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Effect of computer workstation set-ups on muscle oxygen saturation and perceived fatigue

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ABSTRACT

Multiple literatures show evidences of how office workstation set-ups can influence muscle activities. However, the relationship between the postural adoption due to workstation setup and its effect to muscle oxygen saturation among office workers is unclear. The aim of this study was to investigate trends of muscle oxygen saturation and perceived fatigue ratings between different upper limbs posture variations among representative computer users. A repeated measure experiment was conducted on 15 participants to compare the muscle oxygen saturation and perceived fatigue ratings between four different office work posture variations. Parametric and non-parametric statistical analyses were conducted to analyze significant differences on the dependent parameters. Data analysis showed statistically significant trends ($p \leq 0.050$) of lower muscle oxygen saturation in workstation set-ups in which participants were adopting raised shoulder and extended arm positions. In addition, the findings revealed that the perceived fatigue ratings on the shoulder, upper arm and lower arm are the lowest ($p \leq 0.050$) in workstation condition where subject can adopt neutral postures. The results highlight the effect of good office workstation setup and work postures to individual muscle oxygen saturation and fatigue levels.

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1. INTRODUCTION

Cumulative exposures to computer work have been associated with musculoskeletal discomforts, pain and even injuries [1]–[3]. One of the most common issues linked with computer users in office settings are complaints of upper extremity pain and discomfort [4]–[6]. Several publications carried out in Thailand, Taiwan, Netherlands, India, Turkey, Pakistan and Malaysia shows that the prevalence of Upper Limb Musculoskeletal Disorder (ULMSD) symptoms among office workers ranged from 10% to 73% [7]–[14]. This high prevalence of symptoms indicates a high association between office workers and development of musculoskeletal disorders.

Office workers are exposed to ergonomics risk factors such as working in awkward positions, adopting prolonged sitting behavior or performing repetitive tasks when typing or using mouse [15]–[17]. Prolonged and repetitive exposures to these risk factors may have biomechanical and physiological impacts such as restriction of the blood circulation to body parts and consequently reduction of supplied oxygen to the muscles [18]–[20]. Muscle oxygen saturation (SmO2) measure indicates the balance between oxygen delivery and oxygen consumption in human skeletal muscles [21], [22]. This can lead to faster rate of fatigue, and prolonged physiological stresses may even lead to tissue damage and eventually musculoskeletal symptoms will start to emerge [23]–[25]. Since office workers spend most of their working time on computers, workstation set-up can directly influence worker's exposure to ergonomics risk factors.

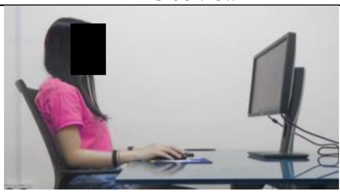
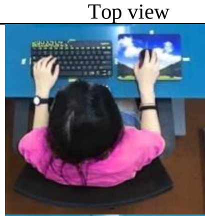
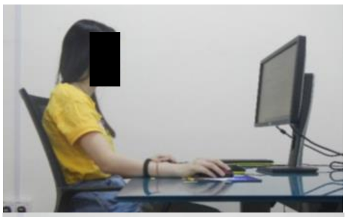
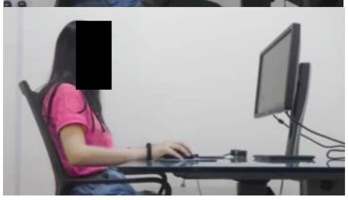
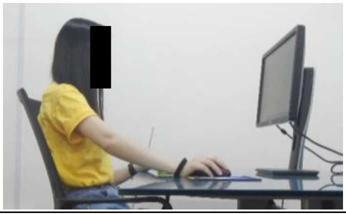
There have been multiple studies conducted to establish relationships between office workstation set-ups and muscle activities [26]–[32]. However, there has been limited study conducted to quantify the effect of office workstation set-ups to muscle oxygen saturation level. Therefore, this study aimed to compare the percentage of muscle oxygen saturation and perceived fatigue ratings between different upper posture variations among representative computer users. This information will provide an insight on the impact of the physiological parameters due to office workplace set-ups.

