Improving Ergonomic Viewing of Spatial XR Workspaces Through 2D Rotational Assistance

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ABSTRACT

Extended Reality unlocks the capability to create virtual workspaces that address and exceed the limitations of existing physical multi-monitor arrangements. We extend the ergonomic benefits of virtual workspaces by applying rotational assistance based on user gaze transitions between displays - meaning as a user looks towards a given display, the workspace would counter-rotate to reduce the amount of head/neck rotation required to view said display. Where prior work examined rotational assistance on one axis (horizontal) we extend this to movements across two axes, examining its impact on horizontal, vertical, and mixed arrangements of display. We found in a user study (n=20) rotational assistance improves ergonomic comfort, decreases necessary head/neck movement, improves workload, and decreases fatigue when viewing wide and tall virtual display spaces, further motivating the transition from physical to virtual displays for productivity.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**.

KEYWORDS

Virtual Reality, Extended Reality, Virtual Displays, Productivity, Workspaces, Ergonomics,

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1 INTRODUCTION

The multi-display workspace has many benefits to users, e.g. increasing access to more information simultaneously [7], providing peripheral awareness to content that is not a current main focus [12], enabling easier multi-tasking, etc. However, such benefits can come at a cost as multi-display workspaces are known to be more physically taxing on users than single-display workspaces [15, 31]. This is due to the increased and repeated head and neck movements required by users using multi-display setups to switch between looking/focusing on different displays of varying orientations and positions [31]. Therefore users are faced with a trade-off, the benefits of increased productivity multi-displays provide at the potential cost of increased physical discomfort and fatigue from their prolonged use [25].

One solution to provide the benefits of multi-display workspaces whilst mitigating against their ergonomic problems is the use of Extended Reality (XR), which has seen increased consideration for its potential in *everyday* spatial computing in recent years [3, 5, 19, 32, 34, 36, 37, 40, 42, 49]. By using XR to render planar digital displays anywhere around the user, XR unlocks the capacity to create dynamic multi-display setups of any shape, scale, orientation, and position of displays [25], freeing the user from the physical constraints and limitations of physical displays [31], enabling new forms of *spatial productivity* [27]. A number of papers have examined the virtual displays that constitute the virtual workspace, arguing they will in time supplant physical monitors [2, 22, 45, 46, 48, 55], and demonstrating benefits in sensemaking [23], screenspace [44], and ergonomics [25] in particular,

One approach to addressing the ergonomic issues of mutli-display workspaces within XR is to apply *rotational assistance* [25] based on user gaze transitions between displays. Simply put, when a user looks towards a given display, the workspace itself would counter-rotate to reduce the amount of head/neck movement required to view said display. This decrease in head/neck movement and rotation, in turn, decreases the physical load of using these display setups on users (reducing discomfort and fatigue) whilst preserving the usability and productivity benefits of multi-display setups. However, prior work investigating rotational assistance has focused exclusively on viewing horizontal display layouts [25]. It has not investigated the use of rotational assistance on vertical or diagonal arrangements, despite such arrangements being more common in XR workspaces compared to physical monitor setups. By comparing rotational assistance in horizontal, vertical, and diagonal arrangements, we can gain insight into the effectiveness of rotational assistance across all three and early user preferences towards the differences in its effectiveness across display arrangements.

In this short paper we present the results of a user study (N=20) where we build upon McGill *et al.* [25] by replicating their controlled approach to examining workspace usability and contrasting the *Horizontal* configuration examined previously against *Vertical* and *Mixed* grid arrangements - significantly expanding our understanding of appropriate layout options for spatial workspaces across a breadth of environments and use cases. We then examine whether the benefits of rotational assistance, previously shown for Horizontal configurations in reducing physical fatigue and enhancing comfort/usability, hold for these newly examined layouts - configurations that have been shown to have increasing importance to productivity in constrained spaces, such as passengers in transit [26, 28, 30].

