

EMG analysis of shoulder muscle fatigue during resisted isometric shoulder elevation

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Abstract

The purpose of this study was to determine if a difference existed in the rate of fatigue of select shoulder muscles during isometric shoulder elevation and if the measured rate of fatigue was consistent from day to day.

Shoulder muscle fatigue has been associated with alterations in joint mechanics and possibly contributes to shoulder dysfunction. While research exists, there is limited information on an objective and reliable measure of shoulder fatigue.

Sixteen asymptomatic subjects were evaluated. The subjects held a weight equivalent to 60% of his/her Maximum Voluntary Isometric Contraction (MVIC) while elevating in the scapular plane. Surface electrodes were applied to collect electromyographic activity from the upper trapezius, middle deltoid, serratus anterior, and lower trapezius muscles while the arm was held at 90° elevation. Data collection ceased when the subject was no longer able to maintain 90° of elevation. The subject then rested and a second trial performed. One week later, the two-trial procedure was repeated.

A significant interaction of trial \times day \times muscle was found for the rate of fatigue. Post hoc analysis revealed that the rate of fatigue of the middle deltoid was significantly greater than the other muscles tested. The intraday reliability was good for all muscles but interday reliability was poor except for the middle deltoid.

This study suggests that the middle deltoid appears to fatigue faster than the other shoulder muscles tested at the selected level of shoulder elevation. This should be considered in designing a rehabilitation program to develop a sequence that does not overly fatigue the middle deltoid.

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1. Introduction

Shoulder muscles are largely responsible for the dynamic stability and joint motion of the glenohumeral joint. When the shoulder muscles fatigue, joint mechanics become altered, thus possibly leading to pathologies such as tendonitis, impingement, and even subluxations or dislocations (McQuade et al., 1998). In addition, shoulder fatigue directly affects the way in which the scapula moves concomitantly with the humerus (McQuade et al., 1998). Since the kinematics of the shoulder depend

largely upon the surrounding muscles, fatigue in any of the muscles could lead to an alteration in the scapulohumeral rhythm. McQuade et al. (1998) demonstrated that as shoulder muscles fatigue, there is a resultant destabilization of the scapula and decrease in the scapulohumeral rhythm, primarily in the mid-range of arm elevation. Ludewig et al. (1996) also studied scapular orientation and muscle activity during shoulder elevation and found that scapular muscle activity increased with arm elevation in the scapular plane. The rate at which these muscles fatigue, as suggested by Bigland-Ritchie et al., depends on the force generated, how long each contraction is held, and the period of rest time in between contractions (Bigland-Ritchie et al., 1986). Other factors

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that influence fatigue may be the fiber-type distribution of the muscles (Gerdle et al., 1993; Komi and Tesch, 1979), the nerve conduction velocity of the fatiguing muscles (Hagberg, 1981), or even central factors within the Central Nervous System (CNS) that affect motivation to perform activities (Enoka, 1995).

One of the generally recognized tools to measure muscle fatigue is Electromyographic (EMG) analysis (Christova et al., 1999; Gerdle et al., 1989; Hagberg, 1981; Komi and Tesch, 1979; Ludewig et al., 1996; Merletti and Lo Conte, 1997; Moritani et al., 1986; Moseley et al., 1992; Öberg, 1995). While surface EMG does have limitations related to electrode placement, skin impedance, and cross-talk, similar information has been used to determine the rate of fatigue of different muscles (McQuade et al., 1998; Moritani et al., 1986). In addition, surface EMG has been shown to be a valid and reliable tool with regards to fatigue (Christova et al., 1999; Gerdle et al., 1989; Hagberg, 1981; Komi and Tesch, 1979; Ludewig et al., 1996; Merletti and Lo Conte, 1997; Moritani et al., 1986; Moseley et al., 1992; Öberg, 1995). Komi and Tesch suggested in 1979 that since type-II motor units are more easily fatigued than type-I motor units, it is reasonable to find a higher relative decrease in mean power frequency (MPF) in a muscle with a high initial mean power frequency than in a muscle with a low initial value (Komi and Tesch, 1979). Hagberg found a mean power frequency decrease in a fatiguing contraction due to alterations in the muscle energy metabolism (Hagberg, 1981). This decrease in the conduction velocity of the muscle fibers caused a shift in the power spectra towards lower frequencies. Gerdle et al. suggested similar results by finding shifts in the mean power frequency that were parallel with mechanical fatigue of the muscles, and finding significant degrees of local muscular fatigue in the trapezius and deltoid (Gerdle et al., 1989). Furthermore, the fatiguing phase correlated with a decrease in mean power frequency and an increasing degree of fatigue of type-II motor units, while the mechanical endurance level reflected the output level of mainly type-I motor units (Gerdle et al., 1989).

