Effect of upper limb muscle activity on different envelope reach measures

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\textbf{ABSTRACT:} Effect of upper limb muscles activity on different reach envelopes were investigated in this study. Ten samples of five females and five males aged between 22-25 years were involved in the study. Subjects were required to accomplish the tasks consisted of repetitive lifting and lowering a three-kg metal disk of dumbbell between two fixed locations. In each experimental session (normal, maximum and extreme workspaces), the distance of the subject from the table edge was varied accordingly. Muscle activity was measured by using surface Electromyography (EMG). The electrodes attached to the skin of each subject’s on biceps brachii, anterior deltoid, and upper trapezius muscles. The muscles were selected based on their functionality during the implementation of the designed task. The results showed that the mean RMS of EMG for anterior deltoid muscle and upper trapezius muscle were increase when working from normal to maximum and to extreme reach level. Anterior deltoid showed an increase of 97.6\% to maximum reach level, and 187.1\% to extreme reach level. While upper trapezius muscle showed an increase of 89.7\% and 128.9\% for maximum and extreme reach level compare d to normal reach level. However, biceps muscle showed an exception which is increase from normal to maximum but slightly decrease from maximum to extreme reach level. The findings indicated that standing repetitive with bench lifting task under normal, maximum and extreme reach envelope effects significantly anterior deltoid and upper trapezius muscles.

\textbf{Keywords:} “Reach envelope, biceps brachii, anterior deltoid, upper trapezius, EMG”.

1. INTRODUCTION

Currently, workers in many industrial workstations perform manual tasks which involved repetitive arm motions. Generally the tasks do not involve heavy exertion, but the risk of fatigue, pain and repetitive strain injuries (RSI) in arm, shoulder and neck region are prevalent [1]. RSI also called cumulative trauma disorders (CTDs) occurs from repeated physical movements or resulting from overuse of a tool. Data from the National Safety Council (1997) suggest that 15-20\% of workers in key industries are potential risk for CTDs, and 61\% of all occupational injuries are associated with repetitive actions [2].

It is known that an improved layout of workplace enables the operators to use their hands correctly and lengthy reaches and contralateral movements, thus preventing the operators from potential serious back injury problems [3]. Reach capability is limited by body dimensions, joint ranges of motions, balance, and strength for some tasks [4]. The reach envelope is 3-Dimensional space within carry out physical work activities at the fixed location [5].

Numerous studies beginning with the work of Farley (1955) and Squires (1956) have provided quantitative measures of normal and maximum area for the able bodied part [6]. 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 vertical. This area is specific to every individual and depends on body size, but generally the normal reach area is about 18 inches from the body. This area represents the most convenient zone within which motion may be made by that hand with normal expenditure of energy. The maximum reach is taken from the surface of your shoulder to the center of your closed hand (or extended middle finger for button operation) [5]. The maximum area is typically 18 – 24 inches. This area may be varying from the people of different physical sizes and different length of their arm. It is less for people with shorter arms and more for people with longer arms. Excessive reaching can increase torque (force) around a joint. The further people lift a weight away from the body the more force is exerted in order to handle the weight. Increased force may increase the risk for injury. Awkward postures also affect circulation. To reach beyond the NRA (normal reach area) the operator must extend the upper limb access the reach point or objects. One concept is to think about the "reach envelope." This is the semi-circle that your arms make as you reach out. Things that you
use frequently should ideally be within the reach envelope of your full arm. Things that you use extremely frequently should be within the reach envelope of your forearms. The normal and maximum working reach envelopes shows in figure 1.

![Figure 1: Normal and maximum working reach envelopes in the horizontal plane](Porter, S and Chhibber, S. 2007)

Electromyography (EMG) is an experimental technique concerned with the development, recording and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fiber membranes. In the laboratory, electromyography (EMG) has frequently been used to assess the effects of workplace layout and tool design on the upper extremity musculature (Ayoub and Lo Presti, 1971; Tichauer, 1978; Strasser, 1991; Freivalds and Eklund, 1993 as quoted by [7]). Through careful recording and processing techniques, EMG can provide information about the relative activation of individual muscle groups during select work activities. Increases on muscle activity would cause general fatigue and may lead on variety of musculoskeletal disorders. The objective of the study is to identify the effect of different reach envelope on biceps brachii, anterior deltoid and upper trapezius muscles.

