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Biomechanical Exposures of Neck and Shoulder in Virtual Reality

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ABSTRACT

BIOMECHANICAL EXPOSURES OF NECK AND SHOULDER IN VIRTUAL REALITY

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Virtual Environment pose certain potential postural discomfort or pain of the neck and shoulder that could be different from a real environment. There has been a lack of ergonomic guidelines for the Virtual Reality (VR) usage with the hand gesture interaction. The purpose of this study was to evaluate the effect of the vertical target locations on biomechanical exposures of the neck and shoulder and task performance during VR interactions. Twenty subjects performed standardized pointing and painting tasks with five different target locations (15° upward, neutral, 15° downward, 30° downward, and self-selected). Users' postures, gravitational moments, muscle activities of the neck and shoulder, and task performance were collected.

Results showed neutral to 15° downward target locations were most effective in reducing biomechanical exposures on the neck (neck sagittal angle, moment, muscle activities, and subjective discomfort) during VR interactions with virtual hand gestures. Neutral to 30° downward target locations were most effective in reducing biomechanical exposures on the shoulder (shoulder angles, moment, muscle activities, and subjective discomfort). The 30° downward and 15° upward target locations caused the greatest stress on the neck and shoulder, respectively. In sum, neutral to 15° downward target location could be effective in reducing postural stresses of both neck and shoulders during VR interactions with virtual hand gestures.

Excessive target locations (15° upward and 30° downward locations) could be avoided to prevent discomfort and pain in the neck and shoulder areas.

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BIOMECHANICAL EXPOSURES OF NECK AND SHOULDER IN VIRTUAL REALITY

BY

SAI AKHIL PENUMUDI

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Thesis Co-Director:
Dr. Jaejin Hwang
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CHAPTER – I

INTRODUCTION

Virtual Reality (VR) has become a state-of-the-art technology for serving a company's future needs in the fields of design, training and organizational communication. According to Whitman et al. (2004), VR allows users to fly, swim, run and walk through different structures to create virtual images in their minds. Patel and Cardinali (1994) mention that VR has an enormous potential for businesses, from education to government to entertainment to virtually every form of business imaginable.

With the rapid development of technology, Virtual and Augmented Reality environments have become an integral part of professional work. According to Lin et al. (2017), VR training systems demand more attention and interaction from the user, which can be termed as human-computer interaction (HCI). HCI adopts the way in which humans interact with real surroundings, which is an important component of an effective system. The use of VR in relation to ergonomics and human factors to improve productivity is gaining interest to professionals involved in the design of some interfaces. Some of the examples of such applications are virtual human simulations and digital human modeling. Backstrand et al. (2007) state that simulation enables early assessment of ergonomic conditions in a virtual environment, which in turn supports the design of an ergonomic workplace. This is supported by the fact that a VR set-up can be modified easily. According to Jayaram et al. (2006), Virtual Environment (VE) can help in the integration of ergonomic issues early in the design and planning phases of workplace layouts.

According to Pontonnier et al. (2014), designing workstations might include assessment steps in a VE to evaluate features of ergonomics. Hu et al. (2011) show that digital mock-ups and VR simulations can be evaluated to identify potential ergonomic issues during an early design stage, which reduces design time and costs, increases quality and improves customer satisfaction. In addition, VE contributes to a new trend in the integration of different technology fields for synergistic use in industry.

Usually, in the VR environment, the visual scene is delayed after the head movement by several hundred milliseconds. Therefore, there is a difference between the interaction of head movement and display in the VR environment compared to the real world. Akiduki et al. (2003) state that the delay in the interaction in the VR can result in visual-vestibular conflict (VVC), which prompts the user to interact with the newly displayed scene. They also state the range of movement between a VR and a real box-lifting task was found to be comparable whereas there were significant differences in terms of movement velocity and acceleration. In the process of adaption with the VR environment, some of the users might feel some motion sickness and show postural disequilibrium.

VR creates a virtual scene in which the user feels immersed. For every active head movement of the user, the computer determines the new direction or layout of gaze and creates a new scene from the updated point of view. According to Nichols (1999), to calculate the biomechanical attributes of a task, the augmentation of VR should be set up with a motion capture system. In turn, these attributes should be analyzed to know the risk factors that lead to discomfort and musculoskeletal disorders.

An effective system requires control with high degrees of freedom that cannot be obtained by traditional input devices, such as the mouse and keyboard. Direct manipulation of a

3D object with a user's hand may provide the best experience compared to the former. With this approach, the user can control the orientation and position of a 3D object with their hands like their usage in the real world. Pereira et al. (2015) state that there are alternatives, such as wearable gloves, that can track hand postures. A computer vision-based gesture recognition system is a more natural alternative as it is part of the environment. A gesture-based interface eliminates the need for pointing devices, which therefore save equipment, time and effort.

1.1 Problem Description

There are some initial concerns regarding the design of VR equipment, particularly the physical ergonomics of head-mounted displays (HMDs) and hand-held input devices associated with display resolution and lags. Many developed countries concentrate on the development of VR technology itself and have potential applications. Recently, little has been reported on the usability and human factor issues. Samani et al. (2015) state that the main reason for this is that present VR users tend to be applications and technology developers. Human factor effects and consequences are considered only when this VE is in wide use in a public domain.

The three-dimensional nature of the VE has introduced new issues concerning the most suitable way to design VR to make moving around a VE as natural and intuitive as possible. There are some studies that indicate that there are some issues of concern with VR usability. Using VR in industries in its current state could be a different sort of issue with manufacturers and industrial users. Whitman et al. (2004) state some of the problems in VR, including experiences of symptoms of postural instability, motion sickness and visual problems. Symptoms might be due to the perceptions of problems associated with the design of VR peripherals and with the quality of the visual display output in terms of resolution and lag in the update. These are the areas in which conventional ergonomic design guidelines and principles should be applied.

Coming to the biomechanical exposure on neck and shoulder, some studies (Backstrand et al. 2007; Nichols, 1999; Samani et al. 2015) find that there are some potential risks posed by postures of the neck and shoulder that are different in a real environment (RE) and VE. Moreover, Samani et al. (2015) state that the complex structure of the shoulder joint and high impact of disorders concentrate higher amount of discomfort in that region. They state that the control of pointing movement can be decomposed into shoulder-elbow and wrist movements to analyze the effects further. So, the target location is a major criterion to maintain the body in equilibrium that reduces all the musculoskeletal disorders and discomfort while performing the tasks.

As we cannot modify the external design and specifications of the VR, in our study, we will concentrate on the target location and the viewing angle (flexion or extension) of the user. The purpose of this study is to evaluate the effect of the target location on physical stresses of the neck and shoulder and task performance during VR interactions. There is a lack of ergonomic guidelines for VR usage. This study will determine the most comfortable target location in the virtual scene to minimize the physical demands of users. We hypothesize that as the virtual location lowers, the flexion angle, moment and muscle activity of the neck will increase. In addition, as the virtual location raises beyond eye level, flexion angle and muscle activity of the shoulder will increase.

1.2 Project Objectives and Scope

The primary goal of this study is to find the most comfortable and efficient target location in the VE. This goal will be met through the following objectives:

1. To reduce the effect of physical stresses on the neck and shoulder by determining the comfortable range of target locations while using virtual hand gestures.
2. To improve task performance by determining the most efficient VR target location hand-based interaction.

The scope of the project will be limited to omni-directional pointing and Painting tasks in a VE. Moreover, selection of target locations is limited to vertical movement of neck flexion/extension angles. The target in which participants work is confined to a two-dimensional plane. All the participants will be university students.

1.3 Potential Deliverables and Benefits

The tangible deliverables of this research are listed below:

1. A most comfortable and efficient range of virtual target locations while using virtual hand gestures.
2. A detailed report on the different aspects of this project and the documented results.

Apart from the anticipated deliverables, the proposed project has several benefits, and some of them are listed below:

1. The optimal target location presented in the proposed study will assist in designing a user-friendly virtual interface with hand-based gestures.
2. It will help to reduce the postural discomfort in the neck and shoulder while using virtual hand gestures.

CHAPTER – II

LITERATURE REVIEW

VR and human interaction with it have been a topic of interest for researchers for the past decade. We used the keywords of ‘virtual reality’ and ‘ergonomics’ to search journal articles and conference proceedings. A total of 18 papers were finally chosen for the systematic review. Recent research on ergonomic effects of the VE can be organized under the following broad categories:

1. VR Tasks
2. Dependent Variables
    - 2.1 Muscle Activity
    - 2.2 Posture
    - 2.3 Motion
    - 2.4 Subjective Measures

2.1 VR Tasks

To know about a new system or environment, any individual requires an appropriate exposure technique. Exposure to the system is availing a correct technique, which can be called tasks. The higher the tasks exposure, the more accurate the data we obtain from the study. Chen and Or (2017) exposed subjects to one-directional pointing, multi-directional pointing, dragging and dropping conditions. As the width of the target increases in those tasks, movement time and error rate decrease as there is good interaction with the target width. In their research, they consider movement time and error rate as dependent variables. Moreover, one-directional pointing has the lowest error rate (6.68%) and movement time (1196 milliseconds).

Table 1. Summary of Past Literature Reviewed

Sources	**VR Tasks**	**Dependent Variables**			
		Muscle Activity	**Posture**	**Motion**	**Subjective Measures**
Akiduki et al. (2003)					X
Akizuki et al. (2005)			X		X
Chen and Or (2017)	X				
Chen et al. (2017)			X		X
Chen et al. (2015)	X		X	X	
Chihara and Seo (2018)			X		X
Kim et al. 2018					X
Lin et al. (2007)	X				X
Lin et al. (2017)	X		X	X	X
Mon-Williams et al. (1998)			X		
Nichols (1999)				X	X
Ohyama et al. (2007)	X				X
Pontonnier et al. (2014)	X	X	X		X
Samani et al. (2015)	X	X	X	X	
So, Lo, and Ho (2001)	X			X	X
Treleaven et al. (2015)	X		X	X	X
Whitman et al. (2004)				X	
Xu et al. (2015)	X		X		
Penumudi (2018)	X	X	X		X

Chen et al. (2015) immersed younger and older subjects in VR, and they were supposed to perform blind spot check movements while driving a car and make a lane change with the foot pedals provided. Older drivers had a detection frequency rate of 46% less than the younger drivers. Similarly, Treleaven et al. (2015) immersed subjects in VR and had them fly a red airplane with their head motion and interact with targets. In addition, Lin et al. (2007) ensured that the subject was immersed in VR for an hour and induced the motion sickness stage by allowing a 40-minute consecutive-curve road in which the subject was supposed to drive. Table 1 shows a summary of the literature collected on the categories as a part of this project, and the collected sources are discussed briefly in the following sections.

