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ORIGINAL RESEARCH

The Impact of Use of Dual Monitor Screens on 3D Head–Neck Posture and Activity of Neck Muscles

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OCCUPATIONAL APPLICATIONS Computers with dual monitor screens are being increasingly used at many workplaces. Altered screen layout and increased viewing space associated with dual monitor screens may affect head–neck working postures and the activity of neck muscles. However, this problem has not been investigated in the past, and standard guidelines based on empirical data are not available for setting up a computer workstation with dual monitor screens. The present study compared the effects of single versus dual monitor screens on 3D head–neck postures and the activity of neck muscles in computer users. The results of this study have demonstrated that working on a video display unit workstation with dual monitor screens involved more rotated, asymmetric head–neck postures and higher activation of the anterior neck muscles than a video display unit workstation with a single monitor screen.

TECHNICAL ABSTRACT ***Background:*** Among workstation design factors, placement of the computer monitor screen is the most frequently identified risk factor for neck and shoulder pain among video display unit users. One of the recent changes in video display unit workstation design that may influence the position of computer monitor screens is the use of dual monitors. Some studies have shown that user performance and efficiency was positively affected by the use of dual monitor screens; however, the effect of use of dual monitor screens on the biomechanical behavior of the head-neck region is currently unknown. ***Purpose:*** This study was aimed at understanding the effect of single versus dual monitor screens on 3D head–neck postures and the activity of neck muscles. ***Method:*** Ten healthy participants performed three types of video display unit tasks: (1) reading for 10 minutes, (2) typing for 5 minutes, and (3) performing search and find tasks for 10 minutes using single and dual monitor screens. An inertial motion-capture system was used to measure 3D head–neck postures. Activity of sternocleidomastoid and cervical trapezius muscles was recorded bilaterally using surface electromyography. ***Results:*** Use of dual monitor screens significantly increased head–neck rotation by 9.0° compared to the single monitor screen. The range of motion of head–neck rotation increased significantly by 8.4° using dual monitor screens compared to the single monitor screen. Corresponding to the increase in the head–neck rotation, a contralateral increase in the activity of the right sternocleidomastoid muscle was observed with the dual monitor screen layout. Activity of cervical trapezius muscle was not affected by the type of monitor layout. ***Conclusions:*** Increased activation of anterior neck muscles caused by asymmetrical, more rotated head–neck postures while operating a video display unit workstation with dual monitor screens may increase the risk of neck musculoskeletal disorders, especially with prolonged computer use.

KEYWORDS Video display unit workstation, dual monitor screens, neck muscles electromyography, 3D head–neck postures

INTRODUCTION

The use of computers or video display units (VDUs) in work and home has drastically increased in recent decades (U.S. Bureau of Labor Statistics, 2005; Statistics Bureau of Japan, 2010). The physical demands of computer work compared with traditional forms of manual labor seems almost negligible; however, the literature consistently demonstrates that VDU users are at increased risk for neck and/or shoulder pain (Gerr et al., 2002; Woods, 2005; Juul-Kristensen et al., 2006; Johnston et al., 2008).

Among workstation design factors, placement of the computer monitor is one of the most frequently identified risk factors for neck and shoulder pain among VDU users (Bergqvist et al., 1995; Cook et al., 2000; Psihogios et al., 2001; Fostervold et al., 2006). General guidelines developed by the International Organization for Standardization (ISO, 1992), Australian Standards (AS, 1990), and the National Institute of Occupational Safety and Health (NIOSH, 1999) recommend a visual envelope of 0° to 60° below eye level as the optimum viewing zone for monitor placement. Specific lab-based experiments and field investigations with a primary focus on either neuromuscular or visual fatigue recommend different monitor placements. Three levels of screen heights–high level (between 0° to 30° above horizontal at eye level), mid level (between 0° to 15° below horizontal at eye level), and low level (between 15° to 45° below horizontal at eye level)–were evaluated in the previous studies. Mid-level placement was recommended over low-level monitor placement in a number of studies based on the relatively neutral head–neck posture, lower activation levels of the neck and shoulder muscles, and higher user preference (Villanueva et al., 1997; Psihogios et al., 2001; Kothiyal & Bjørnerem, 2009). On the other hand, findings of studies evaluating visual strain are inconsistent and recommend a wide range of screen heights from mid to low levels. A gaze angle of 9° to 10° below the horizontal was recommended by a few researchers based on the visual comfort of the users (Burgess-Limerick et al., 1999; Mon-Williams et al., 1999). Other researchers, however, recommended low-level monitor placement based on reduced visual strain due to higher tear volume (Sotoyama et al., 1997), less extra-ocular muscle work (Jaschinski et al., 1998), lower visual discomfort (Villanueva et al., 1997), and personal preference (Fostervold et al., 2006).

One recent change that may impact VDU workstation design is the use of dual monitor screens. Advancements in computer processors and hardware have made use of multiple monitor screens easy and economical, and VDUs with dual monitor screens are becoming increasingly common in workplaces. Studies performed by Tobler and Anderson (2007) and Russell and Wong (2005) suggested that user performance and efficiency is positively affected by the use of dual monitor screens. Although the addition of the second screen increases the total viewing space, which allows users to combine or delete steps required to complete typical VDU tasks, the addition of a second screen may adversely affect working postures. Users may have to rotate and/or bend their heads to a higher degree for longer durations, further affecting activation levels of the neck and shoulder musculatures.