2. METHOD

2.1. Experimental design

A within-subject repeated-measures experimental design was used to determine the influence of different workstation set-ups on the shoulder muscle oxygen saturation and perceived fatigue for each subject. The independent variable was the workstation set-up at 4 condition levels. Condition 1 was the workstation set-up with the posture of subject shoulders at normal position and the arms positioned at the sides of the body. Condition 2 was the set-up with the shoulders at normal position while the arms were extended and deviated. Condition 3 was the set-up where shoulders were raised while the arms were positioned at the sides of the body. Condition 4 had the shoulders raised while the arms were extended and deviated. These four experimental conditions are summarized in Table 1.

Table 1. Experimental condition set-ups

Experimental conditions	Experimental set-ups	
	Side view	Top view
Condition 1: • Shoulders at normal position. • Arm and forearm on the side of body, at neutral position.		
Condition 2: • Shoulders at normal position. • Arm and forearm are extended and deviated.		
Condition 3: • Shoulder at raised position. • Arm and forearm on the side of body, at neutral position.		
Condition 4: • Shoulder at raised position. • Arm and forearm are extended and deviated.		

Dependent variables were the corresponding participants' muscle oxygen saturation of the right shoulder and perception of fatigue on shoulders, upper arms and lower arms. Muscle oxygen saturation was captured using a near-infrared spectroscopy (NIRS) sensor technology, in which near-infrared was emitted to capture the changes in hemoglobin and myoglobin wavelength color. The captured range of wavelength color indicates the SmO2 utilization in the targeted muscle. SmO2 has been associated with muscle fatigue [33],

[34]. The Moxy Muscle Oxygen Monitor device (Fortiori Design LLC, Hutchinson MN, USA) collected the data through a sampling rate of 2Hz. During testing, the sensor was connected with VO2 Master Manager App (v0.17.8) (VO2 Master Health Sensors Inc., Vernon, Canada) to collect the SmO2 data for each subject. These data were then processed, and statistical analyses were conducted to evaluate the differences in the effect of workstation set-ups to muscle oxygen saturation at the right shoulder and perception of fatigue, across participants. The method has been cleared by the university's ethical committee (clearance number: UTeM.11.02/500-25/1/4).

2.2. Participants

A total of 15 Malaysian participants (eight females, seven males) participated voluntarily in the study. Sample size of 15 participants for the experiment is deemed acceptable, as referenced from the sample sizes of similar type of experimental design capturing continuous muscle activities related data, adopted in other studies [35], [36]. Their age ranged from 18 to 29 years old (mean=23.73, standard deviation (SD)=3.28). All recruited participants are computer users, with at least 2 cumulative hours of computer use daily. More than half of the participants are using the computer for more than six hours per day. Participants were screened for issues that may affect their physical performance of computer usage. Recruited participants verified that they did not have: i) injured/broken upper limbs, ii) muscle pain and discomfort on upper limbs, and iii) other conditions of limiting movement on upper limbs in the past six months prior to the study. All participants were asked to have sufficient rest at least a day prior to experiment session. The demographic data are presented in Table 2.

Table 2. Demographic data of participant (n=15)

Characteristics	Number of populations (n)	Percentage of populations (%)
Gender		
Male	7	47
Female	8	53
Age in years		
<20	1	7
20-24	8	53
25-29	6	40
Duration of cumulative computer use per day		
<3 hours	2	13
3-5 hours	5	33
6-8 hours	7	47
>8 hours	1	7
Duration of cumulative mouse use per day		
<3 hours	2	13
3-5 hours	6	40
6-8 hours	6	40
>8 hours	1	7
Duration of cumulative keyboard use per day		
<3 hours	2	13
3-5 hours	5	33
6-8 hours	7	47
>8 hours	1	7

2.3. Data collection protocol

Participants were asked to have sufficient rest on the day prior to the experimental session. Upon arrival, the participants were given a brief description of the study and experimental protocols. Each subject signed consent and demographic form before being prepared for data collection. After cleaning the trapezius muscle region with alcohol, the Moxy muscle oxygen sensor was positioned 2 cm below the midpoint between C7 spinal segment on the neck and acromion on the shoulder blade as shown in Figure 1. The sensor placement to collect data for trapezius muscle is similar to location described in other studies [37]–[42].

The session started with the determination of the reference work surface height. The reference height will allow standardized experimental set-up conditions to be set up for all participants, as they have different anthropometrical dimensions. Participants were instructed to sit all the way back on the seat pan in an upright position. The keyboard was placed in front and close to the subject's body, 7 cm from the edge of the work surface with the alphanumeric portion of the keyboard centered on the body's midline. The monitor was placed in front of the subject and aligned to body's midline, and monitor height was adjusted at eye level. The table height was then adjusted such that the surface was level with the resting elbow height. The reference height of work surface and chair were measured and recorded for each subject.

