THE EFFECTS OF FORCE AND JOINT ANGLE ON MUSCLE CONDUCTION VELOCITY ESTIMATION

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Abstract - **Conduction velocity estimated from the surface myoelectric signal has been proposed as a potential index of fatigue for dynamic muscle contractions, in which joint angle and/or muscle force may be changing unpredictably. To be more useful as an index than power spectral parameters such as mean frequency, the conduction velocity estimate would have to be more resilient to changes in joint angle and/or muscle force. Results from this study using myoelectric signals collected from the biceps brachii, indicate that conduction velocity may indeed be more resilient to dynamic factors but also revealed that measurement techniques must be refined before reliable estimates can be obtained at joint angles in which extreme shortening of the muscle occurs.**
Keywords - **conduction velocity, muscle force, joint angle, fatigue, dynamic contractions**

I. INTRODUCTION

Being able to assess muscular fatigue yields important ramifications in many applied contexts such as sport science, ergonomics, worker's compensation and rehabilitation; a physiotherapist, for instance, could use such an assessment to help determine whether or not fatigue is a contributing factor to a client's impairment. For a fatigue assessment to be practical, the methodology from which it originates must be simple to implement, non-invasive, and robust. From a biomedical engineering perspective, an intriguing solution is to use the surface myoelectric signal (MES) to track changes in muscle biochemistry which are caused by fatigue.

By estimating the power spectrum of the surface MES during sequential intervals of a muscular contraction, a characteristic frequency, such as mean or median frequency can be determined which decreases with fatigue. While this fatigue assessment protocol offers a simple and non-invasive measurement methodology, it can only yield an accurate index of fatigue under conditions in which both muscle force and joint angle are constrained during contraction. Indeed, this methodology has been shown to work superbly under isometric (constant joint angle) and isotonic (constant muscle force) conditions [1], and sufficiently even under dynamic conditions as long as the distribution of changes in joint angle and/or muscle force remains consistent during the sequential intervals [2]. Unfortunately, these restrictions limit significantly the applicability of this index, since many clinical scenarios certainly involve dynamic contractions in which muscle force and/or joint angle are changing unpredictably.

Changes in the MES power spectrum with fatigue have been shown to be due, in part, to a decrease in muscle conduction velocity (CV) which results from a combination of an accumulation of hydrogen ions and a depletion of other electrolytes within the muscle's surrounding tissue [3]. An obvious alternative to tracking changes in power spectral parameters with fatigue therefore, is to use the surface MES to track corresponding changes in CV.

Commonly, estimating CV with surface MES is achieved by taking the cross-correlation of two signals separated along the propagation path by a known distance [4]. The shift in this cross-correlation from zero represents the time taken by the propagating signal to travel the separation distance; thus dividing this distance by this time yields CV.

Estimates of CV are more difficult to obtain than power spectral parameter estimates, since they require the acquisition of two MES channels of data and are hindered by accurate placement of the electrodes in order to avoid the muscle's innervation zone and to align the channels with the propagating direction of the signal. Nevertheless, some of the factors that cause power spectral parameters to change with joint angle and/or muscle force, such as the tissue filter effect [1], may not affect CV. Thus, CV may be more resilient to changes in muscle force and/or joint angle during contraction and therefore yield a more robust fatigue index. The purpose of this investigation was to test this hypothesis.

II. METHODS

To examine the effects of muscle force and joint angle on CV parameter estimation, a test was conducted on five participants to compare CV values obtained using the cross-correlation technique on two channels of MES generated from the biceps brachii with the elbow held at five different joint angles (50°, 70°, 90°, 110°, and 130°, where 180° is full extension) while the muscle was resisting three different loads (20%, 50%, 70% maximal voluntary contraction (MVC)) per angle.

The apparatus used in this study consisted of a large disc attached to a central pulley at its axis as depicted in Figure 1. The central pulley and disc were supported by a frame which allowed participants to rest their arms upon a platform in supinated position, elbow aligned with the pulley-disc axis. A perpendicular force could then be applied to the participant's forearm, while the elbow joint was held at any specified angle.

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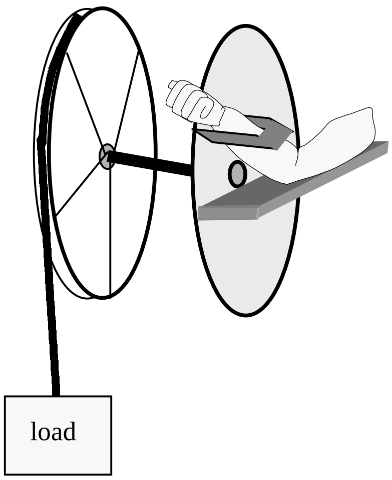

Figure 1: Pulley-disc Apparatus used to apply a known load perpendicular to the forearm at various angles.

Using the pulley-disc apparatus fastened at the specified angles, MVC measurements were obtained for each participant at each angle. The pulley was fastened via a cable to a LC105 Aluminum 'S' Beam Load Cell which output a voltage proportional to the force being exerted.

