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PHYSIOLOGICAL EFFECT ON DIFFERENT REACH DISTANCES: A CASE STUDY FOR MALAYSIAN ADULTS

S. Z. DAWAL[1]*, S. J. SARTIKA[2], H.R ZADRY[3], Y. SAN[4], S. N. MAKHTAR[5] & S. F. KHYASUDEEN[6]

Abstract. The effects of oxygen uptake, heart rate and muscle activity while performing a repetitive lifting task in normal, maximum and extreme reach distances were investigated in the study. Ten subjects (5 females and 5 males) of age between 22-25 years were involved in the study. The results of oxygen uptake showed an increased of 11% and 39% from normal reach to maximum and extreme reach respectively. As for heart rate the results showed an increased of 8% and 17% from normal reach to maximum and extreme reach respectively. Electromyogram reading of anterior deltoid and upper trapezious muscles showed a tremendous increased of more than 80% while bicep brachii muscles showed an increase of only about 1 % from normal reach. The findings from the study showed an increased in the physiological responses when the work reach distance was increased. And lifting task, posture and load on this study developed back pain.

Keywords: Electromyography; muscle activity; oxygen uptake; heart rate; reach distance

Abstrak. Kesan pengambilan oksigen, kadar degupan jantung dan aktiviti otot ketika melaksanakan kerja mangangkat secara berulang pada kadar normal, maximum dan capaian melampau telah dikaji dalam kajian ini. Sepuluh orang peserta kajian, lima perempuan dan lima lelaki yang berumur antara 22-25 tahun terlibat dalam kajian ini. Keputusan kajian terhadap pengambilan oksigen menunjukkan kadar peningkatan sebanyak 11% dan 39% dari kadar normal untuk mencapai kadar maximum dan capaian melampau. Manakala untuk kadar degupan jantung keputusan menunjukkan peningkatan sebanyak 8% dan 17% dari keadaan normal untuk mencapai kadar maximum dan capaian melampau. Bacaan electromyogram pada anterior deltoid dan otot bahagian atas trapezious menunjukkan peningkatan yang besar iaitu sebanyak 80% manakala otot bicep brachii menunjukkan peningkatan sebanyak 1% sahaja dari keadaan normal. Penemuan dalam kajian ini menunjukkan peningkatan dalam tindak balas psikologikal apabila jarak capaian kerja meningkat. Dan pekerjaan mengangkat, postur dan beban dalam kajian ini mengakibatkan sakit belakang badan

[1-6] Department of Engineering Design and Manufacture, Engineering Faculty, University of Malaya, 50603 Kuala Lumpur, Malaysia

[*] Corresponding author: sitizawiahmd@um.edu.my

Kata kunci: Electromyography; aktiviti otot; pengambilan oksigen; degupan jantung; jarak capaian

1.0 INTRODUCTION

Currently, workers in many industrial workstations perform manual tasks that involved repetitive arm motions. The repetitive strain injury (RSI), occupational overuse syndrome (OOS), and cumulative trauma disorder (CTD) reflect the notion that repetition and overuse were the key factors resulting in injury or disease [1]. The main cause of RSI is frequent and repetitive movements of a part of the body. Other factors may be contributed by poor postures, application of excessive force and in adequate breaks from tasks. The cost of work-related musculoskeletal disorders such as CTDs in U.S industry was considerably high, although not all were due to improper work designs. Jeffress (1999) indicated that approximately 650,000 workers suffer serious injuries and illnesses caused by overexertion, repetition, and other types of physical stress every year. Such injuries could cost U.S. businesses between $15 to $20 billion dollars a year in workman compensation [2].

It is known that an improved layout of workplace might allow the operators to use hands for reaches and contra lateral movements, thus preventing the operators from potential serious back injury problems [3]. In addition, designing the workplace, equipment, and tools to meet the simultaneous goals of increased production and efficiency of the operation and decreased injury rates for the human operator [4]. Therefore, it is important to design ergonomically the workplaces for workers to assume good posture and to develop ergonomic guidelines for designing workplaces. Understanding and planning for capabilities and limitations of users are critically important to obtain optimum design of a product or system for initiated by workers [5].

