space movement, where the cursor simply continues across monitor boundaries without reinitialization. Beyond these screen-based methods, researchers explored gaze- and head-based warping, demonstrating that visual attention can provide an effective cue for cursor placement. MAGIC pointing and Ashdown et al.'s work showed that warping the cursor toward the user's gaze or head direction reduces acquisition time and further minimizes pointer search [1, 50], serving as the foundation for our Gaze-Fixation technique.

Prior work demonstrates that the timing and placement of cursor warping are central design levers for efficient cross-display cursor interaction. However, all prior work assumes displays remain fixed relative to the user. This assumption no longer holds in XR, where view manipulation techniques dynamically alter the spatial relationship between the user, the displays, and the cursor (see

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subsection 2.3). Consequently, it remains unclear how established cursor warping strategies behave when coupled with a workspace that responds to the user's movements.

2.2 XR Workspaces as Virtual Multi-Display Environments

Recent work extends these ideas into XR, where head-mounted displays can render large virtual workspaces that function as portable, virtual multi-monitor setups. A range of works demonstrate that virtual monitors can offer comparable or greater screen real estate than physical displays while supporting productivity in constrained settings such as public transit or shared offices [7, 27, 28, 33]. These studies also emphasise privacy and the ability to shield sensitive content from bystanders [28, 33]. Although XR systems are increasingly supporting mid-air and hand-based interaction, recent evidence suggests that users performing productivity tasks still rely heavily on physical keyboards and mice. This is due to users being familiar with it, but mouse input has been shown to support effective 3D target acquisition in XR [51]. Long-term field studies report that XR users commonly pair headsets with traditional input devices for text editing and multi-window work [8]. To support these workflows, toolkits such as WindowMirror integrate desktop windows and traditional input into XR, streaming 2D applications into an egocentric virtual multi-monitor layout, for example, WindowSpace [9]. Recent systems have also investigated cursor control across spatially distributed two-dimensional windows in XR but assume a stable spatial relationship between the user and the workspace [20, 26]. In contrast, we consider cursor warping in interaction with view manipulation.

Layout studies compare large continuous canvases with subdivided, multi-monitor–style configurations in XR. Continuous canvases offer flexible window placement and can reduce extreme head rotations, whereas structured multi-display arrangements support faster window organization [37, 38]. Horizontally arranged displays further help maintain peripheral awareness without harming primary-task performance, enabling lightweight background monitoring [23]. Such arrangements also align with users' preference for symmetric configurations [24]. Extending this line of work, rather than a large continuous canvas, McGill et al. designed horizontally arranged virtual displays to study rotational assistance and peripheral access in wide virtual workspaces [27]. In our work, we adopt a similar horizontally structured virtual multi-display setup to integrate and evaluate Boundary-Switching under comparable conditions.

2.3 View Manipulation in XR

As virtual workspaces expand beyond the immediate field of view, users must rotate their heads substantially to access peripheral content, creating an ergonomic burden in knowledge work that persists over time [24, 35]. To increase the portion of the workspace that can be inspected with limited physical motion, several studies apply rotation gains that amplify head movements, showing that small to moderate gains can reduce effort, whereas larger gains often lead to disorientation and degraded spatial knowledge [14, 40]. McGill et al. applied a 2.0 counter-rotation gain to substantially reduce required head rotation when accessing wide virtual workspaces [27]. A complementary line of work investigates discrete "snap" rotations and translations, which can substantially lower cybersickness scores without measurable costs to task performance [11]. Other techniques use controller-driven [45], gesture-based [18], and gaze-based view manipulation [21], collaborative viewpoint sharing [46], or oscillatory camera motion that simulates walking [29], each targeting different application contexts with mixed effects on comfort and performance.

Within this broader landscape, McGill et al. introduce counter-rotational workspace motion as a view manipulation technique for XR multi-display environments. Their first implementation applies a continuous counter-rotation gain, rotating the virtual workspace opposite to head yaw so that more content remains in view with smaller physical rotations. To improve comfort in seated, wide-display scenarios, they further propose Boundary-Switching, where rotation is triggered only when the user's head gaze crosses a display boundary, thereby creating a larger dead zone and reducing unnecessary motion [27]. O'Hagan et al. extend this boundary-triggered approach to additional axes and layouts, reporting ergonomic benefits and reduced workload across a range of virtual workspace configurations [34].

However, the implications of view manipulation for fine-grained pointing remain underexplored. Studies on rotation gain and induced jitter suggest that while moderate gains may leave overall task performance unchanged, they can impair spatial knowledge, and that unintended rotational noise clearly harms selection accuracy [3, 14]. Wang et al. further demonstrate that users can tolerate small rotation gains without conscious awareness, but existing evaluations rarely consider how these manipulations affect precise cursor placement during target selection [48]. Although Boundary-Switching has been evaluated for coarse workspace navigation [27], its interaction with cursor warping is unknown. Specifically, when the workspace itself rotates during a display transition, it is unclear whether established cursor warping strategies still help users locate and acquire targets, or whether view manipulation disrupts the spatial cues on which these strategies depend.

3 Study

We investigate how cursor warping and view manipulation jointly influence user performance and experience in XR multi-display workspaces. Prior work has demonstrated the benefits of cursor warping and view manipulation individually [5, 6, 27], but these findings do not address how the two mechanisms interact in dynamic XR settings. In XR, shifting attention to another display triggers cursor warping to reposition the cursor while view manipulation may simultaneously reorient the workspace, creating interactions that could reinforce, offset, or interfere with established warping strategies. This interaction has not been systematically examined, leaving it unclear how cursor warping techniques behave when combined with view manipulation, such as Boundary-Switching, and whether their benefits persist when the workspace moves. This motivates our research questions:

- **RQ1.** Which cursor warping × view manipulation combinations are optimal?
- **RQ2.** Is advanced cursor warping beneficial compared to traditional cursor behaviour?

- **RQ3.** Where should the cursor be initialised when shifting attention to another display?
- **RQ4.** Is Boundary-Switching beneficial for multi-display cursor interaction?

To answer these questions, we closely replicated the setup of Study 1 by McGill et al. [27] and extended it to test multiple cursor warping methods under both 1:1 and Boundary-Switching strategies.

3.1 Study Design

We employed a 5 (cursor warping techniques) × 2 (view manipulation modes) within-subjects study design with two independent variables. The first factor was the cursor warping technique, with five levels representing different ways to reposition the cursor when transitioning between displays. Except for the baseline (World-Space), these transitions are triggered when the user looks at a different display. As illustrated in Figure 1, the five techniques are:

- **Center**: The cursor appears at the centre of the newly focused display, providing a predictable starting point (cf. Benko and Feiner [5, 6]).
- **Gaze-Fixation**: The cursor appears at the first stable fixation point detected, leveraging eye tracking to align with the user's visual attention (inspired by prior work [1, 50]).
- **Frame-Memory**: Each display has its own cursor, and the user only controls the cursor of the display they are looking at (cf. Benko and Feiner [5, 6]).
- **Frame-Relative**: The cursor appears at the same relative position on the new display as it was on the previous display — for example, a cursor at the bottom-left of the previous display will warp to the bottom-left of the new display (cf. Benko and Feiner [5, 6]).
- **World-Space**: The default cursor behaviour in traditional multi-monitor setups, where it transitions seamlessly between adjacent display boundaries as the cursor/mouse moves, regardless of which display the user is looking at (i.e., no warping is applied).

The second factor was the view manipulation strategy, with two levels that determined how the virtual workspace responded to the user's head movement. In the baseline 1:1 condition, the virtual displays remained unmoving (relative to the environment). However, in the Boundary-Switching condition, when the direction the user's head is facing moves past the horizontal edge of a display, the system begins rotating the entire array of virtual monitors in the opposite direction, reducing the required head movement. We follow the implementation of McGill et al. [27], in which the workspace rotates in the opposite direction to the user's head yaw such that the next display is effectively centered in front of the user as the head exits the previous display. We denote this counter-rotational assistance as Boundary-Switching throughout the paper.

Combining these factors yielded 10 experimental conditions (5 cursor warping techniques × 2 view manipulation modes). We employed a mixed counterbalancing approach: half of the participants completed the fixed view (1:1) conditions first, and the other half started with the Boundary-Switching conditions. Within each view manipulation block, the order of the five cursor techniques was determined via a balanced Latin square design.

3.2 Task

Our study was a multi-display target-selection task in which participants moved a cursor between virtual displays (as illustrated in Figure 3) to select buttons by using a physical mouse. The task was repeated 10 times, once for each experimental condition (5 cursor warping techniques × 2 view manipulation modes). Each task involved two selection sequences, one immediately following the other. Each selection sequence consisted of 20 selection trials, generated via a balanced tournament graph traversal such that every ordered pair of distinct displays (e.g., $1 \rightarrow 3$, $3 \rightarrow 1$, $1 \rightarrow 5$, $5 \rightarrow 1$, etc.) occurred exactly once. This ensured that participants experienced an even distribution of jumps between all pairs of displays, eliminating bias toward any particular screen or direction. Selection targets appear randomly within the central 80% of the display (i.e., $\geq$ 10% margin from the edges) to avoid extremely peripheral placements.