There has been an abundance of previous research regarding muscle fatigue, the reasons why muscles fatigue, and how muscle fatigue can affect joint mechanics (McQuade et al., 1998). However, there is still little research on reliable ways to measure muscle fatigue and determine how this information can be beneficial clinically. The ability to measure shoulder muscle rate of fatigue can enhance our understanding of shoulder muscle function and potentially provide a tool for fatigue assessment. The purpose of this study is to determine if the rate of fatigue of four shoulder muscles is different between muscles and if it is reliable for two trials on the same day and between two separate days of testing. Knowledge of fatigue patterns of shoulder musculature is of interest to the clinician when developing protocols for exercise order and progression.

2. Methods

2.1. Subjects

Human subject approval was obtained for assessment of 16 adults (9 female, 7 male) between the ages of 21 and 30 with no history of shoulder pain, pathology, or range of motion restriction. Mean age for the testing population was 23.6 ± 1.4 years, mean height was 171.8 ± 7.95 cm, and mean weight was 72.9 ± 8.72 kg. The test population was selected as a sample of convenience to assess normal subject muscle fatigue. Subjects were recruited from the university setting through requests for volunteers and represented a population of recreationally active young adults, none of which were professional athletes. All of the subjects were right-hand dominant. Each subject was given an oral and written summary of the study design and signed a consent form prior to participation.

2.2. Procedures

Muscle activity was recorded from the upper trapezius, middle deltoid, serratus anterior, and lower trapezius muscles. These muscles were selected because they are the primary muscles used to elevate the arm and upwardly rotate the scapula. Electrode placement locations were selected based on previous published studies involving EMG data collection from the muscles of interest (Basmajian and DeLuca, 1985; Hermens et al., 2000; Jensen et al., 1996; Ludewig et al., 1996; McQuade et al., 1998). Electrodes for the upper trapezius were placed 2 cm lateral to the midpoint between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius. The middle deltoid electrodes were placed midway between the deltoid tuberosity and the acromion process. The serratus anterior electrodes were placed at the apex of the lateral side of the thorax 3 cm caudal to the inferior spine of the scapula, obliquely upward and posterior. The electrodes for the lower trapezius were placed obliquely upward and laterally along a line between the intersection of the spine of the scapula and with the vertebral border of the scapula and the seventh thoracic spinous process. A ground electrode was placed on the left acromion process.

Electromyographic (EMG) recordings were obtained using a Myopac system (Run Technologies, LaGuna Hills, CA). Bipolar silver–silver chloride surface electrodes were used with a constant interelectrode distance of 2.0 cm. The skin was prepared by cleaning with alcohol and abrading with light sandpaper to reduce skin impedance (Basmajian and DeLuca, 1985; Hermens et al., 2000). Subject's skin was shaved prior to alcohol preparation if necessary. Self-adhesive bipolar surface electrodes were then attached (Medicotest Blue Sensor, Chicago, IL). The Myopac belt unit transmitted all raw EMG data at 1000 Hz via fiber optic cable to a receiver unit. The common-mode rejection ratio (CMRR) of the unit was

90 dB. The gain for the electrodes was set at 2000. In addition, the cut-off frequencies for the analog filters was 10–1000 Hz. Standard isometric manual muscle testing was performed to verify electrode placement with simultaneous visual observation of muscle activity on a PC type computer running DataPac 2000 software (Run Technologies, LaGuna Hills, CA) (Daniels and Worthingham, 1986). Individual amplifier gains were adjusted to correct any amplifier saturation that occurred during the manual muscle testing. Cross talk was detected visually during electrode application. Correct location was confirmed by activity with specific muscle activation in manual muscle test positions as described by Daniels and Worthingham (1986). If incorrect location of electrodes was suspected during this process, electrodes were removed and the process of electrode placement and verification was repeated until satisfactory. All data were recorded, stored, and analyzed using the Datapac 2000 software.

