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Loading Thresholds for Rotator Cuff Muscles

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Abstract: Work-related musculoskeletal injuries of shoulder have high prevalence and long recovery time. Among all body parts shoulder injuries are the cause of most days away from work in the US. Although several previous studies deal with ergonomics risk factors for shoulder injuries there is lack of research that indicates a safe loading threshold for rotator cuff muscles. In this study, rotator cuff muscles were studied under different force conditions with a goal of identifying a safe loading threshold. Electromyography data were recorded from supraspinatus, infraspinatus and teres major under 15%, 30%, 45%, and 60% of maximum voluntary contraction (MVC) conditions. Median frequency data were used as the indicator of fatigue. A negative relation between force and slope of median frequency line was observed for supraspinatus and infraspinatus and no noticeable trend was observed for teres major. Supraspinatus showed significant fatigue increment for loads more than 30% of MVC and infraspinatus showed similar trend at 45% MVC level and above.

Keywords: Shoulder injury, rotator cuff muscles, electromyography

1. Introduction

Shoulder injuries caused the highest number of days away from work among all body parts in 2014. The median days away from work caused by shoulder injuries is 26 days while the average of median days away from work is 10 for all the body parts [BLS, 2015]. Recovery of an injured shoulder takes long time and only 50% of shoulder injuries fully recover after 6 months [Croft P et al, 1996]. This proportion becomes only 60% at the end of first year [Van der Windt et al, 1996].

Work-related musculoskeletal disorders (MSDs) have a significant impact on overall health and economics. In a recent report on worker compensation data in the state of Maryland, it was reported that the average cost per shoulder injury was higher than the average cost per lower back injury claim ($25,378 per claim compared to $22,447) [Warnken, 2012].

Among the shoulder structures rotator cuff is the most prone to injuries and the associated pain and discomfort [Ninkovic et al, 2014]. Based on American Academy of Orthopedic Surgeons (AAOS) in 2006, out of 7.5 million people who met a doctor for shoulder injuries 4.1 million suffered from rotator cuff problems [AAOS, 2009].

Despite the frequency and high cost of shoulder injuries, very little research has been done in establishing safe loading limits for shoulder muscles, particularly the rotator cuff muscles. Therefore, the aim of this study was to measure rotator cuff muscle fatigue under different force exertions. By analyzing the fatigue data safe loading limits for the rotator cuff muscles will be established.

2. Methods

2.1 Approach

A lab-based study was performed using human participants. Participants performed shoulder exertions under four different joint demands. Force and muscle activity data was recorded from rotator cuff muscles (Supraspinatus, Infraspinatus and Teres Major) to quantify safe loading limits for each muscle.

2.2 Participants

Three healthy male participants with no history of musculoskeletal diseases or shoulder pain was selected for the data collection. Participants were undergraduate and graduate students at West Virginia University and their mean (SD) Age, weight, and height of the participants were 24.5 ± 5.6 yr, 76.6 ± 10.8 kg, and 174.3 ± 5.3 cm, respectively. Participants were required to complete a physical activity readiness questionnaire to ensure that no serious health concerns are present (i.e., heart disease, seizures, etc.). All participants were also required to read and sign an approved West Virginia Institutional Review Board consent form.

2.3 Equipment

2.3.1 Strength measurement system

HUMAC NORM (Computer Sports Medicine, Inc., MA, USA) system was used to perform shoulder exertions with different joint demands. The system provides accurate methods for force exertion by isolating different muscles. Test speeds, ranging from 1 to 500 deg/sec, and the range of motion is controlled by the computer. A high resolution, full color graphics display monitor can be used for providing visual feedback to the test participant. (Figure 1).

2.3.2 Electromyography (EMG) system

Rotator cuff muscles activity was recorded using Bagnoli -16 desktop EMG system (Delsys Inc., Boston, USA). The system mainly consists of EMG sensors (parallel bars from 99.9% pure silver and 92 dB of Common-mode rejection ratio), a main amplifier unit, input modules, input cable, power supply, and other peripheral cables. 1000 Hz was selected for the frequency of EMG data. (Figure 2).

Figure 1. HUMAC NORM system and seat arrangement.

