

Gender Differences in Safe Loading Thresholds for Rotator Cuff Muscles

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Abstract: The purpose of this study was to investigate gender differences in fatigue development and strength of rotator cuff muscles during isometric exertions. There have been many studies on shoulder in the past and they indicate that rotator cuff complex causes most of the pain and discomfort in shoulder injuries. Generally, women have a higher prevalence rate of musculoskeletal pain but there is a limited research that investigated gender difference for fatigue and strength of rotator cuff muscle. In this study, ten healthy participants (five male and five female) with no history of musculoskeletal diseases or shoulder pain were selected for the data collection. Electromyography and strength data were recorded from supraspinatus, infraspinatus and teres minor under 15%, 30%, 45%, and 60% of the measured maximum voluntary contraction for each muscle. Changes in the median frequency of EMG activity was used as the indicator of fatigue. Endurance and strength of female participants was 45% to 60% less than that of male participants. Similar trend of fatigue development in infraspinatus and teres minor was observed for both genders, i.e., minimum median frequency slope was observed at 60% for infraspinatus and at 45% for teres minor.

Keywords: electromyography, rotator cuff muscles, shoulder injury

1. Introduction

In 2015, injuries of the shoulder complex were responsible for a median of 23 days away from work (BLS, 2015). This median value is higher than any other part of the body, with the next closest being knee injuries at a median of 16 days away from work. Shoulder injuries are not only extremely painful for workers but also very slow to recover (Croft et al, 1996). A single shoulder injury often opens the door to successive injuries and the compounding effect of life-long shoulder problems. Studies have shown that of the shoulder muscles, the most common source of discomfort is the rotator cuff muscles (Horsley et al, 2013). According to the Bureau of Labor Statistics, the total incidence rate of shoulder injuries is 8.4, with 9.6 being male and 6.8 being female (BLS, 2015). Although these injuries are more common in male workers, the prevalence in females still poses a substantial risk to women in the workplace due to the long duration spent away from work by those who sustain shoulder injuries. In addition, the fact that there is such a large difference between the genders may also hint to a difference in fatigue development and endurance capabilities in the shoulder complex.

Many different muscles have been studied to determine if there exists a difference in fatigability between male and female subjects. Several of these studies have shown that the gender of the subject does have an effect on fatigue development. A common trend shows that females show higher endurance capacities at lower percentages of MVC (Maughan et al, 1986). One of the explanations for this is the role of estrogen in fatigue development (Hicks et al, 2001). However not all studies follow this trend. According to a study performed by Dillon and Hicks on the adductor pollicis muscle, no difference in muscle fatigability was found between male and female subjects in three minutes of intermittent, 5 second-long MVC trials. These comparisons were done by finding an analogous initial strength across both sexes. Age, however, was a contributing factor. Younger subjects were much more resistive to fatigue development than older subjects. The data suggests that the resistance to fatigue decreases most significantly after menopause in female subjects (Ditor et al, 2000).

Prior research comparing the fatigue development between genders in isometric exertions of the rotator cuff muscles is limited. In order to establish safe loading thresholds for the rotator cuff muscles, both male and female subjects must be

studied. Therefore, the aim of this study was to compare the muscle behavior and fatigue development between 10 male and 10 female participants in an identical experiment.

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 Minor) to quantify safe loading limits for each muscle.

2.2 Participants

Twenty healthy male participants (ten male and ten female) with no history of musculoskeletal diseases or shoulder pain were 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 23.9 (3.1) yr., 69.35 (8.3) kg, and 173.6 (6.3) 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

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.

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.

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 Minor). 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 scapular 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 minor	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 on 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 minor. 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 MVC trials were completed, the data exported into Excel to determine 15%, 30%, 45% and 60% MVC levels. Subsequently, the test participant was performed percentage MVC exertion trials. Using Humac Norm System, Participant could see the value of the exerted force and could 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. Decrease of median frequency of the muscles' electromyographic (EMG) activity has been employed as an indicator of muscle fatigue (De Luca 1984).

3. Results and discussion

The data and results of this study will be discussed in two different parts in this chapter. First, duration of exertion will be analyzed and then median frequency slope as an indicator for fatigue will be discussed.