Existing guidelines used for setting up a VDU workstation with a single monitor screen are based on the assumption that the monitor screen is placed in front of the user. However, while setting up a VDU workstation with dual monitor screens, both monitor screens cannot be placed in front of the user at a given time. An observed configuration is with the primary monitor screen shifted laterally. With such placement, neither of the monitor screens is in front of the user. Although some research has been performed to evaluate positioning of the monitors in the workplace (Shin & Hegde, 2010), the effect of monitor placement associated with dual-screen VDU workstations on the biomechanical behavior of the neck and shoulder musculature is not well understood. A clear understanding of the effect of such monitor placement on the loading of the neck and shoulder musculature is essential for revising/developing standardized guidelines for setting up a VDU workstation with dual monitor screens.

Therefore, the present study compared the effect of single versus dual monitor screens on 3D head–neck postures and the activity of neck muscles in VDU users. It was hypothesized that the standardized computer tasks performed using a VDU workstation with dual monitor screens would require non-neutral head–neck postures and higher muscle activity as compared to a VDU workstation with a single monitor screen.

METHOD

Approach

A laboratory study was performed to compare the effect of single versus dual monitor screens on 3D head–neck postures and neck muscles activity. The Functional Assessment of Biomechanics (FAB) system was used to measure changes in the 3D head kinematics, and the activity of neck muscles were measured using an electromyography (EMG) system.

Participants

Ten healthy male participants were recruited for this study. The primary inclusion/exclusion criteria used in this study were that (1) participants are free from any type of musculoskeletal disorders, (2) they have at least one year of experience working as a VDU operator, and (3) they spend more than 60% of working time using a VDU. Mean height and weight of the participants were 167.5 (4.14) cm and 69.8 (6.7) kg, respectively, and they were 22 to 35 years of age. Based on the self-reported use, on average, participants used VDUs for more than 82% of the time per week at work. Four of the participants used single-vision glasses at the time of the study. None of the participants were professional typists, and most of them used five to six fingers for typing. Before data collection, the experimental procedures were explained to the participants, and their signatures were obtained on a consent form approved by the local institutional review board.

Apparatus

Telemyo 2400 EMG System

This is a 16-channel telemetry EMG system consisting of a Telemyo 2400T transmitter, pre-amplified lead wires, and disposable self-adhesive Ag/AgCl snap electrodes (Noraxon Inc., Arizona, USA). The bipolar Ag/AgCl pre-gelled surface electrodes (1 cm diameter, inter-electrode distance is 2 cm) connect to the Telemyo 2400T transmitter via pre-amplified lead wires. The pre-amplifier on the lead wires have a band-pass of 10–1000 Hz (gain 500), CMRR $>$ 100 dB, and input impedance $>$ 100 MΩ. The Telemyo 2400 transmitter sends the data to the host computer over a wireless network. The frequency of EMG data acquisition was set at 1500 Hz.

Postural Assessment System

The FAB (BIOSYN, Canada) system was used for postural assessment. This is a full-body 3D kinematic system consists of 13 small, light-weight sensors (4 $\times$ 7 $\times$ 2.4 cm) that go on the selected body areas of the user. Each sensor has a triad of accelerometers, a gyrometer, and a magnetometer that allows real-time detection of angular displacement within biomechanical bodies. This is a completely wireless system and transmits 3D posture data to a host computer using a dedicated wireless network. The posture data was acquired at a frequency of 100 Hz.

VDU Workstation

The VDU workstation used in this study consists of a standard height and armrest adjustable swivel chair with a back rest and a standard computer desk with an adjustable slide-out tray for the keyboard with wrist support. A desktop computer with two 15-inch LCD screens and a document holder was used. The document holder was placed laterally to the left of the monitor screen. When dual monitor screens were used, the LCD screens were placed at an angle of 180° (Fig. 1).

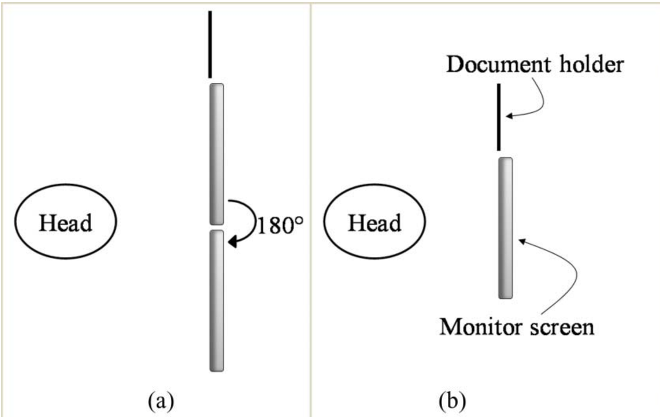

FIGURE 1 **Top views of the VDU workstations used in this study: (a) dual monitor screen VDU workstation and (b) single monitor screen VDU workstation.**

Experimental Design

A two-factor factorial experimental design was used. Factor 1, monitor layout, had two fixed levels (single monitor screen and dual monitor screens); factor 2, type of tasks, had three fixed levels (reading, typing, and search and find). For the reading task, participants read an article for 10 minutes. Only one screen was used to read the article while using dual monitor screens layout; i.e., participants dragged the article to either of the screens (self-selected) and opened it completely (maximized it) before beginning to read. During the typing task, participants typed a document by reading it from a document holder. Search and find tasks required the participants to go to a certain directory on the computer hard drive and find out information by opening a certain file in that directory. After the information was located, participants were required to report that information by typing it into a master file. Once the information was typed into the master file, the next search and find task was displayed to the participant in the master file.

