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Postural and Muscular Responses While Viewing Different Heights of Screen

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This study aimed to examine the effects of visual display terminal (VDT) viewing angle on human postural angle and muscular activity. The participants' neck, thoracic bending, and trunk inclination angles; and the activity of sternocleidomastoid, trapezius, splenius capitis, and erector spinae at 5 viewing angles (+40°, +20°, 0°, –20°, and –40°) of a VDT screen were collected for 1 min. This study showed that neck and thoracic bending angles increased with viewing angle, while viewing angle did not significantly affect trunk inclination angle. In addition, the activity of trapezius and erector spinae increased when viewing a higher or lower VDT screen height compared with viewing a horizontal VDT screen height; however, the activity of splenius capitis decreased with viewing angle.

visual display terminal   posture   viewing angle

1. INTRODUCTION

Visual display terminals (VDTs) are ubiquitous in a modern workplace and society. The introduction of VDT into our life has led to numerous reports of related visual and musculoskeletal disorders. The major sources of these disorders can be attributed to the requirements of continuous fixation on a visual target and a constrained human posture. Over the decades, a series of studies examined the musculoskeletal disorders of VDT users [1, 2, 3]; deficiencies in VDT workstation design [4]; and the effects of ergonomic intervention on musculoskeletal, visual, and psychosocial strain [5, 6, 7, 8, 9, 10] in a VDT workplace. All these efforts aimed to prevent the incidence of visual and musculoskeletal disorders VDT work causes.

The height of a VDT screen is a key facet of the design of a VDT workstation since it affects its user's muscular strain and visual strain [11]. Though there are some guidelines on the design of VDT height, such as the VDT screen being placed below the level of the eye to lessen the strain of visual discomfort, there are debates on whether a higher or lower VDT screen is preferable due to different considerations. It seems that there is a trade-off relationship between muscular strain and visual strain with regards to the optimal height of a VDT screen [12]. For instance, Sommerich, Joines and Psihogios proposed a conceptual U-shaped model to describe the trade-off relationship between a low VDT screen (~45° below eye level) and high one (roughly at eye level) [13]. The reason for such a trade-off relationship is that a high VDT screen results in visual strain [14, 15, 16], whereas a low VDT screen is a source of muscular strain [17, 18]. In general, the argument for a lower VDT screen is based on the observation that there is a subjective preference for targets to be positioned such that the eyes rotate downward relative to the head [19, 20]; a reduction in ocular surface area [15]; and a decrease in perceived viewing exertion [16]. On the contrary, the argument for a higher VDT screen is attributed to the phenomenon that

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cervical and thoracic extensor muscle activity decreases as a VDT screen is placed higher [21, 22]. In addition to the height of a VDT screen, its angle positioning also affects neck–shoulder musclar activity. Szeto and Sham showed greater cervical activity of erector spinae and upper trapezius in both angled left and angled right positions compared with a central screen position [23].

Despite the trade-off relationship between muscular strain and visual strain with regards to the optimal height of a VDT screen being explained, the viewing angle examined in most previous studies ranged from ~45° below eye level to the eye level. Hence, this trade-off relationship may not be applicable for a greater range of viewing angle. To enhance the knowledge of VDT workplace design, this study aimed to examine human postural angle and muscular activity for a wider range of VDT viewing angle.

2. METHOD AND MATERIALS

2.1. Participants

Ten 10 young male volunteers, who received no reward, participated in the study. All of them were free from any visual or musculoskeletal problems; they provided written informed consent for their participation. Table 1 lists their major anthropometrical measurements.

2.2. Experimental Design

This study had a single-factor block design (block on participants). The independent variable was viewing angle at five levels (+40°, +20°, 0°, –20°, and –40°). Viewing angle was defined as the angle formed by a line connecting the center of a VDT screen and a participant's eye (while the participant is sitting erectly), and a horizontal line. A positive viewing angle indicated the center of a VDT screen was above eye height. This study selected viewing angle rather than absolute VDT height to avoid data confounded by the participants' anthropometric data. The dependent variables included the participants' neck, thoracic bending, and trunk inclination angles; and the activity of sternocleidomastoid, trapezius, splenius capitis, and erector spinae while viewing the VDT screen.

