EMG SIGNS OF FATIGUE IN ANTERIOR AND POSTERIOR DELTOID MUSCLES: QUESTIONING THE ROLE OF RMS DURING FATIGUE

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Abstract - When a skeletal muscle fails to maintain a required force of contraction, it is fatigued. While the time-dependent shift in mean power frequency (MPF) of electromyographic (EMG) signals to lower frequencies is a well-established indicator of fatigue, the change in root mean squared (RMS) values of EMG signal has not been interpreted consistently in literature. This research investigates localized muscle fatigue in anterior and posterior deltoid muscles during isometric, isotonic, sustained contractions by examining patterns of fatigue through spectral and amplitude analysis of EMG recordings in terms of MPF and RMS, respectively. The EMG signals were obtained simultaneously from the anterior and posterior deltoid muscles of 10 healthy subjects by placing silver-silver chloride surface electrodes in bipolar configuration over each muscle on the dominant arm of the subject. Subjects held a weight of 2.5 pounds in one hand while maintaining that arm in a constant forward flexion position at 90°, where the anterior deltoid is the agonist muscle and the posterior deltoid is the antagonist muscle. After a rest period of five minutes, the arm was then held in a constant backward extension position at 90° abduction and extended as much as possible. MPF and RMS were calculated for every 4% of endurance time and averaged between subjects. The shift in MPF to lower frequencies was a consistent observation while, the patterns of RMS varied between the positions and subjects, and exhibited an overall decrease. The latter result challenges the common belief that RMS increases during fatigue and lead to the hypothesis that the pattern of RMS during fatigue is not a reliable indicator of fatigue.

I. INTRODUCTION

Despite its ubiquity, little is yet known about the mechanisms contributing to muscle fatigue [3]. However, the development of fatigue in a muscle can be observed by amplitude and spectral analysis of EMG readings [4]. The time-dependent shift in mean power frequency (MPF) of electromyographic (EMG) signals to lower frequencies during the fatigue process is a well-established phenomenon. Conversely, the association between progression of fatigue and an increase in root mean squared (RMS) values of EMG signal is associated with ambiguity and controversy [6]. For example, several investigators have reported a correlation between RMS behavior and fiber type of the muscle [6], but the relationship of the RMS and MPF trends during fatigue to fiber type composition is difficult to define since individual fiber types cannot readily be determined. The functional role of the involved muscle has also been reported to be a crucial determinant of the EMG signal characteristics, specifically for RMS values [6]. A fact that has generally been ignored is that RMS behavior is subject to two opposing trends as muscular fatigue progresses: RMS is expected to decrease as the firing rates of motor units decrease during fatigue, whereas the shift of MPF to lower frequencies would theoretically result in an increase in RMS voltage, since the power spectral density (PSD) within the EMG range has increased (i.e. more signal energy is passing through to the electrodes [1]). These trends may cancel each other out, or one may dominate the RMS pattern [7].

The objective of this paper therefore was to investigate the change in MPF and RMS of the anterior and posterior deltoid muscles during isometric-isotonic sustained contractions in two different arm positions, for clarification of the pattern (if any) of RMS during fatigue.

II. METHOD

EMG signals of 10 healthy subjects (7 females and 3 males) with a mean age of 25 ± 7 years, each with no history of shoulder muscle myalgia, were recorded simultaneously from the anterior and posterior deltoid muscles by silver-silver chloride surface electrodes in bipolar configuration. Studies of EMG activity in the shoulder muscle during specific movements have shown that during forward flexion, the anterior deltoid was significantly activated, while backward extension activated the posterior portion of the deltoid [8]. It was for this reason that two different positions were used, each with a 2.5 lb hand load: A) shoulder in forward flexion at 90^o, brought into position from 90^o abduction, with elbow fully extended and forearm 90^o pronated; B) abduction at 90^o, retracted as much as possible with elbow fully extended. Both positions were maintained until subjective extreme feeling of fatigue. In order to maintain the positions in both experiments A and B, a camera tripod adjusted to the height of each individual subject's arm was placed directly beneath their arm. The subject was asked to not allow his/her arm to lower and hence touch the stand, and to avoid any motion. Each muscle signal was amplified with a gain of 900, and band pass filtered with cut off frequencies of 10-500 Hz. EMG signals were digitized at a 1024 Hz sampling rate and stored with a LabVIEW program. The data was sequestered into 1-second segments with 50% overlap between successive segments. The RMS value of each segment was calculated as per Equation 1, below. The mean power frequency (MPF) was calculated from the power spectrum of each segment, using Equation 2.