2.3. Maximal force production

Shoulder muscle fatigue was measured by having the subject perform an isometric contraction at 60% of their maximal voluntary isometric contraction force (MVIC). Sixty percent was chosen as research has shown that above this level of force output there is a greater recruitment of Type II muscle fibers as compared to lower levels of force output. The maximal force was determined on the first day of testing using a PowerTrack II Commander hand-held dynamometer (JTech Medical Industries, Salt Lake City, UT). For all subjects, the same researcher assessed the force output, as to eliminate discrepancies in usage. The fatiguing procedure was carried out isometrically for multiple reasons. Primarily it was selected to allow for greater control during testing. An isometric lift allowed for the researchers to have better control of subject performance, decreasing the possibility of compensatory strategies involving musculature not involved in the study. A secondary factor in selecting isometric contraction was consistency. As the subjects' maximum output was assessed in a static position, performing the fatiguing procedure in

the same manner allowed for a more accurate representation of muscle output. After performing one sub-maximal contraction to become comfortable with the feel of the testing position and contraction, each subject performed two maximum contractions against the hand-held dynamometer while in the 90° shoulder elevation testing position (Fig. 1), described below. The level of shoulder elevation assessed was chosen as 90° as it is a common functional position for many occupations. The mean value from the two trials represented a subject's 100% MVIC force, and the 60% MVIC was calculated from that number. Mean muscle output was used to determine MVIC as it was believed to be a more accurate representation of a subject's strength than a single contraction. For testing, the subjects sat in a rigid wood chair with a straight back while holding their shoulder at 90° elevation in the plane of the scapula, which for this study was 45° anterior to the coronal plane (Ludewig et al., 1996). The subject's forearm was at a point midway between supination and pronation such that while elevated, the radial styloid process was on the superior aspect of the forearm. The fatigue study was conducted over a series of two days, with two trials per day. On the initial trial day, the subjects' MVIC was determined, followed by a 5-min rest period. The subjects then performed the required elevation task to fatigue twice with a 5-min rest period between trials. A 5-min rest period has been shown to be an acceptable rest period following a localized muscle fatiguing contraction (Sabbahi et al., 1979). At the end of the second fatiguing test the surface electrodes were removed. The same electrode set-up application and two-trial fatiguing procedures using the previously determined weight was performed one week later. Subjects verbally consented to not performing any heavy lifting or upper extremity exercise 24 h prior to testing.

A vertically positioned stationary column was placed adjacent to the dorsal aspect of the subject's arm. The column functioned to assure the scapular plane position was maintained and was a vertical reference to assure the arm was maintained in a constant position. A line was drawn on the column at the level of the subject's radial styloid process while the shoulder was elevated to 90°. The subject

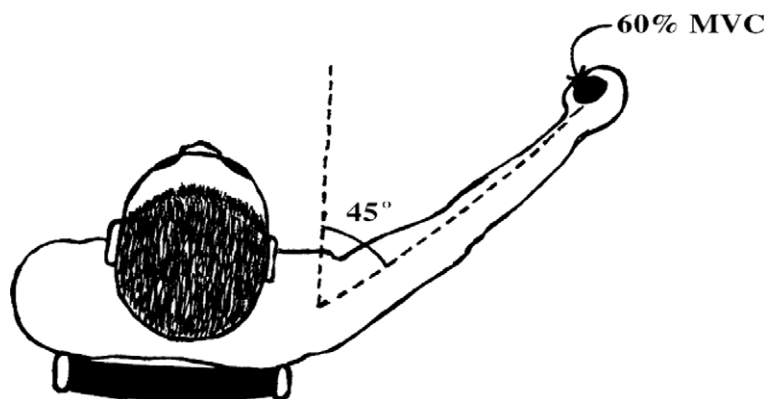


Fig. 1. Testing position.