The reference height would allow the subject to assume natural shoulder posture for Conditions 1 and 3. A compact keyboard was used for these conditions as it allows a neutral arm posture, where the mouse can be located without the need for forearm extension and deviation. Conditions 2 and 4 were set for raised shoulder position, so the height of work surface was adjusted 2 inches higher than the subject's reference work surface height. Footrest was used if the subject's feet were hanging in the air. A standard keyboard was used for these conditions, and the mouse was positioned with distance (horizontal 40 cm and vertical 10 cm) away from the key for letter "H" of the keyboard. These experimental set-ups were based upon authors' previous observational study among 399 office workers across 16 different offices.

Each subject was instructed to perform standardized task activities using keyboard and mouse in all 4 workstation set-up conditions. The subject's SmO2 data on trapezius muscle was recorded for 60 minutes for each experimental condition, with SmO2 data sampled every 0.5 second. One-hour rest was provided before each experimental condition, to reset muscle's freshness. Experimental conditions' order was counter-balanced to minimize order bias. Subjective 10-scale ratings of perceived fatigue as shown in Figure 2 on shoulders, upper arms and lower arms were rated by each subject before and after each experimental condition.

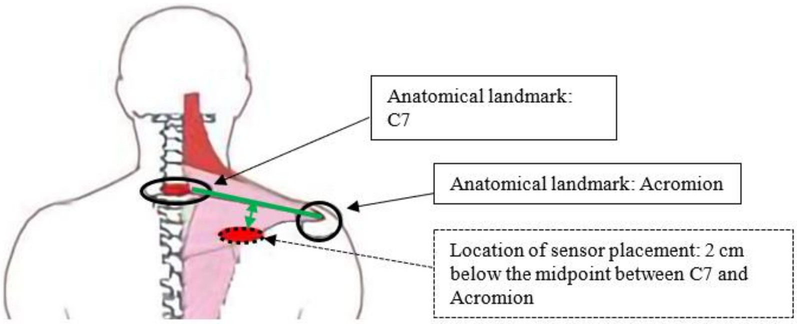


Figure 1. Location of sensor placement applied to participants' trapezius muscle

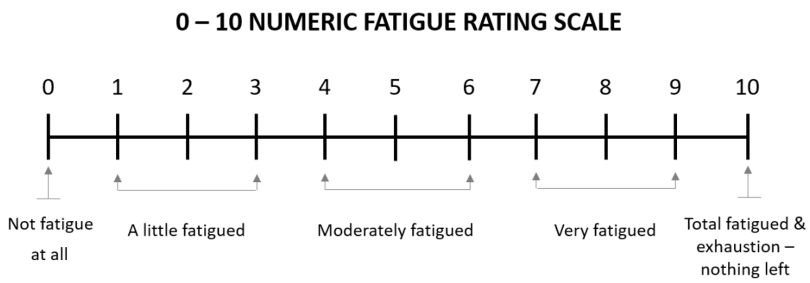


Figure 2. Perceived fatigue rating scale (Adapted from Micklewright *et al*. [43])

