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Abstract

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The design and functionality of the computer or video display unit (VDU) workstation has continuously evolved since its advent. One of the recent developments in the design of VDU workstations that may affect working postures of the head and neck and the activity of corresponding musculature is the use of dual screen monitors. VDU workstations with dual screen monitors are becoming increasing common at offices, libraries, and many other workplaces. A few studies show that user performance and efficiency is positively affected by the use of dual screen monitors, however, currently effect of dual screen monitors on the overall behavior of the neck and shoulder region is unknown. Therefore, this study was aimed at understanding the effect of use of dual screen monitors VDU workstation on the biomechanical behavior of the neck and shoulder musculature. A laboratory study was performed to compare the effect of dual and single screen VDU workstation on the 3D head and neck postures and neck muscles activities. Nine healthy participants were recruited for this study. Each participant performed three types of tasks: (1) reading for ten minutes; (2) typing for five minutes; and (3) search and find tasks for ten minutes using single and dual screen monitors. The results of the present study have showed that user adopted asymmetrical, more rotated, head and neck postures while working with dual screen monitors. Working postures and muscle activity pattern with respect to the monitor layout were found to depend on the type of the task. Typing task elicited higher postural and muscle activity load followed by search and find, and reading tasks. Independent of the tasks, right sternocleidomastoid muscle showed higher activity levels for dual screen layout. This increased activity level may be due to increased head rotation associated with the dual screen monitors.

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Chapter 1: Introduction

In the recent years, growth in information technology has made use of computers or video display units (VDU) at modern offices a basic necessity. Not only employees in modern offices use computers to a major part of the day, but also the people in general, are becoming highly dependent on the computers for most day to day activities such as social networking, shopping, banking, travel booking, etc. According to the Bureau of Labor Statistics, in United States, 77 million workers use computers at work, which constitute 55.5% of the total employment (BLS, 2005). In a different study by the Australian Bureau of Statistics, nearly 78% of the population was reported to have computer access at home (Australian Bureau of Statistics, 2005).

The physical demand of computer work may seem relatively low in terms of forces and moments; but excessive use of computers had led to a number of health and occupational problems. One of the consequences of sustained computer use is the increased prevalence of neck and shoulder musculoskeletal disorders among the VDU users (Francisco, 1992; Gerr et al., 1996; Gerr et al., 2002). In USA, an annual incidence rate of neck-shoulder MSD of 58% and a prevalence rate of up to 62% was reported for VDU users (Gerr et al., 2002; Jensen et al., 2002). Some specific disorders that are typically associated with the low level sustained force demand during the computer use are the neck and shoulder pain syndromes such as trapezius myalgia, tension neck syndrome and cervicalgia (Juul-Kristensen et al., 2006). The occupational groups that are more severely affected by musculoskeletal disorders with regard to prolonged use of computers include office secretaries, data entry workers, and call center employees (Kothiyal and Bjonerem, 2007).

VDU users often perform seated tasks for long durations that cause static loading of the neck and upper extremities (Turville et al., 1998a). From a human machine perspective, keyboard and mouse of a VDU workstation are considered as the primary input devices, and the monitor screen is considered as the output device. While physical aspects of a well-designed workstation such as arm rest, mouse pad, keyboard stand, provide sufficient support to the body parts used in operating input devices, the postural fixation of the head and neck region is primarily governed by placement of the output device (i.e., the monitor). The position of the head and neck is extremely important in setting the preferred viewing angle with respect to the monitor screen. Awkward head neck postures (forward head/neck) adopted during the VDU use are known to be the risk factors for neck pain among the VDU users (Chiu et al., 2002; Szeto et al., 2002). Some studies also provide an evidence for a relationship between musculoskeletal symptoms of neck and shoulder with the increased cervical extension (Aarås et al., 2001; Marcus et al., 2002) or flexion (Ariëns et al., 2001) caused by high or low levels of monitor placements, respectively. Thus, monitor placement is a key facet of the VDU workstation design. General guidelines developed by International Organization for Standardization (ISO, 1992) and Australian Standards (AS, 1990), and National Institute of Occupational Safety and Health (NIOSH, 1999) recommend a visual envelope of 0 to 60 degrees below eye level as optimum viewing zone for monitor placement. Specific epidemiological research, lab-based experiments, and field investigations recommend different positions within the extreme locations suggested by the standards. A comprehensive review of these studies is presented in the literature review chapter. One of the recent developments in the design of a VDU workstation with respect to the monitor screen is the increased use of dual screen monitors at various workplaces. Dual screen monitors are claimed to have positive effect on the efficiency of the workers. However, currently it is unknown how working on a VDU workstation with dual screen monitor affects the biomechanical and physiological behavior of the neck and shoulder musculature.

Chapter 2: Literature review

Growing concern about the physical impact of computer use has led to a number of epidemiological, lab-based, and field investigations that explore musculoskeletal effect of VDU use. In this chapter previous research that primarily focuses on the neck and shoulder MSD among the VDU users are reviewed.

2.1 Epidemiological studies

Musculoskeletal discomfort, especially in the neck and shoulder region, was listed as the main occupational health concern for the people who work with the VDU in a number of studies. Gerr et al.,(2002) conducted a prospective study performed over a duration of three years using newly hired employees from eight big firms in metropolitan Atlanta (n=632). These employees on an average spent more than 15 hours/ week working with computers. Neck-shoulder and hand-arm musculoskeletal symptoms were found to be common among the computer user with an annual incident rate of 58 and 39 cases/100 person-year, respectively. Korhonen et al., (2003) reported an incidence rate of 34.4% for neck pain among the VDU employees in three administrative units of a medium-sized city in Finland (n = 515). Sillanpaa et al., (2003) performed a study using survey questionnaire to estimate the prevalence of musculoskeletal symptoms and disorders among full-time VDU users. Three types of VDU users, office workers (n=298), customer service workers (n=238), and designers (n=247), participated in this study. The results for all the occupations combined showed that the prevalence of musculoskeletal symptoms in the neck were most common followed by shoulders, elbows, lower arms and wrists, and fingers. The corresponding prevalence rates were 63%, 24%, 18%, 35% and 16%, respectively. Woods (2005) performed a study to estimate the prevalence of musculoskeletal pain/discomfort and visual strain symptoms among data processing VDU workers. A questionnaire was used to collect discomfort data from the VDU workers (n=175) and the control group (n =129) in the same organization. Eighty-six percent of the VDU workers reported musculoskeletal pain/discomfort, with the highest prevalence rate of 58% for the neck pain. More recently, Johnston et al., (2008) found in cross-sectional survey study that mild level of neck pain was experienced by 53% of the of female office workers (n= 333).

The risk factors for MSD of the neck and upper extremity among the computer users can be classified into following four categories:

(1) Individual factors: age, gender, obesity, physical activity, smoking habits, use of vision correction, and inherent psychological states (Johnston et al., (2008)

(2) Physical workstation design factors: position of computer monitors, method, type and location of other input devices such as keyboard and mouse (Punnett and Bergqvist, 1997)

(3) Task demand factors: duration of computer use, frequency of breaks (Punnett and Bergqvist, 1997)

(4) Workplace psychosocial factors (Ariëns et al., 2001; Johnston et al., 2008)

Among the workstation design factors, placement of computer monitor is the one of the most frequently identified risk factor for neck and shoulder pain among the VDU users. Bergqvist et al., (1995) conducted a cross sectional study using a sample of 260 computer users. Among the workstation design variables, higher monitor placements was linked with the neck MSD among the VDU users. Higher monitor placement was also listed as the risk factors for neck and upper extremity musculoskeletal symptoms in the computer users by Cook et al., (2000) based on a cross sectional study (n= 270). Psihogios et al., (2001) found that in the field setting, workers spend 60 to 80% of the time looking at the computer monitor and the perceived discomfort in the neck is related with the monitor placement. In a different field investigation, Fostervold et al., (2006) found that the discomfort in the neck and shoulder was significantly affected by the placement of the monitors. Ariens et al.,(2001) stated that neck flexion and rotation in the seated work postures commonly adopted by the office workers can result in neck pain and Black et al., (1996) found that sitting postures with excessive cervical flexion is associated with the neck pain.

2.2 Experimental Studies

Considering the importance of the location and height of display screen in overall VDU workstation design and its impact on musculoskeletal symptoms and disorders among the VDU users, several laboratory studies have looked at effect of different monitor configurations on the behavior of neck shoulder region.

Villanueva et al., (1997) studied effect of VDU screen heights on the changes in the body postures and the EMG activity of the neck muscles during a non-keyboard task. Ten healthy subjects performed mouse-driven interactive task at the screen heights of 80, 100 and 120 centimeters above a standard height desk. The postural analysis showed that at higher screen heights, neck became significantly more erect and subjects adopted a more backward leaning trunk position. EMG activity of the neck-shoulder muscles was associated with the neck angles. Increased neck extensor muscle activity was found to be related with the flexed neck postures adopted while using low level monitor screen.

The relationship between head and neck posture and VDU screen heights was also studied by Kietrys et al.,(1998). Two screen heights (38 in and 43 in) were studied. Twenty-seven participants (three male, 24 female) participated in this study. Subjects were photographed over two 10-minute periods and cervical spine flexion angles were recorded using goniometers. The results of this study show that an elevated position of the VDU screen significantly increased the upper cervical angle due to increased extension of the head relative to the neck. Turville et al., (1998b) also examined the effect of two VDU screen locations (15° and 40° below horizontal eye level) on the activities of neck muscles, head/ neck posture, heart rate and operator performance. Five male and seven female from North Carolina University population participated in this study. Participants performed reading and typing tasks using the different monitor configurations. Low level VDT location (40° below horizontal eye level) demonstrated significantly greater head tilt angles and elevated muscle activity levels for the neck muscles. No considerable differences in the operator performance or heart rate were noticed as a result of changes in the monitor locations. Seven of the 12 subjects preferred the 15° monitor position. In a similar type of study, Burgess-Limerick et al., (1999) evaluated the influence of eye level and low level monitor locations on the head and neck postures. Twelve subjects from the university population performed a document correction task for 30 minutes. Low level monitor condition were found to be associated with a higher degrees of neck flexion.

In addition to the monitor location, Sommerich et al., (2001b) examined the effect of monitor size and participant characteristics on the loading of neck and mid-back muscles. Eight touch typists and non-touch typists performed six experimental trials using three viewing angles (0°, 17.5°, and 35° below the horizontal eye level) and two monitor sizes (14 in and 19 in). Muscle activities were found to be generally higher for the low viewing angle, 14 inch monitor size, and for non-touch typists. Participant preferred the midlevel placement (17.5° below the horizontal eye level).

The relationship between the monitor placement and chair type on the risk factors associated with developing musculoskeletal pain/discomfort of the back and neck were evaluated by Babski-Reeves et al., (2005). Eight subjects (four male and four female) performed 2 hours of standard data entry tasks using different combinations of monitor height (low and high) and chair types (high and low cost). The ineteraction between the monitor height and chair type was significant for neck and back muscles. For the neck muscles, the lowest level of activity was observed for high monitor position combined with high cost chair.

Recently, Szeto and Sham (2008) studied effect of angled position of display screen on the activity of neck and shoulder stabilizing muscles. Twenty university students performed typing task for 20 minutes using central, angled left, and angles right screen positions. Angled positions showed higher level of activities for the cervical spinae and upper trapezius muscles. Kothiyal and Bjornerem (2009) looked at the effect of computer monitor setting on the muscular activity, user comfort and acceptability. Ten subjects performed typing task for 10 minutes using three monitor settings (15°, 30°, and 45° below horizontal at eye level). Results of this study indicate that muscle activity data were not significantly different between the different monitor settings. However, comfort and acceptability data show that high monitor setting was most preferable among the participants of this study.

