The XXXV[th] Annual International Occupational Ergonomics and Safety Conference
Munich, Germany
October 9-10, 2023

Effect of Screen Configuration on the Neck Muscle Activity, Range of Motion, and Simulator Sickness Symptoms in Virtual Reality

Sobhit Pokhrel[1], Mobasshira Zaman[1], and Jaejin Hwang[1]*

[1]Department of Industrial and Systems Engineering, Northern Illinois University, DeKalb, IL

Corresponding author's Email: jhwang3@niu.edu

Author Note: Sobhit Pokhrel is a master's degree student in the Industrial and Systems Engineering (ISYE) department at Northern Illinois University. Mobasshira Zaman is a Ph.D. student in the Industrial and Systems Engineering (ISYE) department at Northern Illinois University. Jaejin Hwang is an associate professor in the Industrial and Systems department at Northern Illinois University.

Abstract: There is a lack of information regarding the optimal configuration of multiple screens in virtual reality (VR) office work. This study aimed to assess the impact of different screen configurations on neck flexion, rotation, and simulator sickness symptoms during VR office work. Twelve participants (7 males, aged 21 to 27 years) completed copy-paste and drag-drop tasks in three randomized screen configurations: single screen, primary-secondary screen, and double screen. Measurements were taken using an optical motion capture system and simulator sickness questionnaire (SSQ). The results showed that the screen configurations significantly influenced neck rotation angles, and VR sickness symptoms ($p < 0.021$). The primary-secondary screen configuration exhibited the highest right rotation angle (median: -33.47°) and left sternocleidomastoid (SCM) muscle activity (median: 12.57%MVC). Both the single screen (median: 22.42) and primary-secondary screen (median: 22.40) had the highest SSQ scores. The screen configurations in VR have a notable impact on the neck motion and VR sickness symptoms. Asymmetric neck rotations resulting from the primary-secondary screen conditions should be avoided.

Keywords: Virtual reality, Screen configurations, Neck angles, Office work

1. Introduction

Virtual reality (VR) has become a valuable asset for businesses in diverse sectors. Its utility spans from training and simulating experiences to designing and prototyping products. When utilized effectively and to its fullest extent, VR simulations can provide users with a vast amount of information and data. With VR, users can mentally manipulate and engage with objects just as they would in the real world. This state-of-the-art technology has evolved to fulfill the future requirements of companies in terms of design, training, and corporate communication. One of the primary benefits of VR is its capacity to replicate intricate environments, enabling users to undergo training in a controlled and secure setting. This capability proves particularly advantageous in industries with high risks, such as aerospace and medicine. By delivering a realistic and immersive experience, VR facilitates efficient and effective training for workers, thereby mitigating accidents and enhancing overall performance.

VR has emerged as a powerful educational tool, offering users an immersive learning experience that facilitates interactive engagement with various subjects. Within a VR office, the environment can adapt to meet the user's specific work requirements, establishing a calm workspace that fosters heightened productivity. Utilizing multiple screens in VR creates an exceptionally immersive experience, promoting privacy and eliminating distractions, resulting in a focused environment conducive to efficient multitasking. By personalizing their virtual workspace with customized screen positions and sizes, users can tailor their workspace to suit their individual needs, leading to a more enjoyable and productive work experience overall. Additionally, the enjoyable and engaging aspects of VR can enhance motivation and creativity, rendering it a valuable tool for both work and educational purposes. As VR technology continues to advance, it holds the potential to revolutionize the ways in which we work, learn, and interact with the world around us.

Studies have demonstrated that using dual-display configurations can enhance user satisfaction and productivity; however, it can also result in increased neck rotation compared to single-screen setups (Burruss et al., 2021). Although working in VR can offer an incredibly immersive experience, it can also lead to motion sickness and cybersickness over prolonged usage (Kia et al., 2020). Potential adverse effects of VR, including ocular fatigue, disorientation, and nausea, have the potential to diminish the immersive virtual reality encounter for users. Therefore, it is crucial to evaluate both the comfort and discomfort levels associated with performing tasks in VR. Thorough assessment of these factors is essential to ensure a

ISBN: 9781938496615

DOI: https://doi.org/10.47461/isoes.2023.pokhrel

gratifying and safe virtual experience. As VR technology continues to advance, it is imperative to consider both the advantages and risks associated with its usage, and to ensure that users can fully enjoy its benefits while minimizing potential adverse effects.