Experimental Procedure

Anthropometric Measurement

As a first step, a set of anthropometric measurements, height, weight, upper arm length, forearm length, trunk length, shoulder width, and neck length were recorded for each participant. Some of these measurements were required as input to the FAB software, while other measurements were used for determining the exact location of EMG electrodes in the neck and shoulder areas. FAB software requires the basic anthropometry data to form the real-time humanoid during data collection and to precisely compute 3D kinematics between the biomechanical bodies.

Data Collection Preparation

Participants were fitted with the following three FAB sensors using elastic bands:

1. pelvis sensor was mounted at the approximate L5S1 level,
2. trunk sensor was mounted at the approximate T10–11 level, and
3. head sensor was mounted at about the occipital region.

Subsequently, neck skin was prepped for EMG electrode placement by shaving hair (if needed) and cleaning with 70% rubbing alcohol. EMG data was recorded from two neck muscles: sternocleidomastoid and cervical trapezius.

EMG from the sternocleidomastoid muscle was recorded by placing an electrode along a line drawn from the sternal notch to the mastoid process at one-third the length of the line from the mastoid process. Electrodes were located midway between the innervation zone and the insertion of the muscle at the mastoid process (Nimbarte et al., 2010). EMG from the cervical trapezius muscle was recorded by placing an electrode at the C4 level, which was determined as 2.5 times the distance between the C6–C7 vertebrae above the C7 level. The electrode at this location was placed slightly inclined (approximately 35°) to the vertical line between the spinous processes of the C7 and C4 (Nimbarte et al., 2010). The EMG data was collected bilaterally.

Once the FAB and EMG sensor were mounted on the participant, the FAB system was calibrated. To calibrate FAB system, the participant stood in anatomically neutral position with his feet shoulder-width apart and pointing straight ahead, knees locked, back straight, hands at the side (thumbs pointing forward palms against the leg), and head looking straight ahead (Fig. 2a). The participant had to hold this anatomically neutral posture for a brief period of 30 seconds. During the calibration step, the FAB software set the head–neck flexion, lateral bending, and rotation angles to zero (Fig. 2b). Each FAB sensor has orthogonal triads of accelerometers, magnetometers, and gyroscopes. A tri-axial accelerometer provides inclination estimates

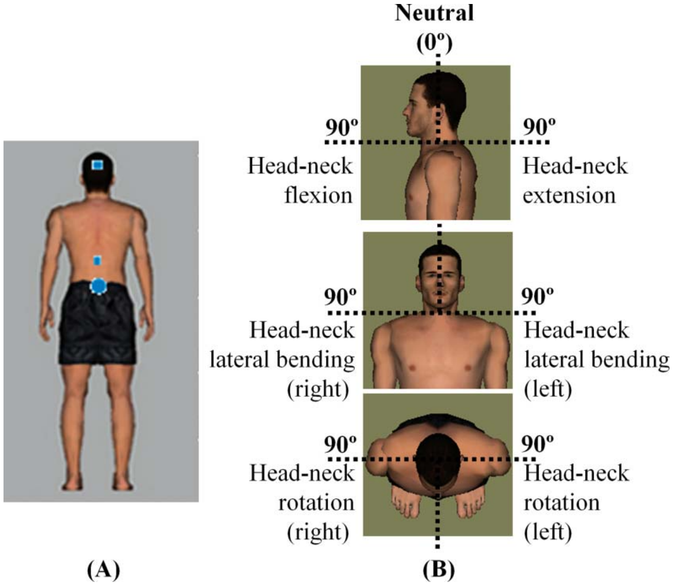

FIGURE 2 **Anatomically neutral posture used for calibrating FAB sensors (color figure available online).**

by sensing the gravity vector and provides orientation of the sensor relative to a horizontal plane. The magnetometer triad provides an estimate of rotation about the vertical axis based on the measures of the local magnetic field vector. The combined information from the accelerometer and magnetometer is sufficient to estimate the orientation of a static or slow-moving rigid body in a global coordinate system. However, under dynamic conditions, inclination data provided by accelerometers is subjected to errors, and magnetometers cannot measure rotation about the axis in the direction of the earth's magnetic field and can be disturbed by local magnetic fields. These two weaknesses are compensated by a triad of gyroscopes, which requires frequent estimation of initial position for accurate sensor orientation to avoid drifting errors in the estimation. Furthermore, to eliminate the effect of local magnetic field on the kinematic computation, based on the manufacturer's recommendation, while calibrating the FAB system, the participant stood close (<0.5-meter radius) to the VDU workstation. Ultimately, FAB sensors quantify the angular displacement within the biomechanical bodies by time-integrating the signals from a triad of mutually orthogonal accelerometers, magnetometers, and gyroscopes in a unique manner such that one sensor's weakness can be compensated by another sensor.

Upon calibration, the participant started working on the VDU to get familiarized with the workstation setup. They were instructed to adjust their chair height to achieve a comfortable sitting posture. Comfortable sitting position was defined based on the previously published guidelines (Saito et al., 1997; Turville et al., 1998; Szeto & Lee, 2002; Szeto & Sham, 2008): back straight, hip joint flexed 90°, knee joint approximately 90°, shoulder joint in anatomically neutral posture, elbow joint approximately 90° flexed, and forearm supported by the adjustable arm rest. Reading/viewing distance was set to 56–58 cm for the VDU screen. Pictures of a participant with two VDU workstations are shown in Fig. 3.