2.3 Recent changes in the VDU workstation

The design and functionality of the computer workstation has continuously evolved since its advent. One recent development which may significant affect the working postures, especially of the head and neck region, is the use of dual screen monitors. VDU workstations with dual screen monitors are becoming increasing common at offices, libraries and many other workplaces. A few researchers have looked at the effect of dual screen monitors on the efficiency and overall productivity of the users. Tobler and Anderson (2004) conducted a study to compare the effect of single and dual screen monitors use on the user performance. In this study, 108 university and non-university personnel performed various computer operations using single screen, multi-screen and multi-screen with hydravision display monitors. Participants performed simulated office tasks that involved editing slide shows, spreadsheets and text documents. Performance (including task time, number of errors made) and usability (learning ease, time to productivity, quickness of recovery from mistakes, ease of task tracking,) measures were significantly higher for the multi-screens displays. In another study, Russell and Wong (2005) investigated the effect of dual-screen monitors on task organization, ease of use, and productivity. A self-administered questionnaire survey was used to collect information from 17 employees working at University Libraries. All respondents agreed that dual-screen monitors were very easy to use. Additionally, all participants responded that their individual productivity and efficiency had increased with the addition of a second monitor screen since it often allowed them to combine or delete steps required to complete a certain task.

Chapter 3: Methods

3.1 Rationale and Objective

The findings of literature review show that neck and shoulder MSD are highly prevalent among the computer or VDU user. Epidemiological studies divide the risk factors for MSD of the neck and upper extremity among the computer users into four categories: (1) individual; (2) workstation design related; (3) task demand related; and (4) workplace psychosocial factors. Variables associated with the computer monitor placement, such as height, location, and size, etc. were identified as the key facets of workstation design in a number of epidemiological studies, lab-based experiments, and field investigations, because of their influence on neuromuscular and biomechanical behavior of the neck and shoulder region. Recent advancements in the computer processors and hardware have made use of multiple screen monitors easy and economical. VDU with dual screen monitors are becoming increasingly common at a number of workplaces. Although, two of studies show that user performance and efficiency is positively affected by the use of dual screen monitors, the effect of dual screen monitors on overall behavior of the neck and shoulder region is still largely. Therefore, this study was aimed at understanding the effect of use of dual screen monitors VDU workstation on the biomechanical behavior of the neck and shoulder region.

3.2 Approach

A laboratory study was performed to compare the effect of dual screen monitor VDU workstation and a single screen monitor on the 3D head and neck postures and neck muscles activities. Functional Assessment of Biomechanics (FAB) system was used to measure changes in the 3D head neck postures. The activities of neck muscles were measured using Electromyography (EMG) system.

3.3 Participants

Nine healthy subjects between the ages of 21 to 40 years were recruited for this study. Before the data collection, the experimental procedures and possible risks associated with the study were explained to the participants and their signatures were obtained on a consent form approved by the Institutional Review Board at West Virginia University (Appendix A). The primary inclusion exclusion criteria used in this study were:

1) at least two years of experience working with VDU workstation
2) user spends more than 60% of time at work, working on a VDU
3) free from any type of musculoskeletal disorders

3.4 Apparatus

3.4.1 Electromyography system

Telemyo 2400 Electromyography system (Noraxon Inc., AZ, USA) is a 16 channel telemetry EMG system consisting of Telemyo 2400T transmitter, pre-amplified lead wires, PC-interface receiver, and disposable, self-adhesive Ag/AgCl snap electrodes (figure 3.1). The bipolar Ag/AgCl pre-gelled surface electrodes (1 cm diameter, interelectrode distance is 2 cm) connect to 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, Input Impedance >100 MΩ. The Telemyo 2400T transmitter was mounted on the participants using a pouch and belt clip. This transmitter transmits data wirelessly to the PC-interface receiver connected to the host computer. The frequency of EMG data acquisition was set at 1000 Hz.

(A) (B) (C)

Figure 3.1: Telemyo 2400 electromyography system consisting of (A) Telemyo 2400T transmitter, pre-amplified lead wires,(B) PC-interface receiver, and(C) disposable, self-adhesive Ag/AgCl snap electrodes.

3.4.2 Functional Assessment of Biomechanics

Functional Assessment of Biomechanics (FAB) (BIOSYN, Canada) system is a full body 3D kinematic system. It consists of 13 small, light weight sensors (4x7x2.4 cm), that goes on the selectable body segments of the user (figure 3.2). Each sensor has a triad of accelerometers, gyrometer and magnetometer that allows real time detection of angular displacement within biomechanical bodies. This is a completely wireless system that transmits the 3D posture data to a host computer using a dedicated wireless network. The posture data was acquired at a frequency of 100 Hz.

Figure 3.2 Functional assessments of biomechanics (FAB) system

3.4.3 VDU Workstation

Standard VDU workstation furniture, which includes an adjustable pneumatic chair, a standard office desk, and a document holder, was used. VDU screen monitor/s placed on the desk at a floor-to-tabletop distance of 70 cm and a chair with height adjustment range of 42 to 50 cm was used.

3.5 Experimental tasks

Participants performed following three tasks using single and dual screen monitor layouts (figure 3.3):

(1) reading for ten minutes

(2) typing for five minutes

(3) search and find tasks for ten minutes.

For the reading task, participants read an article for ten minutes. During the typing task, participants typed a document while 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. Once the information was located, participants were required to report that information by typing it in a master file. Once the information was typed in the master file, next search and find task were displayed to the participant in the master file.

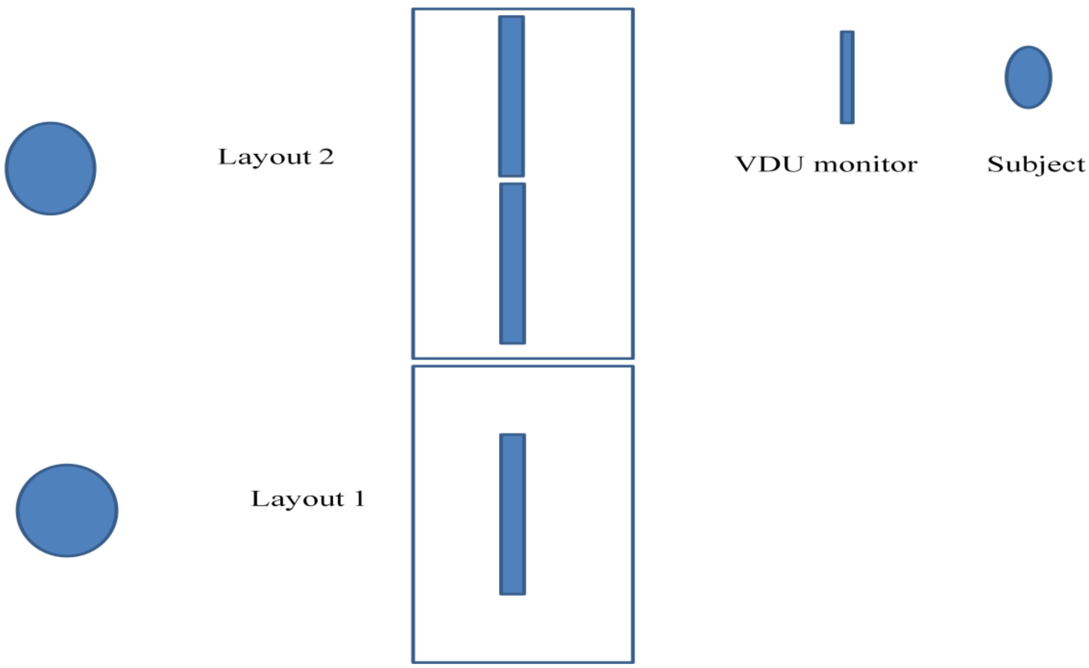


Figure 3.3 Top views of the two monitor screen layouts. Layout 1 is a single screen monitor layout. Layouts 2 is the dual screen monitor layout

3.6 Experimental design

A two factor factorial experimental design was used. Factor 1, monitor layout, had two fixed levels (single and dual) and factor 2, type of tasks, had three fixed levels (reading, typing, and search and find).

3.7 Hypothesis

Following hypotheses were tested in this study:

H_{01}: main effect of "monitor layouts" will not be significant

H_{02}: main effect of "type of tasks" will not be significant

H_{03}: interaction effect will not be present

3.8 Data collection Procedure

3.8.1Anthropometric measurement

A set of anthropometric measurements, height, weight, upper arm length, fore arm length and trunk length, shoulder width, neck length, were recorded for each participant. Some of these measurements were required as an input to the FAB software, while other measurements were used for determining the exact location of EMG electrodes in the neck and shoulder area. 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.

3.8.2 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 approximate T10-11 level

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 major neck-shoulder muscles: (1) sternocleidomastoid (SCM) and (2) 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 1/3 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 . 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 degrees) to the vertical line between spinous processes of the C7 and C4 (Nimbarte et al., 2010). TThe EMG data was collected bilaterally.

The sternocleidomastoid muscle electrode location was tested by a measurable EMG signal during head rotation (Vasavada et al., 1998). The cervical trapezius muscle electrode location was tested by a measurable EMG signal during flexion-extension of the head (Nimbarte, 2009).

Participant then started working on the VDU to get familiarized with the workstation set up. They were instructed to adjust their chair heights to achieve a comfortable sitting posture. Comfortable sitting position was defined based on the previously published guidelines (Saito et al., 1997; Szeto and Lee, 2002): back straight, hip joint flexed 90 degrees and knee joint flexed 60 to 90 degrees (depending on the personal preference), shoulder joint in anatomically neutral posture and elbow joint flexed 60 to 90 degrees and forearm supported by adjustable arm rest. A foot rest was provided based on the personal preference. The location of the document reader was kept constant, which was lateral to the left monitor. Reading/viewing distance was set to 58 cm for the VDU screen and the document reader. The viewing distance was measured from the top of the viewable part of the screen to the midpoint between the eyes with the participant in a relaxed sitting position (Figure 3.4).

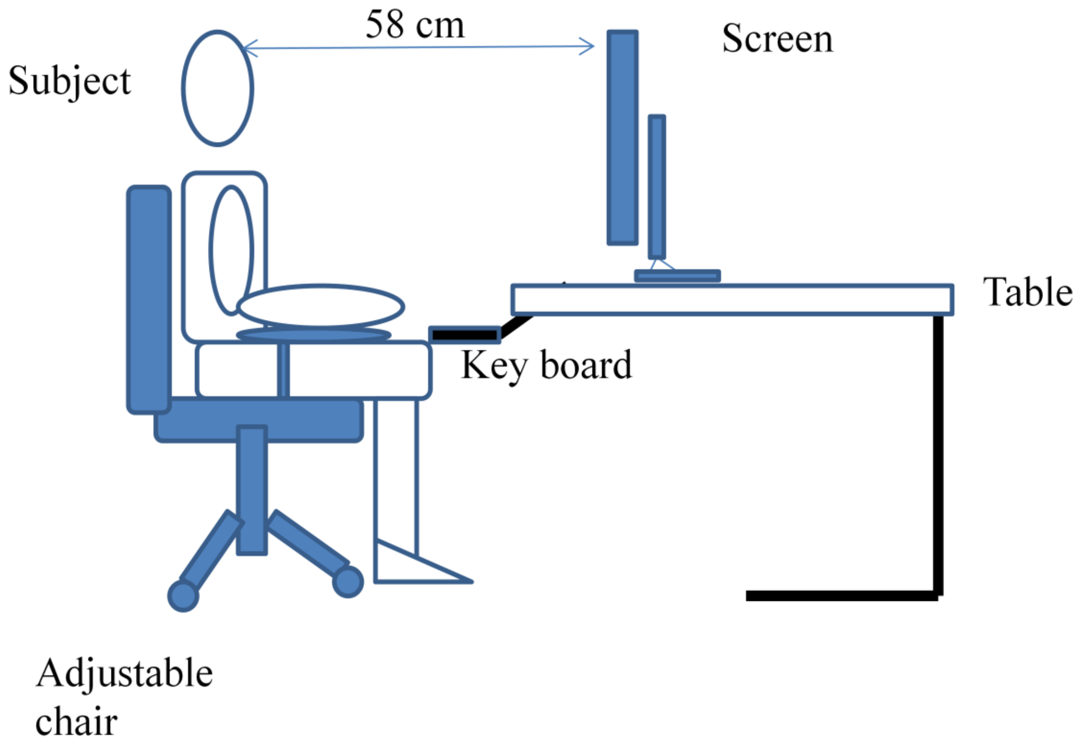


Figure 3.4 Experimental workstation

3.9 Actual data collection

Once the workstation parameters were set up, before the data collection trials, participants were asked to browse on the internet for five minutes to get familiarize with the set up. Participants then performed the standardized VDU tasks comprised of (reading, typing, and performing search and find tasks) for a total duration of 25 minutes. EMG and 3D motion data were recorded continuously during the three types of VDU activities.

