ELIMINATION OF ECG CONTAMINATION FROM EMG SIGNALS: AN EVALUATION OF CURRENTLY USED REMOVAL TECHNIQUES.

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INTRODUCTION

Trunk electromyography (EMG) is often contaminated with heart muscle electrical activity (ECG) due to the proximity of the collection sites to the heart and the volume conduction characteristics of ECG through the torso. Few studies have quantified ECG removal techniques relative to an uncontaminated EMG signal (gold standard or criterion measure), or made direct comparisons between different methods for a given set of data. The purpose of this study was to concomitantly evaluate four current and commonly used methods for ECG contamination removal from EMG signals.

METHODS

ECG recordings at two intensity levels (rest and 50% maximum predicted heart rate) were superimposed on 11 uncontaminated biceps brachii EMG signals (rest, 7 isometric, and 3 isoinertial levels). The removal methods used were high pass digital filtering (HPF: finite impulse response (FIR) using a Hamming window, and 4th order Butterworth (BW) filter) at five cutoff frequencies (20, 30, 40, 50, and 60Hz), a template technique (template subtraction, and a zero-replacement template), combinations of the subtraction template and HPF, and a frequency subtraction/signal reconstruction method. Four performance indicators were calculated from the cleaned signals: root mean square error, mean power frequency, and two coefficients of determination. The indicators were individually ranked from a low of 1 up to 23, averaged, and natural logged for each contraction level. A two-way ANOVA with two repeated measures was used to investigate the effects of the contraction level, heart rate level, and cleaning method. A Least Square Means test was used to decipher interactions.

RESULTS AND DISCUSSION

For muscle activation levels between 10-25% of maximum voluntary contraction (MVC), the template subtraction and BW with a 30Hz cutoff were the two best individual methods for maximal ECG removal with minimal EMG distortion (Figure 1), ranking 3 and 5 out of 23 respectively across all contraction and heart rate levels. Only combinations of the subtraction and filtering outperformed these methods (Table 1). The subtraction method has been shown to be more effective than gating [1], and using a FIR with a 30Hz cutoff to be more effective than with a 60Hz cutoff [2] for ECG removal. This study supports these findings.

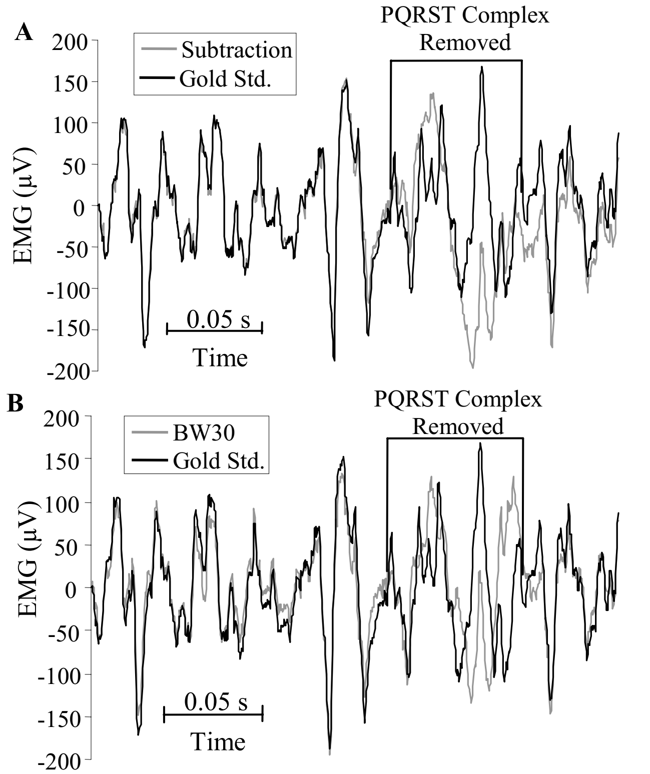

Figure 1: A comparison of the uncontaminated EMG signal (Gold Standard) and the cleaned contaminated signal using the BW30 (A) and subtraction (B) methods.

CONCLUSIONS

For the EMG levels evaluated in this study, the BW filter with a 30Hz cutoff provided the optimal balance between ease of implementation, time investment, and performance across all contractions and heart rate levels.

REFERENCES

1. Bartolo et al. *J Appl Physiol*, **80**, 1898-1902, 1996.
2. Redfern et al. *Clin Biomech*, **8**, 44-48, 1993.

Table 1: Comparison of the methods (per technique) with the lowest error based on the least mean square probabilities. A lower rank equates to a better performance (in parentheses). The number with the technique represents the cutoff frequency (Hz).

4 Main Techniques	High Pass Filtering		Template (Time Domain)		Combination	Frequency
EMG (% MVC)	FIR	Butterworth	Subtraction	Gating	Sub + HPF	Sub+Inverse FFT
Isometric: Rest	FIR60 (7/23)	BW60 (6/23)	Sub (23/23)	Gate (5/23)	cFIR50 (1/23)	InvFFT (17/23)
Isometric: 10.1%	FIR40 (9/23)	BW30 (4/23)	Sub (6/23)	Gate (13/23)	cBW20 (1/23)	InvFFT (22/23)
Isometric : 13.0%	FIR40 (7/23)	BW30 (5/23)	Sub (4/23)	Gate (15/23)	cBW20 (1/23)	InvFFT (22/23)
Isometric : 15.6%	FIR30 (8/23)	BW30 (4/23)	Sub (2/23)	Gate (12/23)	cBW20 (1/23)	InvFFT (21/23)
Isometric : 24.7%	FIR30 (7/23)	BW20 (4/23)	Sub (2/23)	Gate (13/23)	cBW20 (1/23)	InvFFT (19/23)
Isoinertial: 38.8%	FIR30 (9/23)	BW30 (4/23)	Sub (1/23)	Gate (5/23)	cBW20 (2/23)	InvFFT (20/23)