Farley (1955) and Squires (1956) had provided quantitative measures of this area for the able bodied part [5]. Reach capability was limited by body dimensions, joint ranges of motions, balance, and strength for some tasks [6]. The reach envelope is 3-Dimensional space among people in carrying out physical work activities at fixed location. The limits of envelope were determined by functional arm reach which, in turn, was influenced by the direction of reach and the nature of the task performed [7]. Typically the normal reach area (NRA) dimensions are presented as 5th, 50th and 95th percentile curves. In theory, the 5^{th} percentile curve results in a design within which the majority (95%) of operators could comfortably reach in performing tasks [5]. The normal area of the left hand may be similarly established. Since movements are made in the third dimension, as well as in the horizontal plane, the normal working area also applies to the vertical plane [4]. The normal workspace is a reach envelope on the table surface enclosed by the sweep of the forearm, while the upper arm and torso are kept close to the vertical. The maximum workspace maybe defined by the reach envelope as enclosed by the movement of the extended arm with vertical torso.

The maximum reach, even in vertical or horizontal reach, is limited by how far a person can reach and grasp object above or below shoulder height without stretching or bending. It is taken from the surface of one's shoulder to the center of one's closed hand (or extended middle finger for button operation) [7]. To reach beyond the NRA the operator must extend the upper limb to reach points or objects. With the upper limb fully extended and the trunk stable, the maximum reach envelope (MRE) can be measured when subjects move their upper limbs throughout their full range of motion [5].

In standing workspace, the limit of the workspace envelope for a user while standing can be shown as the space within which an object can be reached and gripped comfortably. While standing the arms and hand are most powerful when elbows are close to the body side and bend at the right angles or more, and with slight extension. The work surface should allow this kind of manual work that requires strength. Any work that involves motion, a distance maybe involved. The greater the reach, the larger the muscular effort induced, control and time required. Hence, it is important to minimize reach distances.

The rate of heart beats is a function of workload and oxygen uptake. Heart rate may pose as a signal that integrates the total stress on the body and can be used as an index of the physiological cost of work. Any increase in oxygen uptake over and above that required for basal metabolism can be used as an index of the physiological cost to an individual of performing tasks. When an individual commences on a task from rest, heart rate and oxygen consumption increase to meet the new demands. Since this response is not instantaneous, the immediate requirements for energy are met by local (i.e., muscular) energy stored [8].

Increases in oxygen uptake and heart rate may cause general fatigue and pain, and may induce a variety of musculoskeletal disorders that leads to risk of injuries. Repetitive or prolonged exertion can cause pain through accumulation of waste products in the muscles (cramp). The increases on muscle activity would cause general fatigue and may lead to musculoskeletal disorders. Many industrial workers experience arm, shoulder and neck problems when performing tasks that require repetitive arm movements.

Thus, the objective of this study is to identify the effect of different reach distances on oxygen uptake (VO2), heart rates (HR) and muscle activities.

2.0 METHOD

2.1 Subjects

Ten subjects (5 males and 5 females of university students) of aged between 22-25 years, with no past medical history of musculoskeletal and metabolic problems were involved in the study. The subjects were informed about the experimental procedure before commencing the experiment. All the participants were right hand dominance. The age and anthropometric data for five males and five females are shown in Table 1.

Table 1 Age and anthropometric data

	Male					Female				
	Dimensions (cm)				Age	Dimensions (cm)				Age
No	**ARF**	**FHL**	**STEL**	**SEL**	**(years)**	**ARF**	**FHL**	**STEL**	**SEL**	**(years)**
1	81.0	46.0	103.7	34.5	22.0	74.1	40.5	98.0	31.8	24
2	79.5	43.0	103.7	33.8	25.0	75.0	44.2	97.3	32.7	23
3	85.6	48.5	112.2	35.3	24.0	68.5	40.8	97.1	31.1	24
4	80.6	47.2	105.1	34.0	25.0	75.2	42.6	103.7	32.7	25
5	81.0	43.6	104.0	31.4	25.0	76.9	41.5	101.0	33.8	24
Mean	81.5	45.7	105.7	33.8	24.2	73.6	41.8	99.4	32.4	24.0
Stdev	2.35	2.34	3.66	1.46	1.30	3.61	1.69	2.86	1.17	0.71
5th %ile	77.68	41.83	99.74	31.40		67.70	38.98	94.73	30.44	
95th %ile	81.54	45.66	105.74	33.80		73.63	41.75	99.42	32.35	