3.10 Data Processing and Analysis

3.10.1 Head-shoulder posture

The kinematic data was processed to evaluate the postural load on the cervical spine. Postural load in this study was defined as a measure of combination of the deviation of the head from the anatomical neutral position and the amount of time user work in that non-neutral posture. To quantify the postural load, each kinematic trajectory, flexion, bending and rotation, was divided into segments of 5 degrees of joint rotation (e.g. 0 to 5, 5 to 10,….,40 to 45) and the corresponding durations in terms of percent of time were calculated. The percent time was then multiplied by the loading scores. Table 3.1 represents the loading scores used for the different joint rotation segments. Thus, for each kinematic trajectory, separate postural loads were quantified. A computer program used for performing this analysis can be found in Appendix B. The equation used for calculating postural load is as follows and:

$$PL_x = \sum_{i=1}^{9} i \times (T_x)_i \quad (3.1)$$

Where, PL_x is the postural load, where x = flexion, bending, rotation
i is the loading scores for the different joint rotation segments (Table 3.1)
Tx is the percent time for the joint rotation segments (Table 3.1)

Table 3.1 Loading scores used for the quantifying the posture load index.

Joint rotation segment	**Loading scores (i)**
0-5	1
5-10	2
10-15	3
15 – 20	4
20 – 25	5
25-30	6
30 – 35	7
35-40	8
40-45	9

3.10.2 Electromyography

EMG data was processed to calculate mean absolute values (MAV). 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 et al., 2007). The resulting data was averaged to determine the mean absolute values (MAV) (Acierno et al., 1995). Comparison of EMG between and within subjects involves normalizing the EMG data. Typically, EMG can be normalized with respect to 1) muscle activation at the maximum voluntary contraction; 2) reference muscle contraction while performing a standardized task (Mathiassen and Winkel, 1990; Turville et al., 1998a) and; 3) the peak or mean activation during the tasks (Finsen, 1999; Sommerich et al., 2001a). In this study, EMG was normalized with respect to the reference contraction as explained by Nimbarte et al., (2010) to determine the Normalized MAV (N-MAV).

3.11 Statistical Analysis

The effect of monitor layouts and type of tasks on the postural load and activities of neck muscles was evaluated using the following linear model. Since the individual participants are different in their skills and abilities to use the VDU workstation, participants were treated as blocks.

$$yD_{ijl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_l + \epsilon_{ijl} \quad \begin{cases} i = 1, 2 \\ j = 1, 2, 3 \\ l = 1, \ldots, 9 \end{cases}$$

Where,

yD represents dependent variables. Seven dependent variables were evaluated in this study: (1) flexion score; (2) bending score; (3) rotation score; (4) NMAV of right sternocleidomastoid; (5) NMAV of left sternocleidomastoid; (6) NMAV of right cervical trapezius; (7) NMAV of left cervical trapezius;

μ is the overall mean to all treatments.

α_i is the effect of monitor layouts. Two levels of this factors represent single and dual monitor layout, therefore i = 1, 2.

β_j is the effect of type of tasks. Three levels of this factors represent reading, typing and search and find, therefore j = 1, 2,3.

γ_l is the effect of subjects (block effect), $l = 1,2,3,4,5,6,7,8,9$

$(\alpha\beta)_{ij}$ is the interaction effect between monitor layout and type of task.

ϵ_{ijl} is a random error term.

Monitor layout (α_i), type of task (β_j) are treated as fixed factors. It is assumed that each factor and the two-way interaction factor have no effect on the dependent variables i.e.

$$\sum_{i=1}^{2} \propto_i = 0 \,,\ \sum_{j=1}^{3} \beta_j = 0 \,,\ \sum_{i=1}^{2} \sum_{j=1}^{3} (\alpha\beta)_{ij} = 0 \ .$$

Subjects (γ_l) are treated as a random factor and it is assumed that it is NID (0, σ_γ^2) random variable. Random error and ϵ_{ijl} follows NID (0, σ^2). In this study, the Type I error α = 0.05 and Power of the test (1-β) = 0.90 were chosen for the hypothesis test. The power analysis for the sample size of nine is explained in the following section.

3.11.1 Power Analysis

Operating characteristics curves (OC curves), a graph of β (type II error probability) versus the true difference in means, was used for performing the power analysis for the sample size of nine used in this study. The random factor subject (γ_k) is treated as a block, so here the number of subjects is same as the number of blocks. Based on the above statistical model, the OC curves are used with the equation:

$$\lambda = \sqrt{1 + \frac{c{\sigma_\gamma}^2}{\sigma^2}} \tag{3-1}$$

Where,

${\sigma_\gamma}^2 = MSBL,$ Mean square of blocks

$\sigma^2 = MSE,$ Mean square error

c= number of subjects

Based on the data collected from nine subjects (c = 9), *MSBL* and *MSE* were calculated. For nine subjects (c=9), from the OC curve, it was found that β was less than 0.03 for all the dependent variables. Therefore, the power of the test was approximately (1 – β) = 1 – 0.03 = 0.97, which is more than the pre-selected power of at least 0.90.

Chapter 4: Result

Participants in this study were in the age group of 22 to 35 years and had more than 5 years of experience with the single monitor VDU. All the participants were males. Average height and weight of the participants were 167.5(4.14) and 69.8(6.7), respectively. On an average, participants used VDU for more than 82% of the time per week at work. None of the participants were professional typist and most of them used 5 to 6 fingers for typing.

4.1 Posture

ANOVA tables for the postural load caused by the cervical flexion, bending and rotation are shown in the Table 4.1. The raw postural load data can be found in appendix D. Type of task significantly affected the postural load caused by cervical flexion and bending ($P<0.000$). Results of Tukey HSD All-pairwise comparison test showed that the mean of the postural load caused by the cervical flexion and bending during typing task was different than the corresponding reading, and, search and find tasks (Table 4.1, Figure 4.1 (A)). The overall cervical spine flexion and bending postures, expressed in terms of average of the percent time of different joint angles are shown in figure 4.2. During typing tasks, around neutral postures (0 to 10 degrees of flexion) were adopted for least amount of time and users worked in flexed head postures, between 10 to 20 degrees, for over 45% of the time. The average of the percent time, when more flexed postures were used (20 to 30 degrees, > 20 degrees), was also higher during typing task than search and find, and reading task. A relatively stable and around neutral cervical bending postures were used by the users during the search and find and reading tasks. During the typing task, some increase in the cervical bending was observed. It was found that on an average, for 15% of the time users worked in postures, with cervical bending between 10 to 20 degrees. The effect of monitor layout on the postural load caused by the cervical flexion and bending was statistically insignificant. However, a general trend showed that dual screen monitor layout was associated with somewhat higher postural loads.

Table 4.1 ANOVA table for postural load by the cervical flexion, bending and rotation.

General Linear Model: Flexion versus Sub, Monitor, task

Factor	Type	Levels	Values
Sub	random	9	1, 2, 3, 4, 5, 6, 7, 8, 9
Monitor	fixed	2	Dual, Single
task	fixed	3	Reading, S&F, Typing

Analysis of Variance for Flexion, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sub	8	398864	398864	49858	16.35	0.000
Monitor	1	4004	4004	4004	1.31	0.259
task	2	266437	266437	133219	43.69	0.000
Monitor*task	2	469	469	234	0.08	0.926
Error	40	121966	121966	3049		
Total	53	791740				

General Linear Model: Bending versus Sub, Monitor, task

Factor	Type	Levels	Values
Sub	random	9	1, 2, 3, 4, 5, 6, 7, 8, 9
Monitor	fixed	2	Dual, Single
task	fixed	3	Reading, S&F, Typing

Analysis of Variance for Bending, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sub	8	26010.7	26010.7	3251.3	3.57	0.003
Monitor	1	2241.0	2241.0	2241.0	2.46	0.125
task	2	8464.6	8464.6	4232.3	4.64	0.015
Monitor*task	2	1169.8	1169.8	584.9	0.64	0.532
Error	40	36475.1	36475.1	911.9		
Total	53	74361.1				

General Linear Model: Rotation versus Sub, Monitor, task

Factor	Type	Levels	Values
Sub	random	9	1, 2, 3, 4, 5, 6, 7, 8, 9
Monitor	fixed	2	Dual, Single
task	fixed	3	Reading, S&F, Typing

Analysis of Variance for Rotation, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sub	8	512094	512094	64012	17.31	0.000
Monitor	1	113044	113044	113044	30.57	0.000
task	2	78572	78572	39286	10.62	0.000
Monitor*task	2	32098	32098	16049	4.34	0.020
Error	40	147915	147915	3698		
Total	53	883723				

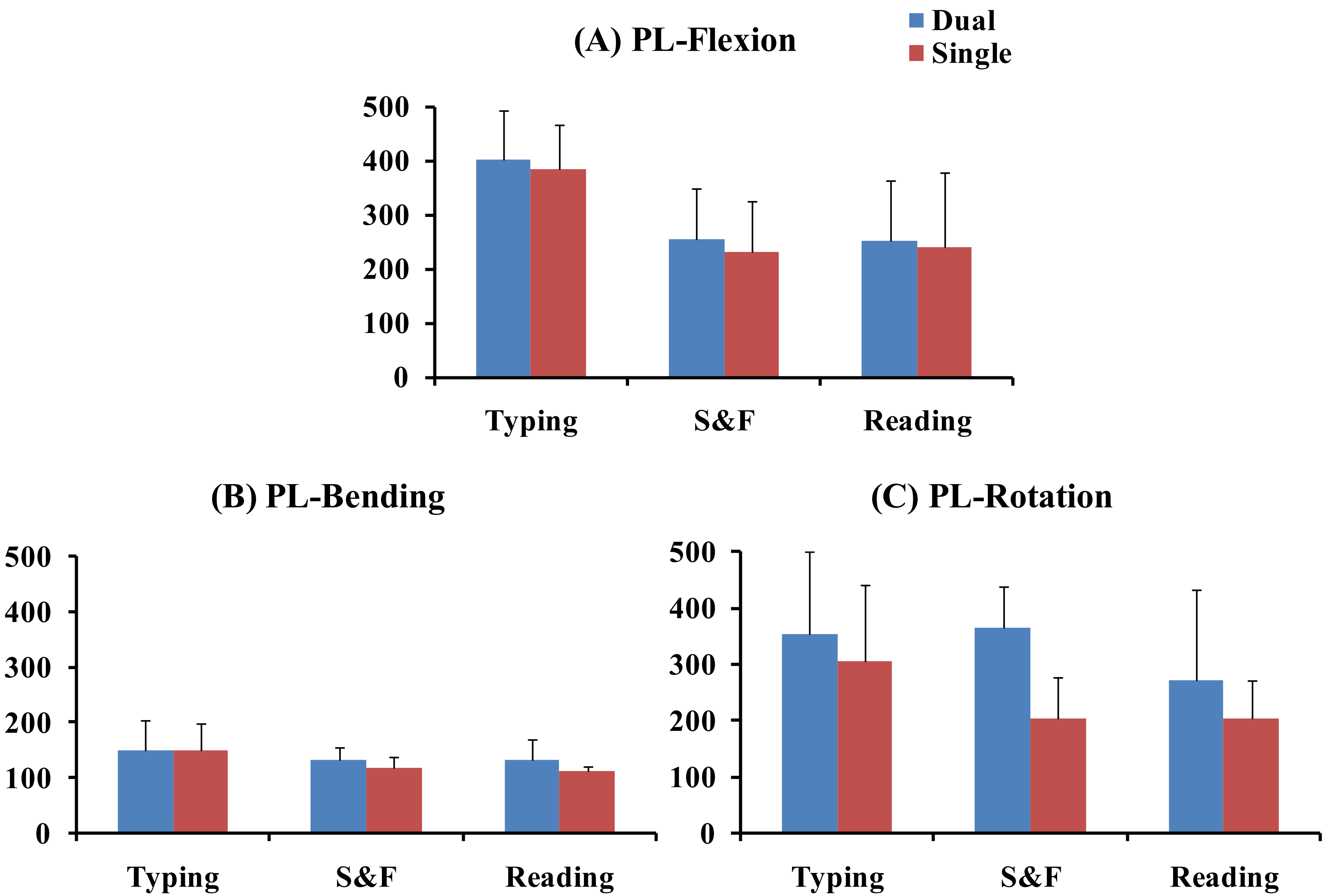


Figure 4.1 Overall postural load by (A) cervical flexion; (B) cervical bending; (C) cervical rotation as a function of type of tasks and monitor layouts.