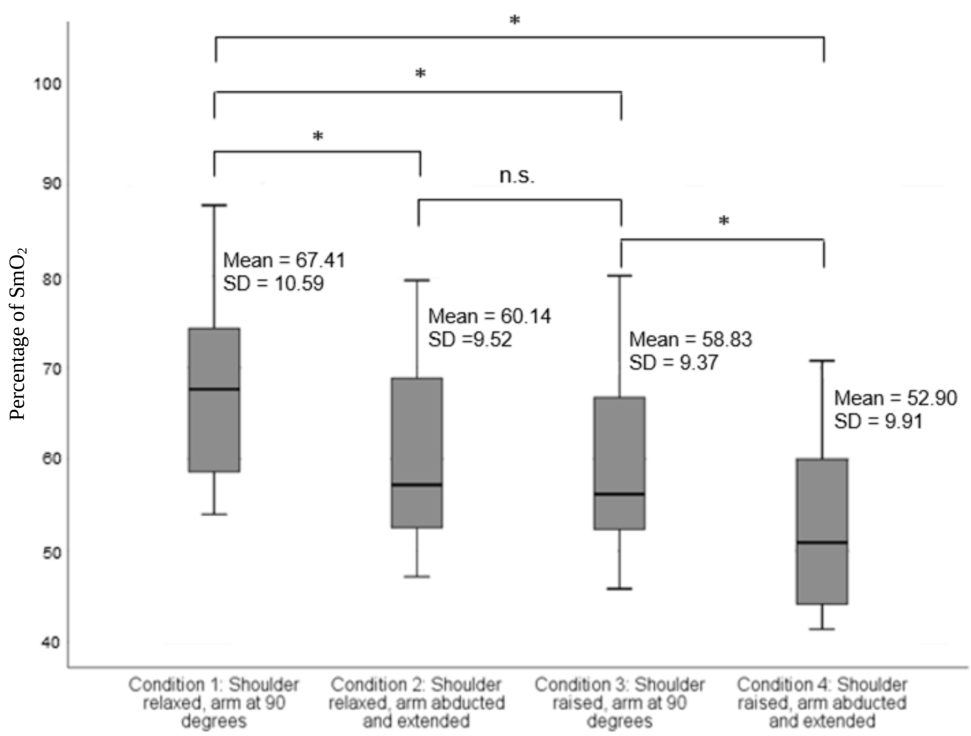
2.4. Statistical analysis

The Shapiro-Wilk test was selected to test the normality of muscle oxygen saturation data. The raw SmO_2 data for each subject was then processed and the 10^{th} percentile data was used for analyses. The 10^{th} percentile data represents the static muscle effort required by tasks, whereas the 50^{th} and 90^{th} percentiles represent more dynamic muscle requirements associated with tasks [44], [45]. Majority of the office works are sedentary; therefore the 10^{th} percentile of the average percentage was chosen as the parameter of muscle oxygen saturation because it refers to the low levels of muscle activity [46], [47]. One-way repeated measure ANOVA was used to examine the effect of different workstation conditions on muscle oxygen saturation. Bonferroni pairwise comparison test was performed as post-hoc analysis. Differences in the fatigue ratings between the start and end of each condition were calculated for each subject. Friedman test was conducted to assess if there were differences among the perceived fatigue ratings across the four experimental conditions. Post-Hoc analyses were conducted using Wilcoxon Signed Ranks Test. Statistical computations were performed using Microsoft Excel (version 2012) 2019 for Windows and IBM SPSS Statistics (v23) for Windows (IBM Corp., Armonk, N.Y., USA). In all statistical tests, alpha level was selected to be at 0.05 value.

3. RESULTS

3.1. Effects of workstation set-up on shoulder muscle oxygen saturation

As participants performed the computer tasks, there was a trend of fluctuating muscle oxygen saturation on trapezius muscle throughout the data collection process. The average SmO_2 fluctuation ranged within 8 to 25% (mean=16.80%, standard deviation (SD)=2.10%) across all experimental conditions, among all study participants. Overall, the findings showed the average percentage of shoulder muscle oxygen saturation was the highest in Condition 1, followed by Condition 2 and 3, and lowest percentage in Condition 4. It was found that the average percentage of shoulder muscle oxygen saturation in Condition 1 was approximately 14% higher than the average percentage in Condition 4. Meanwhile, in Condition 2 and 3, the average percentage of shoulder muscle oxygen saturation were almost the same. The percentage average and standard deviation of shoulder SmO_2 for 10^{th} percentile data analyses in different workstation set-ups among 15 participants are shown in Figure 3.



Note: *Signifies statistically significant difference ($p \leq 0.05$). Significant differences identified using post-hoc Bonferroni test.

Figure 3. Average percentage (standard deviation) of shoulder SmO_2 in different workstation conditions among 15 participants

Processed data were found to meet normality assumption. One-way repeated measured ANOVA test was used to statistically test the differences of muscle oxygen saturation data between the experimental conditions. Analysis of variance showed that the workstation conditions had a significant effect on the average percentage of shoulder SmO_2 (p=0.000). Post Hoc analyses using Bonferroni test revealed that there were statistically significant differences ($p \leq 0.050$) between average percentages in Condition 1 to all other experimental conditions (p=0.000–0.001). Besides, the analyses also showed statistically significant differences ($p \leq 0.050$) between Conditions 2 and 4, as well as Conditions 3 and 4. Post Hoc test of significance results for shoulder SmO_2 data between all experimental conditions are tabulated in Table 3 below. This evidence supports the hypothesis that the workstation conditions affect participants' shoulder muscle oxygen saturation. Specifically, these findings suggest that Condition 1 is the best workstation set-up due to the highest average percentage of shoulder muscle oxygen saturation across participants' sample population.

