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Biomechanical Exposures in the Neck and Shoulders during Virtual Reality Interactions

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1. Introduction

Although virtual reality (VR) provides natural and intuitive interactions in immersive three-dimensional surroundings, poorly designed VR interface (e.g., display layout), prolonged static postures and repetitive movements of the arms and neck could increase risks for musculoskeletal discomfort and decrease a task performance (Chihara & Seo, 2018; Kim & Shin, 2018; Nichols, 1999). The objective of this study was to evaluate the influence of vertical target locations on the biomechanical exposures in the neck and shoulders and task performance during VR interactions with hand gestures. It was hypothesized that biomechanical exposures and task performance would be affected by varying target locations.

2. Method

In a repeated-measures laboratory study with 20 participants (10 females), each participant performed two standardized VR tasks (omni-directional pointing and painting tasks) with five different target locations (15° above eye height, eye height, 15° below eye height, 30° below eye height, and self-selected height). The order of tasks and target locations were randomized and counterbalanced to minimize a systematic bias due to the experimental order. An Oculus Rift VR headset (Oculus VR; Menlo Park, CA) and a hand gesture recognition controller (Leap Motion; San Francisco, CA) were utilized to perform VR interactions with hand gestures.

For the omni-directional pointing task, participants were asked to use their dominant hands' index finger to push a randomly appeared target out of 18 targets as quickly and accurately as possible. For the painting task, participants colored a randomly highlighted square out of 9 squares while balancing the speed and accuracy. During the VR tasks, the joint angles in the neck and shoulders, and task performance (speed and accuracy) were recorded.

An 8-camera optical motion capture system (Flex 13; Optitrack; Natural Point, OR) with 100 Hz was used to measure kinematic data of participants' neck and shoulders during VR interactions. Eleven reflective markers were placed on participant's left/right tragus, vertex of head, C7 spinous process, sternal notch, xiphoid process, T8, right acromion, right elbow lateral/medial epicondyle, and right wrist ulnar styloid. Joint angles were computed using a biomechanics software (Visual3D; C-Motion Inc., Germantown, MD). International Society of Biomechanics recommendations were considered for determining the local coordinate system of head, trunk, and shoulders (Wu et al., 2005).

Repeated measures Analysis of Variance (ANOVA) was conducted to evaluate the effect of a vertical target location (fixed effect) on joint angles of neck and shoulders and task performance. Participant was treated as a random effect. Significance level (p-value) was set as 0.05.

3. Results & Discussion

The neck flexion/extension and shoulder flexion and abduction angles were significantly affected by vertical target locations (p's < 0.001). The greatest neck extension (up to -10°), shoulder flexion (up to 52°), and shoulder abduction (up to 32°) occurred when targets located at 15° above eye height while the highest neck flexion (up to 20°) was revealed at 30° below eye height (Table 1). The shoulder flexion exceeding 60° is known to be associated with increased risk of musculoskeletal disorders in shoulder regions (Putz-Anderson et al., 1997). This indicates that prolonged VR use with overhead target location (15° above eye height) could increase a risk of musculoskeletal discomfort.

The speed ($p = 0.061$) and accuracy ($p = 0.960$) were not significantly affected by the target location during omni-directional pointing task while the speed ($p = 0.001$) significantly varied by target locations during the painting task. The greatest time was required at 30° below eye height during painting task, which could be associated with the highest neck flexion and potential neck discomfort (Table 1).

Table 1. Mean (standard error) of joint angles and task performance by target locations during standardized VR tasks.

Task	Variable	Target locations				
		15° above	Eye height	Self-selected	15° below	30° below
Omni-directional pointing	Neck flexion/extension (°)	-10.2 (1.9)	-0.1 (1.7)	-0.5 (3.1)	10.9 (1.7)	20.1 (1.5)
	Shoulder flexion (°)	52.2 (1.8)	43.1 (2.1)	42.9 (2.8)	34.4 (2.1)	24.6 (2.1)
	Shoulder abduction (°)	25.6 (3.8)	16.5 (2.1)	19.0 (4.2)	9.9 (1.5)	9.0 (1.4)
	Completion time (seconds)	18.5 (0.9)	18.5 (0.7)	16.9 (0.6)	18.6 (1.0)	17.4 (1.1)
	Deviation from target (mm)	12.3 (0.7)	12.7 (0.8)	12.9 (1.0)	12.6 (0.8)	12.9 (0.8)
Painting	Neck flexion/extension (°)	-8.5 (1.8)	1.3 (1.5)	7.4 (1.8)	10.0 (1.6)	19.3 (1.6)
	Shoulder flexion (°)	49.2 (1.7)	38.6 (1.6)	31.7 (1.9)	29.4 (1.6)	18.4 (2.0)
	Shoulder abduction (°)	31.5 (5.3)	14.5 (2.9)	12.6 (3.2)	11.4 (2.4)	12.4 (2.2)
	Completion time (seconds)	59.3 (6.0)	53.1 (5.2)	49.8 (3.6)	49.6 (3.4)	60.8 (4.8)

Note: Negative value indicates neck extension angle.

4. Conclusion

Given more extreme neck and shoulder postures and reduced task performance (speed), target locations at 15° above or 30° below eye height should be avoided to reduce potential awkward postures in the neck and shoulder as well as task inefficiencies. Considering lower biomechanical exposures and better task performance, vertical target locations at eye height and 15° below eye height would be recommended for VR use.

5. References

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