Table 4.2: Mean (SD) of the postural load by cervical flexion, bending, and rotation

		Flexion	Bending	Rotation
Dual	Typing	403.3(91.8)	149.7(55.0)	353.2(147.4)
	S&F	256.1(93.7)	133.0(22.4)	364.0(75.5)
	Reading	251.7(113.6)	132.7(37.4)	270.1(163.6)
Single	Typing	385.5(83.2)	149.6(48.6)	306.0(135.3)
	S&F	232.0(94.7)	116.7(19.8)	204.6(72.9)
	Reading	241.9(138.3)	110.5(11.2)	202.2(68.6)

In case of postural load by cervical rotation, interaction effect between the type of task and monitor layout was statistically significant. In general, during all the tasks, dual screen monitor layout caused increase in the postural load. The results of Tukey HSD All-pairwise comparison test showed that, mean of postural load during the search and find task for dual screen monitor layout was different than single screen monitor layout (Table 4.1). On an average, use of dual screen monitor increased the postural load during typing, search and find, and reading tasks by 15%, 78%, and 34%, respectively. The primary reason of this increased postural load during the search and find task was that participants were working in non-neutral, more rotated head postures, for comparatively higher duration of time. Figure 4.3 shows averages of the percent of time spent by the users at different degrees of cervical rotation during single and dual monitor use. The overall trend indicates that, single monitor layout was primarily associated with more symmetrical working postures. These postures were characterized by higher durations of lower degrees of cervical rotation (0 to 10 degrees). However, dual monitor layout was associated with asymmetrical (more rotated) head postures, characterized by higher durations of higher degrees of cervical rotation (20 to 30 degrees). This trend was quite apparent during search and find, and reading tasks.

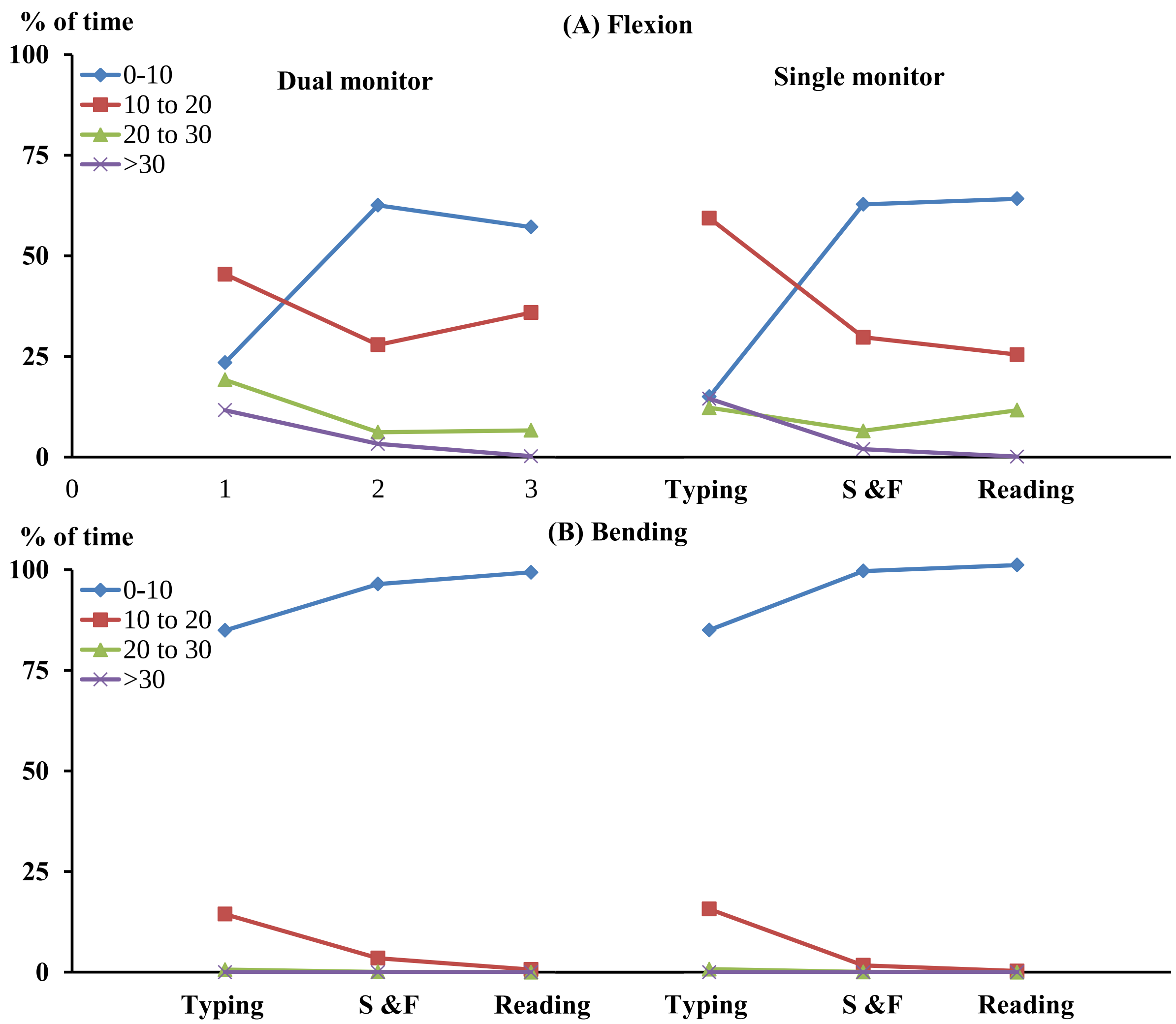


Figure 4.2: Flexion and bending postures during the typing, search and find, and reading tasks

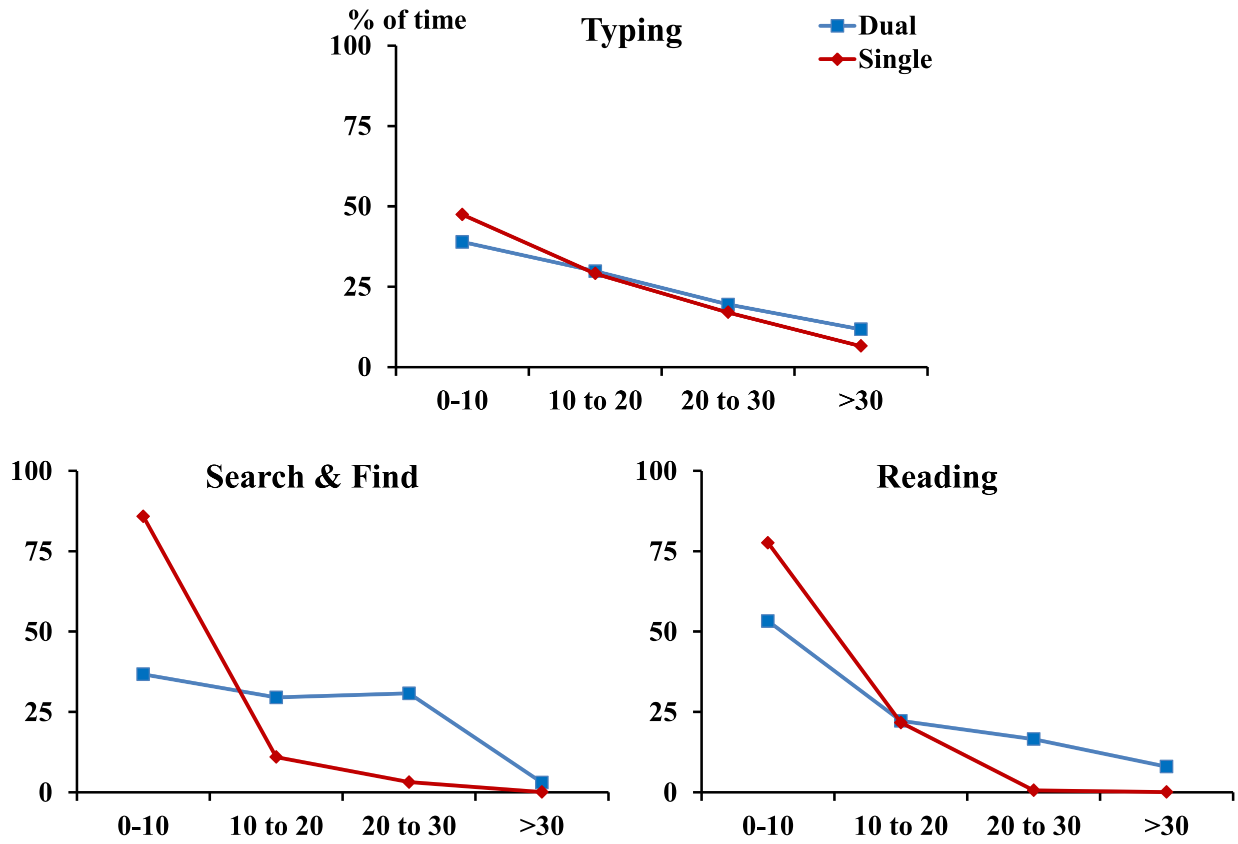


Figure 4.3: Cervical rotation during typing, search and find, and reading tasks

The adequacy of general linear model used for studying postural load by cervical flexion, bending, and rotation was evaluated by using normal probability plot of residuals. This plot was almost a straight line for the postural loads by flexion, bending and rotation, indicating that error distribution is approximately normal (Appendix C).

4.2 Muscle Activity

ANOVA tables for the electromyographic activities of the anterior neck muscle, sternocleidomastoid, are shown in Table 4.3. The raw muscle activity data can be found in appendix E. For the sternocleidomastoid muscle on the right side, main effects of the type of task and monitor layout was statistically significant ($P<0.000$). Results of Tukey HSD All-pairwise comparison test show that mean of activation level of this muscle when working with dual screen monitors was different than single screen monitor (Figure 4.4). Between tasks comparison shows highest mean activation level for this muscle during typing task, followed by search and find, and reading tasks. Results of Tukey HSD All-pairwise comparison test show that during typing task mean of muscle activation was different than the other two tasks (Table 4.4).

Table 4.3 ANOVA table for N-MAV of the sternocleidomastoid muscles

General Linear Model: R_SCM versus Sub, Monitor, Task

```
Factor   Type    Levels  Values
Sub      random       9  1, 2, 3, 4, 5, 6, 7, 8, 9
Monitor  fixed        2  Dual, Single
Task     fixed        3  Reading, S&F, Typing

Analysis of Variance for R_SCM, using Adjusted SS for Tests

Source        DF   Seq SS   Adj SS  Adj MS      F      P
Sub            8  33.0390  32.1946  4.0243  12.87  0.000
Monitor        1   6.7445   6.6449  6.6449  21.25  0.000
Task           2   7.8805   8.0836  4.0418  12.92  0.000
Monitor*Task   2   0.4108   0.4108  0.2054   0.66  0.524
Error         37  11.5716  11.5716  0.3127
Total         50  59.6464

S = 0.559238   R-Sq = 80.60%   R-Sq(adj) = 73.78%
```

General Linear Model: L_SCM versus Sub, Monitor, Task

```
Factor   Type    Levels  Values
Sub      random       9  1, 2, 3, 4, 5, 6, 7, 8, 9
Monitor  fixed        2  Dual, Single
Task     fixed        3  Reading, S&F, Typing

Analysis of Variance for L_SCM, using Adjusted SS for Tests

Source        DF   Seq SS   Adj SS  Adj MS      F      P
Sub            8  33.8918  31.4581  3.9323   9.61  0.000
Monitor        1   0.0331   0.0074  0.0074   0.02  0.894
Task           2   9.0082   8.7475  4.3737  10.68  0.000
Monitor*Task   2   0.7187   0.7187  0.3594   0.88  0.424
Error         37  15.1473  15.1473  0.4094
Total         50  58.7992

S = 0.639834   R-Sq = 74.24%   R-Sq(adj) = 65.19%
```