Past research has indicated that adjusting display heights and targets on a computer screen can decrease biomechanical strains on the neck and shoulders in a traditional desktop setup (Seghers et al., 2003). While these studies have provided valuable insights for ergonomic guidelines in conventional desktop environments, there is a lack of information regarding optimal interface settings for office work in VR. Previous VR studies have focused on identifying optimal target locations and sizes for gesture interactions (Penumudi et al., 2020), but there is a dearth of research on the optimal configurations of VR screens. Such investigations are crucial as they can impact head movements and associated physical demands for VR users. The objective of this study was to assess the effects of different screen configurations (single, primary-secondary, and double) on neck motion and symptoms of simulator sickness during office tasks performed in VR. Our hypothesis was that users' neck angles and VR sickness would be influenced by the different screen configurations.

2. Methods

2.1 Participants

A total of 12 participants, consisting of 7 males and 5 females, within the age range of 21 to 27 years, were recruited from a university for the purposes of this study. None of the participants had a history of musculoskeletal pain or upper extremity diseases. The average height, age, and weight of the participants were 167.85 centimeters (with a standard deviation of ±8.96), 24 years (±1.95), and 68.23 kilograms (±14.94), respectively. The experimental protocol for this study received approval from the Institutional Review Board of the university, and all participants provided written consent before participating in the study.

2.2 Instrumentation

In this study, the Oculus Quest 2 headset was employed with a resolution of 1832*1920 per eye, a refresh rate of 72-120 Hz, and accompanied by a controller that offered 6 degrees of freedom. To facilitate tasks such as drag-drop and copy-paste, the laptop was connected to the VR device via Bluetooth. Various screen configurations were established by pairing the laptop with the VR device, allowing users to experience different setups within the VR environment. Three distinct display configurations were utilized for the experiment: 1) a single screen display with a size of 24 inches, 2) a primary-secondary screen display with the secondary screen tilted at a 15-degree angle, and 3) a double screen display with both screens tilted at a 15-degree angle. These screen configurations were chosen based on previous research findings conducted in a traditional desktop environment.

For the collection of kinematic data pertaining to the upper extremity of the human body, a 3D optical motion capture system consisting of eight cameras (Flex 13, Optitrack, OR, Natural Point) was utilized. Reflective markers with a diameter of 14 mm were employed for this purpose. The motion capture system recorded the movement of these markers at a rate of 120 Hz. A total of twenty-seven markers were affixed to specific locations on the participant's head, chest, pelvis, back, shoulder, arm, wrist, and hand, following the conventional Plug in Gait marker set.

2.3 Experimental Procedure

Using a repeated-measures laboratory experiment design, participants were given instructions to complete two office tasks: copy-paste and drag-drop tasks using the VR controllers. In the copy-paste task, participants were instructed to copy a picture and paste it into the correct position. In the drag-drop task, participants were given names in an Excel sheet and were required to drag and drop the names from the cells into the correct folder. Each task necessitated different usage of the VR controllers to complete. The Excel sheets utilized in the tasks contained emojis as targets, as well as key numbers. The objective was for participants to refer to the key numbers and either paste or drop them in the appropriate location. In the single screen configuration, two tabs were open on a single screen, and the task involved copying or dragging the targets from the left tab and pasting or dropping them into the right tab. In the primary-secondary screen configuration, participants copied or dragged targets from the front primary screen and pasted or dropped them into the right secondary screen. In the double screen configuration, targets were located on the left screen, and participants were required to paste or drag them into the right screen.

Participants engaged in the copy-paste and drag-drop tasks in three different screen configurations, with each task lasting five minutes and performed in a randomized order. Following the completion of each task, participants were given a five-minute break. The screen display was adjusted to match the eye height of each participant, and a consistent sitting arrangement was provided for all participants. To measure simulator sickness symptoms, a Simulator Sickness Questionnaire (SSQ) was utilized, which involved assessing seven components: general discomfort, fatigue, headache, blurred vision, difficulty focusing, nausea, and eyestrain. These components were used to calculate a final score. The questionnaire items were categorized into three sub-score parameters: oculomotor (general discomfort, fatigue, eyestrain, difficulty focusing, headache), disorientation (difficulty focusing, nausea, blurred vision), and nausea (general discomfort, nausea). Participants were asked to rate the severity of each item on a scale of '0' (none), '1' (slight), '2' (moderate), or '3' (high) before and after each task.

2.4 Data Analysis

To process the kinematic data obtained from the optical motion capture system, a 4th-order Butterworth filter with a cut-off frequency of 6 Hz was applied to the raw data for filtering purposes. The neck flexion and rotation angles were computed using biomechanics software (Visual 3D, C-motion, Inc., Germantown). The kinematic data were then summarized using the 10th, 50th, and 90th percentiles.

