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The interpretation of abdominal wall muscle recruitment strategies change when the electrocardiogram (ECG) is removed from the electromyogram (EMG)

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Abstract

The purpose of this study was to determine the effect of the ECG artifact on low-level trunk muscle activation amplitudes and assess the effectiveness of two methods used to remove the ECG. Simulations were performed and percent error in root mean square (RMS) amplitudes were calculated from uncontaminated and contaminated EMG signals at various ECG to EMG ratios. Two methods were used to remove the ECG: (1) filtering by adaptive sampling (FAS) and (2) Butterworth high pass filter at 30 Hz (BW-30 Hz HPF). The percent error was also calculated between the ECG removed and the uncontaminated EMG RMS amplitudes. Next, the BW-30 Hz HPF method was used to remove the ECG from 3-bilateral external oblique (EO) muscle sites collected from 30 healthy subjects performing a one handed lift and replace task. Two separate ANOVA models assessed the effects of ECG on the statistical interpretation of EO recruitment strategies. One model included EMG data that contained the ECG and the other model included EMG data after the ECG was removed. Large percent errors were observed when the ECG was not removed. These errors increased with larger ECG to EMG ratios. Both removal methods reduced the errors to below 10%, but the BW-30 Hz HPF method was more time efficient in removing the ECG artifact. Different statistical findings were observed among the muscle sites for the ECG contaminated model compared to the ECG removed model, which resulted in different conclusions concerning neuromuscular control.

Keywords: Electrocardiogram; Electromyography; Trunk muscles; Simulation; Criterion methodology

1. Introduction

Surface electromyography (EMG) is commonly used to assess the neuromuscular demand on trunk muscles while performing various tasks. For tasks that only require low-level trunk muscle activation, the ECG artifact is often visible within the EMG. This ECG contamination results from the relative close proximity of the surface electrodes to the heart and the volume conducting properties of human tissue (Farina et al., 2002). The presence of the ECG within the EMG signal influences both amplitude and frequency domain measures of the true EMG (Kumar and Mital, 1996; Soderberg, 1992; Hu et al., 2007). How much the artifact affects the amplitude of the EMG signal depends on the level of muscle activation, which is the main focus of this study. For example, large ECG to EMG amplitude ratios can occur when muscle activation is less than 5% of its maximum voluntary isometric contraction (MVIC) and the electrodes are in close proximity to the heart such as the case with the trunk musculature (Cholewicki et al., 1997; Moreside et al., 2007). In this case, the

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presence of the ECG could result in an overestimation of the reported EMG activation levels. Although these EMG activations are small, they are of functional importance since low-level muscle activations (1–3% MVIC) are required to maintain spinal stability (Cholewicki and McGill, 1996; Cholewicki et al., 1997). Thus, understanding the effect of the ECG artifact is important since ECG contamination could lead to overestimations of EMG amplitudes and misinterpretation of the functional role of abdominal and back extensor muscles.

To reduce the effects of the ECG artifact, the ECG should be removed, however, removal of the ECG is complicated since the EMG and the ECG frequency spectra overlap (surface EMG 20-500 Hz; ECG 0-200 Hz) (Aminian et al., 1988; Christov and Daskalov, 1999). One difference is that the majority of the power of ECG is found at frequencies less than 45 Hz (Aminian et al., 1988) whereas the peak power for EMG is approximately 100 Hz (Winter, 2005). As a result, several studies have presented methods to remove the ECG from the electromyogram, including: digital filtering (Drake and Callaghan, 2006; Redfern et al., 1993; Zhou et al., 2007) and subtraction methods (Aminian et al., 1988; Bartolo et al., 1996; Deng et al., 2000). However, in many of these studies they could not directly determine the effect of the ECG or how effective the removal method was at eliminating the ECG artifact. To accurately quantify the effect of the ECG on EMG amplitudes and the effectiveness of the removal method, the methodology should include the creation of a contaminated signal by combining an uncontaminated ECG with an uncontaminated EMG signal (criterion methodology). Depending on the removal method, either the ECG or EMG signal could be used as the criterion measure. To determine the effect of the ECG artifact, the criterion (uncontaminated EMG) is compared to the contaminated EMG signal. To determine the effectiveness of the removal method, the method is first applied to the contaminated signal. The performance of the removal method can then be determined by the error between the criterion (uncontaminated EMG) and the signal after the ECG has been removed. This methodology has not been used in many studies where the ECG artifact has been removed.

Previous work by Aminian et al. (1988) used the ECG signal as the criterion measure to determine the effectiveness of a subtraction method to remove the ECG artifact. The removal method included reconstruction of the ECG signal by adaptive filtering which was later subtracted from the combined EMG and ECG signals. Comparison of the criterion measure (uncontaminated ECG) with the reconstructed ECG resulted in 17–21% root mean square (RMS) errors associated with the reconstructed ECG signal. Although the results were based on a study from a rat muscle, they quantified the error associated with the removal method, which is an important consideration when comparing different methods. Other authors have used this subtraction method to remove the ECG artifact from the electromyogram during low activation levels from trunk muscles, however, the effect was not determined using the criterion methodology (Cholewicki et al., 1997; Cholewicki et al., 2002). Therefore, it is necessary to determine the error associated with the removal method on human trunk muscle EMG in order to determine the most appropriate method for removing the ECG artifact in studies examining low-level trunk muscle activations.

Recent studies using the criterion methodology determined the effectiveness of a number of different methods commonly used to remove ECG from EMG recorded from human muscle (Drake and Callaghan, 2006; Zhou et al., 2007). Drake and Callaghan (2006) used the uncontaminated EMG from the biceps brachii as the criterion measure. Four different methods were used to remove the ECG from EMG signals of different activation levels (10–25% MVIC). Comparison between the criterion measure (uncontaminated EMG) and the contaminated EMG signals resulted in increased errors as muscle activation levels decreased. This suggests that the *relative* effect of the ECG artifact was greatest at lower level EMG amplitudes. In addition, comparison of the various removal methods showed that the errors associated with many of the removal methods were less than the errors associated with the ECG contamination. Based on higher performance rankings, lower errors and less time investment for removal, they recommended using a recursive second order Butterworth high pass filter at 30 Hz (BW-30 Hz HPF) for activation levels between 10% and 25% MVIC. However, the effectiveness of the removal method at lower activation levels (<10% MVIC) remains unknown. Thus, it is necessary to investigate the impact of ECG contamination on antagonist muscles of the trunk muscles since the activation levels of these muscles commonly occur below 10% MVIC (Davidson and Hubley-Kozey, 2005; Lavender et al., 1992; McGill et al., 1995; Vezina and Hubley-Kozey, 2000).

The first objective of this study was to evaluate the influence of the ECG artifact using the criterion methodology with low-level activation amplitudes from human abdominal wall muscle. Secondly, this study used the same methodology to examine two removal methods: a modified version of filtering by adaptive sampling (FAS) method (Aminian et al., 1988) and a Butterworth 30 Hz high pass filter (Drake and Callaghan, 2006; Zhou et al., 2007). Finally, the third objective of this study was to investigate whether the interpretation of the amplitude recruitment strategy among the external oblique (EO) muscle sites change between an experimental dataset containing ECG and when the dataset was processed to remove the ECG. In addition, the statistical effect of the removal method on the datasets was determined.

2. Methods

2.1. Participants

For the simulation analysis in Parts 1 and 2, the uncontaminated EMG signal was collected from one 30-year old female