Lin et al. (2017) manipulated a virtual hand to grab a virtual die as well as move and release it at a target location. Grabbing and manipulating an object at its center, as compared to its corners, improve the completion time of the task and the subjective usability rating of control. Figure 1 shows the experimental setup. Subjects reported greater rotation control with the center than the corner locations. The time taken to complete the task when held at the center was lower (14.5s) than at the corner (32.5s).

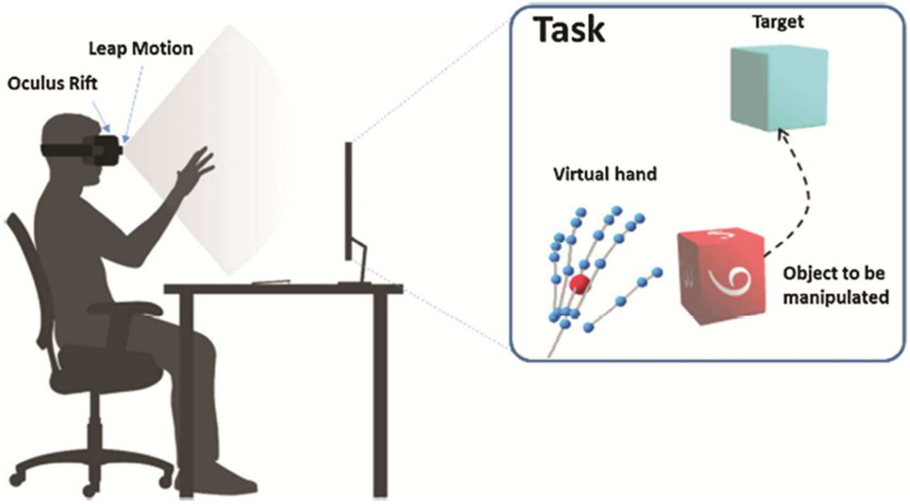


Figure 1. Experimental setup to grab and release a virtual die in the target location

Pontonnier et al. (2014) choose a simplified assembly task, including several elementary operations and conditions that were found in a real industry like target reaching, object manipulation, piece sorting, standing posture and repetitive motion. Total Task Time (TTT) was significantly higher in VE than in a RE for trials (49.6±8.0 s vs 36.5±4.4 s). Samani et al. (2015) developed a work panel with two holes, which could accommodate some of the objects (fitter) whereas the other objects (non-fitter) could not pass through any of the holes. The participants had to pass the fitter objects through the proper hole and place the non-fitter objects on the disposal shelf. The interaction of platform with object type had a significant effect on the cycle time. The cycle time with fitter objects was shortest in RE and longest in VE (2.8 s, 4.7s and 16.8 s for RE, VE, and VE with feedback, respectively). The cycle time with non-fitter was shortest in VE and longest in RE (2.5 s, 2.0 s and 4.8 s for RE, VE, and VE with feedback, respectively).

So et al. (2001) investigated different speeds (3.3, 4.3, 5.9, 7.9, 9.5, 23.6, 29.6, and 59.2 m/s root mean square (RMS)) using a full factorial among subjects in eight different conditions. During the task, participants were asked to turn their heads horizontally to one side (covering about 45° in about 1 s), orally describe what they saw and turn back to face the front. In addition, Ohyama et al. (2007), the subject was immersed in a visual-vestibular conflict produced by VR for 14 minutes, and a virtual ball task was done before and after VR immersion. Xu et al. (2015) immersed subjects in VR and instructed them to align the nine different field goals with the football using head movement.

2.2 Dependent Variables

The following section measures various measures of user responses during VR interactions.

2.2.1 Muscle Activity

Muscle cells generate electric potential or electromyographic (EMG) signals when they are neurologically activated. This EMG data can be used to assess the number of muscular exertions that are required to perform tasks.

Pontonnier et al. (2013) in their research measured the muscle activity from five muscles along the kinematic chain. Bipolar channels were used to collect EMG signals from the Erector Spinae (ES, back extensor), Deltoideus Medialis (DltMed, shoulder abductor), Biceps Brachii (Bscps, forearm supinator and elbow flexor), Triceps Long Head (Trcps, elbow extensor and shoulder stabilizer) and Flexor carpiulnaris (FCU, wrist flexor and adductor) with bipolar surface electrodes. EMG activations were averaged across time for each trial to obtain Averaged Muscle Activations (AMAs), which were calculated as an averaged measure of the activity for a considered muscle. For three of the recorded activations, the AMAs were higher in VE than in RE (Erector Spinae (ES): (0.30 ± 0.11) vs (0.20 ± 0.09), Biceps Brachii (Bscps): (0.18±0.05) vs (0.13±0.05) and Flexor Carpi Ulnaris (FCU): (0.27 ± 0.13) vs (0.20 ± 0.12)). For Deltoideus Medialis (DltMed), the average activation was lower in RE (1.4±0.5) than in VE (2.1±1.0).

Samani et al. (2015) recorded EMG signals with a semi-disposable adhesive grid of 64 electrodes (LISiN-Spes Medica, Italy, model ELSCH064R3S). The 64-electrode grid was placed on the upper trapezius muscle with the fourth row aligned with the C7-acromion line parallel to the muscle fiber direction. The lateral edge of the grid was 10 mm medial to the mid-point of a line between C7 and the acromion. They observed that the intersubjective similarity between the EMG activation maps in RE was lower than intra-subjective similarity in VE and VEF platforms. Moreover, VE required 50% more muscle activity compared to RE to complete the task.

2.2.2 Posture

Experiments which were manipulated with VR had suggested concerns with postural instability. Chen et al. (2017) measured actual head rotation angles for different gains. Detection of the manipulated visual feedback was affected by gain. For normal individuals, head rotation angle decreased or increased 5.45° for every 0.1 increase or decrease in gain respectively, whereas head rotation angle increased 4.29° for every 0.1 decreases in gain for chronic pain individuals. Chihara and Seo (2017) has shown the effect of center of mass (COM) on joint angles (anterior flexion, right lateral flexion, left rotation angles of the head) and joint torque (neck and low back) at four different postures (neutral, look-up, look-down, and body-bending postures). The center of the mass position that minimized the neck joint torque varied depending on the test postures. This states that posture instability also varies with a mass of VR.

Chen et al. (2015) said that the younger drivers demonstrated greater spinal flexibility than older drivers in general. The mean baseline neck axial range of motion (ROM) of the younger and older drivers was 78.1° and 63.48° respectively. Also, the degree of trunk axial rotation was different between the driver groups, with the mean trunk rotation angle being 18.1° and 9.94° for the younger and older drivers respectively. These results stated that younger persons had higher postural instability when immersed in the VE. Pontonnier et al. (2014) measured the Rapid Upper Limb Assessment (RULA) score, which is an indicator of postural discomfort used in relation to the assessment of physical risk factors. To calculate this score, he obtained joint angles by a standard inverse kinematics algorithm. A minimal score of 1 indicates a relatively comfortable posture, whereas a maximal score of 7 indicates a highly uncomfortable posture. The mean RULA score was higher in RE (4.1 ± 0.7) than in VE (3.5 ± 0.5) which said that there is comparatively less postural discomfort in VE.

Moreover, Mon-Williams et al. (1998) also illustrated that the angle at which the eyes had the smallest heterophoria measurement is typically somewhat below the ear-eye line (mean = 34°). As the gaze angle raises from this point, heterophoria becomes more divergent. Results in the study stated that the vertical position of the display screens in VR devices may consequently cause visual stress which results in postural instability. Xu et al. (2015) measured postural stability by immersing subjects into VE and guiding them to work in different postures. Rift-based full ROM was 5.41°, 2.31° for lateral bending, and flexion/extension, respectively.

Akizuki et al. (2005) research findings indicated that VR immersion decreased the visual dependency on postural control. Lin et al. (2017) said that the design of hand gestures should be evaluated to determine design features that are most effective and maintains postural stability. Samani et al. (2015) measured angles at shoulder flexion, internal rotation, and abduction angle to measure the posture stability features. Their results found a smaller elbow angle within the VE platform compared with RE. Treleaven et al. (2015) measured postural stability as time in seconds, in which participant maintained tandem stance and single leg stance with eyes closed.

2.2.3 Motion

In any sort of study, the motion of the hand and neck were interrelated to the tasks. Samani et al. (2015) stated that VE and their interaction fidelities directly influenced the motion and biomechanical load. The interaction of the platform and the object type (platform× object type) had a significant effect on angular velocity ($P<0.02$ in all cases), but a main effect of the platform and the object type was found on shoulder flexion (SF, and shoulder abduction (SA) and the angular velocity of shoulder internal rotation (SI). For the fitter objects the angular velocity maxima in VEF and RE were generally closer to each other compared with those in RE and VE.

So et al. (2001) measured speeds of navigation inside the VE using the viewpoint of the participants as the origin (i.e., a moving origin). The fore-and-aft, lateral, and vertical directions represented the front-and-back, left-and-right, and up-and-down directions relative to the participant. Nausea ratings can be divided into two regions: (a) at speeds from 3 to 10 m/s, both ratings increased with increasing speeds; and (b) beyond 10 m/s, ratings stabilized. This pattern of an increasing region followed by a stabilizing region is partially consistent with the hypothesis that as the speed of scene movement increased, nausea increased, stabilized, and then declined.

Treleaven et al. (2015) measured the interactions challenged range, velocity, and accuracy of neck motion. The custom-made software included three modules: range of motion (ROM), velocity, and accuracy. After completion of each module, the system generated a full kinematic report for each patient. A full description of the VR neck assessment and its outcome measures were found.

Whitman et al. (2004) measured lateral range, sagittal range, twisting angle, maximum lateral velocity, maximum sagittal velocity, maximum twist velocity, maximum lateral acceleration, maximum sagittal acceleration and maximum twist acceleration. The results in their study had shown that data sets for maximum lateral velocity, maximum sagittal velocity, maximum twist velocity, maximum lateral acceleration, maximum sagittal acceleration and maximum twist acceleration differed significantly between the VE and RE.

Nichols (1999) stated that wearing a 600g weight on the head made participants apply more motion to complete the task. Lin et al. (2017) stated that hand motions were continuous and different hand pose guidelines need to be distinguished by constantly tracking hand pose and its movement. Moreover, Chen et al. (2015) concluded that active axial neck motion was higher in performing blind spot-checking movements in a VR environment.

2.2.4 Subjective Measures

Subjective Measure is an important criterion for all the studies where a person's discomfort is observed. Akiduki et al. (2003) and Ohyama et al. (2007), measured levels of severity of motion sickness according to Graybiel's criteria. Total score ranges from 0 to 50. Higher scores of questionnaires reflect severe symptoms. The subjective balance symptom questionnaire was also applied, which assesses four balance-related symptoms: walking, balance, visual illusions and leans. Total score ranges from 0 to 16. Higher scores of the questionnaire reflect severer symptoms. Akizuki et al. (2005) also measured motion sickness with Graybiel's score. The score was 1.8 ± 0.4 after the first and 1.6 ± 0.4 after post-immersion.