Actual Data Collection

Once the workstation parameters were set up, before the data collection trials, participants were asked to browse on the Internet for 5 minutes to get familiar with the setup. Participants then performed the standardized VDU tasks (reading, typing, and performing search and find tasks) for a total duration of 25 minutes. 3D motion and EMG data were recorded continuously during the three types of VDU activities. The order in which monitor layouts were used and the task order within a monitor layout were randomized between the participants.

Data Processing and Analysis

Head-Neck Posture

To estimate the most frequently adopted head–neck postures, 3D kinematic data recorded by the FAB software were processed to determine median of head–neck flexion, bending and rotation angles. Median angles related to the head–neck postures were previously used in a number of VDU studies to evaluate the effect of different workstation design parameters (Aaras et al., 1997; Szeto et al., 2005). In addition, to quantify postural variability associated with the two-monitor layout tested in this study, range of motion data (ROM) were used. The difference between the 90th and 10th percentile of the continuous kinematic data was computed as the ROM.

EMG

EMG data was processed to calculate mean absolute values (MAVs). The raw EMG signal from each electrode location was demeaned and full-wave rectified. The full-wave-rectified EMG signal was low-pass filtered at 4 Hz using a fourth-order dual-pass Butterworth digital filter to form a linear envelope (Burnett etal., 2007).

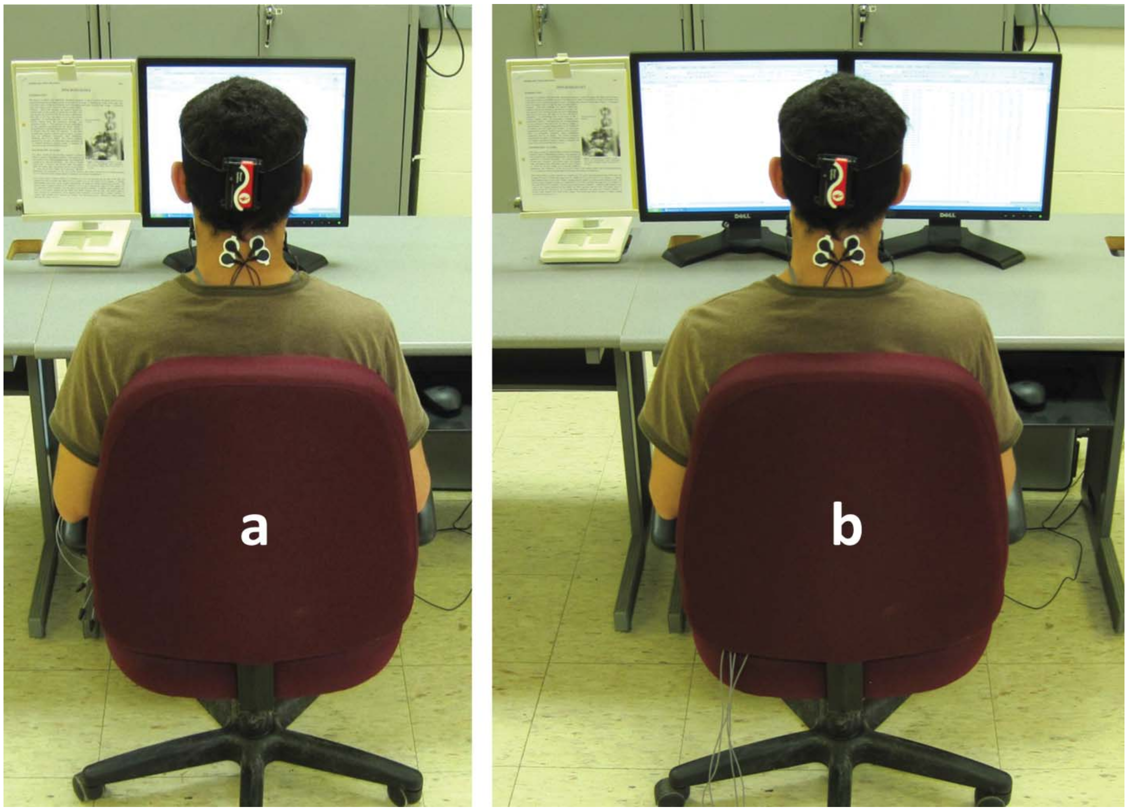

FIGURE 3 Experimental setup: (a) participant with single monitor screen VDU workstation and (b) participant with dual monitor screens VDU workstation (color figure available online).

The resulting data was averaged and normalized with respect to the Maximum Voluntary Contraction (MVC) as explained by Nimbarte et al. (2010) to determine the normalized MAV (N-MAV).

Statistical Analysis

A two-factor general linear ANOVA was performed to evaluate effect of monitor layouts and type of tasks on the postural load and activity of neck muscles. Monitor layout and type of task were treated as fixed effects and subject as a random factor. Minitab 16 statistical analysis software (Minitab Inc., Pennsylvania, USA) was used to perform the analysis. From the ANOVA menu, a general linear model was selected to run the analysis. The adequacy of the linear model was confirmed by normal probability plots of the residuals between the actual and fitted value. Significant main and/or interaction effects were further evaluated by conducting comparisons between means using Tukey's Honestly Significant Difference (HSD) all-pairwise comparison test.