ARF = Arm reach forward
FHL = Forearm-hand length
STEL = Standing elbow Length
SEL = Shoulder elbow length

2.2 Procedure

The experimental setup is illustrated in Figure 1.

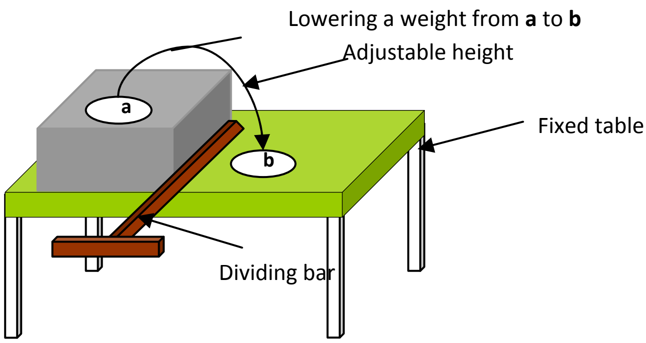

Figure 1 Experimental setup

Repetitive lifting tasks were simulated in the experiments. Subjects were required to accomplish repetitive tasks consisted of lifting and lowering a 3kg metal disk of dumbbell between two fixed locations (**a** and **b**; point **a** was adjustable within a subject's standing elbow height, **b** which was on the fixed table at the height of 76 cm). Adjustable platform was provided to maintain subject's standing elbow height. Lifting frequency was set to a rate of 10 lifts per minute.

The distances of the subjects from the edge of table were varied in each experimental session e.g normal, maximum and extreme reaches. The distances depended on the anthropometrical data of subjects. The exact dimensions of reach envelope of subjects are used in the experiments. Lifting in normal reach distance required a subject to stand close to the table's edge, so that the subject's forearm remains horizontal while doing the task. As for the maximum reach a subject stood at a distance, such that the arm and elbow were fully extended while carrying the task. Finally for the extreme reach, subject was required to simulate the lifting task at a distance beyond the subject's maximum reach at the rate mentioned above. The task involved torso flexion and elbow extension. The position for reach subject was determined prior to the actual experiment.

The experiment involved three consecutive sessions of 15 minutes duration for each reach distance and 15 minutes rest was provided between two consecutive sessions. The sequence of the lifting task was within normal, maximum and extreme reach and was randomized for each subject. It took one and a half hour for each subject to complete the whole experimental procedure.

2.3 Instrumentation

The vernier O_2 Gas sensor was used to determine residual oxygen levels in exhaled air. This method was used to determine the oxygen uptake throughout each lifting session. Vernier O_2 Gas sensor measured the oxygen concentration in the range of 0% to 27% using an electrochemical cell. The cell contained a lead anode and a gold cathode immersed in an electrolyte. When oxygen molecules entered the cell, they get electrochemically reduced at the gold cathode. This electrochemical reaction generated a current that was proportional to the oxygen concentration between the electrodes. The current was measured across a resistance to generate a small voltage output. The voltage output was conditioned and read by a Vernier labpro interface. The exhaled air for each subject was collected after each lifting session. All subjects were asked to take in breath and exhale into a bottle. The tip of O_2 Gas sensor was then placed into the opening of the bottle and pushed into the bottle. The percentage of the oxygen uptake by the subject could be obtained by deducting of the percentage of oxygen volume in exhaled air and the percentage of the atmospheric oxygen level.