The detailed descriptions of the participants' postural angles followed those in Villanueva, Sotoyama, Jonai, et al. [11]; Figure 1 shows them. Neck angle was defined as the angle between Reid's line and a horizontal line. Positive and negative neck angles indicated that the participants' eye was higher and lower than the ear,

TABLE 1. Results of Duncan's Multiple Range Test on Postural Angles

Postural Angle	Duncan Grouping	*M* (°)	*SD* (°)	Viewing Angle (°)
Neck	A	44.0	4.6	+40
	B	27.0	4.3	+20
	C	19.8	4.8	0
	D	5.8	8.6	–20
	E	–6.6	14.0	–40
Thoracic bending	A	146.7	0.8	+40
	B	143.4	1.6	+20
	C	140.8	1.6	0
	D	137.1	1.9	–20
	E	131.9	1.0	–40
Trunk inclination	A	97.9	2.4	+40
	A	98.4	2.5	+20
	A	98.3	3.8	0
	A	99.2	3.5	–20
	A	99.3	2.9	–40

Notes. Means with a different letter in Duncan grouping are significantly different ($p < .05$).

respectively. Horacic bending angle was defined as the angle formed by the seventh cervical vertebra (C7), angulus inferior scapula, and iliac crest. A smaller thoracic bending angle corresponded to a more kyphotic thoracic posture. Trunk inclination angle was defined as the angle formed by the C7 and iliac crest referenced against the horizontal plane. A greater trunk inclination angle corresponded to a more reclining position.

2.3. Procedure

2.3.1. Preparation

The participants were briefed about the purpose of this study before the experiments. They were asked to wear a swimming suit in the experiment. Six markers (2 cm in diameter) were attached on the right side of the participants' outer canthus of the eye, outer canal of the ear, C7, inferior angle of the scapula, iliac crest, and in the middle of the VDT screen to capture the participants' postural angles. Four sets of MyoScan-Pro (Thought Technology, Canada) electromyographic (EMG) surface electrodes were attached to the participants' right sternocleidomastoid (centered above the muscle's midpoint); trapezius (C12, 2 cm from the midline); splenius capitis (C7, 2 cm from the midline); and erector spinae (L5, 2 cm from the midline) muscles after standard skin preparation for monitoring muscular activity. A digital video camera was placed at the height of 100 cm, 5 m to the right of the participants to record their sagittal postural angles during the experiment.

2.3.2. Test

The participants sat erectly, hands on the thighs, on a height-adjustable chair. The chair allowed to adjust the participants' eye height at 120 cm measured from the floor. The horizontal distance between the vertical plane of the VDT screen and the participants' eye was ~50 cm. A 17" VDT screen (Philips, The Netherlands) was placed on a height-adjustable table. The table allowed to adjust the height of the center of the VDT screen to form different viewing angles. The experimenter randomly administered one of the five possible viewing angles. Then, the participants were asked to view the center of the VDT screen for one minute. Throughout that period, the participants' postural angles and muscular activity were continuously collected through the video camera and the EMG instrument. For each participant, the sequence of the five viewing angles was random. There was a 3-min rest (or longer if desired) between tests. All participants were required to repeat the five possible viewing angles twice and finish all tests within one hour.

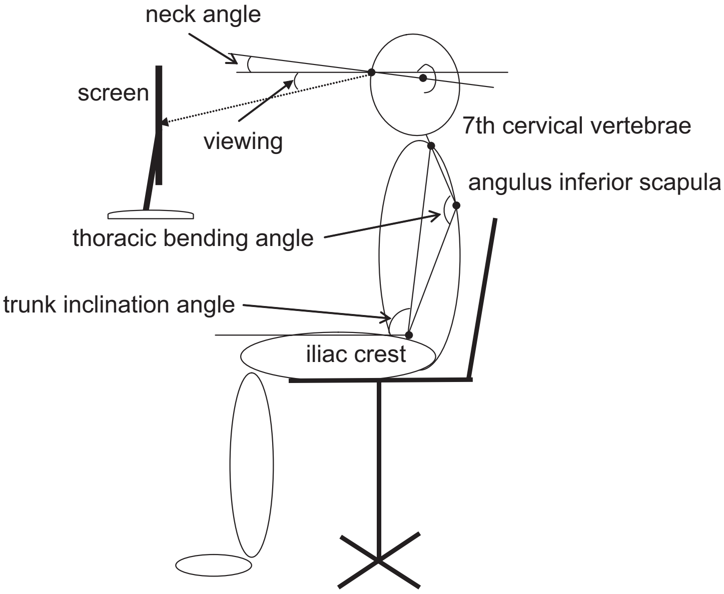

Figure 1. The participants' posture and definitions of angles in this study.

2.3.3. Data treatment

The EMG signals were amplified, filtered (band pass 20–500 Hz), rectified, and processed to provide root-mean-square (rms) EMG. The RMS EMG was sampled at 32 Hz via BioGraph & ProComp+ software (Thought Technology, Canada). For each participant, the sampled EMGs were normalized (expressed as percentage of maximum voluntary contraction, %MVC) for each muscle [24], and the normalized EMGs across the one-minute period were averaged for each viewing angle. The mean normalized EMG data were selected for data analysis.