$$RMS\{v(n)\} = \left[\frac{1}{N-1} \sum_{0}^{N-1} v^2(n) \right]^{1/2} \qquad (1)$$

$$f_{mean} = \frac{\int_0^{\infty} f S_m(f)}{\int_0^{\infty} S_m(f)}, \qquad (2)$$

where $S(f)$ is the power spectrum of the EMG signal.

In order to average the RMS and MPF changes between the subjects, each reading was approximated by a trend line for every 4% of the endurance time, and also normalized by its maximum value.

III. RESULTS

For both experiments A and B, the MPF results showed a steady decrease in frequency, which is consistent with the well-established trend of MPF with fatigue. In both positions, there was no significant difference between the average rates of fatigue for each muscle, as shown in Figure 1.

The averaged results of RMS in both positions exhibited an overall decrease in RMS. The number of subjects experiencing this trend in experiment A is 7 out of 10, and 8 out of 10 in experiment B (with the same 7 subjects experiencing this trend as in experiment A). The RMS follows similar patterns in both muscles for each subject, where the anterior muscle's RMS is either higher than or the same as that of the posterior muscle. It should be noted that RMS patterns widely varied between the subjects that may correspond to differences in proportion of fiber type between individuals, though individual fiber type composition was not known. The RMS trend for positions A and B, averaged between the subjects are shown in Figure 2.

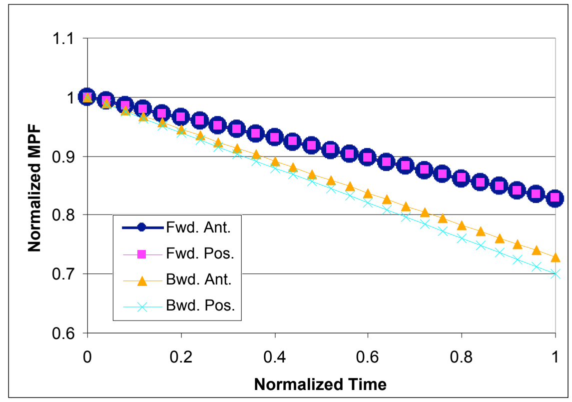

Figure 1. Normalized MPF for both muscles in each position, averaged between subjects. In the legend, "Fwd. Ant." And "Fwd. Pos." represent the trends with fatigue for position A of the anterior and posterior deltoid muscles, respectively, while "Bwd. Ant." and "Bwd. Pos." represent those of position B. Note that the trends of anterior and posterior deltoid for position A are superimposed on each other.

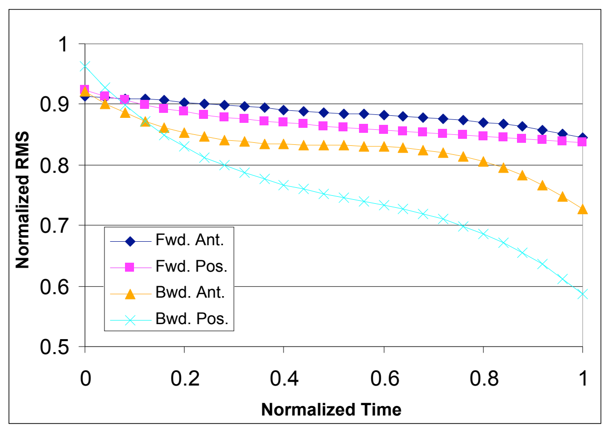

Figure 2. Normalized RMS trend during fatigue for both muscles in each position, averaged between the subjects. The legend captions are same as those in **Figure 1**.

