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Investigation of Upper Limb and Lower Back Muscle Activity: Experimental of Repetitive Task

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Abstract: The paper focused on the effects occurs on upper limb and lower back muscle while performing a repetitive task in the near and far boundary work area during prolonged sitting. Ten healthy subjects (5 females and 5 males) participated in this study. The surface electromyography (EMG) was recorded for levator scapulae, upper trapezius, anterior deltoid and erector spinae (all in right and left side) which are known as the weakened and tightened muscles due to Musculoskeletal Disorders (MSD). The results of the study showed that the muscles activities of all muscles showed significant increases during prolonged sitting. Subjective discomfort ratings showed prolonged sitting causes slight discomfort in the lower back, upper back and hips. All the muscles activities also showed significant increase from near boundary to far boundary work area ($p<0.05$). Thus, these findings should be taken into consideration for industries in designing toward safety and comfortable work place in sitting posture.

Key words: EMG, near boundary, far boundary, upper limb muscle, lower limb muscle

INTRODUCTION

Injuries resulting from sitting for long periods are a serious occupational health and safety problem. This problem will likely become more common in the future because the trend toward work in a sitting position is still increasing. Workers in most industrial workstations usually perform manual tasks which involving repetitive arm motions. The tasks done do not involve heavy exertion, but fatigue, pain and repetitive strain injuries in arm, shoulder and neck region are prevalent Das, B. and Sengupta, A.K., (1998). The design layout for industrial workstations which include the concept of normal and maximum boundary work area has been proposed to the designers. This is to make the decisions about the placement of the workstation components that require manual handling Ashraf *et al.*, (2007).

Generally, the normal work area is within the limits of a comfortable sweeping movement of the arm, with the elbow is bent at a right angle or less Ashraf *et al.*, (2007). It is also known as near boundary that is defined as the boundary at which people no longer using their arm, but must introduce torso movements (rotation and lean) to extend their reach. Within this boundary, work is handled most efficiently and workers can reach with comfortable arm movements. While, maximum work area is the area within comfortable reach of the extended arm. Is also known as the far boundary which is the distance at which people change form using a seated to a standing reached. Beyond this maximum work area, workers choose to stand, which can cause fatigue, exhaustion and lower back pain if maintained for a long period.

MSDs have commonly been associated with physically demanding working conditions. Armstrong *et al.* (1993) in Buckle and Devereux, (2002) assert that physical work requirements and individual factors determine muscle force and length characteristics as a function of time, which in turn determines muscle energy requirements. Muscle energy requirements in turn can lead to fatigue, which then can lead to muscle disorders. According to the survey by European Agency for Safety and Health at Work, (2008), 62% of the workers reported that they were exposed to repetitive hand or arm movements and 46% reported working in painful or tiring positions for at least a quarter of their working time. Researchers suggest that the following occupational risks may contribute to MSD: shoulder load, static tension of the neck, shoulder, and arm muscles, highly repetitive contractions in the shoulder muscles, work at or above shoulder level, repetitive grasping, extreme deviations of the wrists, and repetitive lifting of loads (Bjelle *et al.,* 1979; 1981; Luopaja

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èrvi, *et al.,* 1979; Hagberg, M. and Wegman, D.H., 1987).

One of the most often applied methods for assessing local muscular fatigue is an analysis of the Electromyography (EMG) signals. Processes occurring as an effect of fatigue are visible in the recorded EMG signals as a change of values of selected EMG parameters. Those parameters are obtained as a result of processing the EMG signals in the time and frequency demand Liu *et al.,* (2004). The EMG signal is the electrical manifestation of the neuromuscular activation associated with a contracting muscle. Dubois Reymond in 1849 proves that EMG signals could be detected human muscle activity during voluntary contraction De Luca, C.J., (2006).

Thus, the objective of this study is to investigate upper limb and lower back muscle activity during prolonged sitting while performing a repetitive task in two different boundary work area which are near boundary work area and far boundary work area using an EMG.