RESULTS

Posture

Head–neck postures in terms of rotation and lateral bending angles were significantly affected by the type of monitor layout (Table 1). The mean of median head–neck rotation angles increased for the dual monitor screens compared to single monitor screen by 9.0° ($p = 0.000$). The corresponding increase in the

TABLE 1 Main effect of monitor layout on the median and the ROM of head–neck flexion, lateral bending, and rotation angles (with one standard deviation)

	Dual	Single	*p*-Value
Median (°)			
Head–neck flexion	12.8 (7.6)	10.5 (7.1)	0.080
Head–neck lateral bending	4.6 (3.7)	3.0 (2.1)	**0.018**
Head–neck rotation	17.5 (6.2)	8.6 (4.7)	**0.000**
ROM (°)			
Head–neck flexion	13.7 (7.3)	12.1 (6.0)	0.241
Head–neck lateral bending	6.5 (4.0)	4.9 (3.1)	**0.039**
Head–neck rotation	19.8 (7.5)	11.4 (4.7)	**0.000**

Notes. Bolded *p*-values show statistical significance.

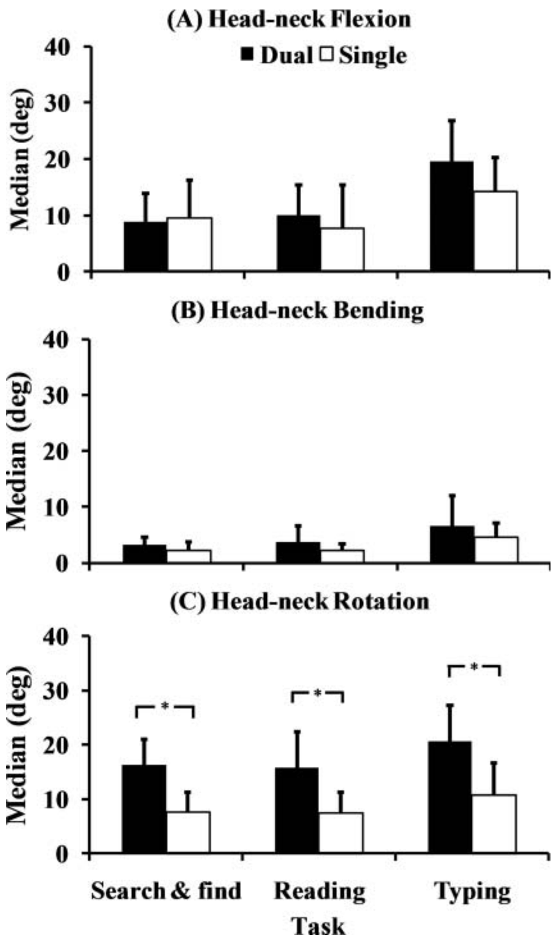

FIGURE 4 Mean of median head–neck flexion, lateral bending, and rotation angles as a function of type of tasks and monitor layouts. Columns marked with bracket and *mark are significantly different from each other. Error bars represent one standard deviation.

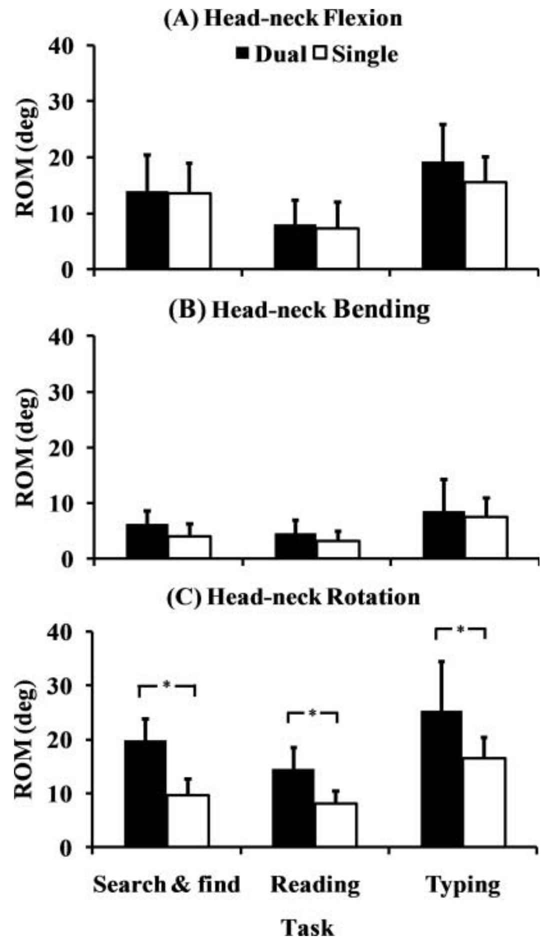

FIGURE 5 Mean of range of motion of head–neck flexion, lateral bending, and rotation angles as a function of type of tasks and monitor layouts. Columns marked with bracket and *mark are significantly different from each other. Error bars represent one standard deviation.

mean of median head–neck lateral bending was 1.5° ($p = 0.018$). No significant difference in the mean of median head–neck flexion angles with respect to two monitor layouts was observed ($p = 0.080$). The mean of ROM of head–neck rotation and lateral bending was also significantly affected by the type of monitor layout (Table 1). The mean of ROM of head–neck rotation and lateral bending for the dual monitor screens compared to single monitor screen increased by 8.4° ($p = 0.000$) and 1.6° ($p = 0.018$), respectively. No significant difference in the mean of ROM of head–neck flexion with respect to two monitor layouts was observed ($p = 0.241$).

