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THE USE OF EXTREME HIGH PASS FILTERING AND WHITENING TO REMOVE FATIGUE ARTIFACT DURING MAXIMAL DYNAMIC CONTRACTIONS – PART I: EFFECTS OF PROCESSING METHODS

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SUMMARY

A variety of biomechanical models have used surface electromyography (sEMG) signals to understand human movement and estimate muscle forces. However, the use of sEMG-to-force models is limited to sEMG signals from rested muscles because, as muscle fatigues, there is an increase in sEMG amplitude even while maintaining a constant force. Therefore, under fatiguing conditions, these models would provide a large overestimation of the actual muscle force due to this fatigue related amplitude “artifact”. Alternative processing methods have been proposed to overcome this limitation but they have only been tested with isometric contractions. This abstract compares three processing methods: 1) standard band pass between 20-500 Hz, 2) extreme high pass (HP) filtering and 3) whitening, to determine each methods ability to remove fatigue related amplitude artifact and accurately estimate muscle force, during dynamic, maximal fatiguing contractions of the quadriceps femoris muscles.

INTRODUCTION

sEMG is one of the few non-invasive methods that can be used to estimate individual muscle forces and their contribution to net moments produced about a joint. It is well known that the best relationship between sEMG and force occurs under isometric conditions, as there is no change in muscle length or velocity [1]. The force-related interpretation of sEMG during dynamic contractions is much more difficult, as the movement of the underlying muscle can cause motion artifact, which affects the fidelity of the sEMG signal.

During a fatiguing isometric contraction, sEMG amplitude has been observed to increase, in spite of the maintenance of a constant muscle force, while the sEMG power spectrum shows a decrease in high frequency power and a relatively large increase in the low frequency power bands [2]. Based on this large increase in the low frequency bandwidth, in the absence of increased force, Potvin & Brown (2004) hypothesized that low frequency bandwidth may have a poor relationship to force. In recent studies, it has been determined that extreme HP filtering and adaptive whitening of the raw sEMG signal improved the sEMG-to-force relationship of rested [3] and fatigued muscles [4] as well as estimations of joint moment [5]. Extreme HP filtering has also been shown to emphasize deeper motor units in comparison to more superficial motor units [5, 6], and improves the correlation between the sEMG signal and the single motor unit signal [7].

The benefits of extreme HP filtering and whitening have not yet been investigated during dynamic contractions. Therefore, the purpose of this study was to determine if these alternative processing methods would improve the sEMG-to-moment ratio compared to the standard band pass filter of 20-500 Hz, during dynamic, maximal fatiguing contractions of the knee extensors.

METHODS

The participants were sixteen right leg dominant males, with no previous injuries to the lower extremity. sEMG signals were collected from electrode pairs placed above the vastus lateralis (VL), rectus femoris (RF) and vastus medialis (VM). Knee extensor moments and position data were obtained using a Biodex System 4 dynamometer. In an orientation session, participants were strapped into the Biodex with the hip, knee and ankle all postured at 90 degrees, and were required to perform three isokinetic, knee extensor maximum voluntary contractions (MVCs) at a velocity of 30°/s between 40-110 degrees of knee flexion during both the CON and ECC phases. The dynamic MVC was calculated as the extensor moments between 50-100 degrees of flexion, averaged across the CON and ECC phases. After at least three days rest, the participants completed the test session by repeatedly exerting maximally against the dynamometer in both the CON and ECC directions, until they could no longer produce 33% of their MVC knee extensor force, at the same speed and range outlined above.

The raw sEMG signals were collected at 2000 Hz and digitally processed using three different processing methods: 1) a 6^{th} order Butterworth filter, band-passed between 20-500 Hz (Standard), 2) a 1^{st} order Butterworth filter, band-passed between 420-500 Hz (Extreme HP) and 3) a 5^{th} order autoregressive signal whitening (Whitened). These signals were then full wave rectified and low pass filtered at 1.5 Hz then normalized to maximum voluntary efforts (MVE).

For both the ECC and CON efforts, a 2nd order polynomial regression curve was fit through the knee moment and quadriceps sEMG data to determine the best estimate of a starting "rested" value and an end "fatigued" value for the different processing methods and exertion directions. These were then used to calculate start and end EMG-to-Moment ratios for each muscle. A three-way (Processing Method, Direction, Time) repeated measure ANOVA was conducted for each of the three quadriceps muscles measured in this study (RF, VL and VM), with the EMG-to-Moment ratio as the dependent variable.