The heart rate was measured using exercise heart rate monitor. Considered the most accurate way to gauge performance. Similar to electrocardiograph (ECG), the sensor monitored the electrical signal of the heart. Each time the heart beats, and electrical signal was generated. Heart rate monitor was a direct measurement of heart rate during the exercise. The heart rate monitor consisted of a transmitter belt, plug-in receiver and an elastic strap. The transmitter belt was worn just below the chest and held in place by an elastic strap. The plug-in was connected to an interface (Vernier Labpro). The transmitter detected each heart beat through two electrodes and transmited the heart rate information to the plug-in receiver. The plug-in receiver wirelessly received the transmission and passed a 3-volt pulse for each heart beat detected by the interface. Similar to the measurement of oxygen uptake, the data was collected after each lifting session. Figure 2 shows the Vernier O_2 Gas sensor, the exercise heart rate monitor and vernier labpro interface.

(a)

(b)

(c)

Figure 2 (a) Vernier O_2 gas sensor with (b) Exercise heart rate monitor and (c) Vernier LabPro interface

Muscle activity was measured using EMG electrodes attached to the skin of each subject. DataLab 2000 (sampling to frequency 2700Hz, filters 60Hz, signal range ± 10 volt) software was used for data acquisition and analysis by exporting to excel file. Its function was to detect the electrical signal in the muscle when contractions occurred in the muscle. Figure 3 shows the EMG equipments. Three types of muscles: biceps brachii, anterior deltoid and upper trapezious, each from arm, shoulder and neck region were selected based on their functionality during the implementation of the designed task [10]. The main mover in forearm flexion was the bicep brachii when the palm was in supine position. The deltoid muscles defined as a thick, triangular muscle covering the shoulder joint was used to raise the arm from of the body. The anterior deltoid muscle was considered as one of the prime movers in inward rotation of the upper arm. The three muscles were measured simultaneously using the EMG.

(b) Three lead electrode cables

(a) DataLab 2000 Systems

Figure 3 EMG equipment

2.4 Data Collection

The experimental data were collected during the experimental process that included the oxygen uptake in percentage, heart rate in beat per minute (bpm) and root mean square (RMS) for the muscle activity in milivolt (mV). The concentration of the oxygen uptake (in percentage) by the subject was obtained by deducting the percentage of oxygen volume in exhaled air from the percentage of the atmospheric oxygen level. The graphs for oxygen concentration were plotted by using the raw data obtained from LoggerPro software during the measurements, where the oxygen volume was assumed to be the constant value of the graph.

The signal for heart rate was picked up after the subject completed each task. The results obtained were in the unit of beat per minute (bpm). For EMG, the commonly used parameters in the time domain was the root-means-square (RMS) values which represented the signal power and might eliminate some of the noise factor that could affect results. The raw data was divided into five cycles and each cycle was three minutes. The RMS value was the mean RMS value from cycle 1 to cycle 5.

3.0 RESULTS

3.1 Physiological Responses

The increase of physiological mean responses over normal reach envelopes is shown in Table 2.

Table 2 The increase of mean effect of physiological responses over normal reach envelopes

	Metabolic (%)		Muscular activity (EMG) %		
Workspace reach envelope	Oxygen Uptake	Heart Rate	Biceps brachii	Anterior Deltoid	Upper Trapezious
Maximum	10.87	7.81	1.42	97.60	89.74
Extreme	39.13	16.97	1.16	187.20	129.03
Mean	25.00	12.39	1.29	142.40	109.38

The findings of the study indicated that the mean oxygen uptake increased from maximum to extreme over normal reach distance with the value of 10.87% and 39.13% respectively. In addition, the mean heart rate also increased from maximum to extreme over normal reach distant values from 7.81% and 16.97% respectively.

3.2 Oxygen Uptake

The concentration of the oxygen uptake (in percentage) by the subject can be obtained by deducting percentage of oxygen volume in exhaled air from the percentage of the atmospheric oxygen level. Figure 4 shows the graph for atmospheric oxygen levels, while Figure 5 shows the oxygen concentration of subject F1 when working in normal reach envelopes. Figure 6 shows the comparison of oxygen uptake for the subjects while they are working in normal, maximum and extreme reach envelope.