2 STUDY DESIGN

2.1 Conditions

We investigated whether the benefits of *Rotational Assistance*, previously evidenced in wide horizontal workspaces, would transfer to both *Tall* workspaces, and *Mixed* combinations of Horizontal and Vertical virtual displays. We examined two factors:

Technique: Either **No Assistance (NA)** or **Rotational Assistance (Rotation/ROT)**, which was a replication of what [25] referred to as *Boundary Assistance*, where counter-rotations were triggered when the user head raycast hit the display boundary edge.

Layout: Either **Horizontal (HOR)**, referring to 3 displays arranged horizontally, each display was 50° wide with an additional 10° gap between displays, leading to 60° between display centres; **Vertical (VER)** referring to 3 displays arranged vertically each separated by 30°; or **Mixed (MIX)** which combined the two previous layouts into a 3*3 grid shaped arrangement inspired by [10, 11] (see Figure 1 for a view of all three layouts).

The size of the displays and margins were in-line with prior work [25] which showed the benefits of *Rotational Assistance* at 3 and 5 display workspaces. Each combination of *Technique*Layout* was evaluated within subjects in a partially counterbalanced study. 18 participants were evaluated using a Balanced 6x6 Latin squares, with 2 additional participants evaluated in a randomised condition order.

2.2 Rotational Assistance

The rotation technique counter-rotates the workspace based on the direction the user moves their head. If the user were to look at a different display, the entire workspace would rotate half the angular difference between the new display and the previous one in the opposite direction of the direction in which the user moved their head to make the transition. An example of how this technique would work is: if the user wanted to look at a display the centre of which is 60° to the left of the centre of the central display, then if the user rotates their head to the left 30° then they will end up looking at the centre of that display. See the attached *Video Figure* for a demonstration. The key benefit this technique provides is reducing the required neck movement for users to access any display in the workspace [25]. Another advantage is that this technique maintains spatial consistency between the workspace displays, so users will not need to make any unnecessary transitions due to being unaware of the spatial relationships between each display. Additionally, the movement from this rotation was made instantaneous in order to reduce the simulator sickness experienced.

2.3 Experimental Design

A Meta Quest 2, tethered to a desktop PC using Meta Link, was used to run the study. The only other input device was a mouse attached to the PC which was only used to left-click. Users were seated in a fixed chair throughout, that is a chair which cannot rotate, without wheels, positioned in the same starting position for each condition. Participants performed a targeting task requiring them to make transitions between all of the displays in the workspace. Given the number of displays changed between some conditions, we elected to have a fixed number of 64 target selections per condition, with targets randomly selected and participants always returning to the central display after each target selection. To complete one target selection: the participant looked at the current active target display, left clicked the mouse, then looked at the central target display and left clicked before moving onto the next target. Our task was based on prior work [25] which demonstrated its effectiveness as a basic task representative of ergonomic performance.

The targets were colour-coded so participants could easily determine which target was the active one and which was the central display target. The central target was yellow throughout the task, so it was easily identifiable. When the targets on the non-central display were not the current active target they were blue. Yellow was used to indicate the current active target the participant should look at. When the current active target was clicked, it would turn green and an arrow appeared and pointed towards the current active target so participants would know which way to look.

2.4 Measures

After completing the task for each condition participants answered a questionnaire containing: **Workload** NASA TLX [17]; **Physical Discomfort** Single item: *"Please rate the physical discomfort when viewing the non-central displays"*, from no discomfort to extreme discomfort; **Neck Fatigue** Rated on the Borg CR10 scale [53]; **Visual Discomfort** *"Please rate your general visual discomfort (e.g. feelings of tiredness, soreness, irritation, watering and/or burning in eyes)"*, from no discomfort to extreme discomfort; **Body/Shoulder Movement** *"I had to move my body/shoulders to see the non-central displays"*, from strongly disagree to strongly agree.