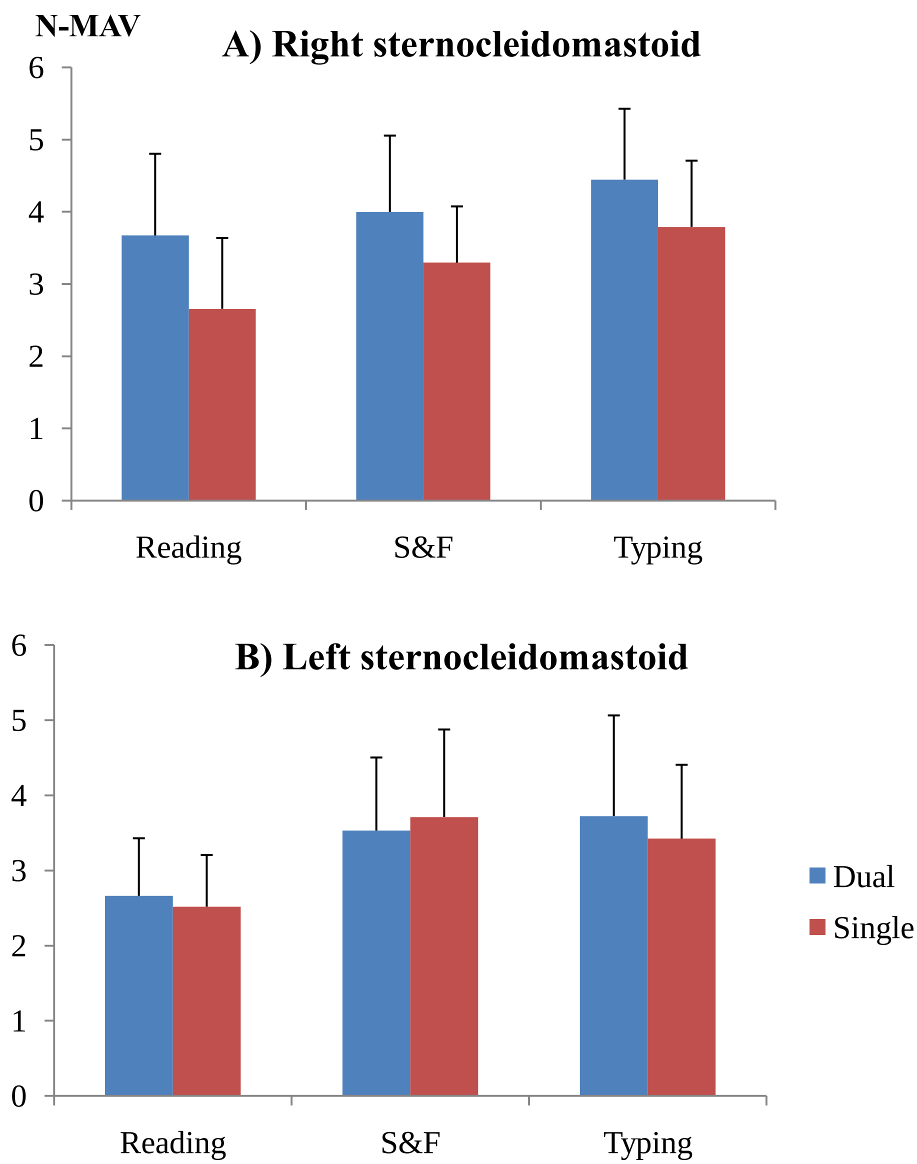


Figure 4.4: Normalized muscle activity of the sternocleidomastoid muscles

The activation level of sternocleidomastoid muscle on the left side was significantly affected by the type of task (P<0.000). This muscle worked to almost a same intensity during search and find and typing tasks. Results of Tukey HSD All-pairwise comparison test show that mean muscle activation during reading task was different (lower) than the search and find and typing tasks. No consistent trend in the behavior of this muscle with respect to the monitor layout was observed (Figure 4.4, Table 4.4). The main effect of monitor layout on the activation level of sternocleidomastoid muscle on the left side was statistically insignificant.

Table 4.4: Mean (SD) of the normalized muscle activity during the reading, search and find, and typing tasks

		Dual		Single	
		Mean	SD	Mean	SD
Reading	Sternocleidomastoid Right	3.67	1.13	2.66	0.78
	Sternocleidomastoid Left	2.66	0.77	2.52	0.69
	Cervical trapezius right	2.49	0.85	2.78	1.19
	Cervical trapezius left	4.33	0.96	4.94	1.03
Search & Find	Sternocleidomastoid Right	4.00	1.06	3.29	0.92
	Sternocleidomastoid Left	3.53	0.97	3.71	1.16
	Cervical trapezius Right	3.78	1.25	3.60	0.94
	Cervical trapezius Left	5.47	1.83	6.16	1.41
Typing	Sternocleidomastoid Right	4.45	0.98	3.79	1.00
	Sternocleidomastoid Left	3.72	1.34	3.42	0.98
	Cervical trapezius Right	5.05	1.70	3.95	1.59
	Cervical trapezius Left	7.01	1.99	6.47	1.72

Table 4.5 ANOVA table for N-MAV of the cervical trapezius muscles

General Linear Model: R_TRP Upper versus Sub, Monitor, Task

```
Factor   Type    Levels  Values
Sub      random       9  1, 2, 3, 4, 5, 6, 7, 8, 9
Monitor  fixed        2  Dual, Single
Task     fixed        3  Reading, S&F, Typing


Analysis of Variance for R_TRP Upper, using Adjusted SS for Tests

Source         DF    Seq SS   Adj SS   Adj MS      F      P
Sub             8   56.0765  58.9182   7.3648  17.32  0.000
Monitor         1    1.1056   1.1509   1.1509   2.71  0.108
Task            2   35.7733  34.2895  17.1447  40.32  0.000
Monitor*Task    2    2.4774   2.4774   1.2387   2.91  0.067
Error          37   15.7335  15.7335   0.4252
Total          50  111.1664

S = 0.652097   R-Sq = 85.85%   R-Sq(adj) = 80.87%
```

General Linear Model: L_TRP Upper versus Sub, Monitor, Task

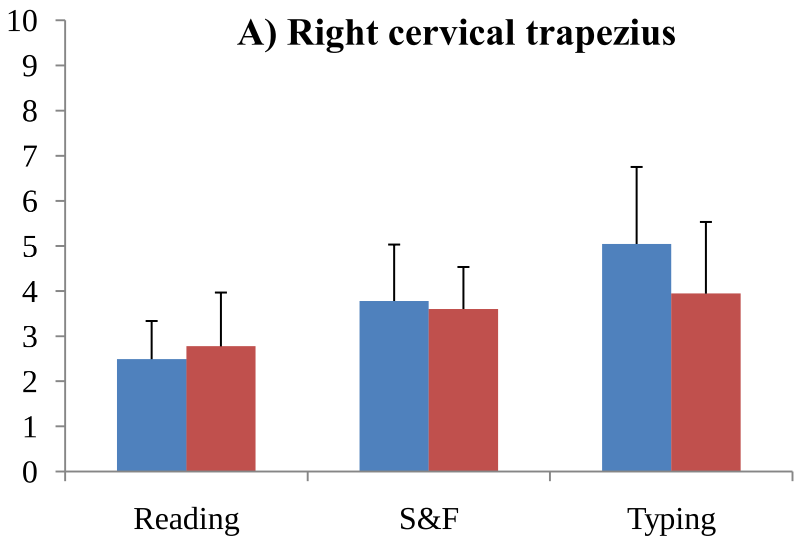
```
Factor    Type    Levels  Values
Sub       random       9  1, 2, 3, 4, 5, 6, 7, 8, 9
Monitor   fixed        2  Dual, Single
Task      fixed        3  Reading, S&F, Typing


Analysis of Variance for L_TRP Upper, using Adjusted SS for Tests

Source        DF    Seq SS   Adj SS   Adj MS      F      P
Sub            8   70.9195  75.2299   9.4037  12.66  0.000
Monitor        1    0.3549   0.2936   0.2936   0.40  0.534
Task           2   44.2531  41.5907  20.7954  27.99  0.000
Monitor*Task   2    2.1655   2.1655   1.0828   1.46  0.247
Error         34   25.2606  25.2606   0.7430
Total         47  142.9535


S = 0.861950   R-Sq = 82.33%   R-Sq(adj) = 75.57%
```

ANOVA tables for the electromyographic activities of the posterior neck muscle, cervical trapezius, are shown in Table 4.5. The activities of cervical trapezius muscle on right side were significantly affected by the type of task. The trend in the mean activation level indicate that this muscle worked the most during typing task, followed by search and find, and reading tasks.



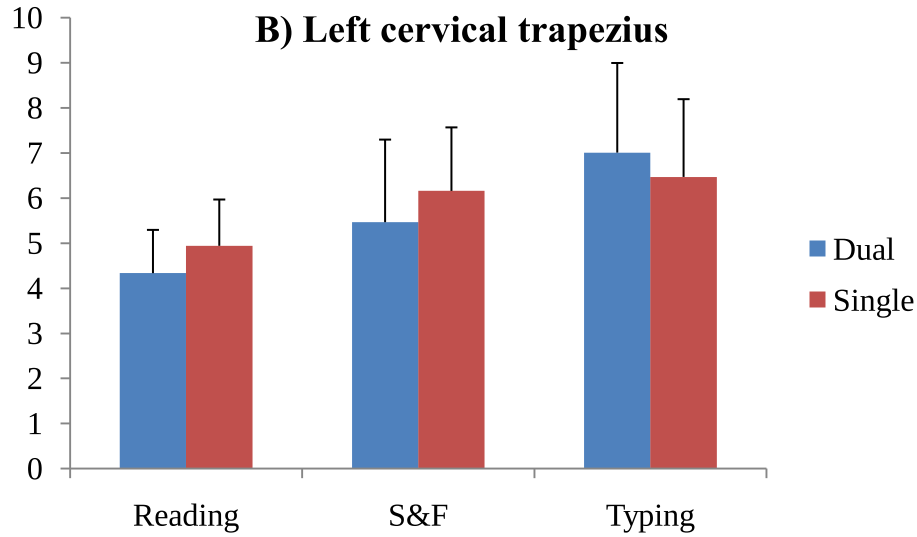


Figure 4.5 Normalized activity of the cervical trapezius muscles

Results of Tukey HSD All-pairwise comparison test show that mean of muscle activation during the three tasks were significantly different from one another (Figure 4.5, Table 4.4). The mean and standard deviation for cervical muscle shown is shown in Appendix C. The effect of monitor layout on the activation level of cervical trapezius muscle on the right side was statistically insignificant. A general trend in the mean activation level indicate that during typing task this muscle worked harder when using dual monitor layout than single monitor layout. During search and find and reading tasks, a slight difference in the muscle activation level between two types of layout was observed.

Figure 4.5 shows the behavior of the cervical trapezius muscle on left side as a function of type of tasks and monitor layout. The overall behavior of the cervical trapezius muscle on left side with respect to the type of tasks was same as the right side. Among the three tasks, this muscle worked the hardest during typing task, followed by search and find, and reading tasks. Results of Tukey HSD All-pairwise comparison test show that means of muscle activation during the three tasks were significantly different from one another (Table 4.4). The effect of monitor layout on the activation level of this muscle was statistically insignificant. During typing task this muscle showed slightly higher activities during dual monitor use and during reading and search and find tasks muscle activation level during single monitor use was slightly higher than dual monitor use.

Normal probability plots of residuals for muscle activity data are shown in Appendix B. These plots also show approximate straight lines indicating that the error distribution is approximately normal.

Chapter 5: Discussion and conclusions

This study was aimed at comparing the effect of single screen to dual screen monitor use on 3D head neck postures and the activation level of neck muscles during common VDU operations. The working postures used while operating VDU are constrained by a number of factors such as positions of monitor, keyboard, and mouse and their relative locations with respect to the seating surface. Findings of previous studies suggest that monitor position affects the orientation of the head, where as upper extremity postures are more sensitive to the positions of keyboard and mouse. A number of previous investigations have studied the effect of different monitor height settings on the head and neck postures. Typically high, medium, and low monitor height settings below the horizontal at eye level were studied. Such monitor locations were found to affect head and neck position primarily in the sagittal (flexion-extension) plane. Addition of a second monitor increases the total desktop area that may require multidimensional head and neck motions while operating dual screen monitor VDU. Based on the analysis of 3D head and neck kinematics, results of this study show that use of dual monitor layout slightly changes the postural load caused by head neck flexion and bending, but significantly increase the postural load caused by head neck rotation. The postural load used in this study was an estimate of combination of non-neutral head neck postures and the corresponding durations. Higher postural load by rotation indicate that users, while working with dual monitor layout, adopted asymmetrical, more rotated, head and neck postures. With a single monitor layout, users adopted working postures with head and neck rotation in the range of 0º to 10 º for over 70% of the time. Whereas in case of dual screen monitor a wide range of head and neck rotation, 0º to 45º degrees, was used by the users and spent on an average 27%, 22% and 8% of the time with their head rotated 10 º to 20 º, 20 º to 30 º, and >30 º, respectively.