MATERIALS AND METHODS

Task:

The experiment was performed in the Ergonomic Lab in the Engineering Design and Manufacturing Department, University of Malaya. This lab is environmentally controlled and sheltered from outside disturbances. The experimental task consists of a simple repetitive task where they have to group all the blocks and then assemble them. This task is done in the near boundary and far boundary work area. Each subject has to sit on a chair in two different work areas, each for 20 minutes. The chair height is fixed and has no back rest. For near boundary, the distance of the chair to the edge of the table was set to each participant's upper-arm length. Thus, when the participant's extended their arm, the elbow was positioned at table edge, and the thumb and forefinger were in contact with the table surface without stretching the arm. For far boundary, the distance between the chair and the table edge was changed to 70% of the participant's total arm length. This distance would enable participants to lean forward without the table edge interfering with their ability to lean forward Gardner, *et al.,* (2001).

2.2 Subjects:

Ten healthy subjects (5 female and 5 male) with no previous lower extremity or back problems volunteered for this study. The subjects were between the ages of 22 and 25 to match the age range of the target working population. Only right handed subjects were accepted. Subjects must have not experienced musculoskeletal injuries.

Experimental Procedure:

Anthropometric Measurements:

Anthropometric measurements were taken for sitting postures: weight, height, sitting height (A), eye height (B), knee height (C), shoulder-elbow length (D), forearm hand length (E), buttock knee length (F), work surface height (G) and maximum head height (H). This anthropometrics data were used to know the near and far boundary area for each subjects.

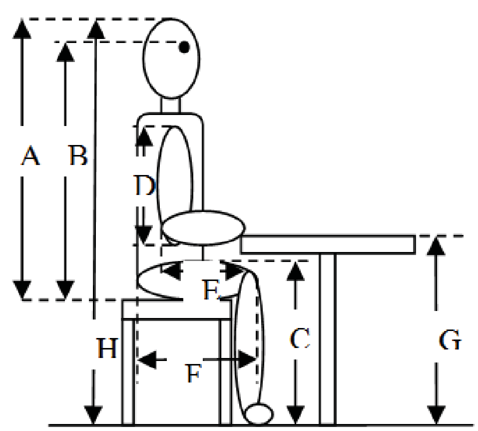


Fig. 1: Anthropometric Measurements

LEGEND
A = sitting height
B = eye height
C = knee height
D = shoulder-elbow length
E = forearm hand length
F = buttock knee length
G = work surface height
H = and maximum head height

Electrode Placement and Preparation:

The participant's skin was prepared for electrode and surface electrodes were placed over the belly of the following muscles: anterior deltoid, trapezius pars descendens, levator scapulae, erector spinae (Figure 2). The electrode positions were located according to Hermens *et al.* (2000). The ground electrodes were placed on the participant's sacrum (S1) vertebrae. Skin resistance was measured using digital multimeter 20 minutes after the electrodes were placed. The required skin resistance must less than 10 k. The higher the skin resistance, more noise will include in the signal.

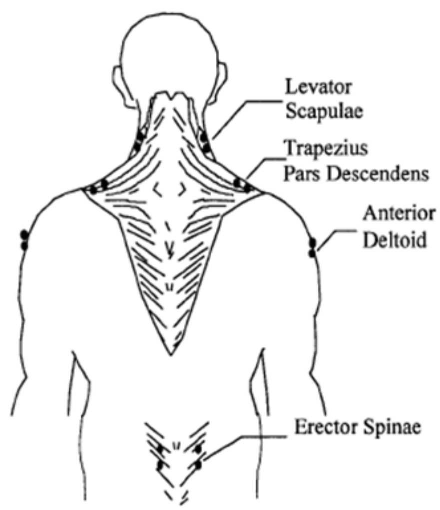


Fig. 2: Electrode Placement

Measuring Maximum Voluntary Contraction (MVC):

The Maximum voluntary contraction is used to Subjects were required to push a wall within 10 seconds before performing their task. They should exert the maximum force for this task.

Fig. 3: Push a static wall to get the value of MVC

Performing the Task:

Each participant is required to do a simple repetitive task within 20 minutes for near and far boundary work area. After they have finished the first task, they were given a Borg General Scale to evaluate their comfort at eight different body parts which is upper back, lower back, hips, upper legs, knees, lower legs, ankles and feet. After 5 minutes of break, they do their second task for another 20 minutes. Then they were given a Borg General Scale to evaluate their comfort during performing the second task. Borg General Scale is range from 0 to 10 and used verbal expression, where 0 is no noticeable stimuli and 10 is an extremely strong (almost maximum level) of exertion. Borg (1990) reports that this scale is correlated with percent maximum voluntary contraction (%MVC).