2. METHOD

The methodology is explained in four subsections that are experimental subjects, procedure, instrumentation and data collection.

2.1 Experimental Subjects

Ten subjects (five males and five females) of aged between 22-25 years with no past medical history of musculoskeletal and metabolic problems involved in the study. The subjects were informed about the experimental procedure before commencing the experiment. All the participants were right hand dominance. The mean, 5%tile and 95%tile anthropometric data for 5 males and 5 females are showed in Table 1.

<table>
<thead>
<tr>
<th>Dimension (cm)</th>
<th>Male/Female</th>
<th>Mean</th>
<th>5%tile</th>
<th>95%tile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm reach forward</td>
<td>M</td>
<td>81.50</td>
<td>77.68</td>
<td>85.40</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>73.60</td>
<td>67.70</td>
<td>79.55</td>
</tr>
<tr>
<td>Forearm-hand length</td>
<td>M</td>
<td>45.70</td>
<td>41.83</td>
<td>49.49</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>41.80</td>
<td>38.98</td>
<td>44.52</td>
</tr>
<tr>
<td>Standing elbow height</td>
<td>M</td>
<td>105.70</td>
<td>99.74</td>
<td>111.74</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>99.40</td>
<td>94.73</td>
<td>104.11</td>
</tr>
<tr>
<td>Shoulder elbow length</td>
<td>M</td>
<td>33.80</td>
<td>31.40</td>
<td>36.20</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>32.40</td>
<td>30.44</td>
<td>34.26</td>
</tr>
</tbody>
</table>

2.2 Procedures

The experiment setup is illustrated in Figure 2. Subjects were required to accomplish the task consisted of repetitive lifting and lowering a three-kg metal disk of dumbbell between two fixed locations (a and b; point a is adjustable according to the subject’s elbow height, b which is on the fixed table is at the height of 76 cm). Adjustable platform was also provided to maintain subject’s standing elbow height. Lifting frequency is set to a rate of 10 lifts per minute.

In each experimental session, for normal, maximum and extreme workspaces, the distance of the subject from the table edge was varied. It is to simulate working within different workspace. For lifts in normal workspace, the subjects stood close to the table edge such that the subject’s forearm remained horizontal while holding and moving the weight between the two points. For maximum workspace, the subject was positioned away from the table edge, such that the elbows remained fully extended through out the lift and
move. For both normal and maximum workspaces, the torso was kept vertical. For lifting in the extreme workspace, the subject was asked to move back to the farthest possible distance from where he or she could lift the weight and could maintain the lifting and moving task at the specified frequency. This posture involved torso flexion in addition to the elbow extension. This position was determined by trial and error for each subject and was maintained during the task session using the dividing bar.

Figure 2: Experimental setup

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

2.3 Instrumentations

Muscle activity was measured using EMG electrodes attached to the skin of each subject. Three types of muscle: biceps brachii, anterior deltoid and upper trapezius, each from arm, shoulder and neck region were selected based on their functionality during the implementation of the designed task [8]. The three muscles were measured simultaneously by using EMG. DataLab 2000 software is use to acquire data and analysis the data by export to excel file. Its function is to detect the electrical signal in the muscle when contractions happen in the muscle.

(a) Three lead electrode cables (b) DataLab 2000 Systems

Figure 3: EMG equipment

2.4 Data Collection

Muscle activity was measured by using EMG electrodes attached to the skin of each subject. Three types of muscle: biceps brachii, anterior deltoid and upper trapezius, each from arm, shoulder and neck regions were selected based on their functionality during the implementation of the designed task [8]. The main mover in forearm flexion when the palm is in supine position is the biceps brachii. The deltoid muscles defined as a thick, triangular muscle covering the shoulder joint, used to raise the arm from the side. The anterior deltoid muscle was considered as one of the prime movers in inward rotation of the upper arm. Bipolar surface electrodes were used to collect electrical signals from the muscles for arm, shoulder, neck, and lower back, which were transmitted to a personal computer using an optical encoder box worn at subjects’ waists.