Chen et al. (2017) measured the pain level using a 10-point visual analog scale (VAS) at the beginning of the session and Neck Disability Index (NDI) questionnaires before the evaluation of tasks. The individuals with chronic neck pain on an average had a self-reported pain level of 2.1 ± 1.3 on the VAS (0 = no pain, 10 = maximum pain) and 15.3 ± 4.7 on NDI (0 = no disability, 50 = maximum disability). Chihara and Seo (2018) measured subjective difficulty in maintaining posture was measured on a scale of 1–5, where 1 meant "none" and 5 meant "very severe". Values of subjective postures were look-up (3 ± 1), look-down (2 ± 1) and body-bending (2 ± 1). In addition, the subjective difficulty decreased with a decrease in the mass.

Kim et al. (2017) proposed Virtual Reality Sickness Questionnaire (VRSQ) to verify and supplement Simulator Sickness Questionnaire (SSQ) which was as a motion sickness measurement tool in a VE. The proposed VRSQ is assumed to replace the SSQ to some extent, and the results of correlation analysis showed a high correlation between SSQ and VRSQ. The results of the ANOVA analysis were also similar. VRSQ is highly recommended over SSQ in the VE, as the existing SSQ includes items not related to the VE and uses more questionnaire items which reduce the efficiency of the tool.

Lin et al. (2017) measured discomfort by completing a survey evaluating subjective usability and comfort for each of the levels tested. The survey presented three statements and subjects rated each statement on a five-point Likert scale (1 strongly disagreed and 5 strongly agreed). The statements were (1) I had excellent control, (2) I had no shoulder fatigue, and (3) I feel motion sickness. Subjects also ranked the levels tested on overall preference, 1 being the most favorite and 3 being the least favorite. Subjects reported lower levels of shoulder fatigue for settings that were easier to control. Participants reported little motion sickness during the experiments (mean rating 1.31 on 1–5 scale).

Lin et al. (2007) designed a motion sickness questionnaire (MSQ) according to the reference of subjective evaluation. The individual responses to MSQ were used as an index to show the measure of motion sickness they witnessed. MSQ composes 10 items, and each of which has six score levels (0-not at all’, 5-very much’). The total motion sickness score was the aggregate score of the 10 items. Each subject reported their sickness level is above to the score of 3, and the average score of all subjects is 3.8.

Nichols (1999) used the modified version of the Equipment and Display Questionnaire (EDQ) was used. In addition, subjective reports of musculoskeletal discomfort were recorded using the technique of body mapping. The body-mapping questionnaire required participants to indicate where they experienced discomfort during VR use, by indicating one or more areas of the body on a simple diagram. They were then asked to describe the severity of that discomfort on a four-point rating scale; slight, moderate, severe and very severe. Out of all the subjects, 70% reported moderate discomfort in the head and neck.

Pontonnier et al. (2014) rated perceived exertion (RPE) directly using a discomfort indicator for each trial using Borg's CR-10 scale, and a modified questionnaire including items from Witmer-Singer's. Comparisons obtained from the questionnaire were used as global indicators for comparing RE and VE, ignoring complexity and timing-regime conditions. The subjective rating of the VE revealed that subjects found the environment and the interaction relatively faithful to the RE. They mentioned (8 of the 16 subjects) in free comments that manipulation of objects was "more complicated" in VE than in RE.

So et al. (2001) used the Simulator Sickness Questionnaire (SSQ) which contained a preexposure questionnaire and a 7-point nausea scale on a 4-point scale at 5-minute intervals. Further analysis of the rating data indicates that navigation speed significantly affects the onset times of mild to moderate nausea (a nausea rating of 3 or more). Treleaven et al. (2015) reported that about 80-95% of individuals interacting with an HMD experience has some level of motion sickness, with 5-50% of them experiencing severe enough symptoms to end participation. They assessed it with Motion Sickness Susceptibility Questionnaire (MSSQ) along with the SSQ.

Participants rated their perceived motion sickness using Simulator Sickness Visual Analog Scale (SS–VAS), on a scale of 0–10, 0 being no symptoms and 10 being the worst possible symptoms. In the Simulator Sickness Questionnaire (SSQ) participants are asked to rate them as 0 (none), 1 (slight), 2 (moderate), or 3 (severe). Symptoms on the questionnaire included general discomfort, fatigue, headache, eyestrain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, blurred vision, dizzy eyes open, dizzy eyes closed, vertigo, stomach awareness, and burping. The MSSQ predicts individual differences in MS susceptibility caused by various stimuli (cars, buses). Participants rated how often they felt sick or nauseated by these stimuli (0 - never, 1 - rarely, 2 - sometimes, 3 - frequently). The results stated that the HMD provoked SS in about one-third of the participants, but these seem to be of a lesser severity than previously reported for other devices.

2.3 Justification

Past research efforts on VE have focused primarily on subjective measures such as motion sickness and postural stability but not as much on target location and its biomechanical effects on neck and shoulder. The techniques explored in past efforts had ranged from motion capture to subjective measures, but the techniques did not involve the integration of them with muscle activity and selection of target location. There is a significant need to evaluate the effect of the target location on physical stresses of neck, shoulder and task performance in VE. Therefore, the proposed project is warranted to meet this important need, which, when fulfilled, will determine the most comfortable target location in VE to minimize physical demands of users.

CHAPTER – III

METHODOLOGY

The method for the project included the selection of appropriate methodologies for the problem. In this section, we had a detailed description of the methodology and experiment protocol we used in this study.

3.1 Participants

Twenty young adult participants with the equal gender distribution were recruited through e-mail solicitation in the university community. All the participants had no current (past 7 days of pain will be asked prior to the study) musculoskeletal pain and a history of musculoskeletal disorders in the upper extremity and neck regions. The experimental protocol was approved by the University's Institutional Review Board and all participants had given their written consent prior to their participation in the study.

3.2 Experimental Design

In a repeated-measures within-subject laboratory experimental design, 20 participants were exposed to ten different experimental conditions (5 levels of target locations X 2 different tasks). Target location was measured from reflective marker positions as shown in Figure 2. Head angle was defined by the line connecting the tragus and canthus with the horizontal eye level.

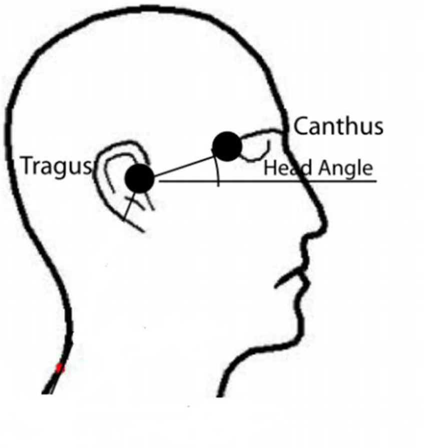
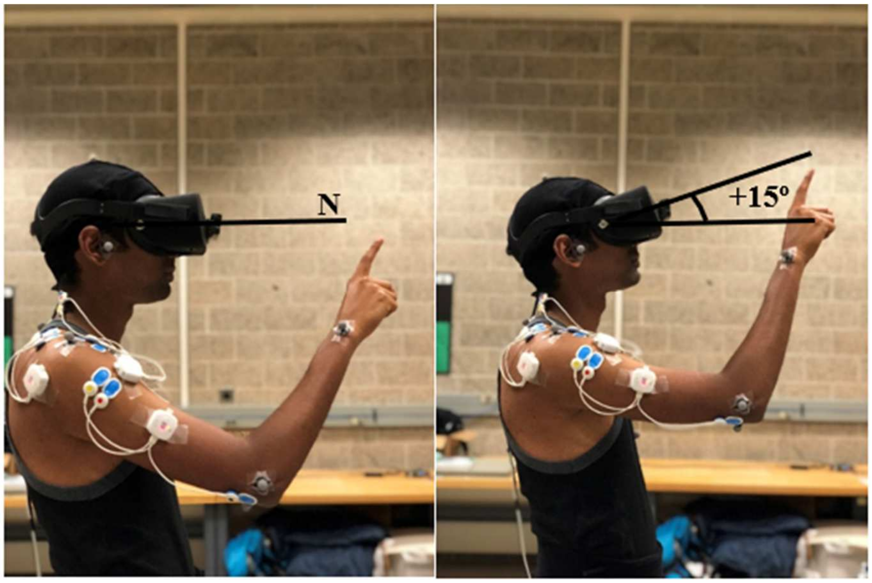


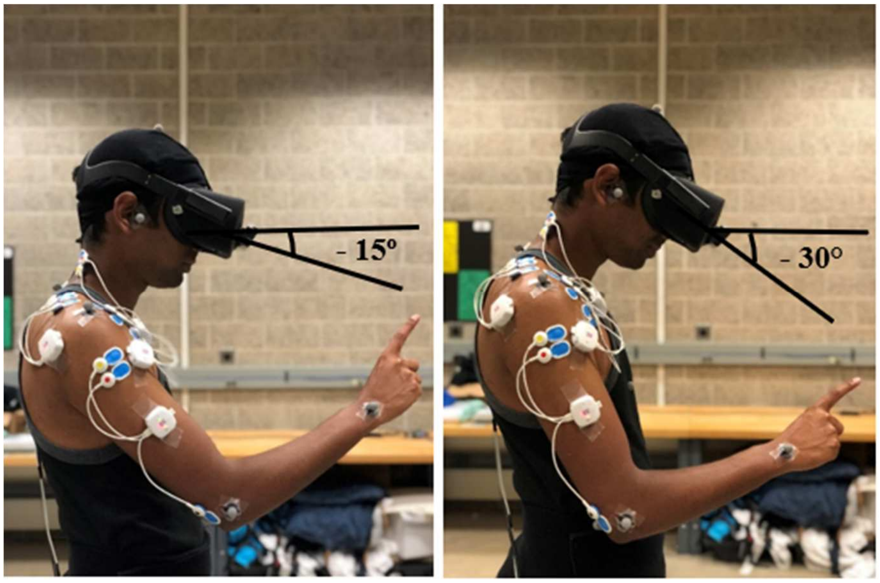
Figure 2. Postural measure of target location

Target location consists of 15° upward, neutral (N), 15° downward, 30° downward, and self-selected. Based on each participant's upright posture, 15° to 30° deviations in upward and downward directions were fixed as their varying target location.