Each selection sequence proceeds as shown in Figure 2. It starts with the initial target at a random location on the center display (Figure 2 left). When a target is selected, it is immediately replaced with a visual cue indicating the location of the next target (Figure 2 middle). The visual cue contains the next target's display number and its relative location on that display (see Figure 2 middle), designed to quickly give users prior knowledge of the target's location, reducing visual search time. As the targets always appear on a different display, participants must move the cursor between displays using a cursor warping technique before moving the cursor within the display using the physical mouse to select the target, thereby ending a selection trial (Figure 2 right). This means for the four cursor warping techniques other than World-Space, participants looked at the indicated display before moving the physical mouse. After 40 selection trials (i.e., after both selection sequences), the task for a given condition ends.

3.3 Procedure

At the beginning of the study, participants were briefed, provided informed consent, and completed a demographic questionnaire that covered age, gender, vision, and prior experience with VR, and eye tracking.

Participants sat on a stationary chair, with a physical mouse and keyboard placed on an office table in front of them. Then, participants were briefed on the task and instructed to complete it as quickly and accurately as possible. Before starting each task, participants were briefed on the cursor warping technique and view manipulation mode. Then, participants wore the VR headset and did eye-tracking calibration, before being given time to practice the condition in a guided training scenario (10 trials per technique). Participants were allowed to repeat training trials until they felt comfortable. The experimenter also ensured that participants understood how each warping method worked (e.g., noting that the cursor would jump to screen centers in Center, or to gaze points in Gaze-Fixation).

Figure 2: Example trial sequence: (1) Initial target is selected on Display 3, (2) a cue highlights Display 1 with the approximate target area, and (3) the cursor warps to Display 1, and the target appears for selection.

The task was repeated 10 times, once for each condition, with the order of the task conditions as described above (view manipulation block order counterbalanced between subjects, and warping technique order counterbalanced within each block). Short breaks were provided between conditions (after each set of 40 trials) to prevent fatigue; additional rest was offered upon request.

After completing the five cursor warping conditions under a given view manipulation mode (e.g., after all 1:1 trials), participants had to choose their preferred cursor warping technique for that viewing mode while briefly explaining their choice. At the end of the study, after completing all conditions, a final questionnaire was administered to gather overall strategy preferences and any additional comments. Each session lasted approximately 60 minutes. Participants received 10 GBP as compensation. The study was approved by the institutional ethics board.

3.4 Apparatus and Virtual Workspace Setup

The study was conducted using a Meta Quest Pro VR headset (per-eye resolution 1800×1920, 106° horizontal field of view), which provided head-tracked stereo rendering and integrated eye tracking. The virtual workspace was rendered in Unity 2021.3 and resembled the setup from McGill et al. [27] XR desktop study. Five virtual displays (each 16:9 aspect ratio) were arranged side-by-side in a semi-circular formation around the user (Figure 3). The displays were positioned at a virtual distance of approximately 1.2m from the user, with their centers aligned at the user's eye height. Each display spanned approximately 60° of the horizontal field, with a 5° gap between them, allowing the five-display array to cover a wide panorama. The selection targets were also sized so they are approximately the size of a standard desktop icon on these displays. The virtual displays were placed within a static virtual living room environment to provide a stable frame of reference and a naturalistic setting.

Participants used a standard USB optical mouse (Lenovo model SM8823) on a desk to control the cursor. The mouse input was captured through the host PC (Windows 10) via Oculus Link. We calibrated the cursor movement to match typical desktop behavior: moving the physical mouse by a certain distance produced a proportional cursor movement on the virtual displays equivalent to the same motion on a real 1080p monitor. We did not apply any custom acceleration or gain beyond the default Windows settings, so the cursor's speed and feel were familiar to users (ensuring that muscle memory from regular PC use would transfer to the XR setting).

3.5 Participants

We recruited 20 participants (12 female, 8 male), aged 22–34 (M = 27.5, SD = 4.2). All 20 were able-bodied and had normal or corrected-to-normal vision. Only 1 was left-handed, but chose to use their right hand to control the mouse like all other participants. Participants had diverse computer backgrounds but generally limited experience with XR. On a 0–3 self-rating scale of VR familiarity (0 = "never used", 1 = "once or twice", 2 = "few times", 3 = "regularly"), the mean was 1.2 (SD = 0.83). Experience with eye-tracking or gaze-based interaction was even lower (M = 0.8, SD = 0.70 on the same scale). Thus, for most, the study represented one of their first exposures to a VR desktop and gaze-assisted cursor techniques. All participants completed the study without noticeable simulator sickness (confirmed via post-study questioning and low FMS scores).

3.6 Measures

We collected both objective performance metrics and subjective ratings for each condition:

- Performance metrics.
  - **Completion Time**: the mean duration (in seconds) required to complete a selection trial, measured as the interval between the end of the previous trial and the completion of the current one.
  - **Target Acquisition Time**: the mean duration (in seconds) of the cursor's final, continuous period on the target's screen — starting from its last entry and ending at target acquisition — and does not include any prior visits to that screen.
  - **Average Head Rotation**: the mean accumulated head-rotation (in degrees), measured as the sum of angular changes between consecutive frames from the start of cursor warping to target selection.
  - **Average Cursor Movement**: the mean accumulated cursor displacement (Unity relative units), measured as the summed cursor movement between consecutive frames from the start of cursor warping to target selection.
  - **Error Rate**: the mean error rate, measured as the percentage of unintended or unnecessary clicks; any click outside the intended target button counts as an error.
- *Subjective measures.*
  - Raw NASA Task Load Index (TLX) [10].
  - Satisfaction: "Overall, how satisfied were you with your experience using the system?" (7-point Likert scale).

Figure 3: Left: Example of the Tournament Graph traversal method used to balance all possible display-to-display transitions; Right: Virtual workspace setup replicating McGill et al.'s Study 1 [27], showing the five horizontally aligned displays arranged in a cylindrical configuration around the user.

- Single Ease Question (SEQ) [43]: "How easy was it to use the system?" (7-point Likert scale).
- Fast Motion Sickness Scale (FMS)[19]: "How sick do you feel right now?" (21-point scale).

After completing all conditions of a view manipulation strategy (e.g., 1:1), participants also indicated their preferred cursor warping technique ("Which cursor warping method do you prefer the most?") and provided a brief open-ended explanation of their choice. Participants could answer this explanation either in writing (via an optional open-ended text box) or verbally, in which case we recorded their response as notes.

4 Results

Our data collection resulted in 8,000 data points (5 cursor warping techniques × 2 view manipulation × 20 trials × 2 repetitions × 20 participants). Data were analysed with two-way repeated-measures ANOVAs ($\alpha = .05$; effect size reported as η_g^2) with cursor warping techniques × view manipulation as independent variables. When normality was violated (Shapiro-Wilk tests and Q-Q plots), aligned rank transform (ART) [49] was applied (effect size reported as η_p^2 instead). When sphericity was violated (Mauchly's test), Greenhouse-Geisser corrections were applied. Bonferroni-corrected post-hoc tests were used when applicable. Subjective measures (Satisfaction, SEQ, RAW NASA–TLX, FMS) were analysed using the same procedure.

We also repeated the quantitative analysis using only the three centre displays, excluding trials that passed through Displays 1 and 5, as shown in the left panel of Figure 3. These results can be found in Appendix A. Results were consistent with the results from five displays.

4.1 Completion Time

Figure 4 illustrates the completion time, measured as the time interval (in seconds) between the start and the end of the trial. We found a significant two-way interaction effect ($p < .001$). Post-hoc tests showed that with 1:1, participants were significantly slower with Gaze-Fixation than Center ($p = .010$). With Boundary-Switching, the World-Space technique was significantly slower than all other techniques (all $p \leq .039$). For Center, Frame-Memory, and World-Space, participants were significantly slower with Boundary-Switching than 1:1 (all $p \leq .010$).

We found a significant main effect of cursor warping Technique ($p = .001$). Post-hoc tests revealed that World-Space was slower than Center and Frame-Memory ($p \leq .024$). We also found a significant main effect of view manipulation. 1:1 was significantly faster than Boundary-Switching ($p < .001$).

4.2 Target Acquisition Time

Figure 5 illustrates the Target Acquisition Time, measured as the duration (in seconds) of the cursor's final, continuous period on the target's screen — starting from its last entry and ending at target acquisition — and does not include any prior visits to that screen. The last trial of Target Acquisition Time for each condition was discarded due to a logging error, leaving 7,800 valid trials for analysis for this metric. We found a significant two-way interaction effect ($p < .001$). With 1:1, participants were significantly slower with Gaze-Fixation than Center ($p = .023$). With Boundary-Switching, they were always faster with Gaze-Fixation and slower with World-Space compared to all other techniques (all $p \leq .001$). Boundary-Switching was slower than 1:1 for all the techniques except Frame-Relative (all $p \leq .005$).