The NASA TLX questions are on a scale from 0-20, the neck fatigue question uses a scale based on the Borg CR10 scale [53] and all the other scales were based on the 7-point Likert scale [18]. We also captured **Quantitative Performance Data** around the ***Time Per Trial*** for each target selection trial; and the ***Accuracy*** based

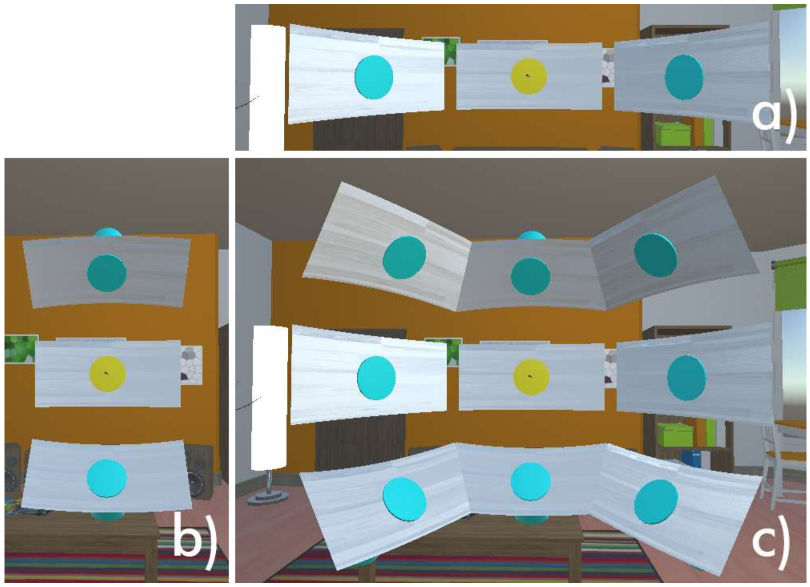

Figure 1: Our display layouts: a) Horizontal; b) Vertical; c) Mixed. Mixed layout shows some overlapping of displays. This was necessary to keep distances between displays consistent so the same range of head/neck movement was required on both axes, to avoid confounding results and because increasing the distance would increase fatigue and reduce comfort, as the physical movement increases to view the displays.

on the angular distance in degrees from the center of the target at the point of selection. Participants were given breaks after each condition until they felt that simulator sickness-induced symptoms, if any, had returned to how they felt at the start of the study. After all conditions were evaluated, participants were asked to **Rank Order** the 6 conditions in order of preference and to think aloud while doing so. Finally, a short **Semi-Structured Interview** was conducted. Participants were asked to reflect on which condition they preferred and why, and if they would be likely to change their current workspace for one like they experienced during the study. Participants were also asked if the movement the rotational assistance provided felt natural, and if they had any comments on any of the conditions they experienced. We also followed up on comments made by participants during the interview.

2.5 Implementation

The study was built using the Unity [51] game engine using long-term support (LTS) version 2020.3.27f1. We recreated McGill *et al's* implementation of rotational assistance based on their paper and video description [25] and extended it to support display transitions on two axes. Each display had 8 colliders attached noting the corners and centres of each edge, used to trigger appropriate counter-rotational movements based on the direction of entry of a head orientation raycast. Diagonal rotation assistance was enacted by performing the rotation on both axes independently but simultaneously, meaning the virtual movement depended on the head movement made. As such, it was possible to trigger one axis but not the other depending on the movement trajectory made.

Participants could not adjust the positioning of the displays in the study. Participants perceived distance from the displays was between approximately 1 to 1.5 metres. Slight individual differences existed between participants depending on how they sat in the chair and adjusted the chair's position for comfort at the start of the experiment. The middle display was aligned with the head height of each participant. That is, the centre of the middle display was aligned with the participant's view looking straight ahead at the start of the experiment.