(a) (b)

Figure 3. Experimental setup with target locations. (a) Neutral Position (N), (b) 15° upward



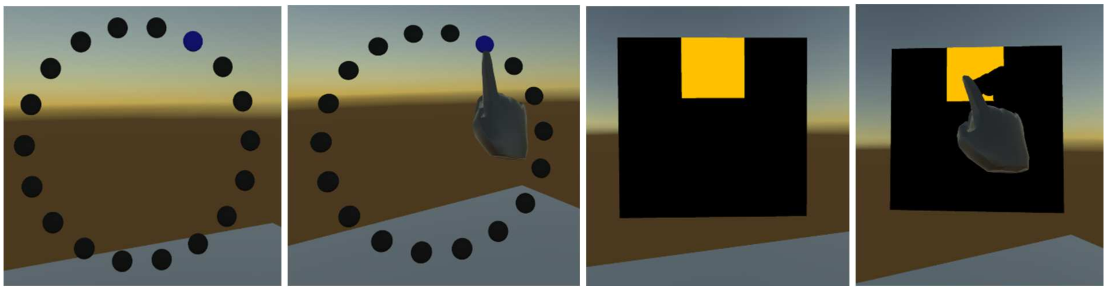
(a) (b)

Figure 4. Experimental setup with target locations. (a) 15° downward, and (b) 30° downward

Figure 3 shows the target locations based on the user's neutral position and 15° upward. The target location was fixed at that position and subject was asked to do the task in the environment. Figure 4 shows 15° and 30° downward respectively.

In this setup, we used Oculus Rift (1080×1200 resolution per eye, a 90 Hz refresh rate, and 110° field of view) and Leap Motion Controller to generate tasks. Two different tasks included omni-directional pointing task and painting task. Figure 5 shows both the tasks with and without hand. The order of ten experimental conditions were counterbalanced and randomized to minimize potential systematic biases due to the order.

Prior to the experiment, each participant had a practice task (about 5min) to become familiar with the VR headset and tasks. Omni-directional pointing task included 18 targets with a target width of 36mm and center-to-center inter target distance of 70mm. At a random, a target was highlighted, and participants moved their index finger to the centroid of the circle and pointed it as quickly and accurately as possible.



(a) (b) (c) (d)

Figure 5. Experimental tasks. (a) Pointing task, (b) Pointing task with hand, (c) Painting task, and (d) Painting task with hand.

Painting task included 3x3 square grids with a length of 1cm. At a random, one of the 9 grid cells were highlighted, and participants colored the cell with their index finger which had a finger radius of 0.125cm. Within each task, five target locations were randomized. For pointing and painting tasks, the target plane was located at a position that subjects could reach all targets without moving the torso.

Before and after each task, the participant rated the subjective discomfort using Borg CR-10 (0 is no discomfort and 10 is high discomfort) (Pontonnier et al. 2015). After completion of each task, subjects rated the motion sickness level on 5-point Likert scale questionnaire (1= strongly disagree and 5 = strongly agree). During each trial, positional data of the neck and the upper extremities, and muscle activities of the neck and shoulders were recorded. A five-minute break was given between the tasks to minimize residual fatigue effects from a previous session.

3.3 Kinematic Data

During the tasks, kinematic data of the head and neck were sampled at 100 Hz using an 8-camera optical motion capture system (Flex 13; Optitrack; Natural Point, OR) with reflective markers. Eleven 14-mm reflective markers (M4; Optitrack; Natural Point, OR) were bilaterally attached on left and right tragus, C7 spinous process, sternal notch, the vertex of head, xiphoid process, T8, right acromion, right elbow lateral epicondyle, right elbow medial epicondyle and right wrist ulnar styloid as shown in Figure 6.

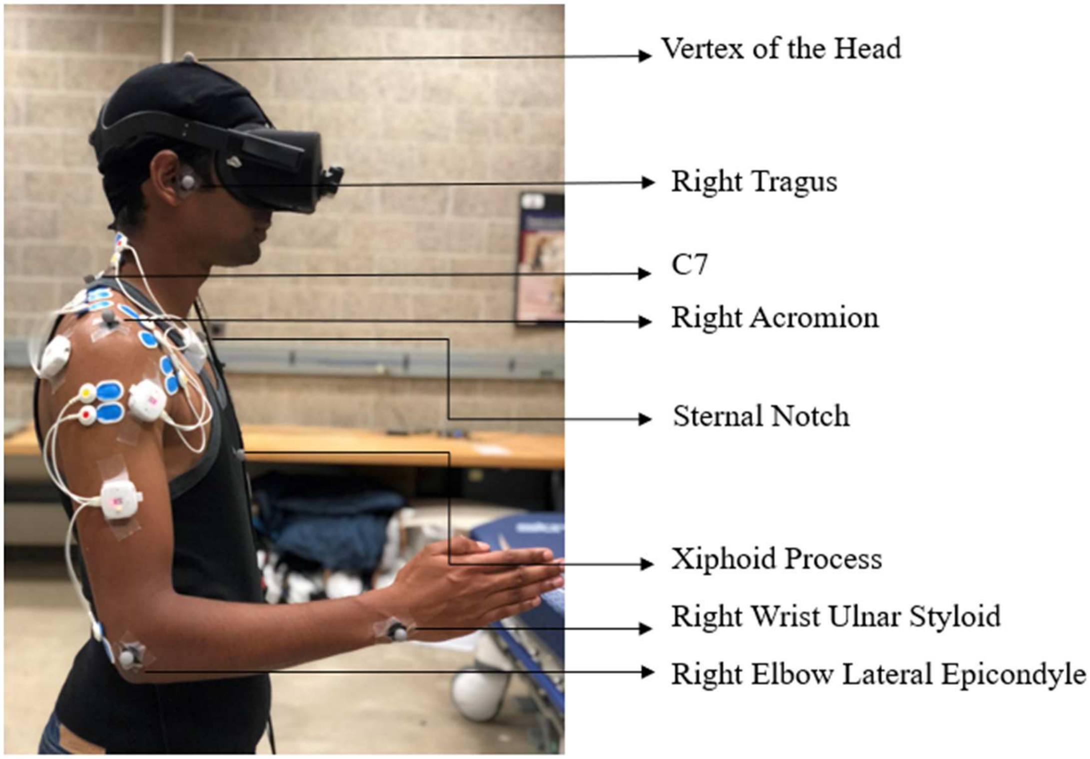


Figure 6. Participant with reflective markers and EMG setup

The raw kinematic data was filtered by a digital zero-phase 4th order Butterworth filter with a cutoff frequency of 6 Hz (Motive; Optitrack; Natural Point, OR). Biomechanical analysis software (Visual3D; C-Motion Inc., Germantown, MD), was used and the head sagittal flexion/extension angle, neck axial rotation angle, neck lateral flexion angle, shoulder flexion/extension angle, shoulder abduction/adduction angle, and three-dimensional neck moment were calculated. The neck moment at C7/T1 was computed by inverse dynamics using gravitational force, neck posture data, head segment mass and inertia. Neck angles were computed using the rotation matrix between the anatomical coordinate system of the head and trunk. Shoulder angles were calculated using instantaneous orientations of the anatomical axes in the right upper arm and the trunk. These kinematic variables were summarized as 10th, 50th, 90th %tile values using the Amplitude Probability Density Function (Jonsson, 1982).

3.4 Electromyography

Muscle activity in the right upper trapezius (TRAP), right cervical extensor (RCE), left cervical extensor (LCE), right anterior deltoid (AD), right middle deltoid (MD) were collected at a sampling rate of 1,000 Hz using Ag/AgCl surface electrodes (Blue Sensor N-00-S; Ambu; Ballerup, Denmark) and a wireless logger (WBA; Mega Electronics; Kuopio, Finland). The skin preparation, muscle identification, and electrode placement were conducted based on the European Recommendation for Surface Electromyography (EMG) (Hermens et al., 1999). The raw EMG data was initially processed by a bandpass filter of 10-350 Hz, and the processed EMG data was rectified and averaged at a 125ms moving window (MegaWin; Mega Electronics; Kuopio, Finland).

At the end of the experiment, three Maximum Voluntary Contractions (MVCs) were collected with a 2-minute break between trials. For the MVCs of TRAP, AD and MD muscles, two tasks were performed. For the first one, participants' shoulder was abducted to 90° in the scapular plane with internal humeral rotation against the isometric resistance by the operator. For the second one, participants' shoulder was flexed to 125° and the resistant force was applied above the elbow and at the inferior angle of the scapula to de-rotate the scapula with the subject sitting in an erect posture with no back support (Boettcher et al., 2008). The MVCs for cervical extensors were collected while the participants attempted to move their head backward by sitting against an isometric resistance by the operator (Kang and Shin, 2017). The peak of the 95th

%tile of EMG values across three MVCs were used to normalize the EMG data (Odell et al., 2007). The normalized muscle activity (%MVC) were summarized as the 10th %tile (static), 50th %tile (median) and 90th %tile (peak) using APDF (Jonsson, 1982).

3.5. Data Analysis

The 10^{th}, 50^{th} and 90^{th} percentile of joint angle, neck and shoulder moment, and muscle activities were summarized using the amplitude probability density function (APDF). For normally distributed data, one-way ANOVA was conducted to estimate the effect of target locations on the selected measures. Non-normal distributed data was converted into a normally distributed function by transforming it by logarithmic or Johnson transformation. Even after the transformation, if the data is non-normal then a non-parametric test (Friedman tests) was conducted to evaluate the effect of the target location on the measures.

One-way ANOVA was conducted to determine the differences in biomechanical measures and muscle activity across different target locations of each task. For the significant variables, a Tukey HSD post-hoc test or Wilcoxon signed rank test was conducted to evaluate the significance level between the groups. A paired t-test was conducted to compare the differences between LCE and RCE. The data was statistically significant if the *p*-value is less than 0.05.

CHAPTER – IV
RESULTS

4.1. Kinematic Data

4.1.1 Neck and Shoulder Posture

The neck sagittal flexion/extension angle was significantly different by target location during pointing task. Highest neck flexion and extension were revealed at 30° downward and 15° upward, respectively (Table 2). The lowest flexion angles were found at both neutral and self-selected target locations. Subjects' average self-selected target location was 6.9° downward from the neutral. The range of motion in neck sagittal angle was not significantly different by target locations.

The shoulder sagittal flexion angle was significantly different by target location during pointing task. The shoulder sagittal flexion angle was the highest at 15° upward (Table 2). The lowest sagittal flexion angle occurred at 30° downward target location. There was no significant difference in flexion angles between neutral and self-selected target locations during the tasks. The range of motion (90th – 10th) was the lowest at 15° upward.

The shoulder abduction angle was significantly different by target location during pointing task. The shoulder abduction angle was the highest at 15° upward (Table 2). The lowest shoulder abduction angles occurred at 30° downward and 15° downward target location. There was no significant difference in the shoulder abduction angles between neutral and self-selected target locations during the tasks. The range of motion (90th – 10th) was the lowest at 30° downward and the highest at 15° upward location.