3.1 Duration of exertion

Figure 1 shows the male and female average duration of exertion for each muscle. All percentage 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 percentage MVC exertions for each muscle was randomized to avoid biased data.

Results demonstrate that all three muscles behave similarly in both genders to the load increment. Increase of MVC percentage leads to faster exhaustion of the participants and reduced exertion time. The analysis of variance (ANOVA) table

for muscles versus exertion time indicates that difference in mean exertion time values are statistically significant among muscles for both genders (table 2).

Time that takes for a muscle to lose its capability to exert a sustained force is the endurance time of that muscle. Endurance time is affected by different factors such as contraction force, anatomy of muscle fibers, type of task, and rest cycle (chaffin et al., 2006). Looking at the data from male participants, Infraspinatus has the most variation among all three muscles. Only in 15% exertion all participants could exert the force for full minute. As we increased the force the duration of exertion decreased gradually. For supraspinatus and teres minor, at none of the percentages all participants could exert the force for the full minute. Looking at female data, teres minor has the most variation among the muscles. For all muscles, at none of the percentages all participants could exert the force full the full minute. This could indicate a lower endurance time for females.

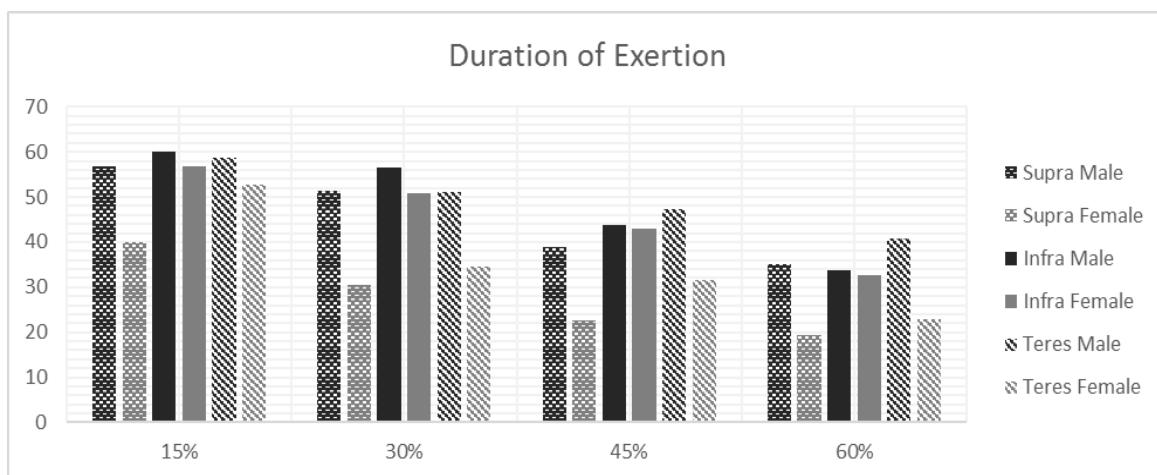


Figure 1. Male and Female average time of exertion for each muscle at %MVC

As anticipated, in both genders all three muscles had a lower exertion time at higher MVC percentages. Previous studies have shown a negative exponential relationship between endurance time and exertion level (Rohmert 1960, Sato et al., 1984, chaffin et al., 2006). Although all trials in this study were performed at maximum of 60 seconds the result of 30, 45 and 60% trials support the previous studies. It is predictable that performing the 15 and 30% trials to the endurance time will lead to exponentially negative correlation between force level and endurance time.

Table 2. Main effect of %MVC on duration of exertion for each muscle and each gender

Duration of Exertion (S) Mean										
	Male					Female				
	15%	30%	45%	60%	P-Value	15%	30%	45%	60%	P-Value
Supraspinatus	56.7	51.4	39	35.2	<0.001	39.9	30.5	22.7	19.2	<0.001
Infraspinatus	60	56.5	43.8	33.8	<0.001	56.9	50.7	43	32.7	<0.001
Teres Minor	58.6	51.2	47.2	40.7	0.003	52.8	34.5	31.6	22.9	<0.001

3.2 Median frequency

We consider muscle fatigue when there is a reduction in the ability of force exertion of the muscle in response to voluntary effort (Edwards 1981; Bigland-Ritchie et al., 1995). Restriction of blood flow which is one of the metabolic factors in muscle fatigue begins at forces around 10 to 20 percent of the MVC (chaffin et al., 2006). This is the reason that we have a negative median frequency slope even in most of the 15% MVC trials which is the lowest percent of MVC in this study.