RESULTS AND DISCUSSION

The participants completed an average of 12.1±2.6 cycles (range: 8 to 17). There were significant 2-way interactions between direction and time for the VL & VM muscles (both $p<0.0001$), but not the RF muscle. Both the VM and VL behaved very similarly from start to end, as the CON EMG-to-moment ratios started approximately 30% higher than ECC ratios, and finished approximately 60% higher (Figure 1). There were no significant changes in the ECC ratios from start to end.

A significant 2-way interaction between processing method and time was found for all three muscles (all $p<0.0001$), however, VM and VL again tended to behave very similarly from start to end, compared to RF. For VM and VL, the 140-500 Hz HP filtering band had the smallest change in ratio (≈ 4%), followed closely by whitening (≈ 9%). This compares to the 20-500 Hz processing band, that had an EMG-to-moment ratio increase of 42% when averaged between the VM and VL (Figure 2). With the RF muscle, a significant increase in the EMG-to-moment ratio was seen for 20-500 Hz filtering band, but with the extreme HP filtering and whitening methods, the ratio actually decreased significantly from start to end.

This study assumed the activation of the three quadriceps muscles would accurately reflect the knee extensors as a group. Upon investigation, VL and VM had very similar activation levels at the beginning and end of the test protocol. However, RF was recruited quite differently from start to end, such that its activation level dropped towards the end of the contraction, especially during ECC contractions

The results indicate that extreme HP filtering and whitening were able to remove more fatigue-related sEMG amplitude artifact from the VM, VL and RF muscles compared to the standard EMG processing method. The standard processing method (20-500 Hz) resulted in the largest disassociation between sEMG amplitudes and the knee extensor moments, which further supports the hypothesis by Potvin & Brown (2004), that the lower frequency content of the sEMG signal may be unrelated to force. These results also support the findings of Cort et al., 2006, who determined that HP filtering and whitening increased the accuracy of sEMG-to-force estimations for fatiguing isometric contractions. Furthermore, the results illustrate the limitation of using sEMG signals to predict muscle force in the presence of fatigue, when using the standard 20-500 Hz bandpass filter, because it would result in large overestimations of those muscle forces.

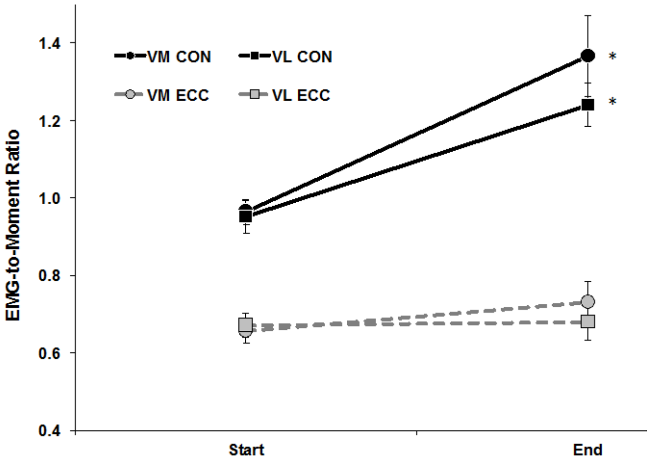

Figure 1: Change in VM and VL EMG-to-Moment Ratio from start to end for CON and ECC directions. Standard deviation bars shown, * indicates End > Start (n=14).

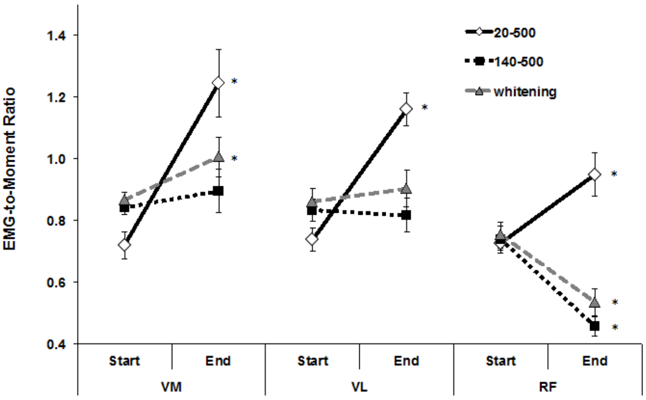

Figure 2: Significant 2-way interactions between processing method and time for all three quadriceps muscles. Standard deviation bars shown, * indicates End > Start (n=14).

CONCLUSIONS

The results of this study showed that extreme HP filtering and whitening were effective in providing a more accurate estimation of joint moment and muscle force during dynamic contractions to fatigue, when compared to the standard 20-500 Hz bandpass filtering method. It is suggested that either of these methods could be used to improve individual muscle force estimates in the presence of peripheral fatigue and during dynamic contractions. Further testing is required for other muscle groups.

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