Table 2. Mean (standard error) joint angle of neck and shoulder by five target locations during pointing task

Measure (Unit)	Percentile	Target Location					*p*-value
		15° upward	Neutral	Self-selected	15° downward	30° downward	
Neck Sagittal flexion(-) /extension(+) Angle (°)	10th	5.4^{D} (1.7)	-5.0^{C} (1.6)	-4.6^{BC} (3.0)	-14.9^{B} (1.7)	-24.3^{A} (1.8)	< 0.001
	50th	10.2^{D} (8.0)	0.1^{C} (7.6)	0.5^{C} (1.37)	-10.9^{B} (7.7)	-20.1^{A} (6.6)	< 0.001
	90th	14.7^{D} (2.0)	4.9^{C} (1.6)	4.7^{BC} (3.2)	-7.0^{B} (1.9)	-16.2^{A} (1.5)	< 0.001
	90th-10th	8.3^{A} (4.7)	9.9^{A} (5.2)	9.4^{A} (8.5)	7.8^{A} (5.0)	7.7^{A} (5.6)	< 0.001
Shoulder Sagittal flexion Angle (°)	10th	32.3^{C} (2.5)	20.1^{B} (2.2)	19.4^{B} (3.1)	9.3^{A} (2.2)	0.2^{A} (1.6)	< 0.001
	50th	52.3^{C} (7.6)	43.1^{B} (9.3)	42.9^{B} (12.7)	34.3^{A} (9.5)	24.6^{A} (9.1)	< 0.001
	90th	71.4^{D} (1.5)	65.6^{CD} (1.6)	63.2^{BC} (2.0)	56.3^{B} (1.8)	46.3^{A} (1.9)	< 0.001
	90th-10th	35.1^{A} (13.8)	45.4^{B} (5.0)	43.8^{B} (7.9)	46.9^{B} (4.7)	43.7^{B} (10.6)	< 0.001
Shoulder Abduction/ Angle (°)	10th	-61.6^{A} (6.6)	-38.5^{BC} (5.0)	-39.7^{CD} (8.2)	-18.9^{DE} (2.1)	-16.7^{E} (1.2)	< 0.001
	50th	-25.6^{A} (16.1)	-16.5^{AB} (9.3)	-19.0^{AB} (19.0)	-9.9^{B} (6.6)	-9.0^{B} (5.9)	< 0.001
	90th	-10.2^{A} (2.6)	-5.8^{BC} (2.0)	-6.5^{CD} (3.2)	-0.8^{DE} (1.6)	-0.4^{E} (1.5)	< 0.001
	90th-10th	46.2^{C} (24.5)	32.6^{BC} (17.1)	33.1^{BC} (24.5)	18.1^{AB} (5.7)	15.4^{A} (5.9)	< 0.001

Note. Letters (A, B, C, D and E) denote significant differences between target locations based on pairwise comparisons.

The neck sagittal flexion/extension angle significantly varied by target locations during painting task. Highest neck flexion and extension were revealed at 30° downward and 15° upward, respectively (Table 3). The lowest flexion angles were found at both neutral and self-selected target locations. Subjects' average self-selected target location was 0.5° downward from the neutral.

The shoulder sagittal flexion angle during the painting task was significantly different across the target locations. The shoulder sagittal flexion angle was the highest at 15° upward (Table 3). The lowest sagittal flexion angle was found at 30° downward target location. Neutral and self-selected target locations did not have significant differences of sagittal flexion during the painting task. The range of motion (90th – 10th) was the lowest at 15° upward.

Table 3. Mean (standard error) joint angle of neck and shoulder by five target locations during painting task

Measure (Unit)	Percentile	Target Location					*p*-value
		15° upward	Neutral	Self-selected	15° downward	30° downward	
Neck Sagittal flexion(-) /extension(+) Angle (°)	10th	2.8^{D} (1.7)	-6.9^{C} (1.5)	-12.9^{BC} (1.9)	-14.6^{B} (1.6)	-25.7^{A} (1.5)	< 0.001
	50th	8.5^{D} (7.8)	-1.3^{C} (6.8)	-7.4^{BC} (7.9)	-10.0^{B} (7.1)	-19.3^{A} (6.9)	< 0.001
	90th	14.7^{D} (1.8)	2.9^{C} (1.6)	-2.3^{BC} (1.8)	-4.8^{B} (1.5)	-13.1^{A} (1.7)	< 0.001
	90th-10th	11.2^{A} (4.4)	9.8^{A} (3.5)	10.5^{A} (3.7)	9.8^{A} (3.1)	11.9^{A} (5.6)	0.113
Shoulder Sagittal flexion Angle (°)	10th	35.7^{D} (1.8)	22.9^{C} (1.6)	15.9^{BC} (1.8)	12.7^{B} (1.7)	2.8^{A} (2.3)	< 0.001
	50th	49.2^{D} (7.2)	38.6^{C} (7.1)	31.7^{B} (8.4)	29.4^{B} (6.9)	18.4^{A} (8.9)	< 0.001
	90th	62.1^{D} (1.7)	52.6^{C} (1.3)	46.7^{BC} (1.7)	44.5^{B} (1.5)	34.3^{A} (1.9)	< 0.001

	90th-10th	25.1^{A} (8.5)	29.7^{B} (3.6)	30.7^{B} (3.9)	31.7^{B} (4.0)	29.9^{B} (8.0)	< 0.001
Shoulder Abduction Angle (°)	10th	-51.7^{A} (6.0)	-28.0^{B} (3.3)	-22.6^{B} (3.8)	-21.6^{B} (2.9)	-19.9^{B} (2.6)	< 0.001
	50th	-31.5^{A} (23.2)	-14.5^{B} (12.8)	-12.6^{B} (14.2)	-11.6^{B} (10.9)	-12.4^{B} (9.6)	< 0.001
	90th	-13.9^{A} (4.2)	-3.8^{B} (2.5)	-4.0^{B} (2.7)	-3.5^{B} (2.1)	-4.9^{B} (1.9)	< 0.001
	90th-10th	25.8^{C} (18.5)	24.2^{B} (8.5)	18.6^{AB} (9.2)	18.0^{AB} (7.7)	14.2^{A} (7.3)	< 0.001

Note. Letters (A, B, C and D) denote significant differences between target locations based on pairwise comparisons.

The shoulder abduction angle during the painting task was significantly different across the target locations. Highest abduction angle was revealed at 15° upward (Table 3). The lowest abduction angle occurred at 30° downward target locations. The range of motion (90th – 10th) was the lowest at 30° downward and the highest at 15° upward location.

4.1.2 Neck and Shoulder Moment

The neck sagittal flexion/extension moment was significantly different by target location during pointing task (Table 4). The sagittal neck flexion and extension moment were the highest at 30° downward and 15° upward, respectively.

Table 4. Mean (standard error) gravitational moments of neck and shoulder by five target locations during pointing task

Measure (Unit)	Percentile	Target Location					*p*-value
		15° upward	Neutral	Self-selected	15° downward	30° downward	
Neck Sagittal Flexion(-)	10th	-0.4^{D} (0.1)	-1.1^{C} (0.1)	-1.2^{C} (0.2)	-2.1^{B} (0.1)	-3.0^{A} (0.1)	< 0.001

/Extension(+) Moment (Nm)	50th	0.0^{D} (0.8)	-0.8^{C} (0.6)	-0.9^{C} (0.9)	-1.8^{B} (0.7)	-2.7^{A} (0.7)	< 0.001
	90th	0.3^{D} (0.1)	-0.4^{C} (0.1)	-0.5^{C} (0.2)	-1.4^{B} (0.1)	-2.3^{A} (0.1)	< 0.001
	90th-10th	0.7^{A} (0.3)	0.7^{A} (0.2)	0.7^{A} (0.4)	0.6^{A} (0.2)	0.6^{A} (0.2)	0.011
Shoulder Sagittal Flexion Moment (Nm)	10th	-7.6^{A} (0.3)	-7.9^{A} (0.3)	-7.8^{A} (0.3)	-7.8^{A} (0.3)	-7.3^{A} (0.3)	<0.001
	50th	-7.0^{A} (1.4)	-6.7^{A} (1.4)	-6.6^{A} (1.5)	-6.2^{AB} (1.4)	-5.3^{B} (1.2)	<0.001
	90th	-6.0^{A} (0.3)	-5.2^{AB} (0.3)	-4.8^{BC} (0.3)	-4.0^{C} (0.3)	-2.8^{D} (0.2)	<0.001
	90th-10th	1.4^{A} (0.7)	2.6^{B} (0.8)	3.0^{BC} (0.9)	3.7^{CD} (0.8)	4.3^{D} (1.3)	0.603
Shoulder Abduction Moment (Nm)	10th	-0.8^{A} (0.2)	-0.7^{A} (0.1)	0.8^{A} (0.2)	-0.7^{A} (0.1)	-0.8^{A} (0.1)	0.931
	50th	0.7^{A} (1.0)	0.7^{A} (0.8)	0.5^{A} (0.8)	0.7^{A} (0.8)	0.5^{A} (0.8)	0.095
	90th	1.7^{A} (0.2)	1.7^{A} (0.2)	1.7^{A} (0.1)	1.7^{A} (0.2)	1.3^{A} (0.2)	0.921
	90th-10th	3.0^{A} (1.2)	3.3^{A} (0.7)	3.2^{A} (0.8)	3.2^{A} (0.6)	3.1^{A} (1.0)	0.075
Horizontal Moment-Arm (cm)	10th	31.6^{AB} (11.4)	37.5^{B} (5.5)	37.1^{AB} (5.4)	37.4^{B} (3.6)	31.3^{A} (8.2)	0.01
	50th	36.2^{A} (12.9)	42.9^{A} (4.7)	42.9^{A} (4.4)	43.5^{A} (3.0)	38.6^{A} (9.9)	0.02
	90th	41.8^{A} (14.9)	49.6^{B} (4.4)	49.7^{B} (3.9)	51.9^{C} (3.4)	48.4^{BC} (12.1)	<0.001

Note. Letters (A, B, C and D) denote significant differences between target locations based on pairwise comparisons.

The shoulder sagittal flexion moment was significantly different by target location during pointing task (Table 4). The shoulder sagittal flexion moment was the highest at 15° upward. The lowest sagittal flexion moment occurred at 30° downward target location. The variability of the shoulder flexion moment (90th -10th) was the lowest at 15° upward while the greatest at 30°

downward target location. For pointing task, shoulder abduction moment was not significantly varied by target location (Table 4).

The horizontal moment arm was significantly different by target location during pointing task. The horizontal moment arm was the highest at 15° downward while the lowest at 15° upward (Table 4). There was no significant difference in distance between neutral and self-selected target locations during the tasks.

The neck sagittal flexion/extension moment was significantly different by target location during painting task (Table 5). The sagittal neck flexion and extension moment were the highest at 30° downward and 15° upward, respectively. The lowest sagittal neck flexion/extension moment occurred at neutral and self-selected target location.