One day after the MVC test, participants returned for signal acquisition. Using the pulley-disc apparatus in non-fastened mode, participants were instructed to hold the disc at each angle against loads equivalent to 20%, 50% and 70% of their MVCs. Each angle-force combination was held for 15 sec and a 1 minute rest interval between each combination was imposed. Also, the order in which the participants engaged in each angle-force combination was randomized.

MES from both channels were recorded using a specially designed bar electrode arrangement with three 0.5 mm x 10 mm bars spaced 5.0 mm apart. The bars were configured in single differential mode yielding two channels with an effective separation of 5.0 mm. The electrode was placed on the long head of the muscle, midway between the belly and the tendon on the proximal side and secured with a breathable elastic cuff.

Both channels of MES data were processed identically first through a pair of pre-amplifiers described previously by Lovely [5] and then through a pair of Tektronix AM502 differential amplifiers with low and high cut-off frequencies set to 10 Hz and 1000 kHz respectively. From the amplifiers, both signals were sent to an oscilloscope for display and through anti-ailing filters with cut-off frequencies set to 500 Hz. Finally, from the filters, the signals were sent to a CIO-DAS16/330I 12 bit A/D system for sampling and recording. Data were sampled at a rate of 5000 Hz/channel with a bit resolution of 2.4 mV/bit.

In total, 15 data records from each channel were obtained for each participant; one for each angle-force combination. Each 15 sec data record was interpolated to increase the time resolution from 1/5000 to 1/15000. Then each interpolated record was split into three 5 second segments. Finally, the cross-correlation was obtained between corresponding signal segments, the delay in each cross-correlation was localized in time, and a CV value was obtained for each delay by dividing the channel separation by the delay. This process yielded 3 CV values for each angle-force combination.

III. RESULTS

Figure 2 depicts the mean (across trials) CV values for each angle-force combination for one participant. This example is representative of all of the data sets obtained, although outliers, defined as CV > 12 m/s, were observed in 3 of the other participant data sets within the 50° and/or 70° trials at various force levels.

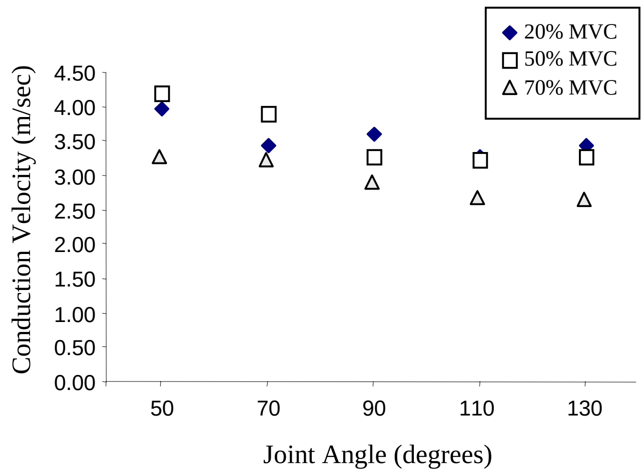

Figure 1: Conduction velocity (mean across three trials) vs joint angle at three different force levels for one participant; Standard deviations for each data point plotted are not resolvable on the plot (< 0.2 m/sec).

A statistical analysis of the data sets collected from all participants revealed significant joint angle and force effects (Anova; $\alpha = 0.05$, $p < 0.001$) even when the outliers were accounted for.

IV. DISCUSSION

While the effects of joint angle and muscle force on CV are statistically significant, they may not be sufficiently large to obscure a trend with fatigue. This is analogous to averaged mean frequency (MF) values which also show significant statistical effects from joint angle and muscle force but still track competently the downward trend with fatigue [2]. The advantage of the CV parameter however, is that it can be estimated without having to average across a range of consistent joint angles and muscle forces, a constraint which is necessary to yield useful MF estimates.

Regardless of the practical significance of the small effects of joint angle and muscle force on CV estimates, the common occurrence of outliers is problematic. If such occurrences cannot be avoided then data sets collected during fatigue assessment will be plagued with contamination. Intriguingly, all of the outliers observed during this study were found in the 50° and/or 70° data sets. These angles correspond to near maximal muscle shortening and bring the electrodes in closest proximity to end-plate and tendon regions. It is therefore speculated that the signal manifestations of action potential origination and extinction, (non-propagating signals), may contribute to the large CV variability at these angles. Revising the acquisition strategy, taking into account these effects, may help to abate their contribution; One simple adjustment, for instance, would be to use a double-differential electrode configuration in order to attenuate the non-propagating signal.

V. CONCLUSIONS

The effects of joint angle and muscle force on CV estimation were examined in order to determine the feasibility of using CV as a robust index of fatigue. While results of this study indicated that the effects were statistically significant, further research is necessary to determine the practical significance within a fatigue assessment context. Furthermore, to avoid outliers, a better signal acquisition protocol must be established to either avoid close proximity of the measuring electrodes to the muscle end-plate and tendon, or to attenuate the non-propagating signal caused by these physical elements.

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