While for the designed task of this experiment, it required moving the weight from one point to another, anterior deltoid was expected to generate the moment required to initiate the inward rotary motion of the upper arm. In addition, especially during working within the maximum and extreme workspace, the lifting task was associated with extension and adduction motion of the upper arm. The upper trapezius was considered as one of the stabilizer muscles of the scapula. The three muscles were measured simultaneously by using EMG. However, the forearm muscles were not monitor as well; the forearm muscles mostly produce forces in the palm and fingers. This is due to the postures of the wrist and the grip anticipated among
the three different workspaces do not change during the experimental session. Consequently muscular activities in the forearm muscles were unaffected by working in different workspaces.

This study was mainly concerned in the determination of the significant effect of different reach level to human upper limb muscle activity while performing repetitive task. The experimental data were collected during the experiment process in form of root mean square (RMS). According to De Luca, 1997 as quoted by [9]), RMS value of myoelectric signals is the most sensitive of all amplitude parameters and contains maximum information. Hence EMG signals from various muscles were processed to obtain the mean of RMS values.

3. RESULTS AND DISCUSSION

The experiment requires subjects to perform repetitive task, which is set to a frequency of 10 lifts per minute for 10 minutes. The commonly use parameters in the time domain is RMS. RMS values represent the signal power and may eliminate some of the noise factor that affects the results. The means of RMS values for each subject and each task were calculated for and used to perform statistical analysis. RMS was computed by using this equation:

\[
x_{\text{rms}} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x_i^2} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}}
\] (1)

Where, \(x\) value is the raw data from DataLab and \(n\) is the number of raw data \(x\).

Figure 4 to 6 show the mean RMS value of EMG from ten samples in normal, maximum and extreme reach envelope for different muscle (biceps brachii, anterior deltoid and upper trapezius).

![Figure 4: Mean RMS of EMG for biceps brachii](image)

![Figure 5: Mean RMS of EMG for anterior deltoid](image)
From the above figures, it can be seen that the mean RMS of EMG values for anterior deltoid and upper trapezius showed a consistent increase for majority of the samples with the increasing of reach envelope. The figures also showed that the mean RMS of EMG values for biceps brachii muscles for male is much higher than the female values. On the other hand, the mean RMS of EMG values for trapezius muscles shows a higher value for females than males. As for deltoid muscles the mean RMS of EMG values did not show any significant different either for males or females.

The changes of mean RMS of EMG for working on normal, maximum and extreme reach envelopes is shown on Table 1.

Table 1: The increase percentage of mean RMS EMG over normal reach envelopes

<table>
<thead>
<tr>
<th>Workspace reach envelope</th>
<th>Muscular activity (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Biceps brachii</td>
</tr>
<tr>
<td>Normal</td>
<td>1.125</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.141</td>
</tr>
<tr>
<td>Extreme</td>
<td>1.138</td>
</tr>
</tbody>
</table>

The EMG value for anterior deltoid and upper trapezius muscles increased tremendously over 100% when the reach distance increased from normal to extreme reach. On the other hand, the biceps brachii muscles showed an increased of only around 1% for such situation, indicating less effect on the muscle (biceps brachii). A similar findings has been observed by [10] that conducted study of ‘reach and repetition affect health at work’, found that the increase in RMS of EMG for anterior deltoit, upper trapezius and erector spinae showed a significant increase from normal to maximum and from maximum to extreme workspaces.

The higher value of EMG indicated that the muscle contraction is higher due to task characteristics. From the result of experiment, it shows that the higher of the reach level, the higher the contraction of muscle. Higher muscle contraction may cause muscle fatigue and pain. Furthermore, repeated muscle fatigue may induce the musculoskeletal disorder.

4. CONCLUSION

The study indicated that the workspace reach envelope is a significant factor which affects the muscle activity of a worker. The trend showed an upward in the muscle activity responses when the work reach envelope increased. The results from this study indicated that whole body fatigue, as well as localized muscular fatigue and consequential hazards for occupational musculoskeletal disorder can be minimized by limiting reach levels to the lowest category for a light manipulative type of industrial task. Thus, it is suggested that industrial tasks should be performed within the normal workspace whenever possible, and working within the maximum and extreme workspace must be avoided in all cases, if possible.
REFERENCES