Table 5. Mean (standard error) gravitational moments of neck and shoulder by five target locations during painting task

Measure (Unit)	Percentile	Target Location					p-value
		15° upward	Neutral	Self-selected	15° downward	30° downward	
Neck Sagittal Flexion(-) /Extension(+) Moment (Nm)	10th	-0.6^{D} (0.1)	-1.3^{C} (0.1)	-1.9^{BC} (0.1)	-2.1^{B} (0.1)	-3.0^{A} (0.1)	< 0.001
	50th	-0.1^{D} (0.6)	-0.8^{C} (0.6)	-1.4^{BC} (0.6)	-1.7^{B} (0.7)	-2.5^{A} (0.8)	< 0.001
	90th	0.3^{D} (0.1)	-0.3^{C} (0.1)	-0.8^{BC} (0.1)	-1.1^{B} (0.1)	-1.9^{A} (0.1)	< 0.001
	90th-10th	0.9^{A} (0.3)	1.0^{A} (0.3)	1.0^{A} (0.5)	0.9^{A} (0.3)	1.0^{A} (0.4)	0.117
Shoulder Sagittal Flexion Moment (Nm)	10th	-7.2^{A} (0.2)	-7.2^{A} (0.2)	-6.9^{AB} (0.2)	-6.8^{AB} (0.2)	-6.0^{B} (0.2)	< 0.001
	50th	-6.9^{A} (1.2)	-6.5^{AB} (1.2)	-5.8^{B} (1.1)	-5.7^{B} (1.2)	-4.5^{C} (1.0)	< 0.001
	90th	-6.2^{A} (0.2)	-5.3^{AB} (0.2)	-4.5^{BC} (0.2)	-4.2^{C} (0.2)	-2.9^{D} (0.2)	< 0.001

	90th-10th	0.9^{A} (0.4)	1.8^{B} (0.6)	2.4^{BC} (0.6)	2.5^{C} (0.5)	2.9^{C} (0.9)	0.857
Shoulder Abduction Moment (Nm)	10th	-1.1^{A} (0.3)	0.8^{A} (0.2)	0.8^{A} (0.2)	0.8^{A} (0.1)	0.9^{A} (0.1)	0.759
	50th	0.2^{A} (1.3)	0.5^{A} (0.9)	0.4^{A} (0.9)	0.4^{A} (0.7)	0.0^{A} (0.7)	0.521
	90th	1.7^{A} (0.3)	1.7^{A} (0.2)	1.7^{A} (0.1)	1.7^{A} (0.1)	1.3^{A} (0.1)	0.281
	90th-10th	2.6^{A} (0.8)	2.6^{A} (0.6)	2.5^{A} (0.7)	2.5^{A} (0.5)	2.1^{A} (0.7)	0.198
Horizontal Moment-Arm (cm)	10th	33.7^{AB} (9.4)	37.5^{B} (5.0)	36.3^{AB} (4.1)	36.3^{AB} (5.1)	31.4^{A} (8.4)	0.04
	50th	37.4^{A} (10.2)	40.7^{A} (4.7)	39.7^{A} (4.0)	39.7^{A} (5.0)	35.6^{A} (9.2)	0.036
	90th	40.7^{A} (10.9)	43.5^{A} (4.6)	43.1^{A} (3.9)	43.0^{A} (5.2)	40.0^{A} (10.2)	0.718

Note. Letters (A, B, C and D) denote significant differences between target locations based on pairwise comparisons.

The shoulder sagittal flexion moment significantly varied by target location during painting task (Table 5). The shoulder sagittal flexion moment was the highest at 15° upward. The lowest sagittal shoulder flexion moment occurred at 30° downward. There was no substantial difference in moment values between 15° downward and self-selected. The variability of the shoulder flexion moment (90th -10th) was the lowest at 15° upward while the greatest at 30° downward target location. The shoulder abduction moment did not vary significantly across target location during painting task (Table 5). There was no substantial difference in shoulder lateral abduction/adduction moment values across target locations. The horizontal moment arm (90th percentile) was not significantly varied across target location during painting task (Table 5).

4.2 Electromyography (EMG)

The results showed muscle activity in right upper trapezius (RTRAP), right cervical extensor (RCE), left cervical extensor (LCE), right anterior deltoid (AD), right middle deltoid (MD) were significantly different across target locations in tasks (painting and pointing).

Right trapezius muscle (RTRAP) muscle was significantly different by target location during pointing task (Table 6). Highest muscle activation was revealed at 15° upward target location. The lowest muscle activation was found at 30° downward target locations.

Right cervical extensor (RCE) muscle significantly varied by target location during pointing task (Table 6). Left cervical extensor (LCE) muscle also significantly different by target location during pointing task (Table 6). Highest muscle activation was revealed at 30° downward target location. The lowest muscle activation was found at 15° upward and self-selected target locations. Left and right side of the cervical extensor were significantly different (p's < 0.001) across pointing tasks. Mean and standard deviation of LCE and RCE were 2.5±1.0.

Table 6. Mean (standard error) muscle activity in trapezius (RTRAP), left/right cervical extensor (L/RCE), anterior deltoid (AD), and middle deltoid (MD) by five target locations during pointing task

Muscle (Unit)	Percentile	Target Location					*p*-value
		15° upward	Neutral	Self-selected	15° downward	30° downward	
RTRAP (%MVC)	10th	4.8^{A} (0.7)	3.9^{A} (0.7)	3.8^{A} (0.7)	3.0^{A} (0.6)	2.4^{A} (0.5)	< 0.001
	50th	9.4^{B} (1.0)	7.7^{AB} (1.0)	7.3^{AB} (1.0)	6.0^{AB} (1.0)	5.1^{A} (0.9)	< 0.001
	90th	16.6^{B} (1.4)	13.8^{AB} (1.5)	12.7^{AB} (1.4)	10.6^{A} (1.5)	9.1^{A} (1.4)	< 0.001
RCE (%MVC)	10th	5.2^{A} (0.6)	4.6^{A} (0.4)	4.5^{A} (0.4)	4.9^{A} (0.4)	5.7^{A} (0.5)	< 0.001

	50th	8.5^{A} (0.9)	7.2^{A} (0.6)	7.0^{A} (0.6)	7.4^{A} (0.7)	8.6^{A} (0.8)	< 0.001
	90th	14.2^{A} (1.6)	11.9^{A} (1.2)	11.7^{A} (1.0)	11.8^{A} (1.1)	12.9^{A} (1.1)	< 0.001
LCE (%MVC)	10th	3.4^{A} (0.3)	3.3^{A} (0.3)	3.2^{A} (0.3)	4.1^{AB} (0.5)	5.4^{B} (0.6)	< 0.001
	50th	4.8^{A} (0.5)	4.9^{A} (0.4)	4.7^{A} (0.4)	6.3^{AB} (0.7)	8.6^{B} (0.9)	< 0.001
	90th	7.7^{A} (0.8)	8.0^{A} (0.7)	7.7^{A} (0.6)	10.0^{AB} (1.0)	13.0^{B} (1.3)	< 0.001
AD (%MVC)	10th	9.2^{C} (1.0)	7.5^{BC} (1.0)	6.6^{BC} (0.6)	4.7^{B} (0.6)	2.2^{A} (0.3)	< 0.001
	50th	19.6^{B} (1.6)	17.9^{B} (1.7)	17.1^{AB} (1.2)	14.7^{AB} (1.2)	11.6^{A} (1.2)	< 0.001
	90th	36.2^{B} (2.8)	33.8^{B} (2.6)	32.6^{AB} (2.3)	29.2^{B} (2.2)	26.1^{A} (2.4)	< 0.001
MD (%MVC)	10th	3.7^{C} (0.7)	2.2^{BC} (0.2)	2.6^{BC} (0.6)	1.5^{AB} (0.2)	1.2^{A} (0.2)	< 0.001
	50th	8.6^{B} (1.4)	6.9^{AB} (1.0)	7.1^{AB} (1.4)	5.2^{AB} (0.9)	3.7^{A} (0.8)	< 0.001
	90th	18.5^{B} (2.7)	15.0^{B} (2.0)	15.8^{B} (2.8)	11.6^{AB} (1.9)	8.8^{A} (1.8)	< 0.001

Note. Letters (A, B and C) denote significant differences between target locations based on pairwise comparisons.

Anterior Deltoid (AD) muscle was significantly different by target location during pointing task (Table 6). Highest muscle activation was revealed at 15° upward target location. The lowest muscle activation was found at 30° downward target location. Anterior Deltoid (AD) muscle was significantly different by target location during pointing task (Table 5). Highest muscle activation was revealed at 15° upward target location. The lowest muscle activation was found at 30° downward target location.

Table 7. Mean (standard error) muscle activity in trapezius (RTRAP), left/right cervical extensor (L/RCE), anterior deltoid (AD), and middle deltoid (MD) by five target locations during painting task

Muscle (Unit)	Percentile	Target Location					*p*-value
		15° upward	Neutral	Self-selected	15° downward	30° downward	
RTRAP (%MVC)	10th	4.9^{A} (0.6)	3.6^{A} (0.5)	3.2^{A} (0.6)	2.8^{A} (0.4)	2.7^{A} (0.5)	< 0.001
	50th	10.8^{A} (1.2)	8.5^{A} (1.1)	7.8^{A} (1.1)	7.2^{A} (1.0)	7.1^{A} (1.2)	< 0.001
	90th	18.1^{A} (2.0)	15.1^{A} (2.0)	13.6^{A} (1.7)	12.8^{A} (1.7)	12.7^{A} (2.0)	< 0.001
RCE (%MVC)	10th	5.2^{A} (0.5)	4.9^{A} (0.4)	5.6^{A} (0.7)	5.4^{A} (0.5)	6.6^{A} (0.5)	< 0.001
	50th	8.6^{A} (0.9)	7.6^{A} (0.7)	8.2^{A} (0.9)	8.2^{A} (0.8)	9.9^{A} (0.9)	< 0.001
	90th	13.1^{A} (1.4)	11.5^{A} (1.2)	12.5^{A} (1.4)	11.9^{A} (1.3)	14.3^{A} (1.5)	< 0.001
LCE (%MVC)	10th	3.3^{A} (0.3)	3.5^{A} (0.3)	3.7^{AB} (0.3)	4.5^{AB} (0.6)	5.8^{B} (0.6)	< 0.001
	50th	4.8^{A} (0.6)	5.1^{AB} (0.5)	5.7^{AB} (0.5)	6.6^{A} (0.9)	8.7^{B} (1.0)	< 0.001
	90th	7.3^{A} (0.9)	8.2^{A} (0.8)	9.5^{AB} (1.0)	10.2^{AB} (1.2)	12.9^{B} (1.3)	< 0.001
AD (%MVC)	10th	7.3^{C} (0.9)	5.0^{BC} (0.6)	3.4^{AB} (0.4)	3.1^{AB} (0.4)	1.9^{A} (0.3)	< 0.001
	50th	15.7^{C} (1.4)	13.2^{BC} (1.3)	11.1^{ABC} (1.0)	10.6^{AB} (1.1)	7.0^{A} (1.0)	< 0.001
	90th	26.9^{C} (2.2)	24.0^{BC} (2.0)	21.3^{AB} (1.7)	20.9^{AB} (1.9)	16.4^{A} (1.7)	< 0.001
MD (%MVC)	10th	3.5^{C} (0.5)	2.1^{BC} (0.3)	1.8^{AB} (0.4)	1.4^{AB} (0.2)	1.1^{A} (0.2)	< 0.001
	50th	8.6^{B} (1.3)	5.5^{AB} (0.9)	4.9^{A} (1.0)	4.0^{A} (0.5)	3.2^{A} (0.6)	< 0.001
	90th	16.3^{C} (2.2)	11.2^{BC} (1.6)	9.8^{AB} (1.8)	8.8^{AB} (1.2)	7.3^{A} (1.3)	< 0.001

Note. Letters (A, B and C denote significant differences between target locations based on pairwise comparisons.