We found a significant main effect of cursor warping Technique ($p < .001$). Post-hoc tests showed that World-Space was slower than Center, Gaze-Fixation, and Frame-Memory (all $p \leq .005$), and that Gaze-Fixation was faster than Frame-Relative ($p = .031$). We also found a significant main effect of view manipulation, with 1:1 being faster than Boundary-Switching ($p = .001$).

4.3 Average Head Rotation

Figure 6 illustrates the average head rotation in degrees, measured as the accumulated head angular difference in each frame from the start to the end of the trial. We found a significant two-way interaction ($p < .001$). With 1:1, it required the least head rotation from the participants with Gaze-Fixation compared to all other techniques (all $p < .001$). This remains true for Boundary-Switching, where Gaze-Fixation yielded less head rotation than Center, Frame-Relative, and Frame-Memory ($p \leq .014$), but not World-Space ($p = 1.0$). World-Space required less movement than Center and

Table 1: Summary of objective results, focusing on interaction effects with means and 95% CIs. Following a compact letter display, subscripts (a–d) denote results of post-hoc multiple comparisons: conditions sharing a letter are not significantly different (and vice versa). Green and red shading indicate the column's best and worst result.

View	Technique	Completion Time (s)	Acquisition Time (s)	Avg. Head Rotation (°)	Avg. Cursor Movement	Error Rate
1:1	Center	$2.04\ [1.91; 2.18]_{d}$	$1.15\ [1.08; 1.21]_{d}$	$56.59\ [49.72; 63.47]_{a}$	$77.13\ [61.17; 93.08]_{bc}$	$0.06\ [0.04; 0.08]_{a}$
	Gaze-Fixation	$2.28\ [2.13; 2.42]_{c}$	$1.31\ [1.23; 1.38]_{b,c}$	$33.54\ [28.87; 38.21]_{b}$	$69.41\ [45.11; 93.71]_{c}$	$0.10\ [0.06; 0.15]_{a}$
	Frame-Relative	$2.18\ [2.04; 2.32]_{c,d}$	$1.27\ [1.19; 1.34]_{c,d}$	$50.76\ [44.78; 56.75]_{a}$	$88.75\ [68.64; 108.85]_{bc}$	$0.09\ [0.06; 0.12]_{a}$
	Frame-Memory	$2.10\ [1.99; 2.21]_{c,d}$	$1.19\ [1.13; 1.26]_{c,d}$	$55.03\ [49.88; 60.18]_{a}$	$94.32\ [77.51; 111.13]_{b}$	$0.13\ [0.08; 0.17]_{a}$
	World-Space	$2.14\ [2.02; 2.26]_{c,d}$	$1.21\ [1.12; 1.30]_{c,d}$	$52.78\ [45.11; 60.44]_{a}$	$151.40\ [140.01; 162.79]_{a}$	$0.11\ [0.07; 0.15]_{a}$
BS	Center	$2.24\ [2.07; 2.41]_{b,c}$	$1.29\ [1.20; 1.38]_{b,c}$	$37.90\ [32.65; 43.15]_{b,c}$	$78.96\ [60.87; 97.04]_{b,c}$	$0.09\ [0.06; 0.12]_{a}$
	Gaze-Fixation	$2.30\ [2.19; 2.41]_{bc}$	$1.11\ [1.05; 1.17]_{d}$	$29.07\ [25.97; 32.17]_{d}$	$68.04\ [50.73; 85.36]_{bc}$	$0.10\ [0.06; 0.13]_{a}$
	Frame-Relative	$2.27\ [2.10; 2.44]_{b,c}$	$1.31\ [1.23; 1.38]_{b,c}$	$41.09\ [36.73; 45.45]_{b}$	$71.81\ [58.28; 85.34]_{b,c}$	$0.11\ [0.06; 0.16]_{a}$
	Frame-Memory	$2.24\ [2.11; 2.38]_{b}$	$1.31\ [1.24; 1.38]_{b}$	$35.48\ [31.45; 39.52]_{c}$	$89.81\ [74.04; 105.58]_{b,c}$	$0.11\ [0.07; 0.16]_{a}$
	World-Space	$2.56\ [2.42; 2.70]_{a}$	$1.55\ [1.46; 1.64]_{a}$	$28.59\ [25.50; 31.69]_{cd}$	$172.48\ [156.27; 188.69]_{a}$	$0.11\ [0.08; 0.15]_{a}$

Reported in a format of *Mean [95% CI]*; BS denotes the Boundary-Switching condition.

Table 2: Summary of objective results, presenting main effects with means and 95% CIs. Following a compact letter display, subscripts (a–d) denote results of post-hoc multiple comparisons: conditions sharing a letter are not significantly different (and vice versa). Green and red shading indicate the column's best and worst result.

		Completion Time (s)	Acquisition Time (s)	Avg. Head Rotation (°)	Avg. Cursor Movement	Error Rate
Cursor Warping Techniques	Center	$2.14\ [1.98; 2.30]_{b}$	$1.22\ [1.13; 1.30]_{b,c}$	$47.25\ [40.80; 53.70]_{a}$	$78.04\ [60.06; 96.02]_{b,c}$	$0.08\ [0.05; 0.10]_{a}$
	Gaze-Fixation	$2.29\ [2.15; 2.42]_{a,b}$	$1.21\ [1.14; 1.28]_{c}$	$31.30\ [27.12; 35.48]_{b}$	$68.73\ [46.49; 90.96]_{c}$	$0.10\ [0.06; 0.14]_{a}$
	Frame-Relative	$2.23\ [2.06; 2.39]_{a,b}$	$1.29\ [1.21; 1.37]_{a,b}$	$45.93\ [40.41; 51.45]_{a}$	$80.28\ [62.22; 98.34]_{b,c}$	$0.10\ [0.06; 0.14]_{a}$
	Frame-Memory	$2.17\ [2.04; 2.30]_{b}$	$1.25\ [1.18; 1.32]_{b,c}$	$45.26\ [40.38; 50.13]_{a}$	$92.07\ [74.89; 109.25]_{b}$	$0.12\ [0.07; 0.17]_{a}$
	World-Space	$2.35\ [2.22; 2.49]_{a}$	$1.38\ [1.28; 1.47]_{a}$	$40.69\ [34.52; 46.85]_{a}$	$161.94\ [147.17; 176.71]_{a}$	$0.11\ [0.07; 0.15]_{a}$
Viewport Conditions	1:1	$2.15\ [2.01; 2.29]_{b}$	$1.23\ [1.15; 1.30]_{b}$	$49.74\ [43.24; 56.24]_{a}$	$96.20\ [76.99; 115.42]_{a}$	$0.10\ [0.06; 0.14]_{a}$
	BS	$2.32\ [2.17; 2.48]_{a}$	$1.31\ [1.23; 1.40]_{a}$	$34.43\ [30.16; 38.70]_{b}$	$96.22\ [79.08; 113.36]_{a}$	$0.11\ [0.07; 0.15]_{a}$

Reported in a format of *Mean [95% CI]*; BS denotes the Boundary-Switching condition.

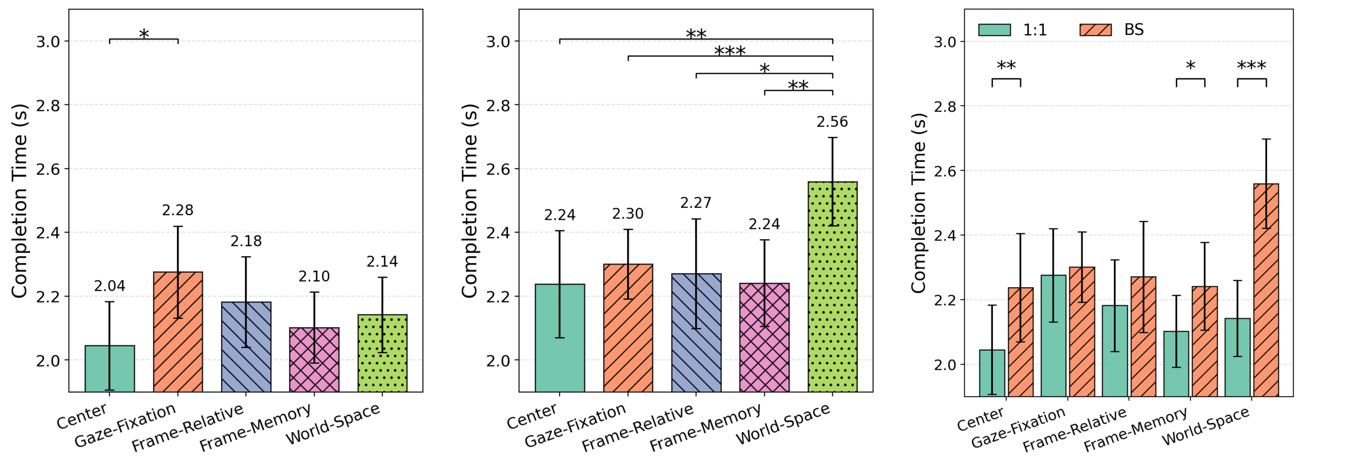
Table 3: Two-way Repeated Measures ANOVA Statistical Analysis on the Objective Dependent Variables. Significant results are highlighted in grey.

