Physical strength and fatigue measurement of the shoulder in a sitting position

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Abstract
This research evaluated the working postures of the shoulder at nine combinations of the shoulder positions of 30 degrees of adduction, 30 degrees of abduction, and neutral(0 degree) as well as 60 degrees, 90 degrees, and 120 degrees of shoulder flexion. Six males and 3 females participated in the study to collect maximum voluntary contractions (MVC), psychophysical workload (Borg’s RPE) and mean power frequency (MPF) of electromyography (EMG) representing muscle fatigue during one-arm lifting at sitting position. Seven surface electrodes were attached to the upper trapezius, lower trapezius, anterior deltoid, posterior deltoid, serratus anterior, elevator scapulae and infraspinatus. In result, MVC and RPE showed the similar trend such that the greater the angle is, the more physical stress was reported. For female subjects, MVC was about 45% to 63% of male subjects. The trapezius muscle showed lower MPF value than any other muscles at 30 degrees of adduction and 90, 120 degrees of flexion. The both anterior and posterior deltoid muscles were the most fatigued muscle in this study. This study provided informative and realistic data on shoulder strength and fatigue at sitting posture and might be helpful for ergonomic workplace design to prevent musculoskeletal injuries.

Keywords: EMG, Fatigue, MVC, RPE, Shoulder

Introduction
Most manufacturing industries replaced workers with automated machines, but automobile industry with assembly line and repair shop still use a human power for performing tasks. Shoulder pain is a common problem experienced by about 30.4% of workers who are exposed to manual material handlings (MMH) or assembly in South Korea [6]. Though the frequency of occurrence of musculoskeletal disorders in the United States has been decreasing, the upper extremity-related disorders tend to only slightly decrease and even occasionally increase [2].

Previously, Park and Kim [6] compared the degrees of muscular fatigue in various working postures of the shoulder muscles. It was found that the pattern of muscle fatigue was different depending on the shoulder postures. Kim et al. [5] measured maximum voluntary contractions (MVC) and psychophysical workload in various shoulder postures [7]. They found that the great workload was observed during particular abduction, adduction and flexion angles. Stephen et al. [8] examined shoulder muscle fatigue at 45 degrees of abduction, 90 degrees of flexion with 60% MVC condition. Mean power frequency (MPF) values dramatically decreased in the middle deltoid during 30-second measurement.

The results of the previous studies can be summarized such that a few shoulder muscles were used more than others to perform particular tasks. Accordingly, the magnitude of muscle fatigue differed as to working conditions and shoulder postures.

Therefore, the purpose of this study is to measure the strength and fatigue of shoulder muscles in various shoulder postures and to find the functional characteristics of the related shoulder muscles in terms of MVC, psychophysical workload, and EMG, to provide field data that can be used to prevent musculoskeletal problem of the shoulder.

Method
Participants
Six male and three female participants who had no shoulder pain for the last 6 months volunteered for the study. Their average age, height, and weight were 27.1 (±6.7) years, 169.6 (±8.4) cm, and 64.7 (±14.6) kg, respectively.

Apparatus
The measuring frame for shoulder strengths was fabricated during arm lifting with the shoulder. It consisted of a force monitor and a load cell (maximum capacity of 50 kg-force (kgf), Bongshin Co., South Korea) installed on a base structure and a swivel chair fixed on a wooden platform. A cable and a handle were connected to the load cell. The chair was adjusted for comfortable sitting postures. The arm was reached to the handle and participant adjusted their position to create the shoulder angles according to the experimental conditions of abduction and adduction [5].

Seven channels of bipolar surface electrodes (Coulbourn Instrument Inc., USA) were used with a gain of ×2500, the bandpass filter of 1 to 1000 Hz, and the sampling rate of 1024 Hz for muscle activity measurement. An analog to digital (A/D) converter card and a personal computer were used for data acquisition.

Procedure
After informed consent, the participant was seated on the chair with the feet off the ground and then the torso, lower legs, and upper legs were strapped on the seat to
isolate them from any involvement of force exertions during the experiment. Surface electrodes were attached to the upper and lower trapezius, anterior and posterior deltoid, serratus anterior, elevator scapulae and infraspinatus in an appropriate location [3].