3 RESULTS

For statistical significance testing, an Aligned-Rank Transform (ART) [8] was used to transform non-parametric data prior to conducting a two-way repeated measures ANOVA, using the *ARTool* R package [20]. For effect size, partial eta squared η_p^2 is reported [29, 47]. Pairwise contrasts for main effects were also conducted [21]. For qualitative data, participants' statements were coded using initial coding [6] where participants' statements were assigned emergent codes over repeated cycles with the codes grouped using a thematic approach. A single coder performed the coding (2 cycles) and reviewed the coding with one other researcher to resolve unclear codes and discuss the depth and specificity of codes.

3.1 Demographic Data

The study was completed by 20 participants (15 male, 4 female, 1 non-binary), aged between 19 and 34 years of age (M=24.1, SD=4.4). Participants were asked how often they used virtual or augmented reality technologies: 4 said never, 9 rarely, 2 at least once per week, 2 at least three times per week, 3 at least once per day. Participants were asked how often they used a computer which has two or more displays: 2 said never, 7 said rarely, 3 said at least three times per week, 8 said at least once per day.

Measure	Factor	Main Effect DoF	F	p	η_p^2	Mean (SD)	Sig. Post Hoc Comparisons
TLX Overall	Technique	1, 95	43.68	<.001	0.31	**NA**: 24.74 (16.34) **ROT**: 16.79 (13.08)	-
	Layout	2, 95	6.35	0.003	0.12	**HOR**: 19.77 (15.40) **VER**: 18.88 (13.77) **MIX**: 23.65 (16.46)	**HOR** - **MIX** (t=-2.8, p<0.05); **VER**- **MIX** (t=-3.31, p<0.01)
	Interaction	2, 95	2.66	0.075	0.06	-	
Time Per Trial	Technique	1, 95	1.01	0.317	0.01	**NA**: 1.01 (0.22) **ROT**: 0.99 (0.17)	-
	Layout	2, 95	22.31	0.001	0.32	**HOR**: 0.98 (0.21) **VER**: 0.96 (0.22) **MIX**: 1.06 (0.14)	**HOR-MIX** (t=-5.03, p<0.01) **VER-MIX** (t=-6.32, p<0.01)
	Interaction	2, 95	1.35	0.263	0.03		-
Nausea	Technique	1, 95	3.92	0.051	0.04	**NA**: 2.05 (1.52) **ROT**: 1.75 (1.19)	-
	Layout	2, 95	2.52	0.086	0.05	**HOR**: 2.18 (1.58) **VER**: 1.70 (1.16) **MIX**: 1.83 (1.32)	-
	Interaction	2, 95	1.91	0.154	0.04		-
Eye Strain	Technique	1, 95	2.56	0.113	0.03	**NA**: 2.10 (1.22) **ROT**: 1.97 (1.22)	-
	Layout	2, 95	0.18	0.838	<0.01	**HOR**: 2.05 (1.26) **VER**: 2.05 (1.11) **MIX**: 2.00 (1.30)	-
	Interaction	2, 95	0.19	0.829	<0.01		-
Discomfort	Technique	1, 95	25	<.001	0.21	**NA**: 3.27 (1.67) **ROT**: 2.28 (1.19)	-
	Layout	2, 95	2.28	0.108	0.05	**HOR**: 2.70 (1.51) **VER**: 2.55 (1.13) **MIX**: 3.08 (1.85)	-
	Interaction	2, 95	0.2	0.822	<0.01		-
Move Body / Shoulders	Technique	1, 95	18.31	<.001	0.16	**NA**: 3.27 (1.89) **ROT**: 2.22 (1.43)	-
	Layout	2, 95	10.99	<.001	0.19	**HOR**: 2.73 (1.89) **VER**: 2.10 (1.22) **MIX**: 3.40 (1.85)	**HOR-MIX** (t=-2.72, p<0.05) **VER-MIX** (t=-4.67, p<0.01)
	Interaction	2, 95	3.23	0.044	0.06		**NA**,**HOR** - **ROT**,**HOR** (t=3.60, p<0.01) **NA**,**HOR** - **ROT**,**VER** (t=3.68, p<0.01) **NA**,**MIX** - **NA**,**VER** (t=3.79, p<0.01) **NA**,**MIX** - **ROT**,**HOR** (t=5.11, p<0.01) **NA**,**MIX** - **ROT**,**VER** (t=5.19, p<0.01)
CR10 - Neck Fatigue	Technique	1, 95	57.66	<.001	0.38	**NA**: 2.83 (1.91) **ROT**: 1.48 (1.30)	-
	Layout	2, 95	1.58	0.211	0.03	**HOR**: 2.01 (1.56) **VER**: 1.93 (1.55) **MIX**: 2.51 (2.11)	-
	Interaction	2, 95	0.63	0.536	0.01		-
Visual discomfort	Technique	1, 95	10.72	0.001	0.1	**NA**: 2.62 (1.54) **ROT**: 2.12 (1.33)	-
	Layout	2, 95	0.8	0.451	0.02	**HOR**: 2.33 (1.58) **VER**: 2.30 (1.27) **MIX**: 2.48 (1.54)	-
	Interaction	2, 95	2.43	0.093	0.05		-
Preferred Technique * Layout	Technique	1, 95	22.33	<.001	0.19	Medians - **NA**: 4.0 **ROT**: 2.5	-
	Layout	2, 95	6.43	0.002	0.12	Medians - **HOR**: 2.0 **VER**: 3.0 **MIX**: 4.5	**HOR-VER** (t=-2.40, p<0.05) **HOR-MIX** (t=-3.51, p<0.01)
	Interaction	2, 95	0.08	0.92	<0.01		-