The participants' neck, thoracic bending, and trunk inclination angles were sampled at four different times in a one-minute period (0, 20, 40, and 60 s). The participants' postural angles at the four time points were selected for data analysis.

3. RESULTS

3.1. Postural Angle

For each participant, the two repeated postural angles at 0, 20, 40, and 60 s time points were averaged and subjected to an analysis of variance (ANOVA). The ANOVA results showed that the participants' postural angles did not vary significantly across 0, 20, 40, and 60 s; hence, postural angles at 0, 20, 40, and 60 s were averaged to examine the effects of viewing angle on postural angle. ANOVA showed that participants ($F(9, 36)$; $p < .05$) and viewing angle ($F(4, 36)$; $p < .05$) had a significant effect on neck and thoracic bending angles, while viewing angle did not affect significantly trunk inclination angle. Duncan's multiple range test was performed on the participants' postural angles to group the means as equal or significantly different. Table 1 summarizes the results of Duncan's multiple range test: the participants' neck and thoracic bending angles increased with viewing angle for viewing angle from –40° to +40°. An 80° change in viewing angle was associated with a change of 50° in neck angle, from 44.0° (*SD* 4.6°) at +40° viewing angle to –6.6° (*SD* 14.0°) at –40° viewing angle. Though the effect of viewing angle on thoracic bending angle was also significant, the effect was smaller than that observed in neck angle. Thoracic bending angle changed only by 15°, from 131.9° (*SD* 1.0°) at –40° viewing angle to 146.7° (*SD* 0.8°) at +40° viewing angle. In contrast, viewing angle did not significantly influence trunk inclination angle, remaining nearly unchanged, ranging from 97.9° to 99.3°, across the five viewing angles.

TABLE 2. Results of Duncan's Multiple Range Test on Muscular Activity

Muscle	Duncan Grouping	*M* (%MVC)	*SD* (%MVC)	Viewing Angle (°)
Splenius capitis	D	2.0	0.9	+40
	C	2.5	1.0	+20
	C	2.9	1.2	0
	B	3.5	1.3	–20
	A	3.9	1.3	–40
Trapezius	AB	9.9	3.6	+40
	B	8.4	3.3	+20
	C	6.2	2.2	0
	B	8.7	4.6	–20
	A	11.6	6.0	–40
Erector spinae	A	8.7	5.8	+40
	B	6.5	3.4	+20
	C	4.9	2.6	0
	B	6.7	3.7	–20
	A	8.3	4.3	–40

Notes. Means with a different letter in Duncan grouping are significantly different ($p < .05$); %MVC = percentage of maximum voluntary contraction.

3.2. Muscular Activity

For each participant, the two sets of repeated normalized EMG data for each muscle were averaged and subjected to ANOVA. The ANOVA showed that participants (*F*(9, 36); $p < .05$) and viewing angle (*F*(9, 36); $p < .05$) significantly affected the activity of all examined muscles. Duncan's multiple range test was performed on the normalized EMG data to group the means as equal or significantly different. Table 2 summarizes the results of Duncan's multiple range test. It shows a U-shaped relationship between viewing angle and trapezius activity, and between viewing angle and erector spinae activity; however, the splenius capitis activity decreased with viewing angle. The highest activity was about twofold higher than the lowest activity for trapezius, splenius capitis, and erector spinae across the five viewing angles.

4. DISCUSSION

In agreement with Villanueva et al. [11], this study demonstrated a strong relationship between viewing angle and neck angle, and between viewing angle and thoracic bending angle, while viewing angle did not significantly influence trunk inclination angle. Though the changes in viewing angle were accommodated by changes in both neck and thoracic bending angles, thoracic bending angle changed much less compared with neck angle. For example, an 80° change in viewing angle was associated with a 50° change in neck angle and a 15° change in thoracic bending angle. From a biomechanical point of view, greater neck, thoracic, and trunk angles in this study were associated with more extended neck, thoracic (kyphotic), and reclined trunk postures, respectively. Hence, the result that the participants mainly changed neck posture in response to changes in viewing angle was not surprising since the eyes are housed in the head and are in close proximity to all the pivot points for the head and neck movement [11]. Additionally, a change in neck posture as a reaction to a change in viewing angle was also easier than a change in thoracic posture and thus can explain the result of this study. The nonsignificant change in trunk inclination angle can be attributed to the participants being asked to sit erectly during experiment.