A within-task comparison of monitor layout showed that during the three tasks–search and find, reading, and typing–the mean of median and ROM of head–neck rotation for the dual monitor screens was significantly higher compared to a single monitor screen (Figs. 4 and 5). A relatively higher head–neck flexion (mean of median angle and ROM) for the dual monitor screens compared to single monitor screen was observed during the reading and typing task, and higher head–neck bending (mean of median angle and ROM) was observed during the search and find, reading, and typing tasks. However, these differences were statistically insignificant.

Muscle Activity

The activity of sternocleidomastoid muscle on the right side was significantly affected by the type of monitor layout (Table 2). This muscle showed higher activity for the dual-monitor layout than single-monitor layout ($p = 0.000$). A within-task comparison of monitor layout showed that the highest increase in the muscle activity was observed during the reading task,

TABLE 2 Mean muscle activity expressed in N-MAVs (%MVC) for different experimental conditions (one standard deviation in parentheses)

	Dual	Single	*p*-Value
Right sternocleidomastoid	4.0 (1.1)	3.2 (1.0)	**0.000**
Left sternocleidomastoid	3.3 (1.1)	3.2 (1.1)	0.894
Right cervical trapezius	3.8 (1.7)	3.4 (1.3)	0.108
Left cervical trapezius	5.6 (1.9)	5.9 (1.5)	0.534

followed by search and find and typing tasks (Fig. 6). Results of the Tukey HSD all-pairwise comparison test showed that mean activation level of the sternocleidomastoid muscle on the right side during the reading task was significantly higher for the dual-monitor layout than single-monitor layout (Fig. 6). For the sternocleidomastoid muscle on the left side, no significant difference in the activation level with respect to monitor layout was observed (Fig. 6).

The activity of the cervical trapezius muscle on both sides was not affected by the monitor layout. A general trend in the mean activation level showed that during the typing task, these muscles were more highly activated when using dual monitor screens than a single monitor screen (Fig. 7). During the search and find and reading tasks, no consistent trend in the behavior of these muscles with respect to the monitor layout was observed (Fig. 7).

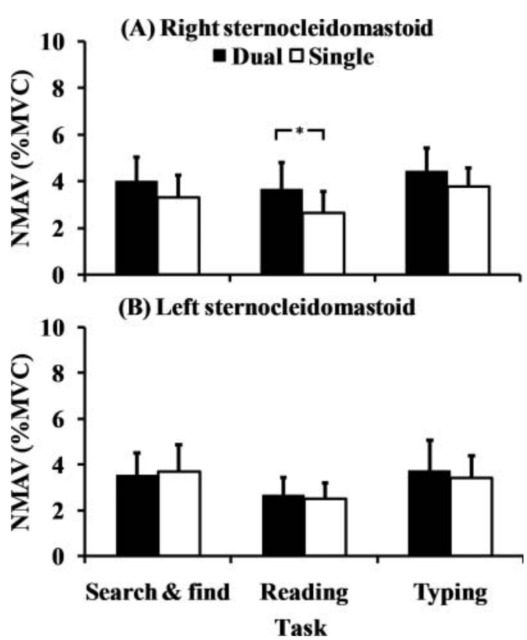

FIGURE 6 EMG activity of the sternocleidomastoid muscles expressed in N-MAVs (% MVC).

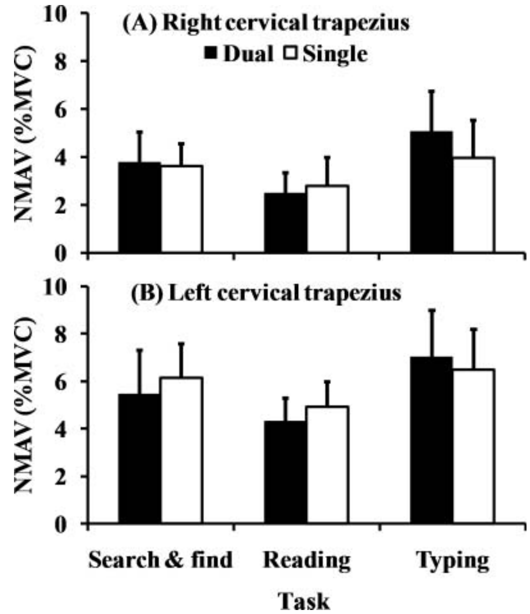

FIGURE 7 EMG activity of the cervical trapezius muscles expressed in N-MAVs (% MVC).

DISCUSSION

This study was aimed at understanding the effect of use of a dual monitor screen VDU workstation on the posture and muscle activity of the head–neck region by comparing it with a single monitor screen VDU workstation. Based on the analysis of 3D head–neck kinematics, results of this study showed that the median and ROM of head–neck rotation and lateral bending angles were significantly affected by the type of monitor layout. Users adopted asymmetrical more rotated head–neck postures while working with dual monitor screens. Corresponding to the increase in the cervical rotation, a significant increase in the activity of right sternocleidomastoid muscle was observed.