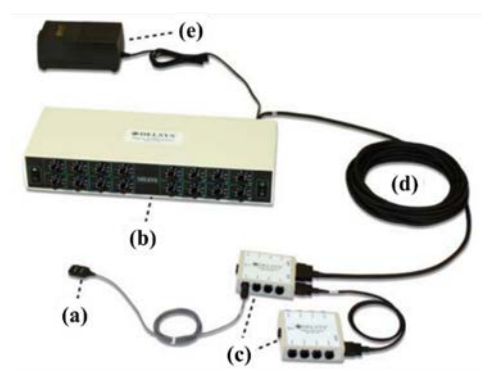

Figure 2. Parts of the Bagnoli -16 EMG system – (a) EMG sensor, (b) main amplifier (desktop) unit, (c) input modules, (d) Input module cable, and (e) power supply.

2.4 Experimental Design

A two-part experiment was designed for this study. First, maximum voluntary contraction (MVC) was measured for each rotator cuff muscle (Supraspinatus, Infraspinatus and, Teres Major). Then, measured MVC was used as a reference for second part of the experiment - the participants performed four exertions at 15%, 30%, 45% and, 60% of the MVC for each muscle.

Since the exertions are dependent to the measured MVC, the process of MVC measurement had to be done precisely. MVC posture and action can be seen in table 1 [Boettcher et al. (2008)]. For each muscle, MVC measurement was repeated until three values within 10% of each other is measured. At least two minutes rest time was provided to the participant between each MVC measurement. Three muscles and four exertions were randomly chosen and each exertion was performed for maximum of one minutes.

Table 1. Muscle name, posture and action for MVC measurement of rotator cuff muscles.

Muscle	MVC posture	MVC action
Supraspinatus	The shoulder abducted in the scapula plane to 90° with elbow rotated internally to 45 degree.	Arm abduction with resistant force applied at wrist.
Infraspinatus	The shoulder flexed in frontal plane to 125 degree.	The participant will resist a force applied above the elbow toward the inferior angle of the scapula.
Teres major	The shoulder 45° abducted and elbow 90° flexed.	The participant will internally rotate their arm with a resistive force applied at the wrist.

2.5 Experimental Procedure

Participants were asked to provide their demographics (height, weight, and age) and informed of the basic procedure to be used for the data collection process. They were then seated in the HUMAC NORM and secured to the chair to ensure that no external forces or movements can affect the measurements. Next, the participant practiced force exertion using the HUMAC NORM system.

In this study, three rotator cuff muscles were tested: (1) Infraspinatus; (2) Supraspinatus; (3) Teres major. The test participant was prepared for muscle activity data collection by placing EMG electrodes on the three muscle. MVC strength for each muscle was measured using the HUMAC NORM to maintain the posture and Delsys EMG system to measure muscle activity.

Each MVC trial was approximately 7 seconds long with at least 2 minute break in-between trials to minimize fatigue. As soon as the trial timer on the HUMAC NORM begins, test participants gradually increased their force level until they reach the maximum and hold the maximum for three seconds. The participant will then gradually return to a level of no force. For the safety of the participant it is crucial that they do not increase their force exertion level too rapidly, as this could lead to muscle strain.

Once the trials for the MVC have been completed the data was exported into Excel to determine 15%, 30%, 45% and 60% MVC levels. Subsequently, the test participant was performed %MVC exertion trials. Using Humac Norm System, Participant was able to see the value of the exerted force and was able to reach and stay at the target torque value. Duration of each trial was controlled at maximum 1 minute. The EMG data was recorded continuously during the trial. Between each exertion, minimum of three minutes rest time was provided to the participant.

2.5.1 Independent variable

For this study, the independent variable is the force exerted by the test participant. Each participant was instructed to apply four levels of force: 15% of MVC 30% MVC, 45% MVC and 60% MVC. Each exertion was performed for a duration of 1 minute.

2.5.2 Dependent variable

The dependent variable for this research project is the muscle fatigue developed by the participant. During the shoulder exertions, the muscle activity data was recorded continuously using the EMG system. The muscle activity data was analyzed to estimate muscle fatigue.

2.6 Data Processing and Statistical Analysis

The raw EMG data for all exertions and each electrode was demeaned and full-wave rectified. EMG data was transformed to frequency domain using fast Fourier transformation to estimate median frequency. The one minute exertion was divided to 10 divisions and then median frequency was calculated for each division. A decrease in the median frequency is considered as a sign of muscle fatigue [Chowdhury and Nimbarte, 2015].

3. Results and discussion

The data was discussed in two different parts in this chapter. First, duration of exertion and then fatigue data was discussed.

3.1 Duration of exertion

In this study, all %MVC exertions were designed to be one minute maximum and the goal was to exert the force as close as possible to one minute (participants were told to stop at any time they felt any discomfort). Order of muscles and %MVC exertions for each muscle was randomized to avoid biased data. Figure 3 shows the average data for duration of exertion for each muscle.