Given the non-normal distribution of the data, Kruskal-Wallis tests was performed to assess the impact of the three screen configurations on various factors, including neck flexion and rotation angles, and SSQ scores. A significance level of 0.01 was set for the analysis given limited sample size. For the SSQ scores, the individual component scores were summed to determine the overall contribution of each screen configuration to the final scores.

3. Results

3.1 Neck Angles

The screen configurations had a significant impact on the peak neck flexion angle (90th percentile) and the entire range of neck rotation angles ($p < 0.001$), as indicated in Figure 1. Regarding the peak neck flexion angle, the primary-secondary screen configuration exhibited the highest angle (median: 18.41°), followed by the dual screen configuration (median: 16.51°). In terms of neck rotation angle, the primary-secondary screen configuration showed the highest right rotation angle (median: -33.47°), while the dual screen configuration showed the highest left rotation angle (median: 24.88°).

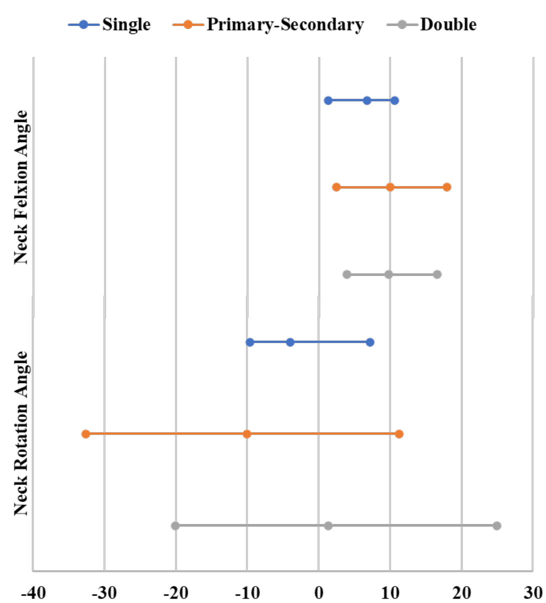

Figure 1. Neck flexion and rotation angles (10th, 50th, and 90th percentile values). Negative value indicates right neck rotation and positive value denotes sleft neck rotation.

3.2 Simulator Sickness Symptoms

The overall normalized SSQ score (post-pre) was significantly influenced by the different screen configurations ($p < 0.001$). Both the single screen (median: 22.42) and primary-secondary screen (median: 22.40) had the highest scores compared to the dual screen configuration (median: 11.22). Additionally, the summed values of each component in the SSQ were compared across the different screen configurations (Table 1). The single screen configuration displayed the highest scores for fatigue, headache, nausea, and eyestrain, while the primary-secondary screen configuration exhibited the highest values for general discomfort, blurred vision, and difficulty focusing.

Table 1. The summed values of each component in the SSQ by different screen configurations.

	Single Screen	Primary-Secondary Screen	Dual Screen
General Discomfort	15	17	8
Fatigue	11	5	6
Headache	18	14	3
Blurred Vision	15	26	12
Difficulty Focusing	17	22	10
Nausea	14	9	5
Eyestrain	22	13	19

4. Discussion

In this controlled laboratory study, the influence of various screen configurations on neck flexion and rotation angles, and simulator sickness symptoms in VR was investigated. The findings revealed significant effects of the screen configurations on neck rotation angles, and simulator sickness symptoms. The primary-secondary screen configuration resulted in the highest right neck rotation angle (median: -33.47°). Participants experienced the lowest levels of general discomfort, headache, blurred vision, difficulty focusing, and nausea when using the dual screen configuration.

The screen configurations had a significant impact on the peak neck flexion angle. The primary-secondary and dual screen conditions exhibited higher values (median: 16.51 to 18.41°) compared to the single screen condition (median: 9.35°). In all cases, the screen configurations were adjusted to match the eye height of each participant while sitting. This difference in neck flexion angle may be attributed to the coupled motions occurring when participants rotated their heads. In the single screen configuration, participants did not need to rotate their necks, maintaining a consistently neutral position. However, both the primary-secondary and dual screen configurations required neck rotation, which likely contributed to the observed increase in neck flexion angle as a result of the coupled motion.