According to Jampel and Shi, the ear–eye line is typically 15° above horizontal eye height for a normal erect posture [25]. This provides the best available definition of a neutral neck angle (–15°) in this study. Previous studies indicated that the human head was held in an erect posture when the visual target was ~15° below horizontal eye height [26, 27]. In the current study, the participants held their neck in this neutral neck posture for viewing angles between 0° and –20°. This result is in agreement with the general suggestion that visual targets should be lower than horizontal eye height [28, 29]. Additionally, this study demonstrated that searching for visual displays higher than 0° viewing angle caused an extension of the atlantooccipital joint, while lower than –20° viewing angle caused flexion of the atlanto-occipital joint, from the neutral posture.

The participants' adaptation to the change in viewing angle mainly includes eye, neck, thoracic, and trunk movements. Due to the nonsignificant change in trunk inclination angle with viewing angle, the eye, neck, and thoracic movements were responsible for the change in viewing angle in this study. One interesting question was the relative ratio of eye, neck, and thoracic movements in response to the change in viewing angle. Though the eye movement was not measured in this study, this study could take the participants' neck and thoracic angles at 0° viewing angle as references and assume the total change in eye, neck, and thoracic angles equaled the change in viewing angle. On the basis of this assumption, Table 3 shows the relative changes in eye, neck, and thoracic angles in response to the change in viewing angle. It clearly indicates that the role of eye movement in viewing a higher VDT screen was greater than viewing a lower VDT screen. For example, the participants' eyeball rotated ~9.2° and 10.2° upwards to accommodate +40° and +20° viewing angles, respectively, while it rotated only ~2.3° and 4.7° downwards to accommodate –20° and –40° viewing angles, respectively. The reason for why the participants did not rotate their head sufficiently posteriorly to view a high VDT screen can be attributed to the biomechanical properties of suboccipital and cervical muscles. Burgess-Limerick, Mon-Williams, and Coppard indicated even a small amount of extension of the atlantooccipital joint was likely to cause a decrement in the tension-generating capabilities of the suboccipital and cervical muscles, and concluded that the posture adopted to view any target represented a compromise between visual and musculoskeletal demands [27].

The center of mass of the participants' head and neck is anterior to the atlantooccipital and cervical joints, thus generating a flexion torque at those joints. The flexion torque increased as viewing angle decreased in this study. Due to the requirement to maintain static equilibrium of the participants' head and neck, extensor torques contributed by suboccipital and neck muscles must be exerted to balance the external gravitational forces acting on the head and neck system. This biomechanical consequence explains why the activity of the participants' splenius capitis increased by nearly twofold from +40° (2.0% MVC) to –40° (3.9% MVC) viewing angles in this study.

This study observed a U-shaped relationship between viewing angle and trapezius activity, and between viewing angle and erector spinae activity, indicating that the activity of trapezius and erector spinae increased when viewing a higher or lower screen height compared with viewing a horizontal eye height screen. Compared with the muscle activity at 0° viewing angle, the activity of trapezius muscle increased by 87% and 59% at –40° and +40° viewing angles, respectively; similarly, the activity of erector spinae muscle increased by 77% and 69% at +40° and –40° viewing angles, respectively. In this study, the participants were asked to sit erectly in experiments, hence the flexion or extension torque of the head, neck and trunk were sensitive to the activity of trapezius and erector spinae. The U-shaped relationship between viewing angle and the activity of trapezius, and between viewing angle and the activity of erector spinae can be attributed to the need for trunk muscles to balance the flexion and extension torque induced by the participants' head, neck, and trunk to accommodate low and high viewing angles, respectively.

Finally, it should be noted that though this study revealed some information on the influence of VDT viewing angle on human postural angle and muscular activity, its results are preliminary since the number of participants was rather low and our participants were limited to young males, which might weaken and limit the generalizability of the results.

5. CONCLUSIONS

The following conclusions can be drawn on the basis of this study. The participants mainly adopted neck posture change in response to changes in viewing angle. Searching for visual displays higher than 0° viewing angle or lower than –20° viewing angle caused the participants' neck posture to deviate from the neutral position. The activity of trapezius and erector spinae increased when viewing a higher or lower screen height compared with viewing a horizontal eye height screen.

TABLE 3. Changes in Eye, Neck and Thoracic Angles (°) in Response to Changes in Viewing Angle

	Viewing Angle (°)				
Variables	**+40**	**+20**	**0**	**–20**	**–40**
Eye angle change	+9.2	+10.2	reference	–2.3	–4.7
Neck angle change	+24.9	+7.2	reference	–14.0	–26.4
Thoracic angle change	+5.9	+2.6	reference	–3.7	–8.9
total change	+40	+20		–20	–40

Notes. Positive changes in eye, neck, and thoracic angles indicate eyeball upward rotation, neck extension, and thoracic extension, respectively.

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