In this study three types of tasks, reading, typing, and search and find, were evaluated. The working postures observed in this study during the reading task performed using a single monitor layout is comparable with the findings of Turville et al (1998b). An average head tilt of 3.1 º (SD= 5.76) was reported by Turville et al (1998b) during a typing task performed over a duration of 10 minutes. The results of the current study show that users worked nearly 64% of the time with their head flexed between 0 º to 10 º degrees while performing the reading task for 10 minutes. During typing task, a more flexed head and neck postures for relatively higher durations of time were observed in this study. On an average, users adopted head neck flexion of between 0 º to 10 º, 10 º to 20 º, 20 º to 30 º, and >30 º degrees for 14.8%, 58.5%, 12.1%, and 14.3% of the time respectively. The corresponding values during the search and find tasks were 61.9%, 29.4%, 6.43%,1.9%, respectively. This observed is trend to some extent similar with the findings of Babski-Reeves et al. (2005). A higher degree of postural shift in the flexion extension plane during typing than simple math task was reported by Babski-Reeves et al.(2005). The overall nature of the simple math task used in this study was similar to the search and find used in the present study.

The type of task was found to significantly affect the postural load. Among the three tasks, the highest postural load by flexion and bending was observed during typing task followed by the search and find, and reading tasks. Three motion components were associated with the typing task: (1) looking at the word document; (2) looking at the keyboard; (3) looking at the monitor. During search and find task although users looked at the keyboards at few instances while typing the target names/words, most of the time they were looking at the monitor. Whereas during the reading task, the primary motion involved was looking at the monitor. Since none of the users in this study were professional typist, they looked at the keyboard for substantial amount of time during typing task which required them to flex and to some extend laterally bend their head, and therefore a higher postural load by flexion and bending was observed during typing. For the postural load by rotation, a significant interaction between the type of task and monitor layout was observed. In general dual screen monitor arrangement involved higher postural load by rotation. For single screen monitor the postural load by rotation for search and find, and reading task was similar and lower compared to typing task. Whereas, for dual screen monitor, the postural load by rotation for search and find, and typing task was similar and higher compared to reading task. Higher postural load by rotation during typing task while using single screen monitor was due to the increased head neck rotation required to read source document from the document holder. In case of dual screen monitor the position of the document holder was shifted laterally of its original position. This arrangement required additional amount of head rotation to read the source document. During search and find task, head rotation was constrained by width of the monitor screen/s and therefore dual screen monitor layout involved almost similar amount of postural load by rotation as typing task. In case of reading task, rotational postures were constrained by width of only one screen and therefore the lowest postural load by rotation was observed for both the configurations. Higher postural load by rotation for dual screen monitor layout during reading task was because of the lateral shift in the position of monitors.

The present study indicates differences in the activities of head stabilizing muscles between the three types of tasks. Typing task has elicited higher activities in the cervical trapezius and sternocleidomastoid muscles, followed by the search and find, and reading task. The cervical trapezius muscle is a major posterior neck muscle that controls head movement in forward and lateral directions. The sternocleidomastoid muscle, on the other hand supports head weight during rotation, bending and extension. Typing task involved head movements in all the three anatomical planes (sagittal, transverse, frontal), and therefore a relatively higher contralateral muscle activity of neck muscles was observed compared to the other two tasks. A number of previous studies have reported increased activity of neck muscles, especially cervical extensor (cervical trapezius) during VDU operations performed with more flexed head postures (Babski-Reeves et al., 2005; Szeto and Sham, 2008; Turville et al., 1998b). In the present study, for single as well as dual screen monitor layout, cervical load by flexion was the highest during typing task indicating that users adopted flexed head postures for higher durations. Therefore, the observed increase in the neck muscle activity during the typing task is in agreement with the previous studies.

The results of the present study show important changes in the muscle activity patterns of right sternocleidomastoid in response to different monitor layouts. Independent of type of tasks, right sternocleidomastoid muscle showed relatively higher activity while using dual screen monitor. As noted sternocleidomastoid muscle, play important role in supporting head weight during rotation. The observed increase in the activity of right sternocleidomastoid muscle was due to the increased postural load by rotation associated with the dual screen monitor layout. Surprisingly for the muscle on the left side, no consistent trend in the activity with respect to different monitor layout was observed. Possible reason for this observation could be that participants may have adopted counterclockwise rotation more frequently, requiring this muscle to act as an antagonist. Only the absolute values of head and neck rotations were evaluated in this study. If positive and negative rotation were evaluated, it would have provided better insight into the relationship of head rotation and activity of sternocleidomastoid muscles. Furthermore, all the participants in this study were right handed and it is possible that additional load due to the use of mouse and keyboard on right upper extremities may have affected the activities of right sternocleidomastoid muscle.

Unlike previous investigations, in this study head neck postures were expressed using postural load index. This index calculates postural load based on the combination of non-neutral joint orientation and the corresponding duration. Most of the previous investigations have reported head neck postures in terms of averaged joint angle data. In these studies, head and neck postures were evaluated either for a relatively small section of experimental tasks (couple of seconds) (Burgess-Limerick et al., 1999) or by using indirect methods based on previously recorded video or photograph (Babski-Reeves et al., 2005; Turville et al., 1998b) or primarily in 2 D (Babski-Reeves et al., 2005; Burgess-Limerick et al., 1999; Turville et al., 1998b). In the present study a direct method was used for postural assessment and the data were recorded continuously during the testing tasks in 3D. It was found that users don't necessarily adopt exact similar postures while performing same task but rather operate in a certain range of motion and therefore averaging the kinematic data would not have represented the actual postures used by the users. Since the postural load index calculation, divide the motion trajectory into segments of motion and final postural load index calculation consider the intensity of the posture, it provides a comprehensive understanding of the postures used and a more accurate estimate of overall postural load. The postural loads quantified in this study matched very well with the muscle activity data, further validating this method of postural assessment. For example higher postural load by flexion during typing matched very well with the higher magnitude of EMG signal for the neck extensor (cervical trapezius) muscles.

5.1 Limitations and recommendation for future studies:

There are a few limitations of this study that need to be acknowledged. The present study mainly examined the situation where dual screen monitors were arranged laterally making an angle of 180 º. The keyboard and mouse were fixed centrally on a side out tray. Although this is one of the arrangement in which dual screen monitors can be used, a number of other arrangements are possible. Furthermore, different arrangements of keyboard and mouse with respect to the display screens are also possible. It is likely that each of these combinations may show different postural and muscle activity pattern. Future studies should examine 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 MSD than males. It is possible that females may adopt different posture and show altered muscle activity pattern while working with dual screen monitors. Future studies should examine 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 dual screen monitors may be more strenuous for neck and shoulder musculature than single screen monitor. These findings were based on a working duration of 30 minutes. It is possible that studied with longer working duration may reveal a different trend, especially for neuromuscular fatigue. Future studied should examine longer working duration, preferably 8 hour working day.

5.2 Conclusions

In the modern offices dual screen monitors are used with increasing frequency. Altered screen layout and increased desktop space associated with the dual screen monitors may affect working postures of head and 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 user adopted asymmetrical, more rotated, head and neck postures while working with dual screen monitors. Working postures and muscle activity pattern with respect to the monitor layout were found to depend on the type of the task. Typing task elicited higher postural and muscle activity load followed by search and find, and reading tasks. Independent of the tasks, right sternocleidomastoid muscle showed higher activity levels for dual screen layout. This increased activity levels may be due to increased head rotation associated with the dual screen monitors.

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Appendix A – Consent form

West Virginia University
Office of Research Compliance

CONSENT AND INFORMATION FORM

OMR ICF

Principal Investigator: Nimbarte, Ashish

Department: ENGINEERING - Ind./Mgt. Sys. Engineering

Tracking Number: H-22923

Study Title:

Effect of single/dual monitor use on behavior of neck-shoulder musculature

Co-Investigator(s):

AlAbdulmohsen, Rabab,

Sponsor

Contact Persons

In the event you experience any side effects or injury related to this research, you should contact Dr.Nimbarte at 304/293-9473. (After hours contact Dr.Nimbarte at 225/226-8813.)If you have any questions, concerns, or complaints about this research, you can contact Dr. Nimbarte at 304/293-9473 or Rabab alabdulmohsen at 304/282-9192.

For information regarding your rights as a research subject, you may contact the Office of Research Compliance at 304/293-7073.

Introduction You, ______________________, have been asked to participate in this research study, which has been explained to you by Dr. AshishNimbarte, Ph.D., and Rabab Alabdulmohsen, B.S. This study is being conducted by Dr. Ashish Nimbarte, Ph.D. and Rabab Alabdulmohsen,B.S. in the Department of Industrial and Management Systems Engineering (IMSE) at West Virginia University. This research is being conducted to fulfill the requirements for a master thesis of Ms. Rabab Alabdulmohsen in the area of neck and shoulder musculoskeletal disorders in the Department of IMSE at West Virginia University, under the supervision of Dr. Nimbarte.

Purposes of the Study

The purpose of this study is to understand the Effect of single/dual monitor use on behavior of neck-shoulder musculature. We expect to enroll approximately 40 subjects.

Description of Procedures

In this study effect of different monitor arrangement on the behavior of neck and shoulder region will be evaluated. You will perform computer work using different monitor arrangements. Five monitor arrangements will be studied. You will perform reading, typing and browsing type of tasks for a total duration of 30 minutes using each monitor arrangement. While working on the computer, position of the head and the activity of neck muscles will be recorded. The position of the head will be recorded using a motion analysis system and the activity of neck muscle will be recorded using surface electromyography. Surface electromyography is a technique, in which sensors are placed on the muscles of interest and electrical activity is recorded using a computer. There is no pain.

Risks and Discomforts

There are no known or expected risks from participating in this study, except for the mild frustration associated with answering the questions during the search and find task.

Alternatives You do not have to participate in this study.

Benefits You will not receive any direct benefit from this study. The knowledge gained from this study may eventually benefit others.

Financial Considerations No monetary compensation will be given for participating in this study and participants do not incur any costs as a result of participation in the study. It is very important for you to understand that neither the investigator nor WVU or it associated affiliates has the funds set aside to pay for the cost of lost work wages or any care or treatment that might be necessary because you get hurt or sick taking part in this study. Any injuries that may result from this study would not be eligible for Workers ´Compensation as this is not joblated injury. Understand that any treatments necessary will be billed to the participant or to your personal health insurance, and you may wish to consult your insurance provider before participating in this study

Confidentiality

Any information about you that is obtained as a result of your participation in this research will be kept as confidential as legally possible. Your research records and test results, just like hospital records, may be subpoenaed by court order or may be inspected by federal regulatory authorities without your additional consent. In any publications that result from this research, neither your name nor any information from which you might be identified will be published without your consent

Voluntary Participation

Participation in this study is voluntary. You are free to withdraw your consent to participate in this study at any time. Refusal to participate or withdrawal will not affect your employee status at West Virginia University or your class standing or grades and will involve no penalty to you. In the event new information becomes available that may affect your willingness to participate in this study, this information will be given to you so that you can make an informed decision about whether or not to continue your participation. You have been given the opportunity to ask questions about the research, and you have received answers concerning areas you did not understand.

Upon signing this form, you will receive a copy.

I willingly consent to participate in this research.

Signature of Subject or Subjects Legal Representative	Printed Name	Date	Time

The participant has had the opportunity to have questions addressed. The participant willingly agrees to be in the study.