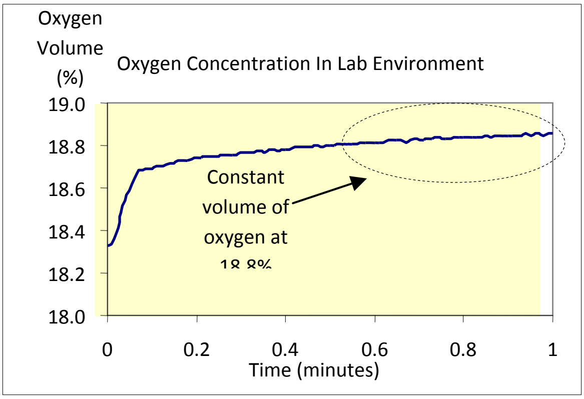

Figure 4 Atmospheric oxygen levels of subject F1

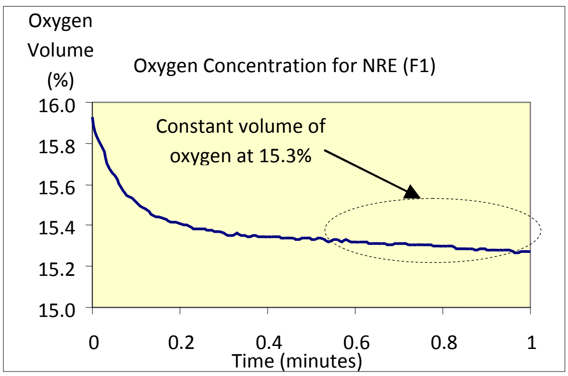

Figure 5 Oxygen concentration of subject F1when working in normal reach envelope

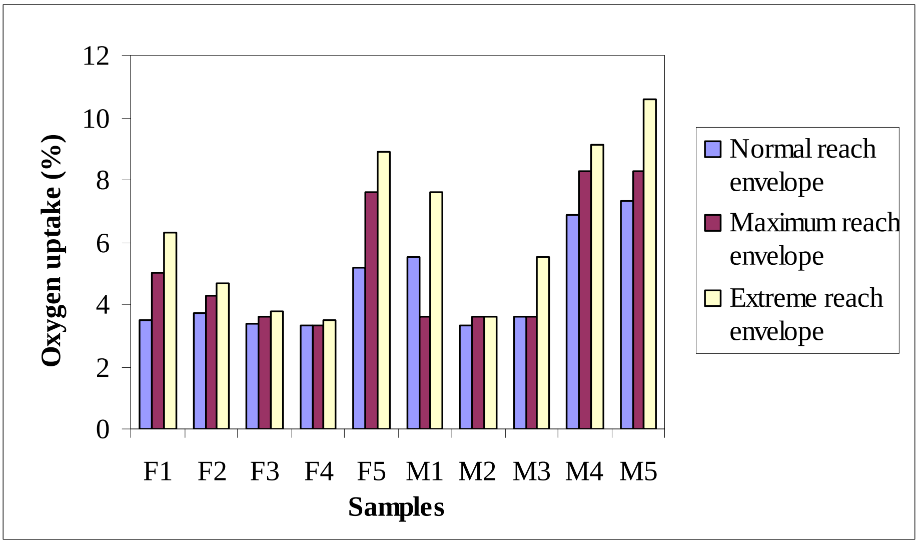

Figure 6 Level of oxygen uptake for the subjects when workingin the normal, maximum and extreme reach envelope

Obviously, the level of oxygen uptake increased from normal to maximum and to extreme reach envelope. The values for oxygen uptake were varied within the subjects from 3.3% - 6.9% for normal reach envelope, 3.3% - 8.3% for maximum reach envelope and 3.5% - 10.6% for extreme reach envelope. The results indicated that most of the males consumed more oxygen while performing tasks compared to that of female subjects.