Fig. 4: Blocks that need to be assemble

RESULT AND DISCUSSION

Subjects:

Five females and five males were participated in this experiment. All of them were right hand dominance. None of them were reported have no history of musculoskeletal injuries that might affect their performance on the experiment tasks. Table 1 below provides the summary of the participants' anthropometric data.

Table 1: Anthropometry data for 10 participants

Measurement	Female Mean±SD	Male Mean±SD
Age (years)	22.4±0.55	23.20±1.30
Weight (kg)	50.60±6.23	74.00±14.63
Height (cm)	162.30±1.40	176.00±4.85
Sitting Height (cm)	123.66±0.88	131.46±2.54
Eye Height (cm)	113.14±3.25	121.26±3.14
Knee Height-Sitting (cm)	44.38±1.28	51.08±2.41
Shoulder-Elbow Length (cm)	31.12±1.31	32.02±0.70
Forearm Hand Length (cm)	31.02±1.31	37.64±1.41
Buttock-knee Length (cm)	48.70±0.93	51.70±0.44

Electromyogrpahy (EMG):

De Luca, (2006) reported that EMG signal was detected during voluntary elicited contractions. A sampling rate of 1500 Hz and band pass filter (20-400 Hz) was used to eliminate the movement artifact. Then the signals were cleaned from ECG signal and rectified and smoothing to root mean square (RMS). In this study, the raw data of EMG was calculated every four minutes, that result on five data for twenty minutes works. The mean of RMS of each subject and each task were calculated that will be used to perform statistical analysis.

Figure 5 and 6 above showed the overall results of the data collected in the near and far boundary work area among 10 samples. It showed that females have the highest RMS of EMG value compared to male samples. According to the questionnaires about their physical activity, all female samples are in non-active category while some of the male samples are in highly active category. This may influenced the result of the EMG value.

Figures 7 and Figure 8 above show the changed in muscle activities over time (each cycle consists of 4 minutes) for all muscles in near and far boundary work area. From the results, the muscle activities increased over time for all muscles. Right upper trapezius showed the largest muscular activities increases over 20 minutes in both near and far boundary work area.