Metric	Effect	ANOVA		
		F Value	p	*Effect Size*
Completion Time^{g}	T × V	$F(3.00, 56.99) = 7.560$	<.001	.045
	T	$F(2.93, 55.72) = 6.537$	.001	.057
	V	$F(1, 19) = 22.286$	<.001	.072
Target Acquisition Time^{g}	T × V	$F(2.33, 44.19) = 24.790$	<.001	.202
	T	$F(3.11, 59.09) = 11.057$	<.001	.117
	V	$F(1, 19) = 13.837$	.001	.062
Avg. Head Rotation^{g}	T × V	$F(2.86, 54.35) = 8.867$	<.001	.087
	T	$F(2.92, 55.40) = 18.337$	<.001	.201
	V	$F(1, 19) = 139.071$	<.001	.303
Avg. Cursor Movement^{p}	T × V	$F(4, 76) = 3.185$	.018	.144
	T	$F(4, 76) = 59.525$	<.001	.758
	V	$F(1, 19) = 0.126$	.727	.007
Error Rate^{g}	T × V	$F(4, 76) = 1.095$	.365	.054
	T	$F(4, 76) = 1.659$	.168	.080
	V	$F(1, 19) = 0.410$	.530	.021

T = cursor warping Technique; V = view manipulation;
Effect size are reported as η_p^2 for Cursor Movement, and η_g^2 for all other metrics.

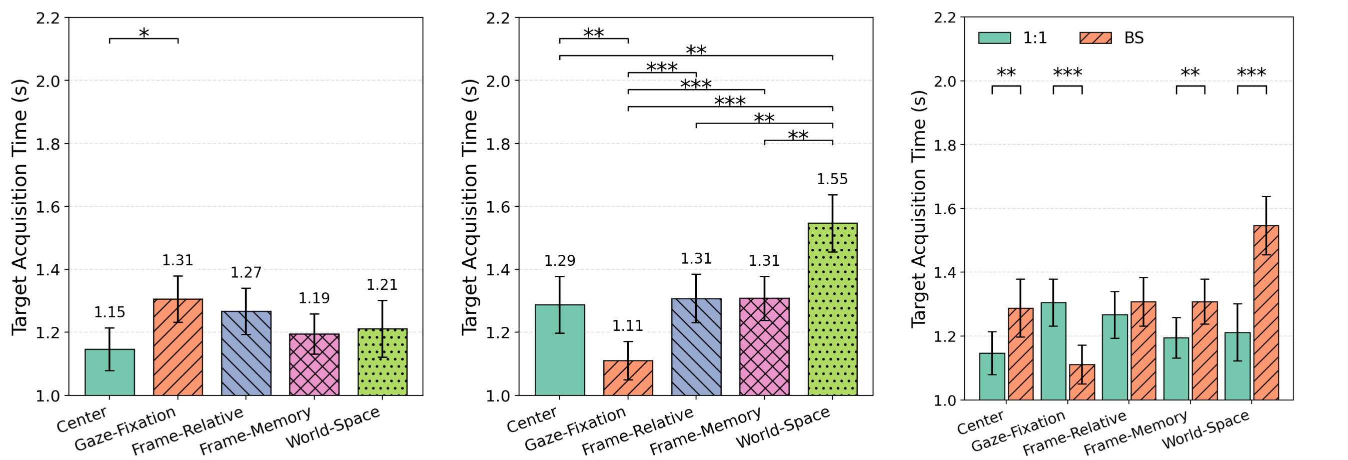
Frame-Relative (all $p \leq .029$), and Frame-Memory required less than Frame-Relative ($p = .001$). Boundary-Switching required less head rotation than 1:1 for all techniques (all $p \leq .048$).

We found a significant main effect of cursor warping Technique ($p < .001$). Post-hoc tests showed that Gaze-Fixation required significantly less head rotation than all other techniques (all $p \leq .002$). We also found a significant main effect of view manipulation ($p < .001$),



(a) Within 1:1 (b) Within Boundary-Switching (c) Within each cursor warping Technique

Figure 4: Completion time of (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Numbers above the bars indicate mean completion times. Exact mean and 95% CI values can be found in Table 2.



(a) Within 1:1 (b) Within Boundary-Switching (c) Within each cursor warping Technique

Figure 5: Target acquisition time of (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Numbers above the bars indicate mean target acquisition times. Exact mean and 95% CI values can be found in Table 2.

with Boundary-Switching yielding less head rotation than 1:1 for all cursor warping techniques (all $p < .001$).

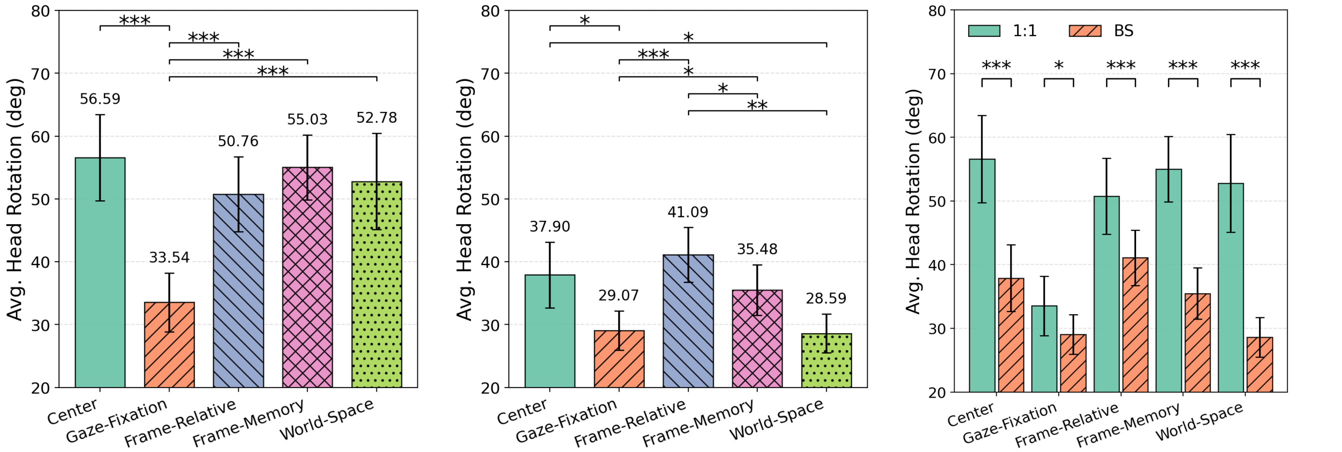
4.4 Average Cursor Movement

Figure 7 illustrates the average cursor movement in relative units in Unity, measured as the accumulated cursor displacement between consecutive frames from the start to the end of the trial. We found a significant two-way interaction effect ($p = .018$). Within both 1:1 and Boundary-Switching, participants moved the cursor significantly more with World-Space compared to all other techniques (all $p < .001$). For 1:1 only, Gaze-Fixation also resulted in less movement than Frame-Memory ($p = .016$).

We found a significant main effect of cursor warping Technique ($p < .001$). Post-hoc tests revealed that World-Space resulted in greater cursor movement than all other techniques (all $p < .001$), and Gaze-Fixation required less movement than Frame-Memory ($p = .003$).

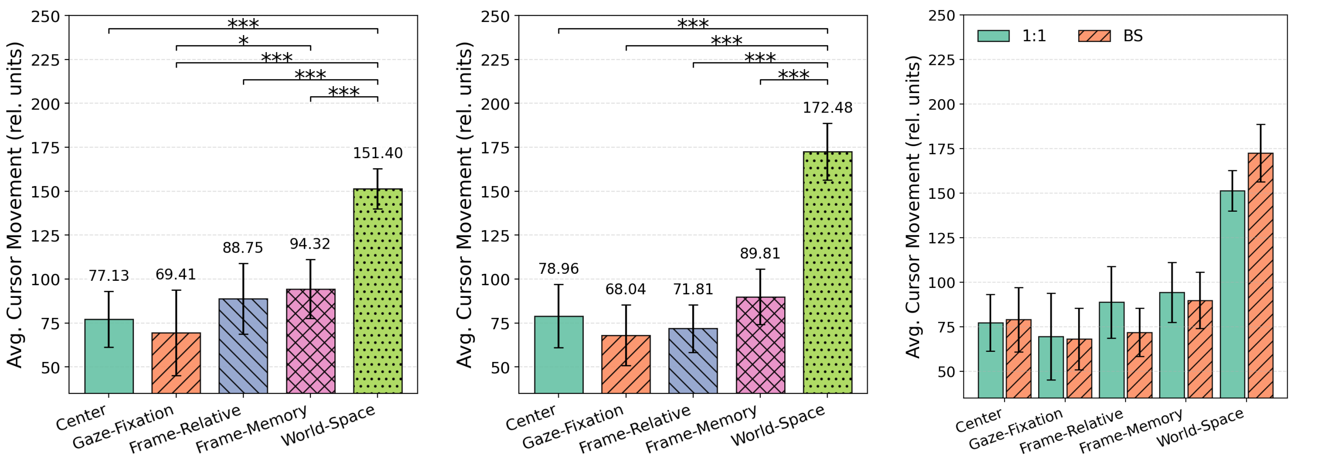
4.5 Error Rate

Error rate was quantified as the percentage of unintended or unnecessary clicks—specifically, instances in which participants clicked outside the intended target button. This measure reflects the likelihood of committing an additional, non-task-relevant click. We found no significant two-way interaction effect ($p = .365$), nor any



(a) Within 1:1 (b) Within Boundary-Switching (c) Within each cursor warping Technique

Figure 6: Average head rotation per trial of (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Numbers above the bars indicate average head rotations per trial. Exact mean and 95% CI values can be found in Table 2.