Table 3. Post Hoc analysis to compare significant differences of muscle oxygen saturation percentages between different experimental workstation conditions

Comparison of conditions		Mean difference	Standard error	p-value Bonferroni
1	2	7.275	1.400	0.001*
	3	8.587	1.395	0.000*
	4	14.516	1.611	0.000*
2	3	1.312	1.086	1.000
	4	7.241	0.802	0.000*
3	4	5.929	1.251	0.002*

*Signifies statistically significant difference (p≤0.050). Significant differences identified using post-hoc Bonferroni test.

3.2. Effect of workstation set-ups on perceived fatigue rating

The perception of fatigue was rated by 15 participants before and after working on each of the four workstation condition set-ups with scale between 0 (not fatigue at all) to 10 (total fatigue and exhaustion). The data from this study revealed that the average differences of perceived fatigue rating (rating after minus start of experimental conditions) on shoulder, upper arm and lower arm shows positive net differences across all experimental conditions. This indicates an increase in subjective perception of fatigue at the end of each experimental condition. A deeper look into the data showed that the positive net differences varied across experimental conditions. In general, the differences in fatigue rating were highest in Condition 4, followed by Conditions 3 and 2, while the lowest differences in perceived fatigue rating was in Condition 1. The trend showed that perceived fatigue rating of shoulder in Condition 4 was about four times higher than Condition 1, and almost double than Condition 2. However, the perceived fatigue rating on shoulder in Conditions 4 and 3 were almost similar. The ratings also showed noticeable differences in fatigue ratings on upper and lower arms between Conditions 1 and 4, but the differences between Conditions 2 and 3 was not apparent. The average differences of perceived fatigue rating across participants, by body parts, are illustrated in Figure 4.

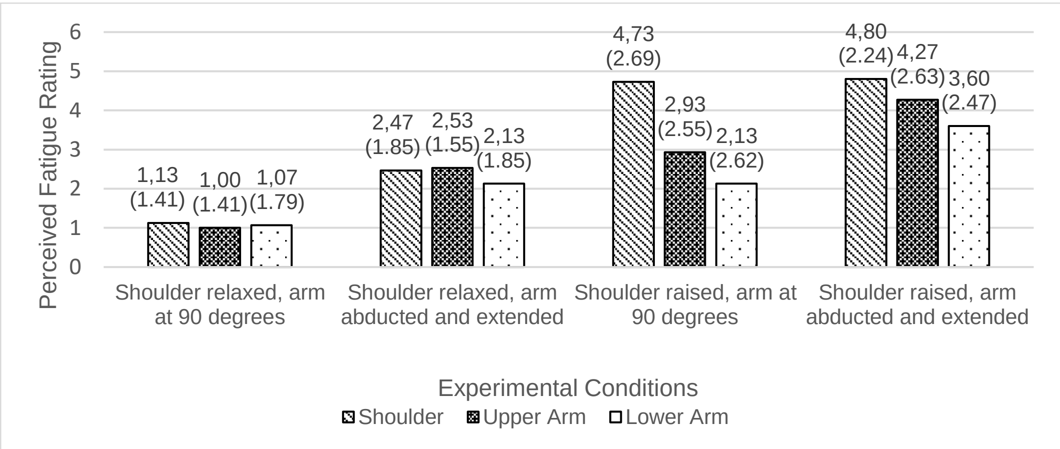


Figure 4. Average differences of perceived fatigue rating (standard deviation) by body parts. Note: Number denotes average differences of perceived fatigue rating. The bracket denotes standard deviation.