Figure 2 shows the changes in the average median frequency slope for tested muscles for both genders. Looking at the figure, behavior of tested muscles can be compared to each other at different MVC percentages. The data of female participants show a negative median frequency slope for all the exertions. Which indicates muscles fatigue in all exertions. Among male participants, all exertions for infraspinatus and supraspinatus had a negative median frequency slope. While for teres minor, 40% of the 15% MVC trials showed a positive median frequency slope. Per this finding, it can be said that teres minor begins to show signs of fatigue in higher percentages than 15%. This might be one of the reasons that number of reported injuries for teres minor are very low compared to other rotator cuff muscles (Martin et al, 2012).

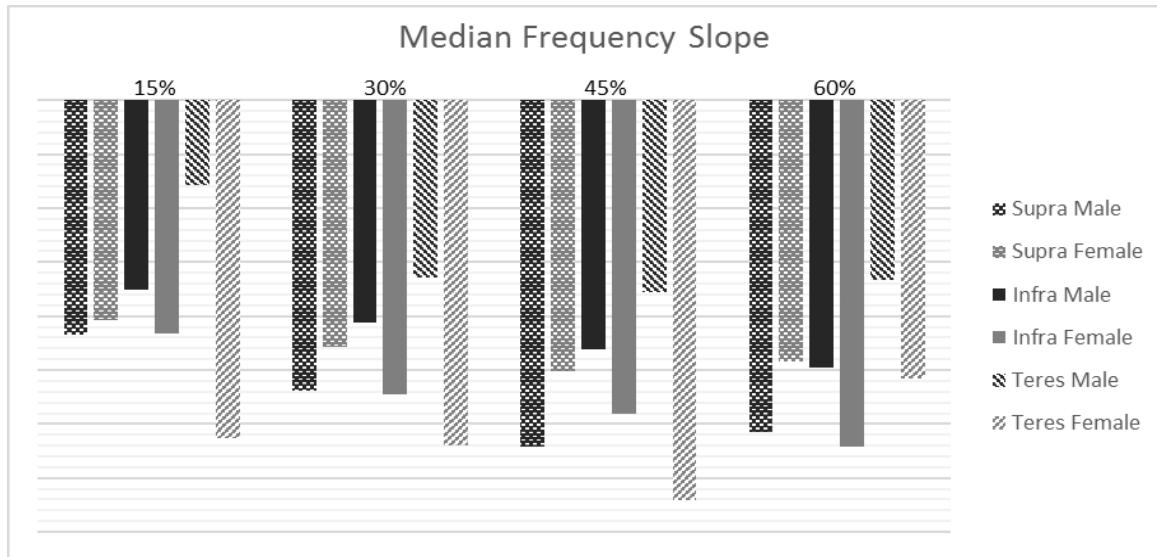


Figure 2. Male and Female average median frequency slope for each muscle at percentage MVC

Result of ANOVA demonstrated a significant effect of percentage MVC on median frequency slope for both genders. In table 3, the main effect of percentage MVC on duration of exertion and median frequency slope can be seen for each target muscle and both genders.

Table 3. Main effect of %MVC on median frequency slope for each muscle and each gender

Average Median Frequency Slope										
	Male					Female				
	15%	30%	45%	60%	P-Value	15%	30%	45%	60%	P-Value
Supraspinatus	-2.17	-2.68	-3.21	-3.07	0.003	-2.04	-2.29	-2.51	-2.43	0.004
Infraspinatus	-1.76	-2.06	-2.31	-2.47	0.018	-2.16	-2.72	-2.9	3.21	<0.001
Teres Minor	-0.78	-1.63	-1.78	-1.66	0.011	-3.13	-3.2	-3.71	-2.58	0.002

Looking at the supraspinatus and teres minor, there is a decreasing trend until 45% MVC which is the lowest average median frequency among all trials. The fact that 45% trials showed a lower median frequency slope than 60% trials can be explained by considering muscle ischemia. Ischemia is a condition that arises from lack of blood supply which results in lack of oxygen and muscles will not be able to function properly at this condition. Some muscles will be ischemic at forces higher than 50% of MVC (chaffin et al., 2006). Due to this fact, it can be said that at 60% trials supraspinatus and teres minor have become ischemic and were not able to generate force. It is possible that participants were recruiting different muscle(s) to maintain the required force for 60% trials. For both genders, among infraspinatus exertions the lowest median frequency slope was recorded in 60% trials. This muscle's median frequency shows a negative trend among 15% to 60% trials. It can be concluded that ischemia occurs in this muscle in higher percentages compared to other two muscles. Therefore, higher loading threshold can be assumed for infraspinatus.

