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THE USE OF EXTREME HIGH PASS FILTERING AND WHITENING TO REMOVE FATIGUE ARTIFACT DURING MAXIMAL DYNAMIC CONTRACTIONS - PART II: NEUROPHYSIOLOGICAL IMPLICATIONS

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SUMMARY

Extreme highpass (HP) filtering and whitening of the surface EMG (sEMG) signal has been shown to both improve sEMG to force estimates [1] and remove some of the fatigue induced sEMG amplitude artifact during prolonged contractions [2]. This abstract examines further potential benefits of using these simple signal processing methods to better understand how the central nervous system (CNS) may regulate lengthening and shortening contractions, particularly, if the amount of neural inhibition is increased as the muscle approaches exhaustion. It is theorized that, if extreme HP filtering and whitening remove some of the signal contamination induced by local muscular fatigue, then we can better understand what the actual neural drive from the CNS is to the muscles when in a rested state compared to an extremely fatigued state, during different contraction modalities.

INTRODUCTION

When compared with isometric and shortening (concentric) contractions, individuals have difficulty achieving absolute maximal muscle activation during voluntary lengthening (eccentric) efforts [3,4]. This phenomenon, also termed "eccentric inhibition", has been postulated to be a tension-limiting mechanism employed by the CNS, to minimize the potential for damage to the muscle and associated connective tissues [3,5]. There has been evidence that a differing neural control strategy is responsible for this inhibitory neural drive during lengthening contractions [5], however, there is much less work, if any, examining how this neural inhibition changes with muscular fatigue.

Difficulties arise when comparing sEMG from fatiguing, isotonic contractions to moment or force, as there tends to be an increase in the EMG amplitude independent of any increase in force [6]. This EMG amplitude artifact represents some combination of central and peripheral effects that combine to elevate the EMG amplitude during fatiguing contractions [7]. Potvin & Brown (2004) hypothesized that, if the EMG amplitude is increasing in the absence of force changes, and most of this increase occurs in the low frequency power range, it is possible that the signal in this low range has little relationship to force.

Recently, it has been shown that extreme HP filtering and adaptive whitening of the raw sEMG signal, where as little as 1% of the signal power remains, may be a simple processing technique that can be used to remove the fatigue induced artifact in sEMG during prolonged, fatiguing isometric [1,2] and maximal dynamic efforts [8]. It is possible that this approach results in a better balance between deep and superficial motor units in the signal [9], and that it attenuates enough uncontaminated biological signal to better represent the neural drive to the muscle, as it appears to be more impervious to peripheral changes to the sEMG signal induced by fatigue.

To further expand upon the findings of Part I, the purpose of this analysis was to examine if the neural drive to the individual quadriceps muscles was inhibited to a greater extent in a fatigued muscle compared to a rested muscle, and between eccentric (ECC) and concentric (CON) muscle actions, presumably as a centrally-modulated protection mechanism. We propose that, if HP filtering and whitening does indeed improve the EMG-to-moment ratios by reducing the amount of sEMG artifact attributed to local or peripheral fatigue effects, the remaining sEMG amplitude signal is a better representation of the output from the spinal cord and can be used to better determine the relative amount of neural inhibition that is being imposed by the CNS as the muscle approaches exhaustion.

METHODS

Sixteen healthy male participants performed maximal, isokinetic CON and ECC quadriceps efforts to exhaustion on a Biodex dynamometer. For each continuous cycle, the dominant leg moved from 110 to 50 degrees of knee flexion (CON phase) and back (ECC phase), with the middle 60% of each exertion cycle being windowed out for analysis to minimize the effects of switching contraction direction. Knee extensor torque and joint angle data were collected, as was sEMG signals from three quadriceps muscles: vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM). The EMG signals were sampled at 2000Hz and processed using autoregressive signal whitening, extreme HP filtering band of 140-500 Hz (1^{st} order) as well as the traditional frequency band of 20-500Hz (1^{st} order). For each concentric and eccentric window, the sEMG amplitude and knee extensor moment were measured and an EMG-to-moment

ratio was calculated. A 2nd order polynomial was then fit through the force and EMG curves to determine the best estimate of a starting "rested" value and an end "fatigued" value. These were then used to calculate start and end EMG-to-Moment ratios. This analysis will extend the interpretation of the findings from Sutherland et al. (2013), by qualitatively examining differences in sEMG activation depending on processing method.