IV. DISCUSSION AND CONCLUSION

The results shown in Figure 1 confirm the fact that the muscles involved in the study did experience fatigue, and imply that both muscles were approximately equally fatigued. In other words, both muscles performed similar functions, and each were quite active in both experiments. This was expected, because placement into both positions A (shoulder flexion) and B (shoulder extension) began from 90° abduction, in which all portions of the deltoid muscle are active [5].

In accordance with this explanation, in all subjects in each position, the RMS values for both muscles follow similar patterns per subject. The anterior RMS was always either higher than or the same as the posterior muscle's RMS. A higher RMS value for the anterior deltoid than that of the posterior deltoid in position A intuitively makes sense. The RMS value is believed to be affected by the number of active motor units, firing rate of motor units, motor unit action potential shape, and cross correlation of motor unit discharges [1]. In this position the anterior, being the agonist muscle, is expected to do a larger percentage of work in holding up the load and thus has a higher number of active motor units.

Using the same rationale for the backward position, one would expect that the posterior deltoid muscle would have a higher RMS value than the anterior muscle. This is not the case, because as mentioned above, there is an overlap of roles between the two muscles in both positions. Furthermore, the anterior muscle, being the more frequently used of the two [2], may take a larger percentage of the workload, but still have a similar work output to that of the posterior.

The trends of overall decrease in RMS shown in Figure 2, may be explained by evidence that the motor unit firing rate decreases with fatigue and that the RMS value of EMG is directly proportional to the firing rate [1,6]. It is known that RMS is also affected by the shift in power spectral density (PSD) to lower frequencies during fatigue, specifically that this shift induces an increase in RMS when using surface electrodes to obtain EMG signals [1,7]. The trends in this study clearly indicate that the former phenomenon is dominant in most subjects. But the RMS patterns of 3 of the 10 subjects in experiment A and 2 of the 10 in experiment B exhibited an increase, leading to the observation that the latter phenomenon does indeed influence the RMS trends as well. Since the 2 subjects in experiment B are 2 of the 3 in experiment A experiencing this trend, it may be postulated that fiber type is of some significance in RMS trends, however again it is beyond the scope of this study to speculate about the fiber type of each individual and prove the postulation.

Though the average RMS graphs for both experiments depict a decrease, the patterns for the anterior and posterior deltoids between positions are visibly different (Figure 2). This trend of difference in patterns was observed for all subjects. As well, for 7 of the 10 subjects, the RMS values overall were greater in position B than in position A for both muscles. All subjects experienced more difficulty in maintaining position B than position A, borne out by the averaged MPF for position B, which shows that the muscles fatigue at a faster rate relative to position A. This greater rate of fatigue has been attributed to the fact that position B requires flexibility in the shoulder muscle - not a natural ability in all persons. The recovery period between the trials, though subjective, is assumed to have been sufficient. As well, there is a visible difference between the RMS patterns of the posterior deltoid in Figure 2. All of the above infers that the EMG signs of fatigue change with the functional role of the muscles involved in the experiments, and this coupled with what was discussed in the previous paragraph leads to the conclusion that RMS is not a reliable indicator of fatigue.

In summary, the results of this study exhibit inconsistencies in RMS voltage of the EMG signals that do not lend support to, and therefore question, the common interpretation of RMS behavior during fatigue, giving rise to the hypothesis that RMS is not a reliable indicator of fatigue. In this study both of the investigated muscles are believed to be mainly (60%) composed of fiber type II. Since the RMS value and its trend is affected by fiber type composition of the muscle, more experiments, in which the functional roles of the involved muscles are known, for different group muscles in which the fiber type compositions are mainly different, need to be designed to further define any relations between RMS and these parameters.

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