The working postures adopted by VDU users are constrained by a number of factors, such as positions of monitor, keyboard, and mouse, and relative locations of these components with respect to the seating surface. Findings of previous studies suggest that monitor position affect the orientation of the head, whereas upper extremity postures are more sensitive to the positions of keyboard and mouse (Saito et al., 1997; Kietrys et al., 1998; Sommerich et al., 2001; Sillanpaa et al., 2003; Szeto & Sham, 2008). In the existing literature, different monitor heights above and below the horizontal at eye level were studied. Such monitor locations were found to affect head–neck postures primarily in the sagittal (flexion-extension) plane. Result of this study showed that addition of a second monitor significantly affected the head–neck postures in the transverse (rotation) plane. Use of dual monitor screens increased the available viewing area in the lateral directions, requiring greater head–neck rotation to maintain appropriate gaze angle. Szeto and Sham (2008) made a similar observation in terms of increased head–neck rotation when centrally located monitor position was compared with the laterally shifted monitor location during typing tasks. Based on the within-task comparison in this study, it was observed that during the typing task, use of dual monitor screens elicited the highest head–neck rotation accompanied by somewhat higher head–neck flexion and lateral bending. For the search and find and reading tasks, head–neck postures between the two monitor layouts were only different in terms of rotation. In general, independent of the monitor layout, the typing task showed postures that required higher flexion, lateral bending, and rotation than the other two types of tasks. This is, to some extent, similar to the findings of Babski-Reeves et al. (2005). A higher degree of postural shift in the flexion-extension plane during the typing task than for a simple math task was reported by Babski-Reeves et al.(2005). The overall nature of the simple math task used in their study is similar to the search and find task used in the present study.

The results of the present study show important changes in the muscle activity patterns of the right sternocleidomastoid muscle in response to different monitor layouts. Independent of the type of tasks, the right sternocleidomastoid muscle showed significantly higher activity while using dual monitor screens. The sternocleidomastoid muscle plays an important role in supporting head weight during rotation. The observed increase in the activity of the right sternocleidomastoid muscle was due to the increased head–neck rotation associated with the dual-monitor-screen layout. In this study, participants adopted leftward (counterclockwise) rotation more frequently, since the monitor screen on the left side was the primary screen; also, the document holder was placed to the left of the primary screen. The increased activation of the sternocleidomastoid muscle corresponding to the increased contralateral rotations observed in this study is consistent with the findings of previous study by Bexander et al. (2005). The activity of the cervical trapezius muscle, which controls the head movement in forward and lateral directions, was not affected by the monitor layout. During the typing task performed using dual monitor screens, a generally higher activation for this muscle was observed; however, for the search and find and reading tasks, this muscle showed similar activation levels between the two monitor layouts.

The muscle activation levels found in this study are comparable with the previous VDU studies. Turville et al. (1997) reported muscle mean activation of 2.6% MVC and 3.6% of MVC during the reading task for the sternocleidomastoid and cervical trapezius muscles, respectively. These activation levels are similar to 2.6% MVC and 3.8% of MVC observed in the present study. Villanueva et al. (1997) reported mean activation of 5.4% MVC for cervical trapezius muscles during the tasks similar to the search and find task evaluated in this study. This is comparable with the mean activation of 4.9% MVC observed in the present study. During the typing task, activation greater than 5% of the MVC was observed, which was further exaggerated with the use of dual screen monitors. Sustained muscle activation greater than 5% of the MVC is known to generate faster muscle fatigue (Jonsson, 1982) and can also increase biomechanical load on passive structures (Harms-Ringdahl et al., 1986), further increasing the risk of neck musculoskeletal pain.

The postural variability assessed using the ROM data showed greater head–neck rotation variability for dual monitor screens than single monitor screen; i.e., dual monitor screens provided more postural options in the transverse plane than the single monitor screen. A few researchers argued that higher postural variability suggested fewer monotonous sustained postures and thus may be critical to explain the associations of work-related exposures with musculoskeletal disorders (Straker et al., 2009). However, empirical evidence for this association is not well established. In this study, while higher postural variability was observed for the head–neck rotation for dual monitor screens than single monitor screen, the continuous posture and muscle activity data indicate that most of these postures were adopted in the asymmetrical more rotated regions (higher median of head–neck rotation angles) and required higher muscular activity of the anterior neck muscles. Thus, a greater biomechanical exposure for the use of dual monitor screens than a single monitor screen was observed in this study. Although there is some evidence for increased efficiency with the use of dual monitor screens (Tobler & Anderson, 2007; Russell & Wong, 2005), higher postural load in terms of more rotated head posture and increased activation of neck muscles indicates increased risk of neck musculoskeletal disorders with the use of dual monitor screens.

The nature of VDU users' job was found to play an important role in the biomechanical response of head–neck region. A between-task comparison showed that certain types of VDU tasks (e.g., the typing task) are more demanding than others (e.g., the reading and search and find tasks), for a single monitor screen layout and the addition of a second monitor screen further augments the biomechanical demands imposed by such tasks on the neck musculature. While the jobs of VDU workers typically consist of a mix of activities demanding reading, information search, and typing, many jobs involve a relatively higher percentage of one type of activity than another. In such cases, the nature of the job should be considered as one of the important decision variable while deciding between the number of monitor screens to be used and their arrangement. A dual monitor screens VDU workstation with the primary monitor placed directly in front of the user may reduce the head–neck rotation and flexion and the resulting stress on the neck musculature during reading and typing activities. For the information search type of job, the arrangement used in this study may be preferred over the aforementioned arrangement. While this arrangement requires bilateral deviation of the head, it can reduce extreme unilateral deviation in the rotational plane.