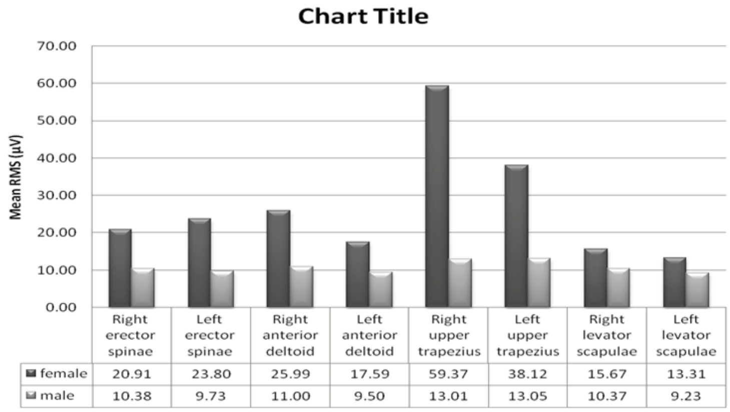


Fig. 5: Mean RMS (µV) in near boundary wok area

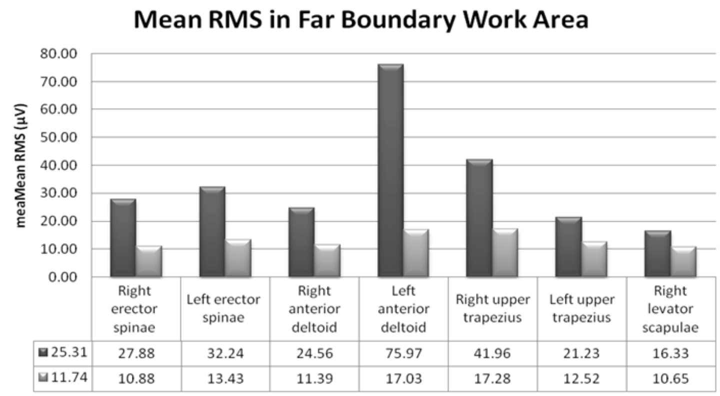


Fig. 6: Mean RMS (µV) in far boundary wok area

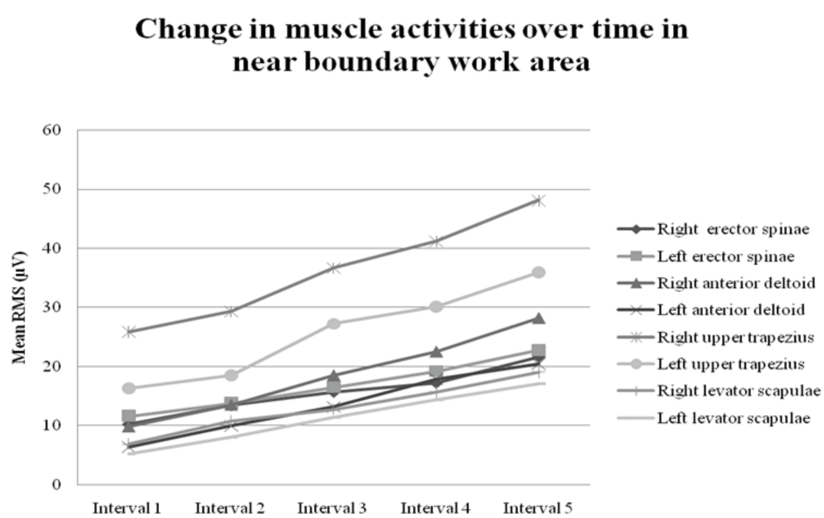


Fig. 7: Change in muscle activities over time in near boundary work area

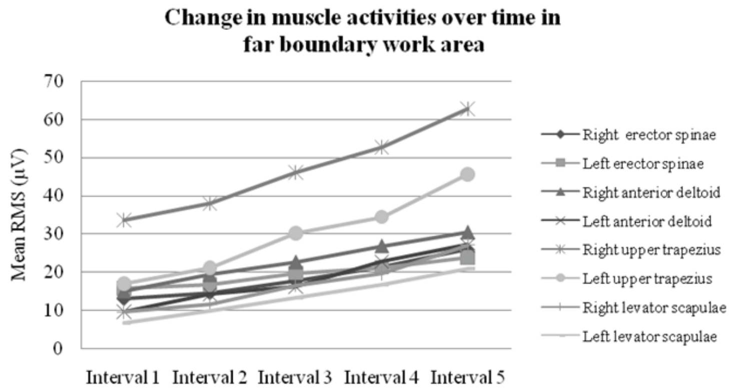


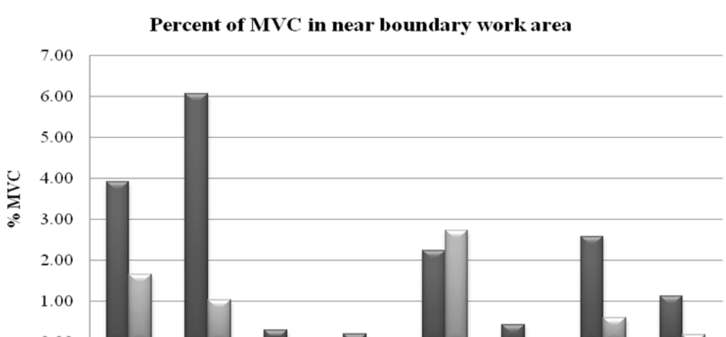
Fig. 8: Change in muscle activities over time in far boundary work area

Figures 7 and Figure 8 above show the changed in muscle activities over time (each cycle consists of 4 minutes) for all muscles in near and far boundary work area. From the results, the muscle activities increased over time for all muscles. Right upper trapezius showed the largest muscular activities increases over 20 minutes in both near and far boundary work area.