Table 1: Questionnaire items and statistical significance reporting.

3.2 Workload

(*See Table 1*) There were main effects on *Technique* and *Layout*, with the *Rotational Assistance* conditions performing better, and the *Mixed* display layout performing worst, in-particular without assistance.

3.3 Physical Impact

(*See Table 1*) There were no effects on *Nausea* or *Eye Strain*; however, *Technique* saw significant main effects around *Body/Shoulder Movement*, *Neck Fatigue*, *Visual Discomfort*, and *Physical Discomfort*, all in favour of the *Rotational Assistance* conditions. Moreover, there was an effect on *Body/Shoulder Movement* on *Layout*, and an Interaction effect. However, this interaction on body/shoulder movement is unsurprising given differences were largely between those configurations with horizontal versus vertical layouts, which effectively required little physical body/shoulder movement to view displays at the extremes compared to the yaw movements necessary for horizontal conditions.

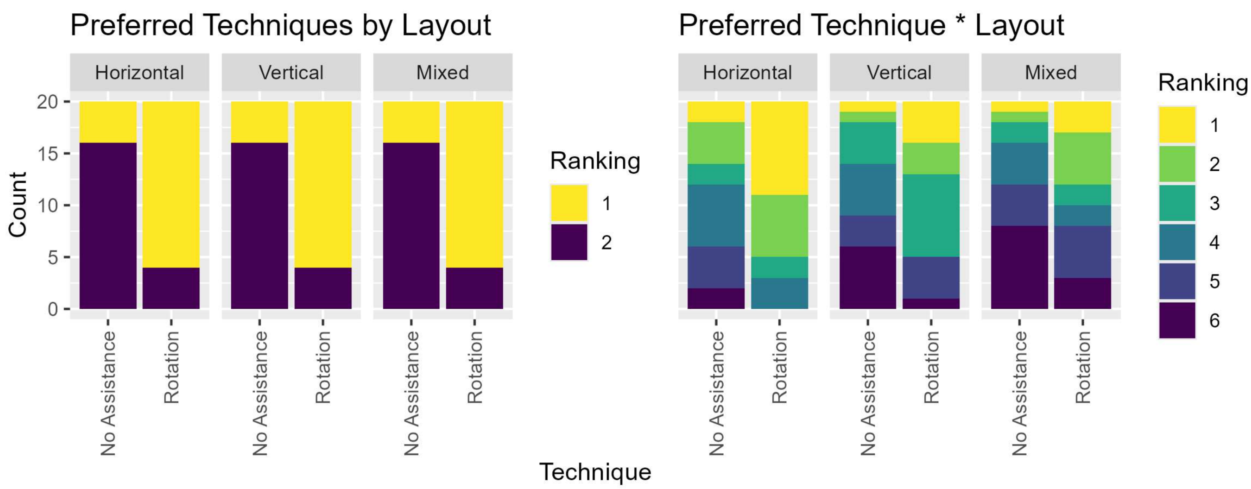

Figure 2: Rankings broken down by *Layout* and *Technique * Layout*.