Friedman Test confirmed that there were statistically significant differences (p≤0.050) in fatigue ratings by body parts, between the four experimental set-ups. In summary, the significant contrast indicated that the workstation set-up allowing neutral postures (Condition 1) had the lowest differences in average perceived fatigue rating across the shoulders, upper arms, and lower arms. Post Hoc analyses using Wilcoxon Signed Ranks Test as shown in Table 4 found statistically significant differences in fatigue ratings between Condition 1 to all other experimental conditions for shoulders, upper arms, and lower arms. Perceived fatigue ratings of shoulder were also found to be significantly different between Conditions 2 and 3, as well as 2 and 4, but there was no significant difference in Conditions 3 and 4. This is likely because both Conditions 3 and 4 are set-ups where shoulders were in raised position. The Post Hoc analyses on perceived fatigue ratings of upper arms and lower arms showed significant differences between all experimental conditions, except between Conditions 2 and 3. This may be due to lower arms were supported in both Conditions 2 and 3.

Table 4. Post hoc analysis to compare significant differences in fatigue rating between different workstation conditions (by body parts)

Body parts	Comparison of conditions		Z-value	p-value
Shoulder	1	2	-3.002	0.003*
		3	-3.304	0.001*
		4	-3.426	0.001*
	2	3	-2.554	0.011*
		4	-2.776	0.006*
	3	4	-0.052	0.959
Upper arm	1	2	-3.228	0.001*
		3	-2.823	0.005*
		4	-3.311	0.001*
	2	3	-0.438	0.661
		4	-2.535	0.011*
	3	4	-2.625	0.009*
Lower arm	1	2	-2.267	0.023*
		3	-2.203	0.028*
		4	-3.185	0.001*
	2	3	-0.251	0.801
		4	-2.291	0.022*
	3	4	-3.115	0.002*

*Signifies statistically significant difference ($p \leq 0.050$). Significant differences identified using post-hoc Post Hoc Wilcoxon Signed Ranked Test.

4. DISCUSSION

The findings offer an insight of how workstation set-ups can directly influence the muscle oxygen saturation. The obtained data provide another physiological evidence on the benefits of working in a neutral upper limb posture afforded by good workstation set-up. Exposure to poor work postures, in combination with frequent and prolonged duration may put the muscle under biomechanical stress and reduce the blood circulation. This may result in reduction of oxygen supplies to the muscles, leading to muscular fatigue and consequently may contribute towards long-term wear-and-tear on musculoskeletal system [23], [48], [49].

This finding on benefits of adopting good upper limb posture is consistent with findings from other researchers. For example, a study by Cook and Kothiyal [26] using electromyography found that mouse placement adjacent to ‘standard keyboard’ resulted in higher level of upper arm muscles activities (interior and middle deltoid muscles) compared to placement beside ‘keyboard without numerical pad.’ The presence of numeric keypad influences mouse position by increasing the distance of the mouse from the user’s body midline, resulting in shoulder abduction and flexion. Another experimental study by Dennerlein and Johnson [50] found that mouse placement influences upper limb postures, and consequently muscles activations. The authors concluded that using compact keyboard reduces wrist extension and promoted more neutral shoulder posture compared to standard mouse position with standard keyboard. In another study, Harvey and Peper [51] also found that the mouse placed to the right of a standard keyboard leads to significant increase in muscle tension in the upper shoulder and arm. These previous findings are similar in that poor upper limb postures can result in direct undesirable outcomes at the musculoskeletal level. This current study offers another dimension by providing muscle oxygen saturation data to support the premise that good upper extremity postures can be achieved through placement of mouse and selection of keyboard type.

The study found that the relative position of chair and table height influences upper limb posture, more specifically raised shoulder position adoption. In a randomized controlled study, office workers who correctly adjusted chair height reported less end of the day pain and reduced average pain [52]. In different study, Cardoso *et al*. [53] showed that the use of active chairs in office work settings has the potential to give biomechanical and physiological benefits as evident by reported lower discomfort compared to non-active chairs. In a systematic review, Niekerk *et al*. [54] found a consistent trend that validates the premise of chair intervention’s effectiveness to reduce musculoskeletal symptoms among seated workers. Zhu and Shin [55] in an experimental study among 24 participants found that arms resting at elbow level height produced lowest muscle amplitude activity. In other studies, researchers found muscle activities on the shoulders are lower when the upper arms are positioned at the side of the torso instead of being abducted to the side [56], [57].