There are a few limitations of this study that need to be acknowledged. The present study mainly examined the situation where dual monitor screens were arranged laterally at an angle of 180°, with the primary monitor located to the left and the secondary monitor located to the right of the user (with respect to the approximate mid-line of the body). The organization of data on the monitor screens was not controlled. Users were allowed to use the monitor screen as they prefer. It is likely that users may have organized the data on the monitor screens unevenly, especially with the dual-monitor setup, requiring the use of asymmetrical postures. In addition, it is also likely that even with a more evenly distributed data on the screen, users may have adopted non-neutral postures by compensating for the head motion using eye motion. Perhaps this could be the reason for the non-zero median of head–neck rotation angles observed in this study for single monitor use. Future studies should evaluate eye tracker data in addition to the posture and muscle activity data. Such studies will provide valuable insight into how the data organization on the monitor screen in addition to the monitor layout would influence the behavior of the VDU users. Additionally, while the overall layout of the VDU workstation used in this study, i.e., arrangement of monitors with respect to the centrally located keyboard and mouse on a slide-out tray, represents one of the arrangements in which dual monitor screens can be used, a number of other arrangements are possible (Fig. 8). Furthermore, different arrangements of the keyboard and mouse with respect to the monitor screens are also possible. It is likely that each of these combinations may show different postural and muscle activity patterns. Future studies should examine the

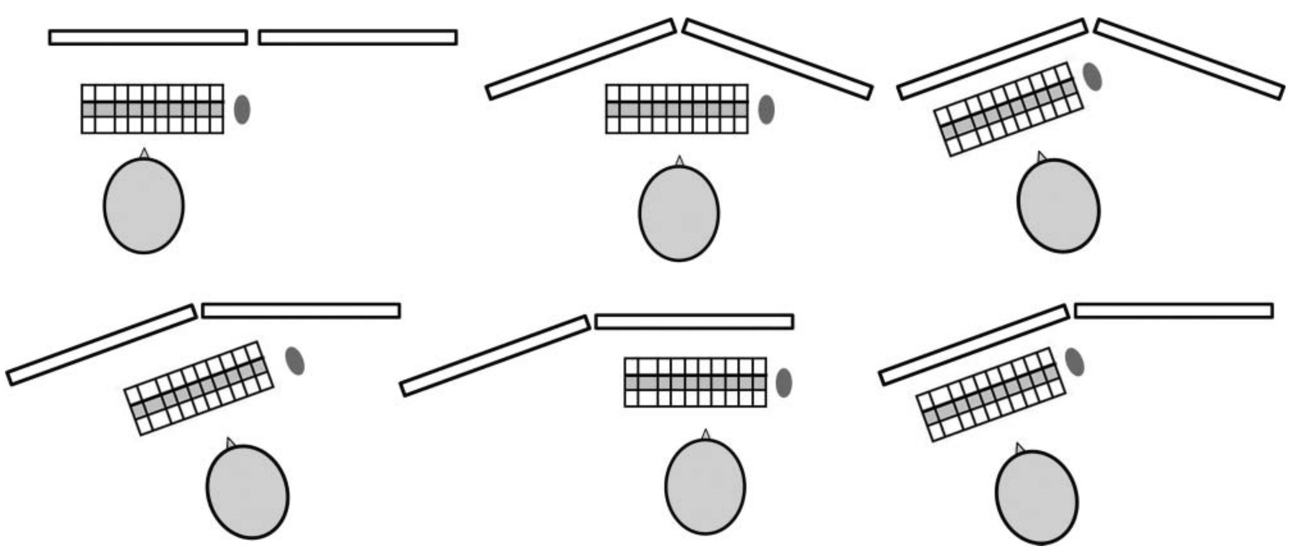

FIGURE 8 Top views of possible arrangements of dual-monitor VDU workstations.

effect of different arrangements of monitor screens, keyboard and mouse, and sitting surfaces. Only male participants were recruited in this study. Female office workers are known to be at a higher risk of neck and shoulder musculoskeletal disorders than males. It is possible that females may adopt different postures and show altered muscle activity patterns while working with dual monitor screens. Future studies should examine the combined effect of gender and different VDU layouts on the overall behavior of the neck-shoulder musculature. The present study seemed to suggest that working on a VDU workstation with dual monitor screens may be more strenuous in terms of posture and muscle activity than a VDU workstation with a single monitor screen. These findings were based on a working duration of 25 minutes. It is possible that studies with longer working durations may reveal a different trend, especially for the neuromuscular fatigue. Future studies should examine longer working durations.

CONCLUSIONS

In modern offices, use of dual monitor screens is growing rapidly. Altered screen layouts and increased viewing space associated with dual monitor screens may affect working postures of the head–neck and the activity of corresponding muscles. However, this problem was not investigated in the past. The results of the present study have shown that users adopted more rotated, asymmetrical head-neck postures while working on a VDU workstation with dual monitor screens. The right sternocleidomastoid muscle showed higher activity while working on a VDU workstation with dual monitor screens than a single monitor screen. Asymmetrical head–neck postures and the increased contralateral activity of the anterior neck muscles associated with a VDU workstation with dual monitor screens may increase the risk of neck musculoskeletal disorders.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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