The screen configurations had a significant impact on all ranges of neck rotation angles. The primary-secondary screen configuration resulted in a 24° increase in the right rotation angle compared to the single screen configuration. This can be attributed to the specific setup of the primary-secondary screen, as depicted in Figure 1. In this setup, the primary screen was positioned in front of the participant, while the secondary screen was placed on the right side. This arrangement required substantial right neck rotation to perform the copy-paste and drag-drop tasks. The asymmetry in neck rotation was further confirmed by the 50th percentile angle for neck rotation. While the median angles for the single and dual screen configurations were -5.02° and 0.07°, respectively, the primary-secondary configuration had a value of -9.84°. Previous research examined the impact of different document locations on neck movement during computer use (Goostrey et al., 2014). The findings revealed that placing the document on a flat desktop surface resulted in greater neck rotation compared to using a lateral document holder or a microdesk platform. These findings suggest that the locations of the screens significantly influence neck rotation angles. Prolonged asymmetric neck rotations associated with the primary-secondary screen configuration may lead to neck discomfort and musculoskeletal disorders.

The screen configurations had a significant impact on participants' simulator sickness symptoms. Both the single and primary-secondary screen configurations resulted in SSQ final scores that were twice as high as those in the dual screen setting. In the single screen condition, the most prominent symptoms reported were eyestrain, headache, difficulty focusing, general discomfort, and nausea. This may be attributed to the limited screen size available for performing the copy-paste and drag-drop tasks (Kim & Shin, 2020). With two Excel sheets open simultaneously on a single 24-inch screen, participants had to exert precise control and concentration. Despite the primary-secondary screen configuration utilizing two screens, participants still experienced high levels of symptoms related to blurred vision, difficulty focusing, general discomfort, and headache. This could be associated with the asymmetric neck rotation required to perform the tasks. These findings suggest that VR sickness may be a concern when performing copy-paste and drag-drop document tasks using either single or primary-secondary screen configurations.

Despite careful design, several limitations were identified in this study. Firstly, the sample size was relatively small, and as a result, non-parametric tests were employed, and a significance level of 0.01 was used instead of the conventional 0.05. While many measures yielded statistically significant results with different screen configurations, increasing the sample size in future studies would enhance the generalizability of the findings. Secondly, the study only examined a limited number of document tasks, specifically copy-paste and drag-drop tasks, which are common in office settings and were selected based on previous research (Burruss et al., 2021). However, it would be valuable to explore the effects of screen configurations on other office tasks such as typing and reading to determine if the same patterns emerge. Lastly, the study focused solely on short-term exposure to different screen configurations. Considering the potential exacerbation of neck strain and VR sickness symptoms over prolonged exposure, future research could investigate the changes in user response over an extended period of time.

In conclusion, the screen configurations had a significant impact on neck flexion and rotation angles, and VR sickness symptoms. Both the primary-secondary and dual screen configurations increased neck flexion and rotation angles. Particularly, the primary-secondary screen configuration resulted in asymmetric neck rotation (right rotation over 30°). According to the SSQ scores, both the single and primary-secondary screen configurations had scores that were twice as high as those in the dual screen setting. Blurred vision, nausea, headache, difficulty focusing, and general discomfort were identified as the major contributing factors. These findings suggest that for copy-paste and drag-drop office tasks, a single screen should offer a display size larger than 24 inches to accommodate the demands of the tasks. In the case of multiple-screen settings, a configuration that promotes more balanced neck rotations (such as the dual screen) may be beneficial in reducing concentrated physical loading on the neck.

5. References

Burruss, C. C., Bjornsen, E., & Gallagher, K. M. (2021). Examining Potential User Experience Trade-Offs Between Common Computer Display Configurations. *Human Factors*, 00187208211018344.

Goostrey, S., Treleaven, J., & Johnston, V. (2014). Evaluation of document location during computer use in terms of neck muscle activity and neck movement. *Applied Ergonomics*, *45*(3), 767–772.

Kia, K., Ishak, H., Hwang, J., & Kim, J. (2020). The Effects of Target Sizes on Biomechanical Exposures and Perceived Workload during Virtual and Augmented Reality Interactions. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *64*(1), 2107–2107.

Kim, E., & Shin, G. (2020). User discomfort while using a virtual reality headset as a personal viewing system for text-intensive office tasks. *Ergonomics*, 1–23.

Penumudi, S. A., Kuppam, V. A., Kim, J. H., & Hwang, J. (2020). The effects of target location on musculoskeletal load, task performance, and subjective discomfort during virtual reality interactions. *Applied Ergonomics*, *84*, 103010.

Seghers, J., Jochem, A., & Spaepen, A. (2003). Posture, muscle activity and muscle fatigue in prolonged VDT work at different screen height settings. *Ergonomics*, *46*(7), 714–730.