3.3 Heart Rate

The signal for heart rate was collected after the subject completed each task. Figure 7 shows the comparison of heart rate for the subjects while they were working in normal, maximum and extreme reach envelopes. Figure 7 indicated that majority of the subject showed an increase in the level of oxygen uptake when the working area increased. Nevertheless, there was an exception as that shown by subject F1 and M4, with slight decrease in heart rate when working in maximum and extreme reach area respectively. For the overall results, there was no significant difference of heart rate between male and female subjects.

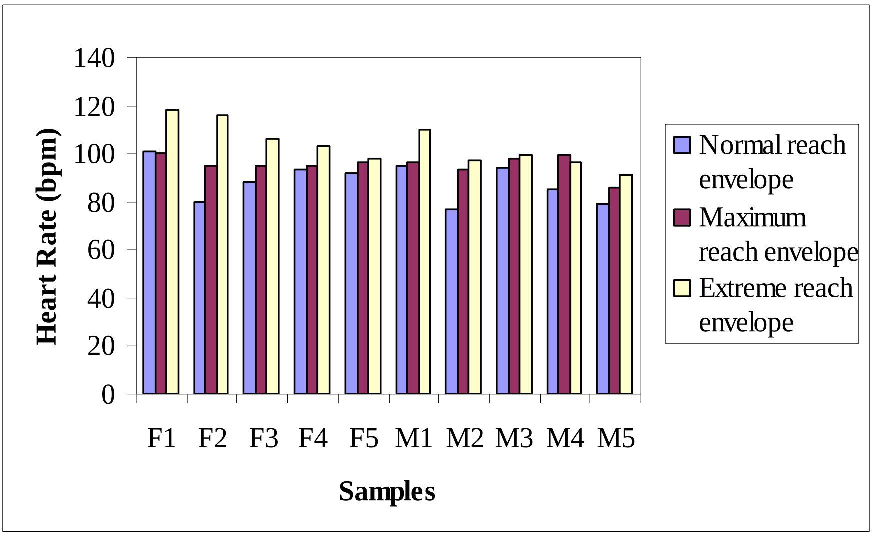

Figure 7 Heart rate for the subjects when working in the normal, maximum and extreme reach envelope

3.4 Muscular Activity

Figures 8 to 10 show the different muscle activity while performing task in the normal, maximum and extreme reach envelope. The EMG values for anterior deltoid and upper trapezious indicated a consistent increase for majority of the subjects with the increasing reach envelope. Figures 8 to 10, clearly show that the RMS values for biceps brachii muscles for male is much higher than that of female. On the other hand, the RMS values for trapezious muscles show higher values for females than males subjects. As for deltoid muscles the RMS values did not show any significant difference either for males or females subjects. After completed the tasks, subject complaint of back pain.

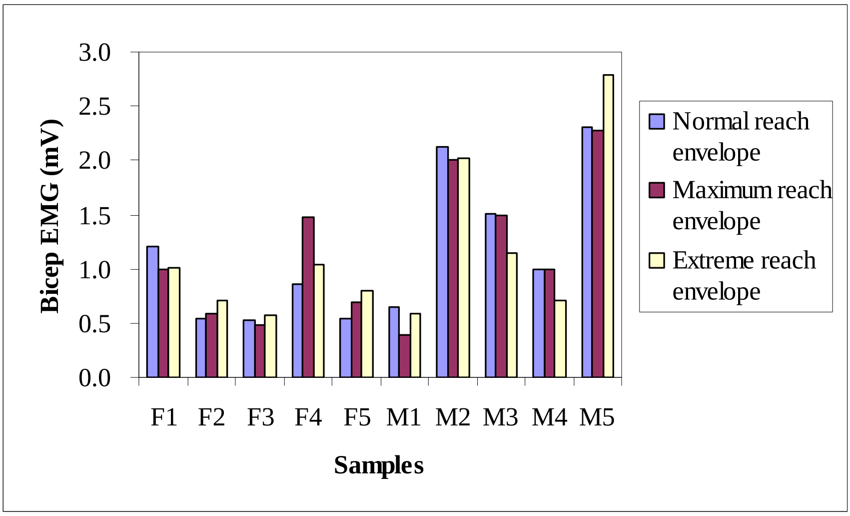

Figure 8 Muscular activities (bicep brachii) for the subjects when working in the normal, maximum and extreme reach envelope