Signature of Investigator or Co-Investigator	Printed Name	Date	Time

Appendix B - Computer program used for calculating postural loads

```
Sub sort1()

Const x = 390000

For i = 25 To x

'If Abs(Cells(i, 6)) <= 5 Then ' RUN FOR 0 TO 5 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 5 And Abs(Cells(i, 6)) <= 10 Then ' RUN FOR 5 TO 10 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 10 And Abs(Cells(i, 6)) <= 15 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 15 And Abs(Cells(i, 6)) <= 20 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 20 And Abs(Cells(i, 6)) <= 25 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 25 And Abs(Cells(i, 6)) <= 30 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 30 And Abs(Cells(i, 6)) <= 35 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 35 And Abs(Cells(i, 6)) <= 40 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 40 And Abs(Cells(i, 6)) <= 45 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 45 And Abs(Cells(i, 6)) <= 50 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 50 And Abs(Cells(i, 6)) <= 55 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

If Abs(Cells(i, 6)) > 55 And Abs(Cells(i, 6)) <= 60 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 60 And Abs(Cells(i, 6)) <= 65 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 65 And Abs(Cells(i, 6)) <= 70 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 70 And Abs(Cells(i, 6)) <= 75 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

'If Abs(Cells(i, 6)) > 80 And Abs(Cells(i, 6)) <= 85 Then ' RUN FOR 10 TO 15 DEGREES OF FLEXION

 a = a + 1

    If Abs(Cells(i, 5)) <= 5 Then

    b1 = b1 + 1

        If Abs(Cells(i, 7)) <= 5 Then

        c1 = c1 + 1

        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then

        c2 = c2 + 1

        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then

        c3 = c3 + 1

        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then

        c4 = c4 + 1

        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then

        c5 = c5 + 1
```

```
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        c6 = c6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        c7 = c7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        c8 = c8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        c9 = c9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        c10 = c10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        c11 = c11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        c12 = c12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        c13 = c13 + 1
        End If

ElseIf Abs(Cells(i, 5)) > 5 And Abs(Cells(i, 5)) <= 10 Then
b2 = b2 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        d1 = d1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        d2 = d2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        d3 = d3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        d4 = d4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        d5 = d5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        d6 = d6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        d7 = d7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
```

```
        d8 = d8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        d9 = d9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        d10 = d10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        d11 = d11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        d12 = d12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        d13 = d13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 10 And Abs(Cells(i, 5)) <= 15 Then
b3 = b3 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        e1 = e1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        e2 = e2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        e3 = e3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        e4 = e4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        e5 = e5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        e6 = e6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        e7 = e7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        e8 = e8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        e9 = e9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        e10 = e10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
```

```
        e11 = e11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        e12 = e12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        e13 = e13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 15 And Abs(Cells(i, 5)) <= 20 Then
b4 = b4 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        f1 = f1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        f2 = f2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        f3 = f3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        f4 = f4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        f5 = f5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        f6 = f6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        f7 = f7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        f8 = f8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        f9 = f9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        f10 = f10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        f11 = f11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        f12 = f12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        f13 = f13 + 1
        End If
```

```
ElseIf Abs(Cells(i, 5)) > 20 And Abs(Cells(i, 5)) <= 25 Then
b5 = b5 + 1
    If Abs(Cells(i, 7)) <= 5 Then
    g1 = g1 + 1
    ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
    g2 = g2 + 1
    ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
    g3 = g3 + 1
    ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
    g4 = g4 + 1
    ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
    g5 = g5 + 1
    ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
    g6 = g6 + 1
    ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
    g7 = g7 + 1
    ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
    g8 = g8 + 1
    ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
    g9 = g9 + 1
    ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
    g10 = g10 + 1
    ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
    g11 = g11 + 1
    ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
    g12 = g12 + 1
    ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
    g13 = g13 + 1
    End If
ElseIf Abs(Cells(i, 5)) > 25 And Abs(Cells(i, 5)) <= 30 Then
b6 = b6 + 1
    If Abs(Cells(i, 7)) <= 5 Then
    h1 = h1 + 1
```

```
ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
h2 = h2 + 1
ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
h3 = h3 + 1
ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
h4 = h4 + 1
ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
h5 = h5 + 1
ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
h6 = h6 + 1
ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
h7 = h7 + 1
ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
h8 = h8 + 1
ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
h9 = h9 + 1
ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
h10 = h10 + 1
ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
h11 = h11 + 1
ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
h12 = h12 + 1
ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
h13 = h13 + 1
End If
ElseIf Abs(Cells(i, 5)) > 30 And Abs(Cells(i, 5)) <= 35 Then
b7 = b7 + 1
If Abs(Cells(i, 7)) <= 5 Then
i1 = i1 + 1
ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
i2 = i2 + 1
ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
i3 = i3 + 1
ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
i4 = i4 + 1
```

```
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        i5 = i5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        i6 = i6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        i7 = i7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        i8 = i8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        i9 = i9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        i10 = i10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        i11 = i11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        i12 = i12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        i13 = i13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 35 And Abs(Cells(i, 5)) <= 40 Then
b8 = b8 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        j1 = j1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        j2 = j2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        j3 = j3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        j4 = j4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        j5 = j5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        j6 = j6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        j7 = j7 + 1
```

```
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        j8 = j8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        j9 = j9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        j10 = j10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        j11 = j11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        j12 = j12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        j13 = j13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 40 And Abs(Cells(i, 5)) <= 45 Then
b9 = b9 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        k1 = k1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        k2 = k2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        k3 = k3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        k4 = k4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        k5 = k5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        k6 = k6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        k7 = k7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        k8 = k8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        k9 = k9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        k10 = k10 + 1
```

```
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        k11 = k11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        k12 = k12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        k13 = k13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 45 And Abs(Cells(i, 5)) <= 50 Then
b10 = b10 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        l1 = l1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        l2 = l2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        l3 = l3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        l4 = l4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        l5 = l5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        l6 = l6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        l7 = l7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        l8 = l8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        l9 = l9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        l10 = l10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        l11 = l11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        l12 = l12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        l13 = l13 + 1
```

```
    End If

ElseIf Abs(Cells(i, 5)) > 50 And Abs(Cells(i, 5)) <= 55 Then
b11 = b11 + 1
    If Abs(Cells(i, 7)) <= 5 Then
    m1 = m1 + 1
    ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
    m2 = m2 + 1
    ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
    m3 = m3 + 1
    ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
    m4 = m4 + 1
    ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
    m5 = m5 + 1
    ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
    m6 = m6 + 1
    ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
    m7 = m7 + 1
    ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
    m8 = m8 + 1
    ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
    m9 = m9 + 1
    ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
    m10 = m10 + 1
    ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
    m11 = m11 + 1
    ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
    m12 = m12 + 1
    ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
    m13 = m13 + 1
    End If
ElseIf Abs(Cells(i, 5)) > 55 And Abs(Cells(i, 5)) <= 60 Then
b12 = b12 + 1
    If Abs(Cells(i, 7)) <= 5 Then
    n1 = n1 + 1
```

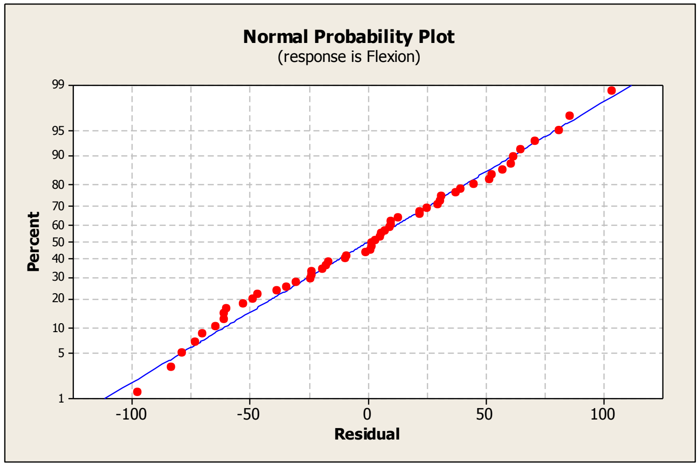
```
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        n2 = n2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        n3 = n3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        n4 = n4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        n5 = n5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        n6 = n6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        n7 = n7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        n8 = n8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        n9 = n9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        n10 = n10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        n11 = n11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        n12 = n12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        n13 = n13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 60 And Abs(Cells(i, 5)) <= 65 Then
b13 = b13 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        o1 = o1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        o2 = o2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        o3 = o3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        o4 = o4 + 1
```

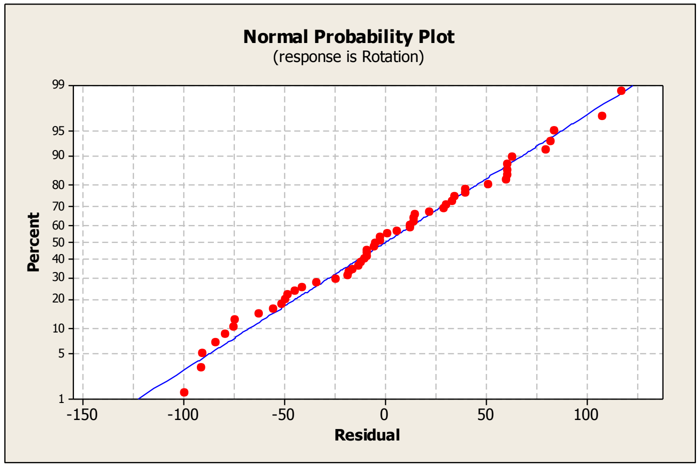
```
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        o5 = o5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        o6 = o6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        o7 = o7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        o8 = o8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        o9 = o9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        o10 = o10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        o11 = o11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        o12 = o12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        o13 = o13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 65 And Abs(Cells(i, 5)) <= 70 Then
b14 = b14 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        p1 = p1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        p2 = p2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        p3 = p3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        p4 = p4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        p5 = p5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        p6 = p6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        p7 = p7 + 1
```

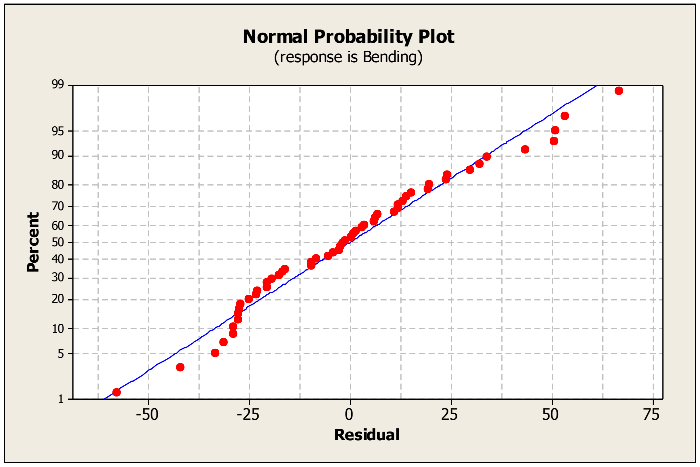
```
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        p8 = p8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        p9 = p9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        p10 = p10 + 1
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then
        p11 = p11 + 1
        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then
        p12 = p12 + 1
        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then
        p13 = p13 + 1
        End If
ElseIf Abs(Cells(i, 5)) > 75 And Abs(Cells(i, 5)) <= 80 Then
b15 = b15 + 1
        If Abs(Cells(i, 7)) <= 5 Then
        q1 = q1 + 1
        ElseIf Abs(Cells(i, 7)) > 5 And Abs(Cells(i, 7)) <= 10 Then
        q2 = q2 + 1
        ElseIf Abs(Cells(i, 7)) > 10 And Abs(Cells(i, 7)) <= 15 Then
        q3 = q3 + 1
        ElseIf Abs(Cells(i, 7)) > 15 And Abs(Cells(i, 7)) <= 20 Then
        q4 = q4 + 1
        ElseIf Abs(Cells(i, 7)) > 20 And Abs(Cells(i, 7)) <= 25 Then
        q5 = q5 + 1
        ElseIf Abs(Cells(i, 7)) > 25 And Abs(Cells(i, 7)) <= 30 Then
        q6 = q6 + 1
        ElseIf Abs(Cells(i, 7)) > 30 And Abs(Cells(i, 7)) <= 35 Then
        q7 = q7 + 1
        ElseIf Abs(Cells(i, 7)) > 35 And Abs(Cells(i, 7)) <= 40 Then
        q8 = q8 + 1
        ElseIf Abs(Cells(i, 7)) > 40 And Abs(Cells(i, 7)) <= 45 Then
        q9 = q9 + 1
        ElseIf Abs(Cells(i, 7)) > 45 And Abs(Cells(i, 7)) <= 50 Then
        q10 = q10 + 1
```