3.4 Objective Performance

(*See Table 1*) There was no objective performance increase based on *Technique* noted. However there was an effect on *Layout* for both *Time Per Trial* and *Accuracy* - with the *Mixed* layout exhibiting the worst time performance. Curiously, the *Horizontal* layout exhibited the worst accuracy, potentially because it alone had the biggest extent of movement required to transition between displays, meaning the biggest ballistic head/neck movement to view.

3.5 Rankings

(*See Table 1 and Figure 2*) There were clear and strong preferences exhibited for the *Rotational Assistance* over *No Assistance* when ranked for each layout. When considering the rankings across *Technique*Layout* (i.e. ranking each combination of Layout and Technique individually), there was a significant effect of *Technique*, with assistance preferred, and a significant effect of *Layout*, with the *Horizontal* layout being preferred over the *Vertical* and *Mixed* layouts.

3.6 Participant Reactions

Reflecting on *Rotational Assistance*, 16 participants said it felt natural and was quick and easy to learn, e.g. *P8: "the first couple it overshot as I wasn't ready for it to meet me but after 3 attempts it felt really natural... you don't need to consciously learn anything, you just subconsciously figure it out"*. This naturalness was due to its design building on existing movements used during use, *P9:"it was the natural motion of my neck"* and *P11: "it is what I would do in the real world anyway"*. Participants were positive also because of the envisioned reduction in head/neck movement, *P18: "[rotation assistance] can help me to move less my neck [sic]"*.

Participants who liked rotational assistance were all positive towards its use for horizontal display arrangements. Participants, generally were more varied towards vertical display layouts with 8 participants stating they found them more strenuous to use than horizontal layouts. 5 singled out lower positioned displays (ones requiring looking down to see) as being uncomfortable, *P6: "my neck didn't appreciate having to look down as much"*. However, 4 of these participants stated that rotational assistance did alleviate some of their discomfort with vertical arrangements and lower positioned displays, *P1:"Without the assistance it was very difficult to look down; it wasn't comfortable, but with the assistance it was"*. For the mixed display layouts, 6 participants found the rotational assistance ineffective for diagonal movements (e.g. starting in the centre display of a 3x3 layout and looking at a corner display). These participants described the assistance when used diagonally as being: *P10: "clunky"*, *P12: "jumpy"*, *P6: "weird"*, *P8: "tricky"*, *P14: "not easy"*, and *P3: "difficult"*. 1 participant even stated using a mixture of horizontal and vertical movement to avoid diagonal motions, *P8: "I would go along and then down, rather than diagonally"*. Finally, 4 participants said they did not like *Rotational Assistance*: 3 because of a perceived lack of control and 1 because it made them feel motion sick.

4 DISCUSSION

4.1 Benefits of Ergonomic Assistance Hold Across Varied Virtual Workspace Layouts

Our study confirms the benefits of *Rotational Assistance*, as first explored for virtual workspaces by McGill *et al.* [25], largely hold for vertical and mixed display arrangements. Rotational assistance lessens workload and physical demand whilst reducing neck fatigue, physical discomfort, and body/shoulder movement, particularly for the most complex *Mixed* layout. It does this by reducing, but not removing, the need for head/neck movement when switching between virtual displays In replicating and extending prior work, our paper demonstrates XR can be used to render multi-display workspaces and, crucially, *improve the ergonomics of those workspaces* - making them easier and more comfortable to view, which could impact their acceptance and adoption given the evidenced benefits. That our results hold across the different display configurations tested suggests these ergonomic benefits can be applied to various context-specific workspace configurations.