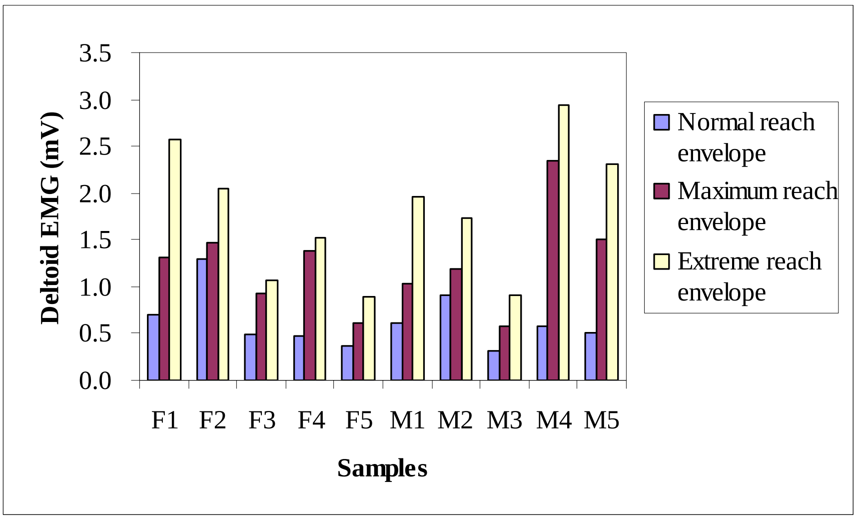

Figure 9 Muscular activities (anterior deltoid) for the subjects when working in the normal, maximum and extreme reach envelope

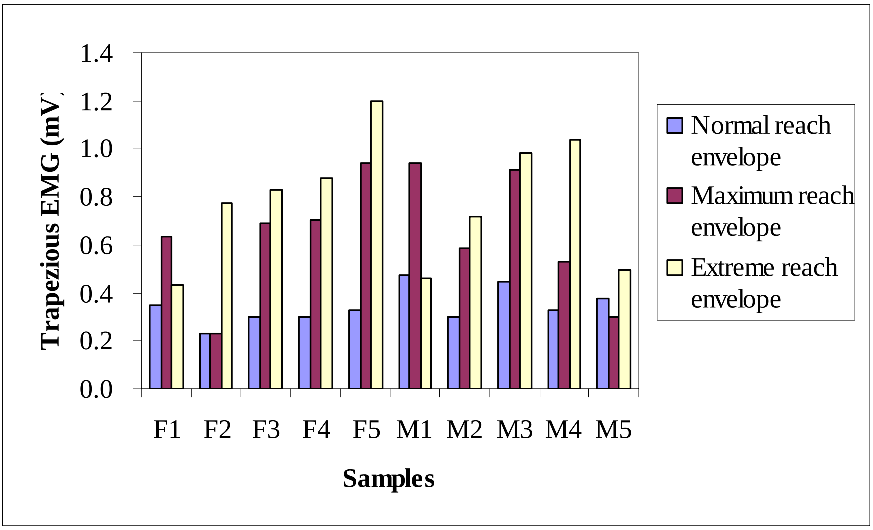

Figure 10 Muscular activities (upper trapezious) for the subjects when working in the normal, maximum and extreme reach envelope