For painting task, Right trapezius muscle (RTRAP) muscle was significantly different by target location (Table 7). Highest muscle activation was revealed at 15° upward target location. The lowest muscle activation was found at 30° and 15° downward target locations. Anterior Deltoid (AD) muscle was significantly different by target location (Table 7). Highest muscle activation was revealed at 15° upward target location. The lowest muscle activation was found at 30° downward target location. Middle Deltoid (MD) muscle was significantly different by target location during pointing task (Table 6). Highest muscle activation was revealed at 15° upward target location. The lowest muscle activation was found at 30° downward target location.

Right cervical extensor (RCE) muscle was significantly different by target location during painting task (Table 7). Left cervical extensor (LCE) muscle was significantly different by target location during painting task (Table 7). Highest muscle activation was revealed at 30° downward target location. The lowest muscle activation was found at 15° upward target location. Left and right side of the cervical extensor were significantly different (p's < 0.001) across painting tasks (Table 8).

Table 8. Mean (standard error) of paired T-test for muscle activity in left and right cervical extensor (L/RCE) muscle activity by five target locations.

Task	Percentile	Muscle Activation (%MVC)		*p*-value
		LCE	RCE	
Pointing	10th	3.9 (0.2)	5.1 (0.2)	< 0.001
	50th	5.9 (0.3)	7.8 (0.3)	< 0.001
	90th	9.3 (0.4)	12.5 (0.5)	< 0.001
Painting	10th	4.2 (0.2)	5.6 (0.2)	0.388

	50th	6.2 (0.3)	8.5 (0.4)	< 0.001
	90th	9.7 (0.5)	12.7 (0.6)	< 0.001

4.3 Subjective Measures

Results revealed that discomfort in neck and shoulder was significantly different across five target location in tasks (pointing and painting).

Discomfort(post-pre) in neck was significantly different by target location during pointing task ($p<0.001$). Higher discomfort in neck occurred at 15° upward target location (Figure 6). Lowest discomfort in neck was revealed at 15° downward target location. For pointing task, discomfort in shoulder was significantly different by target location ($p<0.001$). Discomfort in shoulder was highest at 15° upward target location (Figure 6). Lowest discomfort in shoulder was revealed at 15° downward target location.

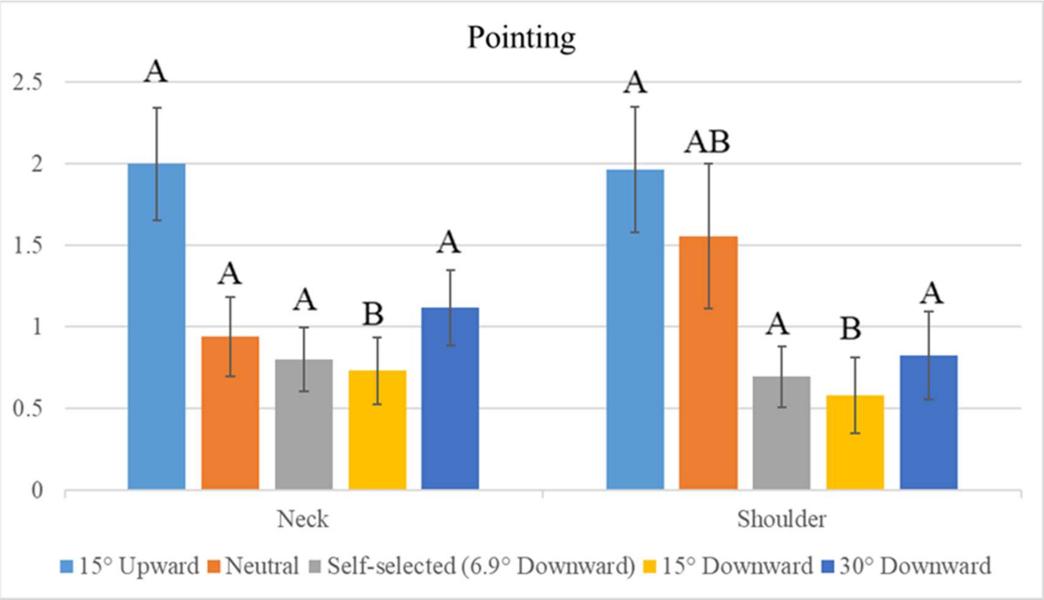


Figure 7. Subjective discomfort (post-pre) in neck and shoulder as a function of the target location in pointing task. Letters (A and B) denote significant differences between target locations based on pairwise comparisons.

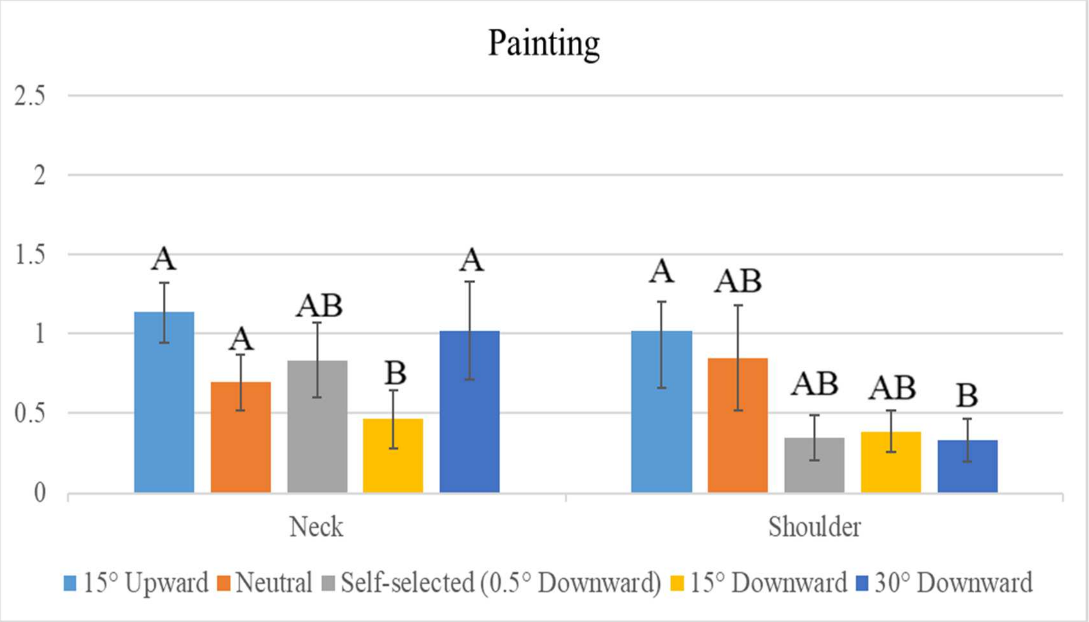


Figure 8. Subjective discomfort (post-pre) in neck and shoulder as a function of the target location in painting task. Letters (A and B) denote significant differences between target locations based on pairwise comparisons.

Discomfort in neck was significantly different by target location during painting task ($p<0.001$). Higher discomfort in neck occurred at 15° upward target location (Figure 7). Lowest discomfort in neck was revealed at 15° downward target location. Discomfort in shoulder was significantly different by target location during painting task ($p<0.001$). Higher discomfort in shoulder occurred at 15° upward target location (Figure 7). Lowest discomfort in shoulder was revealed at 15° downward, 30° downward and self-selected target location.

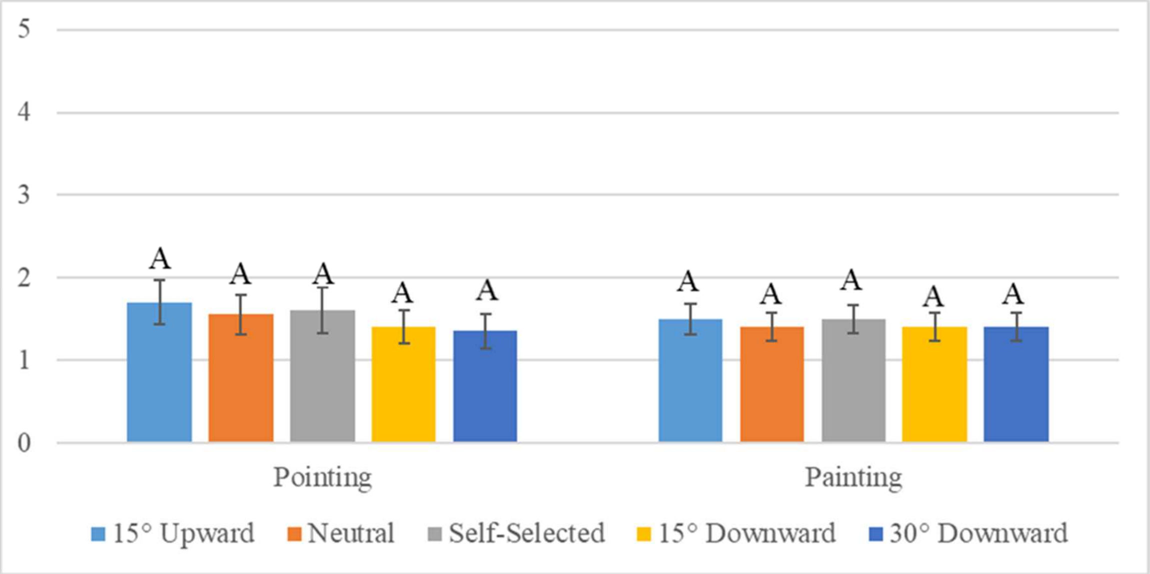


Figure 9. Motion sickness as a function of the target location by task.

Motion sickness did not vary significantly across target location during pointing and painting task (Figure 8). There was no substantial difference in motion sickness values across target locations.

4.4 Task Performance

For pointing task, target locations did not influence on the total completion time (for pointing) significantly (Table 9). Deviation from the target was not significantly different by target location during pointing task ($p = 0.96$). Deviation from target(mm) was highest for 30° downward and lowest for 15° upward target location (Table 9). For painting task, total completion time was significantly different by target location ($p<0.01$). Completion time was longest at 30° downward and shortest at 15° downward target location (Table 9).

Table 9. Mean (standard error) task performance by five target locations during painting and pointing tasks.