RESULTS AND DISCUSSION

As discussed in Sutherland et al. (2013), it was shown that the EMG-to-moment ratio was significantly improved when using HP filtering and whitening compared to the standard processing method (20-500 Hz). As can be seen in Figure 1, when sEMG amplitude is pooled between the three quadriceps muscles tested in this study, there is a much larger drop in sEMG activation with fatigue using extreme HP filtering and whitening, compared to standard processing. For the 20-500 Hz processing method, the sEMG dropped by 28.2% and 40.1% for CON and ECC, respectively, compared to more substantial declines of 55.1% and 68.2% for extreme HP filtering, and 51.1% and 65% for whitening.

Given the previously found ability for these alternative processing methods to remove fatigue induced sEMG amplitude artifact [2], it is suspected the higher sEMG amplitudes at the end of the exertions, and subsequent smaller change over time found using the 20-500 Hz filtering method, can be attributed to fatigue artifact, which would have been removed to a greater extent using extreme HP filtering and whitening. The decline in sEMG amplitude with the alternative processing methods tended to be more in line with the decline in knee extensor moment (55% decline for CON and 57% decline for ECC).

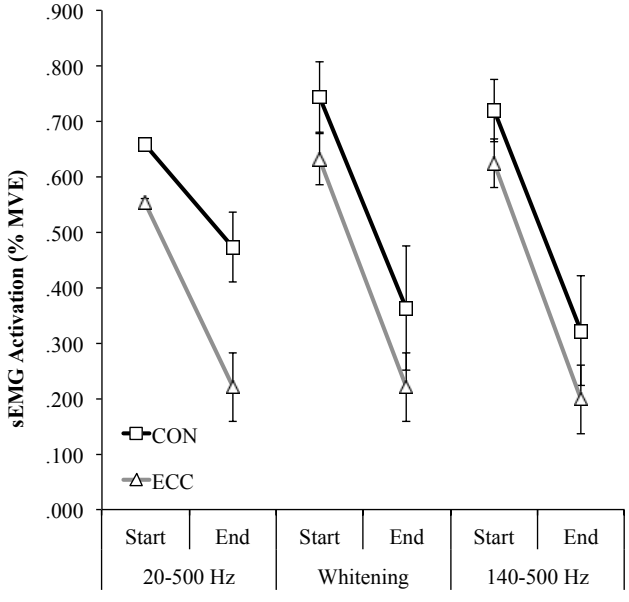

Figure 1: Change in average quad sEMG activation with time. Error bars represent the SD of the three quad muscles.

Despite being required to exert maximal knee extensor effort, the participants' sEMG activations were substantially below the maximal excitation obtained during dynamic reference contractions, with ECC sEMG amplitudes never exceeding the CON amplitudes. This would corroborate previous findings that the CNS may inhibit the neural drive for ECC contractions as an injury prevention mechanism [3,4,5]. What may be of interest in the interpretation of these results is how the magnitude of these inhibitory effects may change as the muscle approaches exhaustion.

As highlighted by Farina et al. (2004), caution must be heeded when interpreting neural strategies from sEMG signals, especially during dynamic contractions. However, there is potential in these alternative processing methods as they may help circumvent some of the known limitations. The fact that there was a larger drop in sEMG activation during the maximal lengthening contractions, despite the exact same level of fatigue in the muscles, agrees with previous findings that ECC efforts are controlled by a different neurophysiological strategy [5]. When extreme HP filtering and whitening were used to presumably mitigate some of the effects of fatigue on surface EMG amplitude, it would appear that the amount of inhibition provided from the CNS is both greater for ECC efforts compared to CON, and when the muscle is exhausted compared to rested.

CONCLUSIONS

The results of this study showed that HP filtering and whitening processing methods may not only provide a better estimation of joint moments and muscle forces during dynamic and fatiguing contractions [8], but also has applications for interpreting neurophysiological control strategies during fatigued contractions that would have been very difficult to obtain otherwise, given the typical barriers to force estimation using EMG amplitude signals from fatigued muscles. These initial findings will hopefully lead to a better understanding of how the CNS modifies the neural drive to muscles as a protective mechanism in response to fatigue, especially during ECC contractions.

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