was instructed to hold a bag loaded with weights equal to 60% of MVIC force $\pm 5\%$ at the level of the line. EMG analysis of muscle activity was initiated when the subject assumed control of the test load from one of the investigators. As one investigator terminated partial support of the load, a verbal cue was given to the secondary investigator, who then initiated computer analysis of subject output. The subject was considered fatigued and the trial over when the subject was no longer able to maintain his or her arm at the predetermined test position or if 30 s had elapsed with the subject maintaining the position. At the completion of the first trial, the subject was allowed a 5-min rest, after which a second trial was performed in the same manner. The trial was terminated at 30 s to provide more consistent data for the statistical analysis.

2.4. Data reduction

The raw data were transformed with the Fast Fourier Transform using DataPac 2000 software (Run Technologies, LaGuna Hills, CA) to determine muscle fatigue. A 512 ms repeating window was used starting 50 ms after initiating data collection. The median frequency for each 512 ms window was recorded for each muscle for both trials on each day.

2.5. Statistical analysis

Muscle fatigue was defined as a decrease in median frequency output over time. Least squares regression analysis was used to determine the linear decline in slope for each muscle's median frequency tested over time and used to determine differences in median frequency output per muscle per trial. Statistical Analytical System software (SAS Institute, Cary, NC) was used to compute a mixed linear model repeated measures ANOVA analysis of each slope

of muscle fatigue to determine any differences between rates of fatigue. The level of significance established for all statistical testing was $p < .05$. Post hoc analysis was then performed through a Bonferroni correction.

3. Results

Figs. 2 and 3 are the mathematical representation of changes in the median power frequencies (MDPF) of the tested muscles throughout the elevation task for each day. Table 1 shows the average slopes for each tested muscle for both test days. The average median power frequency shifts were most apparent in the middle deltoid and upper trapezius muscles, with the serratus anterior and lower trapezius exhibiting slightly lower changes. All of the muscles showed a decrease in median power frequency output indicating fatigue with this task.

Results of the repeated measures ANOVA demonstrated a significant interaction of frame \times day \times muscle ($F = 10.28$, $p < .01$). Post hoc analysis using a Bonferroni correction revealed that the rate of fatigue of the middle deltoid was significantly greater than the other muscles tested. The results also revealed good intrasession reliability for all of the muscles of interest and poor intersession reliability for 3 of the 4 muscles tested, excluding the middle deltoid. Table 2 demonstrates intrasession and intersession reliability for the muscles studied.

4. Discussion

The decrease in the median power frequency towards lower frequencies mainly reflects peripheral fatigue of the type-II muscle fibers (Gerdle et al., 1993, 1989). While all muscles fatigued as demonstrated by a decrease in MPF that reflected the mechanical fatigue of the muscles, the rate of fatigue was different for the muscles studied. These