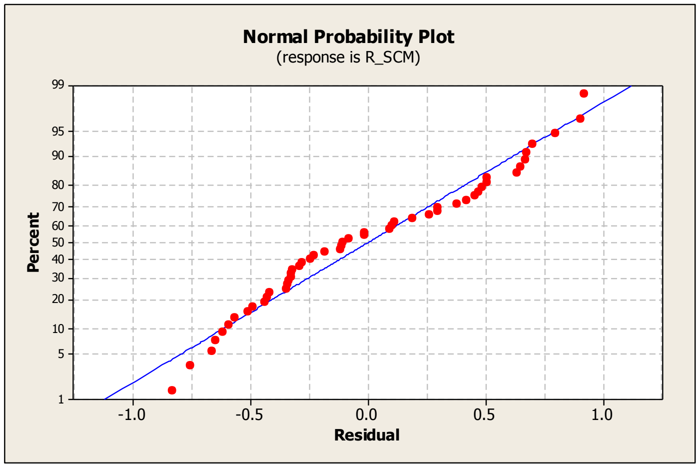
```
        ElseIf Abs(Cells(i, 7)) > 50 And Abs(Cells(i, 7)) <= 55 Then

        q11 = q11 + 1

        ElseIf Abs(Cells(i, 7)) > 55 And Abs(Cells(i, 7)) <= 60 Then

        q12 = q12 + 1

        ElseIf Abs(Cells(i, 7)) > 60 And Abs(Cells(i, 7)) <= 65 Then

        q13 = q13 + 1

        End If

End If

End If

Next i

End Sub
```

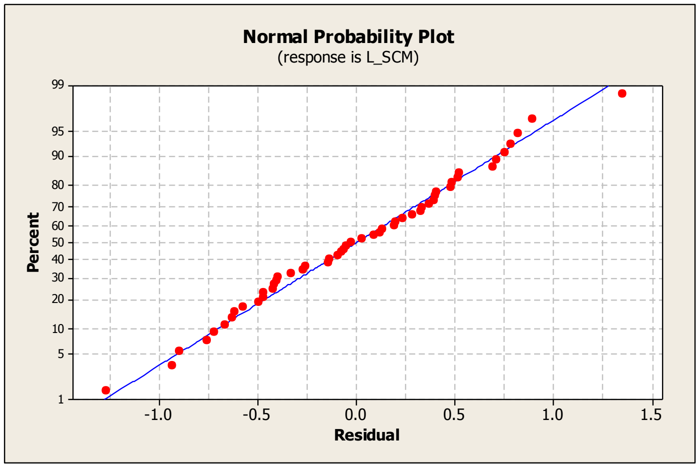
Appendix C - Normal probability plot of residuals

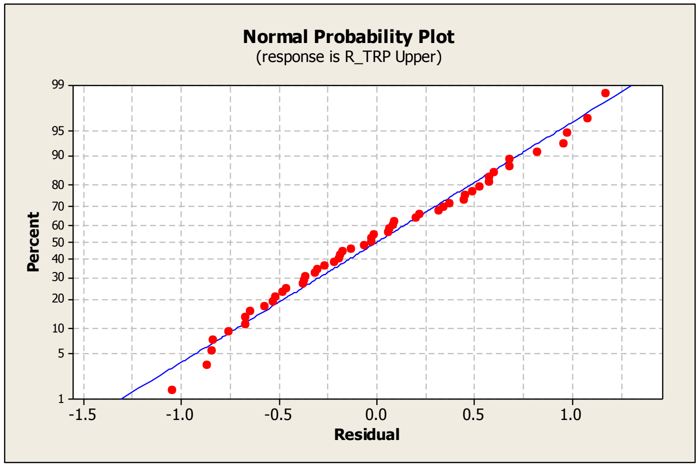


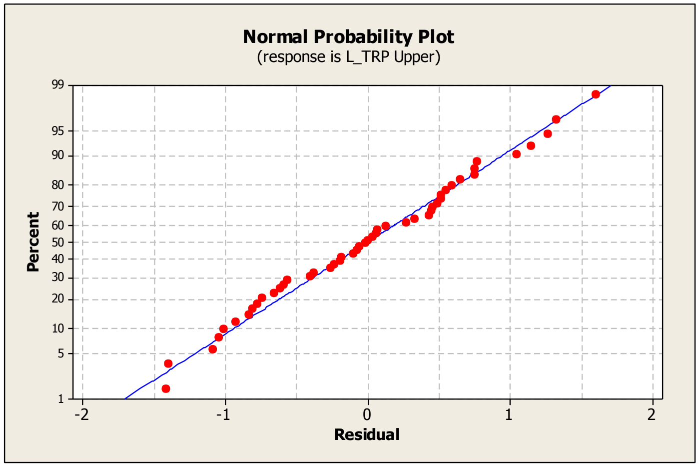





Normal Probability Plot
(response is R_SCM)
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-1.0
-0.5
0.0
0.5
1.0
Residual


Normal Probability Plot
(response is L_SCM)
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-1.0
-0.5
0.0
0.5
1.0
1.5
Residual


Normal Probability Plot
(response is R_TRP Upper)
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-1.5
-1.0
-0.5
0.0
0.5
1.0
Residual


Normal Probability Plot
(response is L_TRP Upper)
Percent
99
95
90
80
70
60
50
40
30
20
10
5
1
-2
-1
0
1
2
Residual

Appendix D – Raw postural load Data

Sub	Monitor	task	Flexion	Bending	Rotation
1	Dual	Typing	539.2756	223.6197	698.2463
1	Dual	S&F	241.8137	115.2131	551.676
1	Dual	Reading	438.993	169.5641	650.4147
1	Single	Typing	526.1095	125.5194	608.3698
1	Single	S&F	268.8772	100.4947	393.0037
1	Single	Reading	462.2836	100.0514	374.0855
2	Dual	Typing	479.7857	113.0653	385.9269
2	Dual	S&F	351.735	160.4544	344.5852
2	Dual	Reading	379.844	111.3424	352.3384
2	Single	Typing	326.8935	105.7758	225.1329
2	Single	S&F	178.244	104.3325	194.0794
2	Single	Reading	102.1925	100.4132	188.7258
3	Dual	Typing	326.8935	105.7758	225.1329
3	Dual	S&F	226.626	124.099	115.3692
3	Dual	Reading	207.1534	101.6854	505.757
3	Single	Typing	528.1776	192.5133	206.5592
3	Single	S&F	178.244	104.3325	194.0794
3	Single	Reading	102.1925	100.4132	188.7258
4	Dual	Typing	160.5967	100	228.9957
4	Dual	S&F	234.1059	103.9037	351.9133
4	Dual	Reading	134.6288	101.7932	132.8407
4	Single	Typing	324.9031	120.0017	206.3895
4	Single	S&F	151.0269	101.8155	151.3424
4	Single	Reading	168.9234	103.4836	178.6371
5	Dual	Typing	488.0422	236.7212	436.5986
5	Dual	S&F	287.7508	111.3128	345.8764
5	Dual	Reading	292.4576	160.7743	202.0657
5	Single	Typing	488.0422	236.7212	436.5986
5	Single	S&F	398.3535	136.2574	193.2068
5	Single	Reading	424.6671	127.459	222.7378
6	Dual	Typing	386.5095	154.9237	332.4207
6	Dual	S&F	190.5755	122.1706	340.9196
6	Dual	Reading	142.8666	104.0436	240.1127
6	Single	Typing	347.497	151.4332	254.3871
6	Single	S&F	246.0769	127.2969	150.4325
6	Single	Reading	170.4143	124.6027	167.6061
7	Dual	Typing	456.2575	195.6077	330.0789
7	Dual	S&F	395.4008	162.3736	364.4407
7	Dual	Reading	327.7898	203.7647	270.3236
7	Single	Typing	455.2512	199.6417	332.0915
7	Single	S&F	361.3789	156.4835	181.7752
7	Single	Reading	373.2659	107.4764	136.633
8	Dual	Typing	349.4703	110.0189	261.0801
8	Dual	S&F	137.962	154.8792	377.3729
8	Dual	Reading	128.6877	104.4554	174.2665
8	Single	Typing	294.1248	108.5273	248.1485
8	Single	S&F	132.263	118.6781	186.0387
8	Single	Reading	133.7213	122.1003	167.3197
9	Dual	Typing	342.4499	107.9307	280.1063
9	Dual	S&F	139.2069	142.3528	283.639
9	Dual	Reading	212.4539	137.2546	103.0554
9	Single	Typing	378.7999	105.9386	236.3209
9	Single	S&F	173.1272	100.733	197.0797
9	Single	Reading	139.275	108.7358	195.3458

Appendix E – Raw normalized muscle activity data

Sub	Monitor	Task	R_SCM	L_SCM	R_TRP Up	L_TRP Upp	Sub	Monitor	Task	R_SCM	L_SCM	R_TRP Up	L_TRP Upp
1	Dual	S&F	2.677892	2.511719	4.371333	4.809583	5	Dual	S&F				
1	Dual	Reading	2.021467	2.265471	2.645801	5.115786	5	Dual	Reading	2.553431	1.99492	2.110903	4.069806
1	Dual	Typing	3.075546	2.530543	5.549921	7.028039	5	Dual	Typing	4.567021	2.225479	5.789625	8.419491
1	Single	S&F	2.245646	2.161161	3.822456		5	Single	S&F	3.144334	2.576339	3.354804	7.628425
1	Single	Reading	1.8126	2.193106	2.656439		5	Single	Reading	2.05695	1.794539	1.909191	5.234522
1	Single	Typing	3.225605	2.460687	5.848764		5	Single	Typing	3.006795	2.643089	4.382424	7.460291
2	Dual	S&F	4.571389	4.06283	4.704291	6.823976	6	Dual	S&F	3.721614	2.960964	3.258959	3.334486
2	Dual	Reading	4.865191	2.411885	4.128721	4.337475	6	Dual	Reading	3.272334	1.862275	1.874055	4.266518
2	Dual	Typing	5.844125	3.497386	7.299399	8.962341	6	Dual	Typing	4.249273	4.162593	4.187357	6.096837
2	Single	S&F	3.18459	4.015749	4.699395	6.776032	6	Single	S&F	3.810747	4.492091	3.643453	5.469254
2	Single	Reading	3.168497	3.070286	4.604151	4.845924	6	Single	Reading	3.367199	1.73318	1.704109	4.388036
2	Single	Typing					6	Single	Typing	4.800835	4.183443	4.102403	5.841185
3	Dual	S&F	3.462202	2.530629	4.497519	7.925113	7	Dual	S&F	4.409333	3.727401	2.048878	6.37721
3	Dual	Reading	2.601437	2.572287	2.273951	5.349254	7	Dual	Reading	4.454571	2.499156	1.812101	5.359921
3	Dual	Typing	4.05351	3.292411	5.582499	9.701241	7	Dual	Typing	5.243528	5.806243	3.979366	7.343658
3	Single	S&F	2.81597	2.240449	3.434357	6.238412	7	Single	S&F	5.32166	4.727627	3.80322	7.476986
3	Single	Reading	2.616735	2.025101	2.183144	5.343034	7	Single	Reading	3.800015	2.723835	2.376252	5.055776
3	Single	Typing	2.860075	2.172641	4.000013	6.281623	7	Single	Typing	5.421234	4.573472	2.396945	8.622666
4	Dual	S&F	5.606843	4.775574	5.692976	7.171044	8	Dual	S&F	4.892431	4.887001	3.374859	3.976679
4	Dual	Reading	5.185573	3.141427	3.559634	4.559609	8	Dual	Reading	4.466292	4.428775	2.490735	3.639308
4	Dual	Typing	5.620531	3.072522	7.328192	7.415003	8	Dual	Typing	4.169479	5.947403	3.234373	4.159437
4	Single	S&F	3.508143	5.225264	5.066518	7.249592	8	Single	S&F	3.304116	4.624738	2.564763	3.765882
4	Single	Reading	2.81373	3.653903	4.703355	6.556173	8	Single	Reading				
4	Single	Typing	4.436989	3.491144	6.314232	8.226285	8	Single	Typing	3.834795	4.719432	2.499444	3.999049
							9	Dual	S&F	2.64676	2.79841	2.314673	3.308524
							9	Dual	Reading	3.632328	2.78214	1.524183	2.316989
							9	Dual	Typing	3.193838	2.977638	2.454484	3.961143
							9	Single	S&F	2.318103	3.339168	2.046069	4.669643
							9	Single	Reading	1.61275	2.948624	2.068801	3.167394
							9	Single	Typing	2.738359	3.141586	2.028602	4.853644