(a) Within 1:1 (b) Within Boundary-Switching (c) Within each cursor warping Technique

Figure 7: Average cursor movement per trial for (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Numbers above the bars indicate average cursor movements per trial. Exact mean and 95% CI values can be found in Table 2.

significant main effects of cursor warping Technique (p = .168) or view manipulation (p = .530) on error rate (cf. Table 2).

4.6 Subjective Measures

We did not find any significant interaction effect in any of the six RAW NASA-TLX dimensions, nor in SEQ, Satisfaction, or FMS (all $p < 0.29$; cf. Table 5 and Table 4). However, we found a significant main effect of view manipulation on Physical Demand ($p < .001$). Post-hoc comparisons showed that participants experienced higher physical demand under the 1:1 compared to Boundary-Switching for the Frame-Relative ($p = 0.02$).

As shown in Figure 8, participants' preferences varied substantially across view manipulation conditions. In 1:1, Center was chosen most frequently (8/20, 40%), followed by Frame-Relative (6/20, 30%), with Gaze-Fixation and World-Space tied (3/20, 15% each). In Boundary-Switching, Gaze-Fixation led the preferences (9/20, 45%), followed by Frame-Relative (4/20, 20%) and Center (4/20, 20%), with World-Space (2/20, 10%) and Frame-Memory (1/20, 5%) less preferred. These descriptive preferences align with our inferential results: Gaze-Fixation tends to yield lower workload and higher SEQ (especially under Boundary-Switching), whereas World-Space is generally less favored.

Table 4: Mean subjective scores for each Cursor Technique under each View Manipulation (1:1 vs. Boundary-Switching).

	Satisfaction		SEQ		Mental Demand		Physical Demand		Temporal Demand		Performance		Effort		Frustration		FMS	
Technique	**1:1**	**BS**	**1:1**	**BS**	**1:1**	**BS**	**1:1**	**BS**	**1:1**	**BS**	**1:1**	**BS**	**1:1**	**BS**	**1:1**	**BS**	**1:1**	**BS**
Center	5.00	4.75	4.73	5.25	20.23	18.25	41.36	29.00	30.23	29.25	16.59	19.00	34.32	25.75	21.59	17.25	4.27	3.95
Frame-Memory	4.44	4.65	4.28	4.85	32.78	24.50	40.00	29.25	38.89	34.00	18.61	14.25	31.94	28.75	23.89	18.75	5.06	4.15
Frame-Relative	4.70	4.85	4.55	5.05	33.50	24.50	50.50	29.00	37.50	26.00	19.00	15.25	33.25	27.00	19.75	16.50	5.00	4.25
Gaze-Fixation	4.90	4.90	4.80	5.35	23.50	25.25	33.00	21.75	36.75	27.50	14.25	15.00	26.50	23.50	24.50	14.50	5.20	3.70
World-Space	4.50	4.10	4.85	4.10	25.75	37.50	45.25	31.75	37.25	38.75	20.75	27.00	34.75	37.25	21.75	34.00	4.30	4.45

Table 5: Two-way ANOVA Statistical Analysis on the Subjective Dependent Variables. Significant results are highlighted in grey.

Metric	Cursor Warping Technique	View Manipulation	Interaction Effect
Mental Demand	$F(4,190) = 1.544,\ p = .191,\ \eta_p^2 = .031$	$F(1,190) = 0.022,\ p = .881,\ \eta_p^2 < .001$	$F(4,190) = 0.700,\ p = .593,\ \eta_p^2 = .014$
Physical Demand	$F(4,190) = 1.242,\ p = .295,\ \eta_p^2 = .025$	$F(1,190) = 15.202,\ p < .001,\ \eta_p^2 = .074$	$F(4,190) = 0.429,\ p = .788,\ \eta_p^2 = .009$
Temporal Demand	$F(4,190) = 0.877,\ p = .478,\ \eta_p^2 = .018$	$F(1,190) = 1.877,\ p = .172,\ \eta_p^2 = .010$	$F(4,190) = 0.508,\ p = .730,\ \eta_p^2 = .010$
Performance	$F(4,190) = 1.420,\ p = .229,\ \eta_p^2 = .029$	$F(1,190) = 0.002,\ p = .961,\ \eta_p^2 < .001$	$F(4,190) = 0.541,\ p = .705,\ \eta_p^2 = .011$
Effort	$F(4,190) = 1.234,\ p = .298,\ \eta_p^2 = .025$	$F(1,190) = 0.956,\ p = .329,\ \eta_p^2 = .005$	$F(4,190) = 0.211,\ p = .932,\ \eta_p^2 = .004$
Frustration	$F(4,190) = 1.170,\ p = .325,\ \eta_p^2 = .024$	$F(1,190) = 0.000,\ p = .999,\ \eta_p^2 < .001$	$F(4,190) = 0.674,\ p = .611,\ \eta_p^2 = .014$
Satisfaction	$F(4,190) = 2.217,\ p = .069,\ \eta_p^2 = .045$	$F(1,190) = 1.010,\ p = .316,\ \eta_p^2 = .005$	$F(4,190) = 0.492,\ p = .742,\ \eta_p^2 = .010$
SEQ	$F(4,190) = 1.196,\ p = .314,\ \eta_p^2 = .024$	$F(1,190) = 0.316,\ p = .575,\ \eta_p^2 = .002$	$F(4,190) = 1.247,\ p = .292,\ \eta_p^2 = .025$
FMS	$F(4,190) = 0.058,\ p = .994,\ \eta_p^2 = .001$	$F(1,190) = 0.514,\ p = .474,\ \eta_p^2 = .003$	$F(4,190) = 0.098,\ p = .983,\ \eta_p^2 = .002$

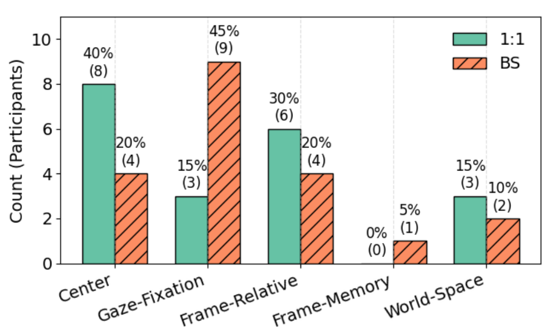


Figure 8: Preference distribution of cursor warping techniques under each view manipulation condition. Bar labels show percentage and count; BS denotes the Boundary-Switching condition. Exact mean values can be found in Table 4.

4.7 Qualitative Feedback

Participants' comments reflected a mix of practical reasoning and personal preference. One recurring theme was the value of predictability, and knowing where the cursor would appear was necessary for a technique to be preferred. For example, "starting point is known; don't have to search" (P8 for Center 1:1), "easy to spot where were my cursor was" (P19 for Center 1:1), "know where to expect the cursor to be" (P03 for Frame-Relative for both 1:1 Boundary-Switching), and "don't have to find the cursor" (P07 for Gaze-Fixation Boundary-Switching), and "When I move to the new display, I still remember where I put the cursor at the previous display." (P20 for Frame-Relative Boundary-Switching).

This is closely tied to perceived effort and efficiency, which also guided preference. For example,"easy to use" (P09 for Gaze-Fixation Boundary-Switching, P08 for World-Space Boundary-Switching, P12 for Frame-Relative 1:1, P19 for Center 1:1), "more efficient" (P04 for Gaze-Fixation Boundary-Switching), and "quickest" (P11 for Frame-Relative 1:1, P17 for Frame-Relative Boundary-Switching).

Familiarity and being intuitive also shaped preferences. A few participants favored World-Space because it felt "the most familiar" (P7, 1:1), while others leaned toward Center as a "neutral" and intuitive option (P6, 1:1).

The Boundary-Switching condition received the most mixed responses, with comments indicating that subjective comfort sometimes outweighed observed efficiency. Some considered it positive, making it "easier to navigate" (P8) and "have a faster transition" (P10). However, others said Boundary-Switching "made me do it slower" (P13) as it is "too fast" (P11). One even mentioned Boundary-Switching was uncomfortable because "the sea wallpaper" "gave them motion sickness" (P15). Thus, while Boundary-Switching relieved physical effort, it slowed operation or introduced discomfort for some participants.