Percent of Maximum Voluntary Contraction (%MVC):

The signals were also normalized to the maximum voluntary contraction (MVC) in order to get the percentage of muscle activity within the work to the maximum that workers can carried out. The normalization was due to comparing and differentiating the muscles capabilities among subjects. Equation to calculate percent of MVC was shown below:

$$\% \, MVC = \frac{RMS}{MVC(RMS)} X100\%$$

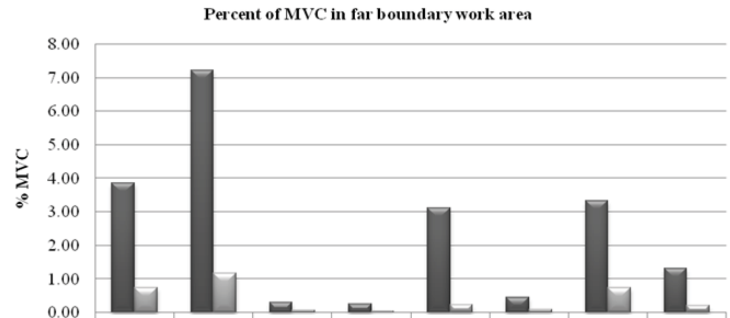


	Right erector spinae	Left erector spinae	Right anterior deltoid	Left anterior deltoid	Right upper trapezius	Left upper trapezius	Right levator scapulae	Left levator scapulae
female	3.91	6.06	0.29	0.20	2.23	0.41	2.57	1.12
male	1.65	1.03	0.06	0.05	2.73	0.07	0.58	0.18

Fig. 9: Summary of %MVC for every muscle in the near boundary wok area

Figures 9 and 10 above show the overall results of % MVC from the data collected above among 10 samples. This study revealed greater EMG readings for females when compared to males. From the % MVC results, it also showed that female have an increased % MVC than do males for all the muscles especially for the Left Erector Spinae muscle.

Figures 11 and 12 above show the changed in % MVC over time (each interval consists of four minutes) for all muscles in near and far boundary work area. From the results, the muscle activities increased over time for all muscles. Left erector spinae showed the highest % MVC while Left Anterior Deltoid showed the lowest %MVC as the time increases in both boundaries working area.



	Right erector spinae	Left erector spinae	Right anterior deltoid	Left anterior deltoid	Right upper trapezius	Left upper trapezius	Right levator scapulae	Left levator scapulae
female	3.86	7.23	0.30	0.25	3.11	0.45	3.33	1.32
male	0.75	1.17	0.07	0.05	0.24	0.10	0.73	0.21

Fig. 10: Summary of %MVC for every muscle in the far boundary wok area

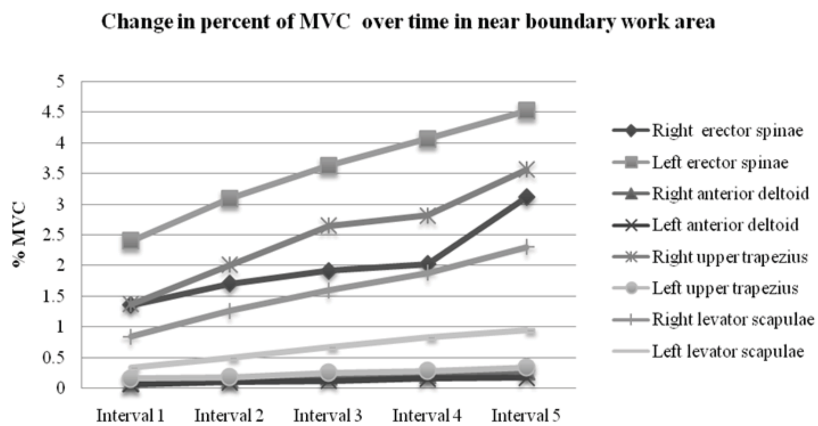


Fig. 11: Change in %MVC over time in near boundary work area

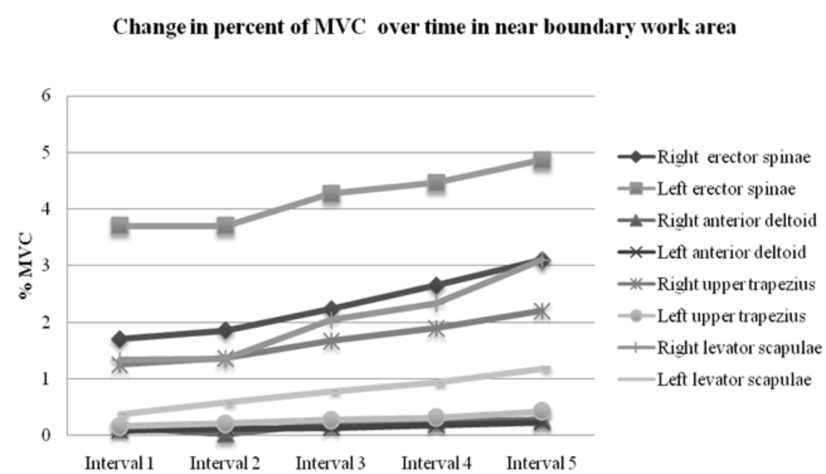


Fig. 12: Change in %MVC over time in far boundary work area

Comfort:

Each subject rated their body comfort using the Borg General Scale for eight different body parts after performing their task. Figure 13 below showed the comfort ratings between those two tasks on a scale of 0-10 where 0 represents no fatigue and 10 represents maximum fatigue.

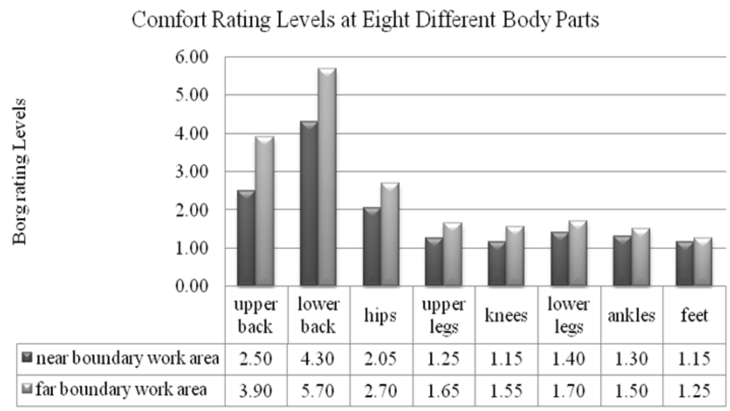


Fig. 13: Summary of comfort rating levels at eight different body parts

Figure 13 aboved shows the summary of comfort rating levels at eight different muscles for 10 samples after they performing their task in two different boundary area. The result indicated that lower back had the highest comfort rating for both near and far boundary work area with each 4.30 and 5.70. While feet and knee have the lowest comfort rating in the near boundary work area with each is 1.15. Feet also had the lowest comfort rating with 1.25 in the far boundary work area.

Independent T-test:

Independent t-test was conducted to evaluate the means of two work area which is near boundary work area and far boundary work area from a single population. The test is to determine if there is a difference in the means between the individual who work in the near boundary and far boundary work area. Table 2 represents the test result.

Table 2: Independent t-Test Result of %MVC in the near and far boundary work area

Muscles	t-test for Equality of Means			
	Near Boundary	Far Boundary	t	p
	Mean±SD	Mean±SD		
Right Erector Spinae	15.64±6.56	18.52±8.39	-3.662	0.005
Left Erector Spinae	16.76±9.93	19.38±10.71	-2.815	0.02
Right Anterior Deltoid	18.50±10.97	22.84±13.47	-4.817	0.001
Left Anterior Deltoid	13.54±5.70	19.97±9.61	-2.653	0.026
Right Upper Trapezius	36.19±35.19	46.50±45.72	-2.929	0.017
Left Upper Trapezius	25.58±21.21	29.62±21.77	-3.129	0.012
Right Levator Scapulae	13.02±3.82	16.88±5.71	-3.87	0.004
Left Levator Scapulae	11.27±2.69	13.49±3.57	-2.853	0.019

By observing the mean and standard deviation, it can be seen that the subjects involved in the far boundary tasks produced high muscular activity more than when a similar test was done in the near boundary condition. The normalized EMG data for all the muscles also significantly differed between sitting in the near boundary and in the far boundary work area ($p<0.05$).

Linear Regression:

Linear Regression was done to determine if there a linear relationship between two variables which is %MVC and time both for near and far boundary work area. Table 3 represents the linear regression result.