Measure (Unit)	Task	Target Location					*p*-value
		15° upward	Neutral	Self-selected	15° downward	30° downward	
Total completion time (sec)	Pointing	18.4^{A} (0.8)	18.4^{A} (0.6)	16.9^{A} (0.6)	18.5^{A} (1.0)	17.4^{A} (1.1)	0.061
Deviation from the target (mm)	Pointing	12.2^{A} (0.6)	12.7^{A} (0.7)	12.9^{A} (0.9)	12.6^{A} (0.7)	12.9^{A} (0.8)	0.960
Total completion time (sec)	Painting	6.5^{A} (0.6)	5.9^{A} (0.5)	5.5^{A} (0.4)	5.5^{A} (0.3)	6.7^{A} (0.5)	<0.001

CHAPTER – V
DISCUSSION

This study investigated the effect of five different target locations in reducing the biomechanical stresses on the neck and shoulder and increasing task performance of users during VR interactions with the hand gesture.

For the pointing task, neck sagittal flexion/extension angle was significantly lower for the neutral to 15° downward target locations when compared to the remaining target locations (Table 1). Since the target location of the self-selected location was close to the neutral location (6.85 ± 9.42°), there were no significant differences between the neutral and self-selected target locations. As expected, 30° downward location caused the greatest neck flexion (24°), and 15° upward location resulted in the greatest neck extension (15°).

During painting tasks, similar results were found as pointing tasks. Kim and Shen (2018) stated that downward target location required significantly higher neck flexion compared to neutral and upward target location. Also, there has been evidence of increased neck pain being associated with both increased head extension (Aaras et al. 1998, Marcus et al. 2002) and increased head flexion (Hunting et al. 1981, Starr et al. 1985, Ariens et al. 2001) during computer use. This trend was similar to the results of the neck sagittal moment.

Neck sagittal moment was significantly lower for the neutral to 15° downward as compared to 30° downward during the pointing and painting task. Neutral to 15° downward position could decrease the moment arm between the center of gravity of the head and C7/T1, which reduced the moment on the neck. The 30° downward location caused the highest neck moment (up to 3Nm), which was similar to the trend of the neck flexion angle. Flexion of the neck could increase the gravitational moment arm on the C7/T1, which increased the moment on the neck. Neck extension moment was small due to the smaller moment arms between the center of gravity of the head and C7/T1. Previous study showed that the gravitational moment was ranged between 1.7 to 5.9 Nm in tablet usage from mild to severe levels (Vasavada et al., 2015). Vasavada et al. (2018) stated that the estimates of gravitational demand were lower ($p < 0.001$) for neutral posture than downward deviated posture in tablet usage for subject specific generic models. This suggests that 30° downward location could be avoided to reduce the neck moment.

The muscle activities in neck regions (L/RCE) were also lower for neutral to 15° downward target locations which is in conjunction with our neck posture and moments results in both tasks. These target locations required less neck moment which in turn reduced muscle activation. Moreover, 15° upward (15%, 8% MVC for RCE and LCE), and 30° downward (13%, 13% MVC for RCE, LCE) target location revealed high muscle activity in the neck areas (RCE, LCE). These results are in conjunction with results obtained from neck posture. Right cervical extensor (RCE) muscle was consistently active across different target locations. RCE muscle showed higher muscle activities than left cervical extensor (LCE) muscle (Table 8). It could be associated that right shoulder’s elevations results in increased muscle activation in RCE.

Kim and Shen (2018) stated that muscle activities of the neck extensor muscle were also significantly greater when conducting the document editing task with the HMD. They also indicated that additional flexion moment at the cervical spine and vertical load from the weight of the HMD might require the neck extensor muscles to generate larger contraction force to support the weight and maintain the posture. Chihara and Seo (2018) stated that in the case of look-up posture, subjects extended their neck joint when the COM position moves backward which increases stress in neck area. Straker et al. (2009) suggest that increasing head/neck flexion represents a greater stress to the musculoskeletal system and is therefore likely to represent a greater risk for neck pain disorders. Subjective ratings on discomfort was associated with biomechanical measures. Subjective ratings showed that as the virtual location moved below the eye level, the discomfort in neck region increased (Figures 5 and 6). As the virtual location moved above the eye level, discomfort in neck region decreased.

Kim and Shin (2018) also stated that greater total rotations of the head might contribute to the greater increments in the neck and shoulder subjective discomfort ratings. Neutral to 15° downward target locations were most effective in reducing biomechanical exposures on the neck (neck sagittal angle, moment, muscle activities, and subjective discomfort) during VR interactions with virtual hand gestures. Our finding was slightly higher related to the ergonomics standard of computer workstations (ANSI/HFES 100-2007) which states that the center of visual display is located to 15 to 25° below horizontal eye level.

Shoulder sagittal flexion angle was significantly different by target location during pointing and painting tasks. Shoulder sagittal flexion angle was the lowest at 30° downward location in both pointing and painting tasks. The 30° downward location did not require users raise their arms to conduct the tasks. Conversely, 15° upward target location revealed the greatest shoulder flexion during pointing and painting tasks. Moreover, neutral and 15° downward revealed minimal risk in shoulder compared to 15° upward. As the target location was above the eye level, users required to raise their arms (up to 71° flexion) to perform the tasks. According to Putz-Anderson et al. (1997), the shoulder flexion exceeding 60° could increase the chance of occurrence of musculoskeletal disorder in shoulder regions due to increased muscle activation.

This indicated that 15° upward target location could increase the risk of musculoskeletal discomfort in shoulder areas.

Shoulder abduction angles were significantly affected by the target locations. The 30° downward and 15° downward required minimal amount of shoulder abduction (17 to 22°) when compared to other target locations in pointing and painting tasks. Moreover, neutral also revealed minimal risk in shoulder compared to 15° upward. The 15° upward location caused the highest shoulder abduction angle (up to 62°) in both pointing and painting tasks. Moreover, 15° upward location has shown a higher range of values in shoulder abduction angle. This indicate that it required more movement in shoulder throughout the pointing and painting tasks. This states that 15° upward location could cause significant amount of flexion and abduction of the shoulder, and prolonged use at this location could increase the risk of the shoulder discomfort.

Muscle activity in shoulder region also followed similar trend as shoulder postures. Muscle activity in right upper trapezius (RTRAP), right anterior deltoid (AD), right middle deltoid (MD) were significantly different across target locations in pointing and painting tasks. The muscle activities in shoulder regions (RTRAP, AD, and MD) were lower for neutral, 15° downward and 30° downward (Table 3) which was in conjunction with shoulder postures. These target locations required less shoulder flexion which in turn reduced muscle activation. Moreover, 15° upward target location revealed higher muscle activity (17%, 37%, and 19% MVC for RTRAP, AD, and MD) in the shoulder areas which is also in conjunction with results obtained from shoulder posture. As the target location is beyond the eye level it required higher muscle activity in the shoulder region.

Shoulder flexion moments were significantly varied by the target locations. The trend was associated with the shoulder flexion angles. The greatest shoulder flexion moment occurred at 15° upward while the lowest one was showed at 30° downward. This trend mirrored the muscle activities of the shoulder. Increased external moment on the shoulder caused greater muscle activities of RTRAP, AD, and MD at 15° upward location. Subjective ratings on discomfort was associated with biomechanical measures. Subjective ratings showed that as the virtual location moved below the eye level, the discomfort in shoulder region decreased (Figures 5 and 6). As the virtual location moved above the eye level, discomfort in shoulder region increased. Neutral to 30° downward target locations were most effective in reducing biomechanical exposures on the shoulder (shoulder angles, moment, muscle activities, and subjective discomfort) during VR interactions.

Moreover, motion sickness did not vary significantly across the target locations. This might give an indication that subjects' motion sickness did not vary by target locations during simple pointing and painting tasks. For the task performance, completion time and target deviation were not significantly different across target location during the pointing task. The completion time for pointing task in our research was about 18 sec (total mean) which was in line with Chen and Or (2017) in which young participants on an average required 17 sec to complete pointing task. For painting task, the completion time was not practically different across target locations (ranged from 6 to 7 seconds). These results suggest that different target locations did not significantly affect their performance during pointing and painting tasks.

So, the biomechanical exposures (shoulder angles, moment, muscle activities, and subjective discomfort) in shoulder and neck areas explain, even though 30° downward target locations have lesser muscle activation in shoulder areas they required higher muscle activity in neck region. Neutral to 30° downward target locations were most effective in reducing biomechanical exposures on shoulder whereas, neutral to 15° downward were effective in reducing biomechanical exposures on shoulder.

Of all the target locations, Neutral to 15° downward target location could be effective in reducing postural stresses of both neck and shoulders during VR interactions with hand gestures. This is also in conjunction with subjects' preference i.e self-selected angle. Subjects have chosen their self-selected as a right target location which required lower stresses in their neck and shoulder. This is in line with the biomechanical measures. Straker et al. (2009) has provided guidelines suggesting computer displays should be positioned to suit the individual, within a moderate height range close to slightly below eye height.

Virtual reality requires high levels of interaction with the user. Interactions that match the way humans usually interact with their surroundings should improve effectiveness. A 3D hand gesture-based interface allows users by simply moving their hands, thereby, creating a more naturalistic interaction process. The preferred gesture design parameter was related to better control and reduced time to complete the tasks. Moreover, in virtual hand gesture interactions, users had to elevate their arms to be captured in their field of view. Lin et al. (2017) reported significantly lower levels of shoulder fatigue for hand gesture interaction as it was easier to control compared to hand-held input devices. Direct manipulation of an object with a user's hands in VE provided an improved usability and lower stress in neck and shoulder regions.

In the current study there were few limitations. First the participated subjects were relatively young (age: 24 ± 2 years) which might be different for the middle and older age participants. The results and suggestion made in the current study were based on the weight of selected commercially-available Oculus Rift (Oculus VR, LLC, USA). Different VR devices (field of view, weight, and screen resolutions) might cause different results. Since we conducted relatively short duration and simple level tasks to users, the difference of the task performance could not be affected by target locations. In future study, complex tasks with longer duration could cause different results. Meanwhile, further research should be conducted regarding proper guidelines for users and designers to prepare for this immerging yet challenging interface.

CHAPTER – VI

CONCLUSION

This study evaluated the effect of different vertical target locations on reducing biomechanical exposures of the neck and shoulder during VR interactions with hand gestures. The findings suggest that target locations from neutral to 15° downward could be effective in reducing postural stresses of both neck and shoulder during VR with hand gesture interactions. Users' preferred target locations were ranged from 0.5 to 6.9° downward, which were associated with low biomechanical exposures of both neck and shoulders.

Excessive target locations (15° upward and 30° downward locations) could be avoided to prevent discomfort and pain in the neck and shoulder areas. At 15° upward location, right shoulder had sustained flexion and various abduction during tasks, which could cause the shoulder discomfort. Right side of the cervical extensor muscle had sustained muscle activities regardless of the target locations, which could be associated with the right arm's elevations. The task performance and motion sickness were not significantly varied by target locations, which might be due to the simple and short duration of the tasks. These findings would be useful to design comfortable target locations of the user interface in virtual environment.

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