5 Discussion

XR headsets enable flexible, immersive multi-display workspaces, but also introduce interaction challenges absent in physical setups. Our study demonstrates that cursor warping and view manipulation are not independent but closely intertwined in XR multi-display setups. They highlight the importance of designing cursor and view manipulation in tandem for efficient and comfortable XR desktop experiences. This is important because prior work has examined cursor control and view manipulation only in isolation, overlooking their combined impact on performance and comfort. In the following sections, we address our research questions.

5.1 RQ1: Which cursor warping × view manipulation combinations are optimal?

A key aim of this work was to examine whether a specific pairing of view control and cursor control consistently outperforms others. Although patterns emerged, no single pairing consistently outperforms across all metrics. Rather, our findings revealed subtle and nuanced differences (cf. Table 1). A key trade-off that emerged is between time and movement cost: For example, 1:1-Center offers fast completion and acquisition times but incurs high head movement. In contrast, Boundary-Switching-Gaze-Fixation is slightly slower but leads to low head rotation. Other combinations, such as 1:1-Gaze-Fixation, showed advantages in cursor movement, respectively, but at the cost of slower completion times. Similar trade-offs are apparent in the remaining combinations, albeit less prominently. This trade-off is particularly important for designers because prolonged head movement can lead to fatigue, and excessive cursor travel may compromise selection performance in VR/AR contexts. Based on this trade-off, we suggest the following strategies for pointing tasks: 1:1-Center for time-critical tasks where increased head movement is acceptable (e.g., gaming, safety operations). Boundary-Switching-Gaze-Fixation for contexts where minimal head and cursor movement is desired (e.g., in accessibility contexts or constrained spaces).

5.2 RQ2: Is advanced cursor warping beneficial compared to traditional cursor behaviour?

We compared advanced cursor warping techniques to assess whether they offer measurable benefits over traditional behaviour. While the optimal combination depends on view manipulation, patterns in our data allow us to reason about the general performance of Center, Gaze-Fixation, Frame-Relative, and Frame-Memory compared to World-Space.

Considering main and interaction effects in Table 1 and Table 3, our results indicate that in each view condition at least one alternative technique outperformed World-Space on key metrics. In 1:1, while World-Space is fast, it leads to high head and cursor movement, and Center or Frame-Relative performed better. In Boundary-Switching, while head movement is low, completion times and cursor movement are high, compared to other combinations with Boundary-Switching.

In our selection task, at least one advanced cursor warping technique outperformed World-Space in each view condition, and most users preferred other warping strategies. Together, this suggests that advanced warping techniques may be preferable for selection tasks, although broader workflows may reveal different trade-offs. Alternatively, advanced gain functions for World-Space need to be researched to improve performance.

5.3 RQ3: Where should the cursor be initialised when shifting attention to another display?

The four tested advanced warping strategies rely on fundamentally different principles. Center provides a clear and consistent initialisation point — likely a key reason for its strong performance. Participants also commented on the predictable starting point, which aligns with Center's competitive performance. Frame-Relative similarly offers consistency but requires users to remember the cursor's position on the previous screen [6]. Overall, this approach appears effective, given its good performance across metrics. User comments support this, such as P20: "When I move to the new display, I still remember where I put the cursor at the previous display." Frame-Memory builds on this idea but requires users to recall the cursor's position on the target screen. While this can make sense in tasks where the cursor is 'parked' while working elsewhere, our task did not favour this strategy because targets did not appear in the same location. Thus, Frame-Memory performed slightly worse in terms of cursor movement (1:1) and completion time (Boundary-Switching) — though these differences are subtle. Benko et al. [5, 6] reported that Frame-Memory yielded the greatest benefits in physical setups, which is not the case in our results. One reason for this might be that physical screens are generally smaller than XR screens, which makes a Frame-Memory-warped cursor easier to find. Finally, Gaze-Fixation does not rely on memory but on gaze behaviour. Because the cursor appears where users look, cursor search time is minimal. However, task completion time does not improve accordingly, likely due to the small delay introduced by our fixation detection algorithm. Despite this, Gaze-Fixation still achieves competitive completion times while requiring minimal head movement in Boundary-Switching.

Together, our findings suggest that initialisation position matters, and predictability and task context should be considered. Center and Frame-Relative offer predictable initialisation and low search effort, which makes them promising for rapid reorientation. Frame-Memory may be appropriate in workflows where the cursor must be intentionally ´parked' on a target for later use (e.g., a button that has to be clicked repeatedly), but its reliance on target-screen memory makes it less effective for dynamic tasks. Gaze-Fixation offers benefits for reducing search time and head movement, making it a good candidate for low-effort gaze-driven interaction or in accessibility contexts. It is noteworthy that the nature of these warping techniques — they do not rely on the spatial layout between screens but on memory, default position, or gaze — should also make them robust against other, more complex arrangements such as those explored in [32], but needs further empirical work for confirmation.

5.4 RQ4: Is counter-rotational gain (McGill's Boundary-Switching) beneficial for multi-display cursor interaction?

McGill et al. [27] and O'Hagan et al. [34] showed the benefits of Boundary-Switching when looking at the centre of screens with various screen arrangements. We set out to investigate the interdependence between view and cursor control and to discuss the benefits of the view manipulation technique in general.

Generally, we can confirm the results of McGill et al. [27] and O'Hagan et al. [34]. Boundary-Switching is beneficial when reducing head movement is a priority, such as in prolonged sessions or accessibility contexts. However, for time-critical tasks, 1:1 remains superior (1:1 tends to be faster than Boundary-Switching, esp. for Center and World-Space). This mirrors the trade-off discussed earlier. This might be an artefact of training and habituation, given our rather short and single exposure. It is possible that repeated long-term exposure reduces the time difference while retaining the benefit of reduced head rotation.

5.5 Post hoc analysis: 3 Displays vs 5 Displays

We examined both the full five-display scenario and a subset of three centre displays. We found that all main patterns of results hold in a 3-display scenario. Results need to be interpreted cautiously, as the three-display subset was not a separate experimental condition but a subset of our data.

5.6 Implications for XR Desktops

Our findings provide concrete implications for the design of next-generation XR desktop environments, such as virtual multi-monitor office setups. Our results indicate potential performance benefits of cursor repositioning in selection tasks. With further tests in more diverse tasks and environments, a future XR OS could offer a setting such as "Automatically reposition cursor when focusing on another window," with configurable options including, for example, Center, Frame-Memory, and Gaze-Fixation. Because advanced warping techniques performed similarly or better than World-Space in our task, they may even serve as promising defaults for rapid selections pending further testing across broader workflows. Failing to explore this might risk repeating a well-documented shortcoming of early physical multi-monitor systems [6, 47] and potentially hinder the adoption of XR in knowledge work environments. Although conceptually equivalent, our findings were obtained in VR and require validation in AR environments.

At a broader design level, our results strongly suggest that viewpoint control and pointer control should be treated as interdependent components rather than independent features. Developing mechanisms such as virtual display rotation in isolation from pointer logic, or vice versa, overlooks the strong coupling between them. We therefore recommend that XR designers and developers co-design these elements.

5.7 Implications Beyond XR Desktops

Although our study was conducted in VR, the patterns might extend to other multi-display contexts with head or eye tracking. For physical multi-monitor setups, prior work has already stated that World-Space cursor is suboptimal [6]. Our results are consistent with these observations.

Further, Frame-Memory and Frame-Relative could act as memory cues in both AR and VR: Lystbæk et al.'s *Spatial Gaze Markers* help users return to prior points of interest by leaving traces at gaze endpoints [25]. This is analogous to Frame-Memory, but the concept might be transferable to Frame-Relative, where a marker indicates the position of the last important fixation of the current view when looking somewhere else. For example, if a user fixates on an object for an extended period and then turns their head so the object moves out of view, a marker could be placed at the object's location. This could support comparisons across distances.

Finally, large, high-resolution single displays, such as powerwalls and CAVEs, pose similar challenges due to their long pointer travel distances. Treating regions of such displays as "virtual monitors" enables designers and developers to apply cursor warping: partition the surface, apply a warping technique (for example, Gaze-Fixation), and warp the cursor. In all cases, matching dynamic view or attention shifts with proactive, screen-based cursor placement preserves continuity and reduces effort.

5.8 Limitations

Our study examined target selection spanning multiple virtual screens, but several limitations remain. First, the task was a simplified selection task. Realistic workflows such as window management, text editing, and drag-and-drop across displays may reveal different dynamics. Previous multi-monitor research suggests that explicit triggers or visual cues can assist such transitions [5, 30, 47]. Future studies should therefore test cursor warping in richer, multi-step workflows to determine if our observed benefits generalise beyond isolated selections and whether various triggers and visual feedback help.