4.0 DISCUSSION

In an industrial workstation, controls, materials, tools and equipment that require manual operation should be placed in the area that can be reached and operated efficiently and safely by most users. Small changes in reach dimensions can have a considerable impact on workers' productivity and comfort. In order to design work system, it is important to involve the structural and functional characteristic of the workers. One approach is to establish work area boundaries based on dimensions of relevant body parts such as forearm lengths (e.g. Farley, 1955; Squires,1956a; Squires, 1956b; Squires 1959, Konz & Goels 1969, Das & Grady 1983, Das & Behara 1995, Wang, Das & Sengupta 1999as quoted by [11])). Other researchers have begun by constructing a human model which considered the degree of freedom of the joints, used to derive the work area boundary (e.g., Jax, Rosenbaum, Vaughan, & Meulenbroek, 2003; Kee & Karwowski, 2002; Zhang & Chaffin, 2002; Zhang, Kuo, & Chaffin, 1998 as quoted by [11]). Both approaches in delimiting work area do not incorporate constraints based on actual human performance. Human performance must be central to any discussion of designing safe and effective workplace layouts. Work can be handled most efficiently when workers perform their task within an area that permits the use of comfortable arm, trunk, and head movements. Avoiding awkward postures and extreme movements not only reduce workers' risk for musculoskeletal injuries, but also increase work efficiency. In addition, physiological cost to perform the task has to be considered in relation to workers productivity and comfort.

The current study was used to determine whether worker physiological cost during task performance would increase significantly with the increase in reach level. Subjects physiological cost was measured in terms of oxygen uptake (VO2), heart rate (HR) and muscular activity with EMG in arm, shoulder and neck muscles. The reach areas (normal, maximum and extreme) described was based on each subject anthropometric dimension. There was no anthropometry limitation in selecting subjects due to the limited size of subjects that limit the generalization of findings.

Oxygen uptake and heart rate were considered as the main indicator of general fatigue in prolonged repetitive task [8]. They reflected the whole body stresses. Thus the standing posture at work confirmed that repetitive task in extreme distance caused high energy consumption and hence could enhance the chance of early fatigue. The EMG value for anterior deltoid and upper trapezious muscles increased tremendously over 100% when the reach distance increased from normal to maximum and to extreme reach. On the other hand, the bicep brachii muscles only showed an increase of 1% for such situation, indicating less effect on the muscle (bicep brachii). The higher value of EMG indicated that the muscle contraction was higher due to task characteristics. This was due to the increased of workspace envelope that increased the muscle contraction. The findings are in line with Sagupta and Das, 2004 [9] who indicated, that worker physiological cost would increase significantly with the increase in workspace reach levels. Higher muscle contraction may cause muscle fatigue and pain. In the current study, normal reach area was the least physiological cost (oxygen uptake, heart rate and muscle activity). This physiological cost was related to biomechanical aspects of the body when doing the task. In normal reach area, the distance from hand and the object was the least compared to maximum and extreme reach area. With regards to muscular effort, moment of force would increase if weight or distance increased [12]. The weight was fixed at 3kg, but the distance changes from normal to maximum and extreme. With the change in distance, moment of force would increase, hence physiological load. The results of this study show that oxygen uptake, heart rate and muscular activity increase as with the distance increase (normal to maximum to extreme).

Furthermore, repeated muscle fatigue may induce the musculoskeletal disorder. On the other hand, working in normal reach envelope will slow down fatigue at the average of 12%for heart rate, 25% of oxygen uptake, 1.29% of bicep brachii, 142% of anterior deltoid and 109% of upper trapezious. These are consistent with previous studies that showed that 85% of workers' maximum arm-only reach distance would delineate the boundary for normal work area, defined as the area where workers could work comfortably and efficiently [11].

After completed three consecutive sessions of 15 minutes duration for each reach distance (normal, maximum and extreme), subjects complaint that they suffered of back pain. This is the effect of standing position, reach distance and the lifting task with 3kg load. To reach beyond the normal reach area the operator must extend the upper limb, involved torso flexion and elbow extension. This posture would develop back pain. Besides that, prolonged standing also associated with development of low back pain [13].

5.0 CONCLUSION

The study indicated that the workspace reach distance is a significant factor which affects the physiological cost. The trend showed an increase in the physiological responses when the work reach distance increased. The lifting task, posture and load on current study also developed back pain. Whole body fatigue, as well as, localized muscular fatigue and consequential hazards for occupational musculoskeletal disorder can be minimized by limiting reach levels. This suggests that industrial tasks should be performed within the normal reach workspace area whenever possible and working within the maximum and extreme reach workspace area must be avoided at all costs. Working in normal reach envelope will reduce fatigue, enhance comfort, improve worker productivity and reduce the possibility of injury.

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