The participant was asked to reach the arm toward the handle comfortably with less than 2 degrees of elbow flexion and pull up the handle with the palm facing up. The participant was allowed to use the scapula to pull the handle up to measure MVC. To maintain the torso in neutral, the horizontal distance from the shoulder to the handle was adjusted by changing the position of the clamp connected to the base structure on the wooden platform. MVC was measured twice with given shoulder flexion, adduction, and abduction angles. Each measurement took 5 seconds. If there was a variation between two MVC values, an additional MVC measurement was made. Then 30% MVC was calculated from the average value of MVCs for EMG measurements. The participant maintained the shoulder in each of nine pre-determined shoulder postures for 60 seconds. The signals of the first and last five seconds were not included in the analysis of MPF. Five-minute resting periods were provided to the participant between trials for both MVC and EMG measurements.

**Experiment Design**

The participant exerted the shoulder muscles for 10 times in different postures. Independent variables for statistical analyses included a neutral shoulder and nine combinations of three levels of shoulder flexion angles in the sagittal plane (60 degrees, 90 degrees, and 120 degrees) and three levels of shoulder adduction and abduction angles in a transverse plane (-30 degrees of adduction, 0 degree of neutral, and 30 degrees of abduction). The shoulder angles were measured with a digital goniometer placing its center at the acromion.

Dependent variables were MVC, Borg’s rating of perceived exertion (RPE) as a psychophysical measure [7], and MPF. Borg’s RPE were collected after each trial of MVC measurements. MPF as a muscle fatigue measure was obtained from the EMG signals by using fast fourier transform (FFT), and then linear regression analyses were applied to the MPF values normalized to the first MPF value as to every trial and muscle.

**Results**

**MVC and RPE**

As the shoulder flexed, MVC dramatically decreased and shown in Figure 1. In addition, MVC was the greatest at the neutral position of the shoulder and decreased at both adduction and abduction in Figure 2. These results were similar to the findings of Kim et al. [5]. Females exerted about 45% to 63% of male in terms of MVC (Figure 3). Åstrand and Rodahl [1] found the similar results that young females with an age of 20 to 30 years had about 50% less MVC than males.

Borg’s RPE increased as the shoulder flexed at adduction and abduction position (Figure 4). The increasing trend was similar with the results of Kim et al. [5]. Therefore, more than 90 degrees of flexion and 30 degrees of abduction were the most stressful position for the shoulder in terms of MVC and RPE.
EMG

The R-square values of linear regression analyses ranged from 0.46 to 0.82. The MPF values of the upper trapezius decreased at both 90 degrees and 120 degrees of shoulder flexions, but this phenomenon was more apparent at 120 degrees. The decrease of its MPF values was greater with adduction than with abduction. The lower trapezius had a significantly lower MPF values with abduction than neutral and adduction positions. The deltoid muscle showed the decrease of MPF values at all shoulder postures. In particular, it had lower values of MPF at neutral and 60 degrees of flexion. The serratus anterior, elevator scapulae and infraspinatus had lower values at abduction and greater than 90 degrees of flexion.

![Figure 5. MPF values of all muscles at 30 degrees of abduction and 120 degrees of flexion.](image5)

![Figure 6. MPF values of the anterior deltoid muscle at various shoulder postures.](image6)

Males showed greater decrease of MPF values with the upper trapezius and posterior deltoid muscles at 30 degrees of adduction, while females had lower values in the trapezius and anterior deltoid muscles at 30 degrees of abduction. The deltoid muscles always decreased at every posture, and the serratus anterior, elevator scapulae, and infraspinatus showed similar decreases for both genders.

Discussion

This study found that the MPF values of the upper trapezius muscle significantly decreased at 30 degrees of adduction and as the shoulder flexed, while those of the lower trapezius muscle decreased at 30 degrees of abduction instead and as the shoulder flexed. It could be concluded that the specific muscles are more vulnerable to fatigue than other muscles. The deltoid muscles particularly showed the consistent decrease of MPF values at all shoulder positions so that it had the high likelihood of being injured during shoulder-related work. Stephen et al. [8] and Ebaugh et al. [4] found the similar results to this study that fatigue occurred in the deltoid muscles was greater than the other shoulder muscles. However, Stephen et al. [8] did not consider various shoulder postures and dynamic working movements.

Since gender difference was significant in MVC and muscle fatigue, it should be considered in assembly operations or manual material handling jobs using the shoulder.

Conclusions

This study found that the muscular characteristics of the shoulder in terms of maximum voluntary contractions, psychophysical workloads, muscle fatigue in various working postures. Specifically, this study would help ergonomists or safety personals realize potential postural risk factor for the shoulder during MMH jobs while sitting. The result of this study may be an assistive information to design workplace to prevent musculoskeletal disorders of the shoulder.

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References