Infraspinatus has the most variation among all three muscles. Only in 15% exertion all participants were able to exert the force for full minute. As we increased the force the duration of exertion decreased gradually. For supraspinatus all participants were able to exert the 15% and 30% force for full minute and duration started to decrease for 45% followed by 60%. Teres major did not show any variation for any of the exertions. All participants were able to exert the force for full minute.

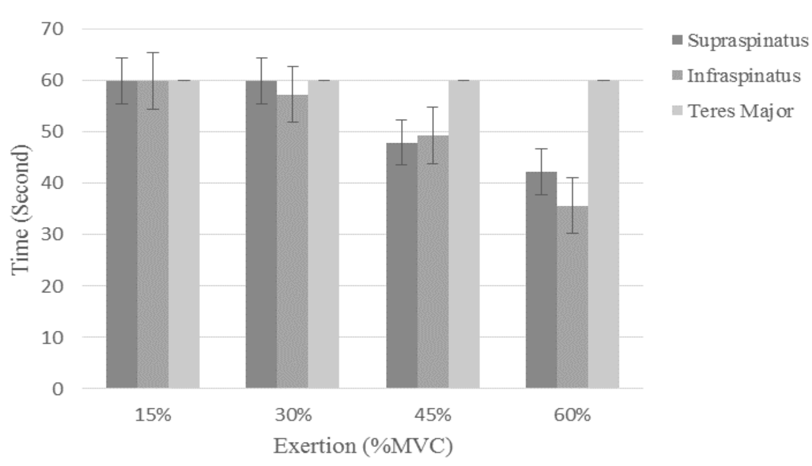

Figure 3. Average time of exertion for each muscle at %MVC.

3.2 Median frequency

Average slope of median frequency data was calculated for same exertion of all participants and results are shown in figure 4. Among three muscles, teres major data did not show any noticeable fatigue trend. Authors believe fatigue trend can be seen in longer duration of exertion for teres major or in more intense force exertion. This supports the fact that number of reported injuries for teres major are very low [E. Martin et al, 2012].

Infraspinatus and Supraspinatus showed similar behavior to the force increment. By moving from 15% to 30% we see an increase in the slope and after that by moving to 45% and 60% slope decreases. The supraspinatus shows significant decrease in median frequency slope from 30% to 45% exertion. Based on this fact we can conclude the start point of fatigue for this muscle is 30% of the MVC. For infraspinatus we have the significant drop in median frequency slope from 45% to 60% exertion. This means for this muscle's start point of fatigue is 45% of the MVC. Supraspinatus is the muscle that fatigues in the lowest level of exertion among rotator cuff muscles. This supports the fact that supraspinatus injuries are the most frequent injuries among rotator cuff muscles [Ninkovic et al, 2014].

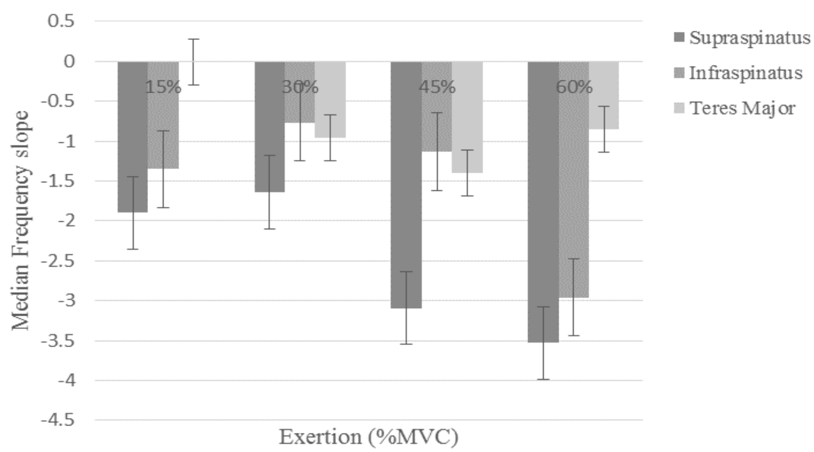

Figure 4. Average time of exertion for each muscle at %MVC.

The final result of this study indicates that not all the rotator cuff muscle show the same behavior at different exertion levels. Loading limits defined in this study can provide a basis to design and/or evaluate the tasks performed by athletes and/or workers in a variety of occupations with the goal of minimizing shoulder injuries.

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