Our counter-rotational gain in Boundary-Switching followed previous work [27]. While larger gains might speed up rotation, they might impair orientation and performance [14, 40]; weaker gains or alternative view manipulation (e.g., vertical-axis assistance [34]) diminish reductions in head movement but also slow down rotation. Broader exploration of different view manipulations is needed to assess the robustness of our findings.

The accuracy and reliability of eye tracking (cf. [17]) limit Gaze-Fixation as gaze-assisted pointing often strongly depends on the quality of the tracker and calibration [12]. As VR/AR eye tracking improves, gaze-initialised warping should become more precise and reliable. To address this, we suggest that XR system designers implement an automatic fallback to screen-based initialisation when gaze tracking becomes inaccurate or is temporarily lost.

Finally, our participant sample and exposure duration limit the generalizability of our findings. Most of our participants had minimal XR experience, and their preferences were likely influenced by their familiarity with desktop metaphors. This likely contributed to World-Space feeling "familiar" despite significantly slower performance, and to Gaze-Fixation being less preferred during the 1:1 condition. We believe that continued use over time would likely shift preferences toward gaze-based warping as users become more familiar with it and begin to value its greater efficiency. As our study captured only initial use, longitudinal deployments are needed to understand how users integrate warping into daily workflows, whether preferences evolve (e.g., increased acceptance of Gaze-Fixation), and whether long-term strategies emerge. Expert or frequent XR users may also behave differently from novices, underscoring the need for broader sampling and extended exposure.

6 Conclusion

This study examined how five cursor-warping techniques interact with Boundary-Switching in XR multi-display environments. The results show that cursor behaviour and view manipulation are tightly linked: their combination produces different trade-offs in task performance, pointer travel, and head movement. Warping techniques reduced cursor movement and improved efficiency in many situations, but their benefits depended on the view-control method, and no single technique consistently outperformed the others. Boundary-Switching lowered head rotation but introduced timing costs for some techniques, highlighting the need to co-design cursor repositioning with viewport control. These findings provide guidance for developing XR desktop systems that strike a balance between speed, physical effort, and spatial predictability. Future work should explore complex tasks, longer-term use, and a broader range of users.

Acknowledgments

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A Appendix

We repeated the quantitative analysis from section 4 using only the center three displays, excluding trials that passed through Displays 1 and 5 shown in the left panel of Figure 3. Full statistical results for this can be found in Table 6 and Table 7.

A.1 Completion Time

Figure 9 illustrates the completion time for 3-display subset in seconds. We found a significant two-way interaction effect ($p < .001$). With 1:1, participants were significantly slower with Gaze-Fixation than Center, Frame-Relative, and Frame-Memory (all $p \leq .012$). Within each technique, 1:1 was significantly faster than Boundary-Switching when using Center, Frame-Memory, and World-Space (all $p < .001$).

We found a significant main effect of cursor warping Technique ($p = .001$). Post-hoc tests showed that Gaze-Fixation was significantly slower compared to Frame-Relative and Frame-Memory ($p \leq .015$). We also found a significant main effect of view manipulation ($p < .001$), with 1:1 being faster than Boundary-Switching ($p < .001$).

A.2 Target Acquisition Time

Figure 10 illustrates the target acquisition time for 3-displays subset in seconds. We found a significant two-way interaction ($p < .001$). With 1:1, participants were slower with Gaze-Fixation compared to all other techniques (all $p \leq .043$). With Boundary-Switching, participants were slower with World-Space than Frame-Relative and Gaze-Fixation ($p \leq .006$), and Gaze-Fixation was also faster than Center and Frame-Memory ($p \leq .028$). Within each technique, 1:1 was significantly slower than Boundary-Switching for Gaze-Fixation ($p = .008$), while being significantly faster than Boundary-Switching across all other techniques (all $p \leq .001$).

We found a significant main effect of cursor warping Technique ($p < .001$). However, post-hoc tests showed no significant difference (all $p \geq .227$). We also found a significant main effect of view manipulation ($p = .001$), with 1:1 being faster than Boundary-Switching ($p < .001$).

A.3 Cumulative Head Rotation

Figure 11 illustrates the cumulative head rotation for 3-displays subset in degrees. We found a significant two-way interaction ($p < .001$). With 1:1, it required participants the least head rotation with Gaze-Fixation compared to other techniques (all $p < .001$). With Boundary-Switching, participants performed less head rotation with both Gaze-Fixation and World-Space compared to Center and Frame-Relative (all $p \leq .007$). For all techniques, 1:1 resulted in greater head rotation than Boundary-Switching (all $p \leq .016$).

We found a significant main effect of cursor warping Technique ($p < .001$). Post-hoc tests showed that Gaze-Fixation required less head rotation than all other techniques (all $p \leq .004$). We also found a significant main effect of view manipulation ($p < .001$), with Boundary-Switching resulting in less rotation than 1:1 ($p < .001$).

A.4 Cumulative Cursor Movement

Figure 12 illustrates the cumulative cursor movement for the 3-displays subset. We found a significant two-way interaction ($p =$

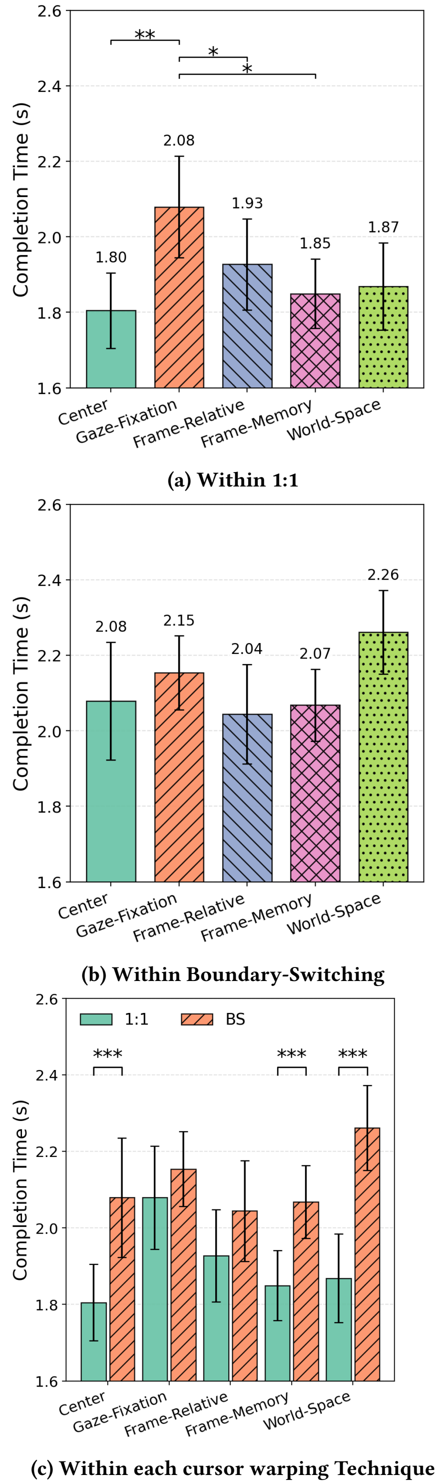
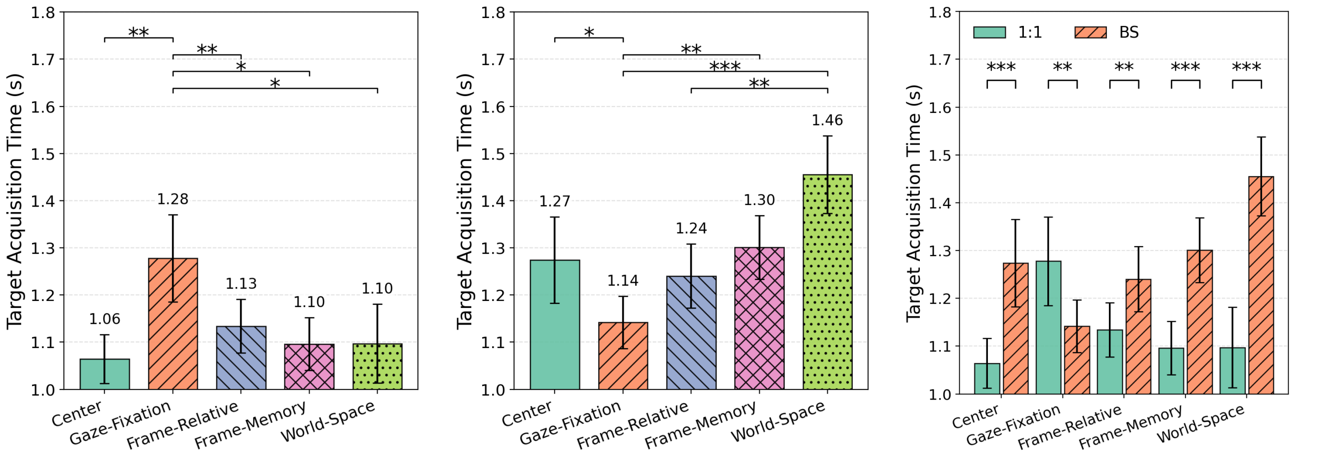
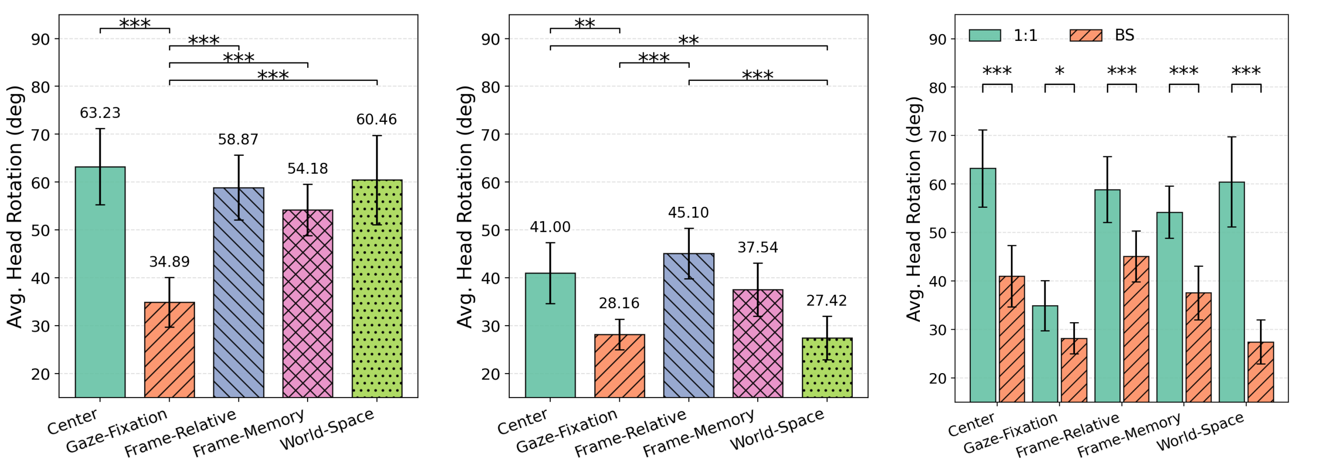