Generally, slightly different muscle behavior was observed for male and female participants of this study. Endurance time was the main difference between two genders. Female participants showed significantly lower endurance time for supraspinatus and teres minor. Both genders had same trend of fatigue development for the same muscle.

4. References

Bigland-Ritchie, B., Rice, C. L., Garland, S. J., & Walsh, M. L. (1995). Task-dependent factors in fatigue of human voluntary contractions. In *Fatigue* (pp. 361-380). Springer US.

Boettcher CE, Ginn KA, Cathers I. (2008). Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG. *J Orthop Res.* 26:1591-7, DOI: 10.1002/jor.20675

Bureau of Labor Statistics (BLS), (2015). Nonfatal occupational injuries and illnesses requiring days away from work, Retrieved from: <http://www.bls.gov/news.release/pdf/osh2.pdf>

Chaffin, D. B., Andersson, G., & Martin, B. J. (2006). Occupational biomechanics. Hoboken, N.J: Wiley-Interscience.

Croft, P., Pope, D., & Silman, A. (1996). The clinical course of shoulder pain: Prospective cohort study in primary care. *BMJ*: British Medical Journal, 313(7057), 601-602.

De Luca CJ (1984) Myoelectrical manifestations of localized muscular fatigue in humans. *Crit Rev Biomed Eng* 11:251-279

Ditor, D.S., Hicks A.L.. The effect of age and gender on the relative fatigability of the human adductor pollicis muscle. *Can. J. Physiol. Pharmacol.* 78: 1-10, 2000.

Edwards, Richard HT. "Human muscle function and fatigue." *Human muscle fatigue: physiological mechanisms* (1981): 1-18.

Hicks, Audrey L., Jane Kent-Braun, and David S. Ditor. "Sex Differences in Human Skeletal Muscle Fatigue." *Exercise and Sport Sciences Reviews* 29.3 (2001): 109-12

Horsley, Ian G., Elizabeth M. Fowler, and Christer G. Rolf. "Shoulder Injuries in Professional Rugby: A Retrospective Analysis." *Journal of Orthopaedic Surgery and Research* 8.1 (2013): 9. Web.

Martin, E., Lotito, G., Viton, J. M., Delarque, A., Bensoussan, L., Coudreuse, J. M., & Lecoroller, T. (2012). Teres major and latissimus dorsi myotendinous injury in a professional boxer. *Annals of Physical and Rehabilitation Medicine*, 55, e258. doi:10.1016/j.rehab.2012.07.1056

Maughan, R.J., Harmon, M., Leiper, J.B., Sale, D., Delman A.. Endurance capacity of untrained males and females in isometric and dynamic muscular contractions. *Eur. J. Appl. Physiol.* 55: 1986, 395-400.

Ninković, S., Simjanovski, M., Harhaji, V., Kovacev, N., Janjic, N., & Obradović, M. (2014). Surgical treatment of shoulder rotator cuff injuries. *Medicinski Pregled*, 67(7-8), 239-245. doi:10.2298/MPNS1408239N

Rohmert, Walter. "Ermittlung von Erholungspausen für statische Arbeit des Menschen." *European Journal of Applied Physiology and Occupational Physiology* 18.2 (1960): 123-164.

Sato, H., Ohashi, J., Iwanga, K., Yoshitake, R., & Shimada, K. (1984). Endurance time and fatigue in static contractions. *Journal of human ergology*, 13(2), 147-154.

vanderWindt, D., Koes, B., Boeke, A., Deville, W., DeJong, B., & Bouter, L. (1996). Shoulder disorders in general practice: Prognostic indicators of outcome. *British Journal of General Practice*, 46(410), 519-523.