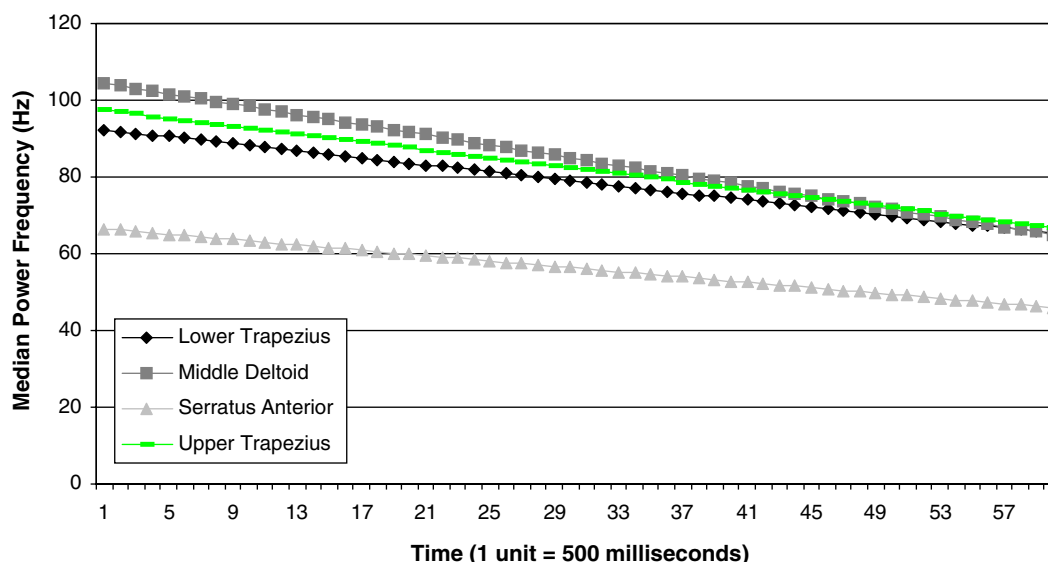


Fig. 2. Average shifts in median power frequency across subjects and trials for day 1.

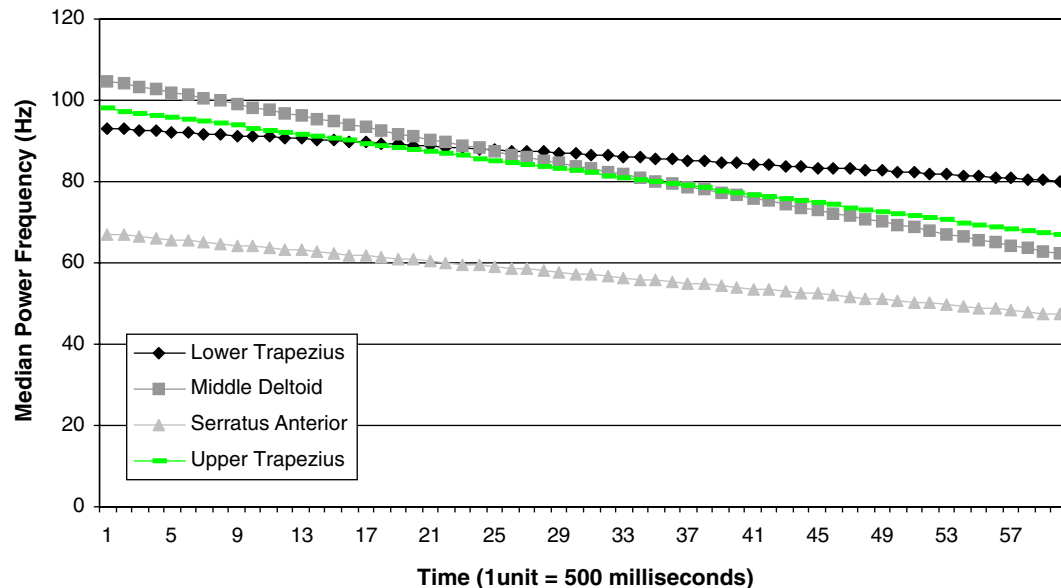


Fig. 3. Average shifts in median power frequency across subjects and trials for day 2.

Table 1
Average slopes of each tested muscle for both test days

Muscle	Average slope	
	Day 1	Day 2
Upper trapezius	-.5176	-.5280
Middle deltoid	-.6676	-.7242
Serratus anterior	-.3487	-.3349
Lower trapezius	-.4590	-.2191

Table 2
Reliability correlation coefficients

Muscle	Intrasession correlation	Intersession correlation
Upper trapezius	.82	.03
Middle deltoid	.80	.76
Serratus anterior	.75	.29
Lower trapezius	.83	.20

results suggest that during a sustained sub-maximal isometric contraction at 90° elevation in the scapular plane, the rate of fatigue for the middle deltoid is significantly greater than that of the upper trapezius, lower trapezius, and serratus anterior muscles. A shift to lower frequencies is indicative of muscle fatigue for both static and dynamic contractions as well as with varying intensities of exercise (Gerdle et al., 1993; Hagberg, 1981; McQuade et al., 1998; Moritani et al., 1986; Öberg, 1995). Such studies support the use of median frequency output analysis as an accepted tool for measuring muscle fatigue.