Figure 9: Completion time for the 3-displays subset for (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Exact mean and 95% CI values can be found in Table 7.



(a) Within 1:1 (b) Within Boundary-Switching (c) Within each cursor warping Technique

Figure 10: Target acquisition time for the 3-displays subset for (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Exact mean and 95% CI values can be found in Table 7.



(a) Within 1:1 (b) Within Boundary-Switching (c) Within each cursor warping Technique

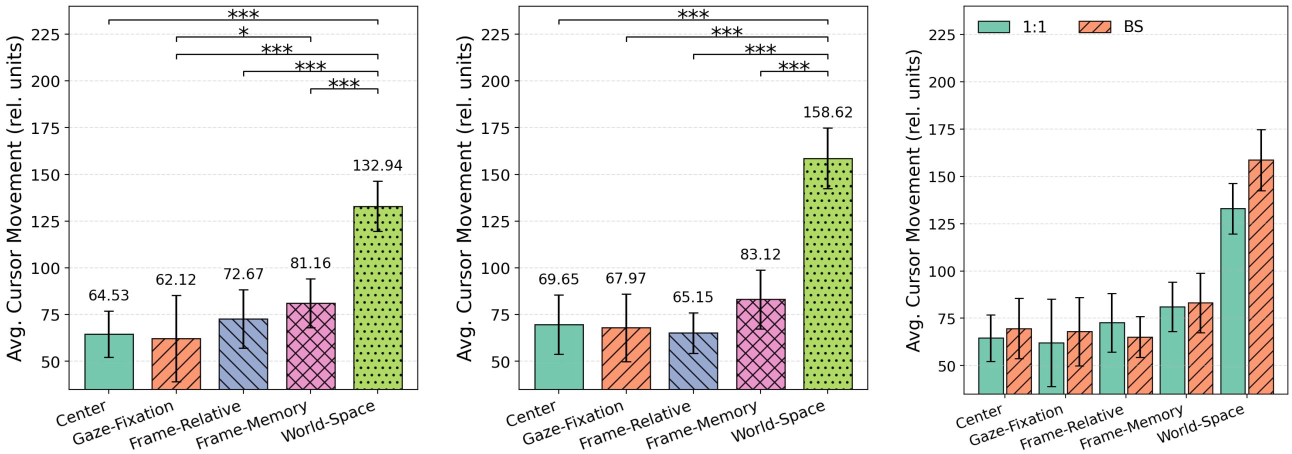
Figure 11: Cumulative head rotation for the 3-displays subset for (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Exact mean and 95% CI values can be found in Table 7.

.018). Within 1:1, participants moved significantly more with World-Space than with all other techniques (all $p \leq .018$). Gaze-Fixation also produced less movement than Frame-Memory ($p = .019$). Within Boundary-Switching, it again resulted in significantly larger cumulative movement for World-Space than all other techniques (all $p \leq .001$). Within each cursor warping technique, we found no significant differences between 1:1 and Boundary-Switching (all $p \geq .147$).

We found a significant main effect of cursor warping Technique ($p \leq .001$). Post-hoc tests showed that World-Space required greater cursor movement than all other techniques (all $p < .001$), and that Frame-Memory required greater cursor movement than Center and Gaze-Fixation ($p < .042$).

A.5 Errors

We found no significant two-way interaction error rates ($p = .365$), nor any main effect for the 3-displays subset. Complete statistics can be found in Table 6 and Table 7.



(a) Within 1:1 (b) Within Boundary-Switching (c) Within each cursor warping Technique

Figure 12: Cumulative cursor movement for the 3-displays subset for (a) each cursor warping Technique with 1:1, (b) each cursor warping Technique with Boundary-Switching, and (c) 1:1 and Boundary-Switching for each level of cursor warping techniques. Error bars represent the 95% CI. Exact mean and 95% CI values can be found in Table 7.

Table 6: Two-way Repeated Measures ANOVA Statistical Analysis on the Objective Dependent Variables (3 Displays). Significant results are highlighted in grey.

Metric	Effect	ANOVA (3 Displays)		
		F Value	*p*	*Effect Size*
Completion Time^g	T × V	$F(3.12, 59.24) = 5.934$	.001	.045
	T	$F(3.12, 59.32) = 5.557$	.002	.061
	V	$F(1, 19) = 48.157$	<.001	.146
Acquisition Time^g	T × V	$F(2.60, 49.44) = 17.325$	<.001	.206
	T	$F(3.34, 63.48) = 3.548$	.016	.049
	V	$F(1, 19) = 57.618$	<.001	.177
Head Rotation^g	T × V	$F(3.13, 59.40) = 8.602$	<.001	.094
	T	$F(2.95, 56.04) = 20.273$	<.001	.231
	V	$F(1, 19) = 113.266$	<.001	.312
Cursor Movement^p	T × V	$F(4, 76) = 3.388$	.013	.151
	T	$F(4, 76) = 56.503$	<.001	.748
	V	$F(1, 19) = 1.77$	.199	.085
Error Rate^g	T × V	$F(4, 76) = 1.205$	.316	.060
	T	$F(4, 76) = 1.613$	.180	.078
	V	$F(1, 19) = 0.247$	.625	.013

T = cursor warping Technique; V = view manipulation;
Effect size are reported as η_p^2 for Cursor Movement, and η_g^2 for all other metrics.

Table 7: Mean values and 95% CI of objective metrics for the 3-displays sub-dataset.

		Completion Time (s)	Acquisition Time (s)	Head Rotation (°)	Mouse Movement	Error Rate
Cursor Warping Techniques	Center	1.94 [1.80; 2.08]	1.17 [1.09; 1.25]	52.12 [44.52; 59.72]	67.09 [52.12; 82.05]	0.08 [0.04; 0.11]
	Gaze-Fixation	2.12 [1.99; 2.24]	1.21 [1.13; 1.29]	31.53 [26.99; 36.06]	65.04 [43.22; 86.87]	0.10 [0.05; 0.15]
	Frame-Relative	1.99 [1.85; 2.12]	1.19 [1.12; 1.25]	51.99 [45.59; 58.39]	68.91 [54.81; 83.01]	0.09 [0.04; 0.14]
	Frame-Memory	1.96 [1.86; 2.06]	1.20 [1.13; 1.26]	45.86 [40.12; 51.60]	82.14 [66.92; 97.35]	0.15 [0.08; 0.22]
	World-Space	2.07 [1.95; 2.18]	1.28 [1.19; 1.36]	43.94 [36.21; 51.67]	145.78 [130.16; 161.40]	0.10 [0.06; 0.15]
Viewport Conditions	1:1	1.91 [1.79; 2.03]	1.13 [1.06; 1.21]	54.33 [46.84; 61.81]	82.68 [65.86; 99.51]	0.10 [0.05; 0.15]
	Boundary-Switching	2.12 [1.99; 2.25]	1.28 [1.20; 1.36]	35.84 [30.48; 41.21]	88.90 [72.57; 105.23]	0.11 [0.06; 0.16]

Reported in a format of *Mean (95% CI)*.