Journal of Electromyography and Kinesiology 24 (2014) 902–909

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Effects of electrocardiography contamination and comparison of ECG removal methods on upper trapezius electromyography recordings

Ryan J. Marker [a], Katrina S. Maluf [a,b,*]

[a] Rehabilitation Science Program, University of Colorado Anschutz Medical Campus, Aurora, CO, USA
[b] Physical Therapy Program, University of Colorado Anschutz Medical Campus, Aurora, CO, USA

ARTICLE INFO

Article history:
Received 28 August 2013
Received in revised form 5 August 2014
Accepted 18 August 2014

Keywords:
Subtraction template
Gating
Artifact removal
Decontamination

ABSTRACT

Electromyography (EMG) recordings from the trapezius are often contaminated by the electrocardiography (ECG) signal, making it difficult to distinguish low-level muscle activity from muscular rest. This study investigates the influence of ECG contamination on EMG amplitude and frequency estimations in the upper trapezius during muscular rest and low-level contractions. A new method of ECG contamination removal, filtered template subtraction (FTS), is described and compared to 30 Hz high-pass filter (HPF) and averaged template subtraction (ATS) methods. FTS creates a unique template of each ECG artifact using a low-pass filtered copy of the contaminated signal, which is subtracted from contaminated periods in the original signal. ECG contamination results in an over-estimation of EMG amplitude during rest in the upper trapezius, with negligible effects on amplitude and frequency estimations during low-intensity isometric contractions. FTS and HPF successfully removed ECG contamination from periods of muscular rest, yet introduced errors during muscle contraction. Conversely, ATS failed to fully remove ECG contamination during muscular rest, yet did not introduce errors during muscle contraction. The relative advantages and disadvantages of different ECG contamination removal methods should be considered in the context of the specific motor tasks that require analysis.

1. Introduction

Electromyography (EMG) is a prominent method of recording and quantifying muscle activity. These recordings can be contaminated by environmental noise, as well as by other electrical signals within the body. Specifically, the electrical signal from the heart can cause electrocardiography (ECG) contamination. EMG recordings from trunk muscles are especially vulnerable to contamination by the ECG signal, due to their proximity to the heart (Butler et al., 2009).

The upper trapezius is particularly susceptible to ECG contamination, and is often investigated with EMG. For example, occupational exposure studies commonly investigate how insufficient muscular rest and sustained periods of low-level muscle activity may contribute to overuse injury and pain in the upper trapezius muscle (Veiersted et al., 2013). The validity of these investigations depends on the ability to distinguish between a fully resting muscle and low-level muscle contractions in the EMG signal. The presence of ECG contamination may result in errors in the determination of muscular rest, and may overestimate the amplitude of muscle activity during low intensity contractions. However, the issue of ECG contamination and its removal is inconsistently addressed in studies of low amplitude postural activity and muscular rest. Few studies have investigated the influence of ECG contamination on EMG amplitude and frequency estimates in the upper trapezius, or the effectiveness of existing ECG artifact removal methods for this muscle (Lu et al., 2009; Spalding et al., 2003).

Several methods of ECG contamination removal have been proposed (Hof, 2009; Mak et al., 2010; Redfern et al., 1993; Spalding et al., 2003; von Tscharner et al., 2011; Willigenburg et al., 2012). These methods, however, are typically applied in low back musculature (Redfern et al., 1993; von Tscharner et al., 2011), or in artificially contaminated signals (Drake and Callaghan, 2006; Mak et al., 2010; Willigenburg et al., 2012). Furthermore, most methods are investigated during periods of muscle activity for varying tasks (Mak et al., 2010; von Tscharner et al., 2011; Willigenburg et al., 2012), rather than during muscular rest (Drake and Callaghan, 2006; Spalding et al., 2003).

Several proposed ECG contamination removal methods, such as by independent component analysis (ICA), require significant pro-

* Corresponding author at: Rehabilitation Science and Physical Therapy Programs, MS C244, Education 2 South, Bldg #L28, 13121 E. 17th Ave, Room 3108, Aurora, CO 80045, USA. Tel.: +1 (303) 724 9139.
E-mail address: Katrina.Maluf@ucdenver.edu (K.S. Maluf).

http://dx.doi.org/10.1016/j.jelekin.2014.08.003
1050-6411/

cessing time and power, as well as input signals from multiple muscles to successfully isolate the ECG signal component (Mak et al., 2010; Willigenburg et al., 2012). Thus, ICA and similar methods may not be feasible for many EMG applications, including occupational exposure studies that collect prolonged EMG recordings from a limited number of muscles. ICA also requires the skill of personnel trained specifically in that method (Mak et al., 2010), making it less practical for widespread application.

The most recommended method to efficiently remove ECG contamination from the EMG signal is a 30 Hz high-pass filter (Drake and Callaghan, 2006). This method, however, may remove important EMG data arising from muscle activity along with ECG contamination (von Tscharner et al., 2011; Willigenburg et al., 2012). The creation and subsequent subtraction of an averaged template derived from multiple ECG artifacts has been investigated in the upper trapezius at rest (Spalding et al., 2003), but this method may not adequately account for variability in the shape of individual ECG artifacts. Finally, gating completely removes all time intervals containing ECG contamination from the EMG recording (Bartolo et al., 1996), but may also result in a significant loss of data, as multiple time intervals are deleted from the signal.