Table 3: Linear regression result of the %MVC and time in near and far boundary work area

Muscles	Near Boundary	Far Boundary	Near Boundary	Far Boundary
	R±R square	R±R square	Sig.	Sig.
Right Erector Spinae	0.987±0.975	0.985±0.971	0.002	0.002
Left Erector Spinae	0.996±0.993	0.991±0.982	0	0.001
Right Anterior Deltoid	0.998±0.995	0.999±0.999	0	0
Left Anterior Deltoid	0.997±0.995	0.989±0.978	0	0.001
Right Upper Trapezius	0.994±0.989	0.992±0.984	0	0.001
Left Upper Trapezius	0.986±0.971	0.978±0.974	0.002	0.002
Right Levator Scapulae	0.996±0.992	0.98±0.96	0	0.003
Left Levator Scapulae	0.999±0.999	0.999±0.997	0	0

From the Table 3 above, R represents the correlation between the observed and predicted values of the dependent variable. It showed that the sign of the R (+ve) is indicates a stronger relationship. R square is the proportion of variance in the dependent variable which can be predicted from the independent variable. It tends to optimistically estimate that almost 99% of the model fits the populations. Value under Sig, holds the significance value of the regression where it should be under 0.05. It showed that all the significant value of regression is below 0.05 ($p<0.05$).

Discussion:

Results of the study showed that muscle activities increased over time under near and far boundary work area. When working in near and far boundary work area, right upper trapezius had the largest RMS value of EMG increase over 20 minutes. This maybe because the trapezius helps to carry the weight of arm for prolonged period while performing repetitive tasks. The chair used also did not have arm support and all the sample are in right hand dominance which may influence this result. However left levator scapulae had the smallest RMS value of EMG increases over time in both boundary work area. The reason for this could be that there was limitation of head and neck rotation where the passive side bending may be reduced to 45° or less. These results significantly showed that prolonged sitting affect the muscle activities in the upper limb and lower limb.

The results also showed that female samples have high muscular activity and easily to felt fatigue rather than male samples. Females showed higher muscular activity compared to males in both boundary work area. This showed that gender affect on the EMG results was found to be significant in the muscular activities for all muscles.

The results of % MVC were increasing as the time increases in both boundaries working area. The results obtained were differs where the highest %MVC was at the left erector spinae compared to right upper trapezius in EMG activities. While the lowest of %MVC was at left anterior deltoid compared to left levator scapulae in the EMG activities. It also showed that females have the largest % MVC compared to males in near and far boundary work area. The subjective comfort ratings for eight different body parts after performing the task in near and far boundary work area were summarized in Figure 13. It showed that lower back are the highest discomfort parts affected by prolonged sitting for both working area. This followed by upper back and everything below the upper legs which showed least discomfort parts affected.

A hypothesis was developed in order to know whether there is a significant difference of %MVC in near and far boundary work area.

Null hypothesis:

There were no differences of %MVC in near and far boundary work area.

Alternative hypothesis:

There were differences of %MVC near and far boundary work area.

Based on the result shown in Table 2, it indicated that when working in the near boundary work area, the muscular activity were significantly lower than in the far boundary work area ($p<0.05$). Thus the null hypothesis was rejected for all the muscles and the alternative hypothesis was accepted. These differences had supporting the objectives where work area affects the muscle activity on upper limb and lower back.

A hypothesis was also developed in order to know whether there is a linear relationship between %MVC and time.

Null hypothesis:

There is no linear relationship between %MVC and time.

Alternative hypothesis:

There is linear relationship between %MVC and time.

Based from the results, it significantly showed that as the time increases, the %MVC of muscles also increases ($p<0.05$). Thus the null hypothesis was rejected and alternative hypothesis was accepted. These had supporting the objectives where prolonged sitting affects the upper limb and lower back.

Conclusions:

Knowing the boundary work area, all industrial workstation tools, controls, and other elements can be placed in a safe and easy-to-reach position. Ergonomics recommendation indicates that as the boundary work area exceeds the limit from near to far boundary work area, the increased reach requirement increases fatigue, pain and lower worker productivity.

The muscle activities for right and left erector spinae, right and left anterior deltoid, right and left upper trapezius and right and left levator scapulae showed a significant increase from near boundary to far boundary work area. All the muscles activities also showed significant increase from near boundary to far boundary work area ($p<0.05$). It appears that muscles activities (EMG) on upper limb and lower back were increased significantly during prolonged sitting when the boundary work area increases with 10.33% from near to far boundary work area. Thus, these findings should be taken into consideration for industries in designing towards safety and comfortable work place.

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