4.2 Horizontal Layouts Still Preferred

Our participants were near-uniform in their preference towards having *Rotational Assistance* (preferred by 16/20 participants irrespective of layout), but were more varied in their preference regarding display layout - with *Horizontal* configurations being the most popular, but some participants nonetheless preferring *Vertical* or *Mixed*. This finding is not unexpected, as the configuration of multi-display workspaces will inevitably be influenced by preferences, past experience, use around others, the kinds of multitasking users engage in, and this diversity of use is likely reflected in our findings. For example, prior research has shown vertical arrangements of displays could be well suited to use by passengers in planes to avoid social collisions [30] - thus, despite the range of preferences, demonstrating rotational assistance benefits all layouts tested gives hope, regardless of the display layout used, we can improve the ergonomics of any given workspace arrangement of 2D virtual displays.

4.3 Assistance Proves Robust for Short Durations - But Longitudinal Impact Remains to be Explored

Moreover, as McGill *et al.* [25] also found, we did not evidence any significant impact on users regarding cybersickness when perceiving the rotational assistance transitions. However, that is not to say that such an effect may not be present given longitudinal use of such an approach. Indeed, our assumption of VR-based productivity would also impact perception here - use in AR (be it optical see-through or video passthrough) might also impact perceived cybersickness differently. Realistically, whilst we demonstrate the benefits of assistance transfer to different display configurations, we, as with prior work, are yet to robustly assess these approaches longitudinally. Where previously research has been limited by the comfort and fidelity of XR headsets, we are now reaching a turning point where such a longitudinal [4, 35, 50, 52, 54], cross-cultural [1] evaluation becomes not only practical, but paramount if we are to definitively prove the utility of ergonomic assistance for viewing virtual workspaces.

4.4 Implications for Future Research into Ergonomics of Spatial Interfaces

Recent works have shown mobile XR users may use a variety of display configurations [9], influenced by their preferences, current tasks and surrounding environment [24, 26, 33, 38, 39, 41, 43] and the presence of bystanders around them [13, 14, 16]. For example a passenger in transit who might previously limit themselves to vertical layouts to minimize awkward eye contact with other passengers [26] might opt for horizontal or mixed layouts because *Rotational Assistance* enables them to limit their head movements and avoid unintended staring at others. Consider also the applicability to workers within physically constrained spaces, e.g. a submarine crew member, a tunnelling miner, many engineering and technician roles, etc. If we are to arrive at ergonomic and effective XR use within physically constrained spaces, we need spatial ergonomics research to consider non-standard configurations of spatial virtual content, and our work serves as provocation to such an end.

4.5 Limitations

Our design examined only a small number of display configurations, concentrating on contrasting and combining vertical and horizontal layouts. Personalized workspaces might be expected to exhibit atypical 2D layouts (e.g. five displays arranged in a cross shape) varying by preference, current tasks/demands, etc. Our study also only examined short durations of use in a controlled lab-based study, rather than longitudinally with ecologically valid productivity tasks. However, given McGill *et al.* [25] showed ergonomic assistance transferred from a controlled study to practical use, it is reasonable to assume the same performance improvements for vertical and mixed display configurations would hold in practice.

5 CONCLUSION

We evaluated the application of *Rotational Assistance* - discretely counter-rotating displays in the opposite direction to the VR user's head movement - to enhance the ergonomics of both wide and tall virtual multi-display workspaces. Across the majority of measures (workload, neck fatigue, body movement, discomfort, etc) we found rotational assistance meaningfully and significantly improved the user experience for *Horizontal*, *Vertical* and *Mixed* arrangements of virtual planar displays. Our results demonstrate the benefits of this assistance can be transposed to a variety of display layouts, and further provoke the need to consider the ergonomic benefits of spatial virtual interfaces.

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