One of the discoveries from the analysis is that muscle oxygen saturation across participants changed in the first few minutes of the experimental conditions. The data was especially noticeable in Condition 4, where the muscle oxygen saturation decline was prominent even at the early stage of data collection. The data provides indication that there are immediate effects of poor postures to muscle oxygen saturation level. Several studies documented the sensitivity of oxygenation sensor used in this study. For example, Oatyimprai *et al*. [58] found that the percentage of SmO2 immediately increased after the subject received traditional Thai massage due to the improvement in blood flow. In another study, Schlegel and Hiblbauer [59] found that the SmO2 dropped from 55% to 10% during the isometric exercise. In resting, the percentage returned rapidly to above 70%. These results from the previous studies suggest that the muscle oxygen saturation can immediately change when there are changes in blood flow and muscle tension. The data from this study supports the notion that muscle oxygen saturation rate changes instantaneously when an individual is adopting poor work posture. The small fluctuation and somewhat stabilized muscle oxygen saturation seen after initial corrections at the beginning of experimental conditions can possibly be explained because of the sedentary work being performed in this study.

Poor workstation set-ups can lead to poor posture and cause fatigue to the muscle [60]. The findings in this study also found that workstation set-ups can influence perception of fatigue, especially on the upper limbs. Although the participants were exposed only to one hour in each condition, the differences on perception of fatigue on upper limbs between the experimental conditions were found to be statistically significant. Physical fatigue can result in tissue damage but can be reversible with enough recovery. However, when fatigue outruns body’s recovery process, cumulative wear and tear on musculoskeletal system will occur [23]. There have been several studies documenting positive associations between fatigue and musculoskeletal disorders among office workers [23], [24], [61], [62]. Daneshmandi *et al.* [63] in a cross-sectional study among 101 office workers found that the severity of discomfort and pain can be correlated to fatigue level. In addition, another cross-sectional study with 6 and 12 months of follow-up among 188 office workers in Iran indicated that improving working posture can reduce the occurrence of fatigue and musculoskeletal symptoms [64]. As such, the workstation set-up is critical as poor set-ups can be linked to work-related ergonomics risk factors’ exposures, contributing to fatigue, and eventually leading to development of musculoskeletal symptoms.

The study found that good posture through good workstation set-ups can improve blood oxygen saturation and reduce perception of fatigue. However, the findings should not be interpreted in isolation of other contributing factors. By itself, adoption of good posture through appropriate workstation set-ups may not be enough to improve blood circulation and reduce fatigue among office workers. Computer work is considered as sedentary work which is associated with static postures. Previous studies demonstrated benefits of microbreaks, periodic stretches, and movement awareness to disrupt continuous static posture adoption. For example, Crenshaw *et al.* [65] in an experimental study on computer mouse work found increasing trend of hemoglobin volume changes and oxygen saturation in both active (high intensity extension activities) and passive (resting) breaks. In another study, Nakphet *et al.* [66] in a randomized controlled trial on different types of activities during rest-break intervention among video display unit operators found significant difference in muscle discomfort level overtime. Other studies investigating frequency of breaks showed that frequent breaks (at least once every hour) and short breaks (less than 10 minutes) lead to a significant improvement in the musculoskeletal disorders in office workers [67], [68]. Putsa *et al.* [17] found that frequently changing position from sitting to standing at work can lead to reduced risk of MSD disorders. Kar and Hedge [69] studied the sit-stand-walk intervention and reported decreased discomfort and perceived physical fatigue compared to sit-stand intervention. Callegari *et al.* [70] in a longitudinal case series study found that inclusion of specific strategies such as microbreaks and using wrist support can influence the speed rate of fatigue development. Although the study described in this manuscript does not include microbreaks or stretching activity as specific parameters of interest, it might be interesting for future study to capture muscle oxygen saturation data to further examine the interaction effects of these work habit factors with work set-up factor.

5. CONCLUSION

The results of the present study indicate a direct relationship between the workstation set-ups with individual’s muscle oxygen saturation and perceived fatigue. Data analysis showed a trend of lower muscle oxygen saturation in workstation set-ups in which participants were adopting raised shoulder and extended arm positions, compared to set-ups where participants adopt a more neutral shoulder and arm positions. Besides, this study revealed that the perceived fatigue ratings on shoulder, upper arm and lower arm are lowest in workstation condition where participants can adopt neutral posture. Hence, improvement of workstation set-up and implementation of ergonomic interventions in the office workplace are recommended as necessary measures to reduce the perceived fatigue rate on upper limb and consequently lower the risk of development of musculoskeletal disorders among office workers. The findings provide guidance for organization management and office workers focus on improving their office workstation set-ups, especially for workers who are spending most of the working time on the computer.

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