Based on previous research, mean fiber type proportions of muscles revealed that predominantly tonic muscles have a higher percentage of type-1 fibers and predominantly phasic muscles have a higher percentage of type-2 fibers (Johnson et al., 1973). Also, at higher force levels (>50% MVC), it is reasonable to assume that a higher proportion

of type-2 fibers are being utilized as compared to lower force levels (Gerdle et al., 1993). Since type-II fibers are easier to fatigue than type-I fibers, it is logical to expect a higher decrease in MPF in muscles with more type-II fibers, as reflected by the progressive fatigue of type-II fibers being recruited. While three of the muscles examined in this study act to stabilize and upwardly rotate the scapula, the deltoid is considered to be the primary humeral elevator. Since the middle deltoid's purpose is predominantly phasic in this aspect as compared to the other three muscles, it can be theorized that the middle deltoid will fatigue at a faster rate than the other three muscles. As the results of this study demonstrate, across trials and days, the middle deltoid fatigued at a rate significantly higher than the upper trapezius, lower trapezius, and serratus anterior.

Research in the past has shown that initial decreases seen in MPF during EMG analysis reflect a fatiguing of type-II muscle fibers (Gerdle et al., 1993, 1989; Komi and Tesch, 1979). However, to say that the greater decrease in MPF seen in the middle deltoid was caused because there were more type-II fibers present is unjustified. Other muscle interactions could have produced the same results, such as the fatiguing of unstudied rotator cuff muscles that would place greater stress on the middle deltoid and cause quicker fatigue. One hypothesis of the results of this study would be to suggest that the middle deltoid fatigues faster because it has more type-II fibers present. However, to conclude such cannot be done at this time. Further studies are needed to examine this issue in more detail before more questions can be definitely answered.

Another explanation for these results could be due to the testing position used in this study. According to research published by Inman et al. (1944), the middle deltoid increases activity from 0° to 110° of elevation, where it reaches a plateau and maintains this amplitude of activity

until full elevation. In contrast, the other three muscles used in this study become more active throughout elevation with no plateau (Bagg and Forrest, 1986; Inman et al., 1944). If this study were conducted in a similar manner at a higher elevation in the scapular plane, there may have been more stress placed on these other three muscles, and the rate of fatigue may have been different.

4.1. Limitations

The ability to measure fatigue in a reliable and non-invasive manner would provide a useful and clinical tool to assess muscle fatigue. However, the interday reliability of this study is poor and demonstrates further investigation into more reliable methods is necessary. The reliability is compromised by surface electrodes, introducing the chance of cross-talk and interference from other muscles and the heart. Furthermore, the shoulder musculature is comprised of over 25 muscles, and only four of those muscles were targeted for this study. The addition of other muscles responsible for scapular elevation could lead to an increased understanding of how and when the muscles fatigue during shoulder elevation. Lastly, even when looking at an asymptomatic group of subjects, the variability among subjects is important to consider. All subjects will not follow the pattern of the mean of the group, whether due to individual variation or motor learning patterns. This individual variation has been reported to be present but not quantified in previous research looking at shoulder elevation (Bagg and Forrest, 1986). Other factors that would improve this study would be a larger number of participants to give better validity to the results and examination of different positions of shoulder elevation, not just one static position.

5. Conclusion

Further studies are needed to determine exactly how the different muscles of the shoulder complex interact during fatiguing contractions. Future studies need to examine a larger number of muscles responsible for shoulder elevation, various angles of elevation in the scapular plane, how the muscles fatigue during movement, and how and if muscles fatigue differently in persons with shoulder pathologies. In addition, further research can assess fatigue during functionally related activities to better understand fatigue during daily activities.

5.1. Clinical implications

The results of this study suggest that in the mid-range of elevation in the scapular plane, the middle deltoid fatigues more quickly than other scapular muscles. Therefore, when implementing therapeutic exercises in the clinic that work in this range of shoulder elevation, a therapist must be careful to avoid over fatiguing the middle deltoid. The implication to work on endurance for the deltoid muscula-

ture during rehabilitation is further supported in these findings. In addition, for people that work in this range of shoulder elevation, careful consideration must be given to the middle deltoid to avoid over-fatigue, which could alter joint mechanics and possibly lead to pathology. There are many options for further studies in this area, and hopefully this study will give future researchers a baseline of information. By examining normal fatigue, it will be easier to assess abnormal in the future.

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