The purpose of the current investigation is to quantify the effects of ECG contamination on EMG amplitude and frequency estimates during muscle rest and low intensity isometric contractions, and to compare new and existing methods of ECG removal on reducing errors introduced by ECG contamination when present. The filtered template subtraction (FTS) method is proposed as a modification of the averaged template subtraction technique to account for variability in the shape of individual ECG artifacts while minimizing loss of the actual EMG signal.

2. Methods

2.1. EMG and ECG data collection

Surface EMG was collected from a total of 11 participants (age = 26.1 (range 22–34) years, body mass index = 22.5 (range 19.1–29.8) kg/m^2, 9 women). Not every task was completed by all participants, and technical complications resulted in the loss of EMG data from the right upper trapezius in one participant. Sample sizes for all calculations are reported. EMG was collected using bipolar surface electrodes (silver–silver chloride; 8 mm electrode diameter; In Vivo Metric, Healdsburg, CA, USA) placed over the left upper trapezius (LUT) and right upper trapezius (RUT). Electrodes were placed with a 10 mm inter-electrode distance, 20 mm lateral to the midpoint between C7 and the posterior lateral acromion. Reference electrodes were placed over a bony portion of the ipsilateral clavicle. ECG signals were collected by two electrodes, separated by a 10 mm inter-electrode distance and positioned along the midsagittal line on bony aspects of the manubrium and upper sternum, with a ground placed on the right ulnar styloid process. This position was chosen to minimize the influence of muscle activity on the ECG signal.

EMG and ECG data were amplified (1000×), band-pass filtered (13–1000 Hz LabLinc V, Coulbourn Instruments, Whitehall, PA), and sampled at 2000 Hz (Power1401, Cambridge Electronic Design, Cambridge, UK). Data were collected online with Spike2 software (Cambridge Electronic Design, Cambridge, UK), and all offline data processing was performed with custom software (LabVIEW, National Instruments, Austin, TX, USA).

2.2. Experimental protocol

Participants were informed of the purpose of the study before providing written consent in accordance with procedures approved by the Colorado Multiple Institutional Review Board. After placement of surface electrodes, participants were instructed to lie supine on a cushioned table, with arms by their sides and palms facing up, a position placing no postural demand on the upper trapezius. They were told to completely relax their neck, shoulder, and arm muscles in this position for 5 min, and the complete absence of muscle activity was confirmed by online inspection of all EMG signals throughout the rest trial. Participants were visually monitored by study personnel, and any periods of voluntary movement or changes in the EMG signal indicating possible muscle activity were marked for offline removal.

Participants transitioned to a custom experimental chair with adjustable shoulder restraints positioned bilaterally over the acromion process to restrict shoulder elevation. Visual feedback of smoothed muscle activity from the LUT and RUT was presented on a computer monitor. Participants performed 2–4 isometric maximal voluntary contractions (MVCs) by elevating both shoulders against resistance while receiving loud verbal encouragement. The maximal EMG value recorded from each muscle during these trials was designated as the MVC. Participants then were presented with concurrent visual targets for sub-maximal contractions of the LUT and RUT, set at 2%, 5%, 10%, and 15% of the MVC for each respective muscle. This range of contraction intensities reflects those typically observed with routine postural tasks. Participants practiced matching the target contractions for approximately 3–5 min, and then maintained a stable isometric contraction at each target level for 1 min. Sub-maximal contractions were performed in random order, with at least 2 min rest between contractions.

2.3. ECG contamination removal

2.3.1. ECG artifact detection

ECG contamination is primarily comprised of QRS complexes in the EMG signal, referred to here as ECG artifacts. With the exception of 30 Hz high-pass filtering, all ECG contamination removal methods investigated in the present study first required identification of the time intervals corresponding to each ECG artifact in the EMG recordings. ECG artifacts were identified using a semi-automated threshold detection procedure, similar to that described by Mak et al. (2010). Briefly, an envelope of the ECG signal was created by obtaining the instantaneous amplitude via a Hilbert Transform, which was then passed through a 50th order median filter to magnify the QRS complex. An amplitude threshold was manually selected for each participant, such that only the QRS complexes exceeded threshold. ECG artifact time intervals were automatically defined as a 0.2 s window surrounding the peak of each enveloped QRS complex in the corresponding EMG signal. To account for transmission delays between the ECG and EMG recording sites, this interval was manually adjusted for each participant to include only the QRS complex, based on visual inspection of the EMG signal.

2.3.2. Gating

Fig. 1 illustrates three existing methods of ECG artifact removal on a contaminated EMG recording from the LUT during a 5 min rest period for a representative participant. Gating (Fig. 1C) involves the complete removal of ECG artifact time intervals from the contaminated EMG signal (Bartolo et al., 1996). This process assumes that any 'true' EMG signal contained within the ECG time intervals selected for removal is redundant of EMG activity occurring outside of these intervals; therefore, calculations made on the gated signal will accurately represent calculations made on an uncontaminated signal.

The primary assumption of the gating method is often violated during dynamic motor tasks, which are typical of most functional activities. Furthermore, the loss of data resulting from removal of