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Myoelectric activity detection during a Sit-to-Stand movement using threshold methods

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ABSTRACT

Myoelectric signals recorded via surface electrodes contain rich muscle activity information that is beneficial for both clinical diagnosis and biomedical research. When synchronized with the kinematic data, these signals provide investigators an insight into muscle activation sequence, onset, levels, and periods. A primary difficulty with the analysis and interpretation of electromyography (EMG) signals lies in the inherent stochastic nature of the EMG process, which arises from its biological variability as well as noise added during the collection process. Various techniques for muscle onset and activity detection from the myoelectric signal have been proposed in the literature. Our focus in this study is myoelectric activity detection from EMG signals collected during Sit-to-Stand (STS) and Stand-to-Sit (STST) movements. We explore a previously established double threshold detection method, and compare its results with a novel detection scheme based on the energy of the signal. Accordingly, EMG signals from four lower extremity muscles, and synchronized kinematic data, were collected for 180 trials of STS and STST movements performed in the laboratory. Detection thresholds above baseline in the case of both algorithms were computed and analyzed using a 2 (detectors) $\times$ 4 (activity thresholds) repeated measures analysis of variance. Our statistical analysis revealed that the energy detection method performed similarly to the double threshold method, while both methods required a considerably higher threshold above baseline for detection.

1. Introduction

The STS and STST transfers are functional movements routinely performed by a majority of the population. Though simple in appearance, the underlying coordination of the musculoskeletal dynamics necessary to ensure successful STS and STST transitions are quite complicated. Clinical studies attempting to diagnose deficiencies in daily functional movements stand to benefit from precisely identifying muscle onset/offset and periods of muscle activation during different phases of the movement. Detection of muscle activity from EMG signals in STS and STST movements will benefit daily functional movement analysis of patients with clinical conditions such as stroke [1,2] and Parkinson's disease [3,4] as these applications require an accurate detection of onset, offset, and duration of the EMG burst.

Voluntary muscular activity results in an EMG signal that increases in magnitude due to increment in the number of recruited motor units and/or increased frequency of the motor unit (MU) firing rates. Generally, application areas of surface EMG signal include: [5] (1) the activation timing of muscles, (2) the force/EMG signal relationship, and (3) the use of the EMG signal as a fatigue index. In this paper, we focus on the first application area i.e., the timing and duration of muscle

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activation and explore a new method in an attempt to accurately determine muscle activity periods during STS and STST transfers.

Several methods are described in the literature for detecting the onset and duration of muscle activation. These range from simple heuristic algorithms to optimal statistical techniques and wavelets based algorithms. For example, Di Fabio used a 50 sample window of the EMG signal to make a baseline reference, consequently the muscle was considered ON if 25 consecutive samples exceeded three standard deviations (σ) of the mean baseline activity [6]. The EMG signal was full-wave rectified and low pass filtered before application of the detection algorithm. Lidierth proposed a detection method which was identical to Di Fabio with extended post-processing procedures in an to improve detection results [7]. Hodges and Bui also used the same algorithm as Di Fabio, yet compared different window sizes, low pass filter frequencies and one, two or three standard deviations (σ) above base line to examine differences in threshold selections [8]. The authors used EMG signals that were rectified before application of the detection algorithm. Results were then compared to human experts to see the effects of different parameters. Abbink et al. proposed a method based on Hodges and Bui with a change of cut-off frequency and window length to optimize detection of muscle activation periods [9]. Algorithms used by [6–9] can be classified as more of a heuristic approach based upon defining a baseline and then detecting muscle activity using various thresholds.

Bonato et al. provided another perspective to muscle activity detection schemes which was a statistical method based upon two thresholds, called the double threshold method and presented Receiver Operator Characteristic (ROC) curves for performance of double threshold method [10]. EMG signals were whitened (de-correlated) before application of their detection algorithm, but methods of de-correlating EMG signal were not discussed. Generalized Likelihood Ratio (GLR) test was proposed by Micera et al. to find muscle activity onset from the EMG signal [11]. Staude extended the statistical methods to include other optimal change detection algorithms based on cumulative sum type (CUSUM) and Approximated Generalized Likelihood Ratio (AGLR) [12]. Despite the complexity of the likelihood ratios algorithms proposed by Micera [11] and Staude [12] in their implementation to the EMG signal, Staude states his method is appropriate for real-time applications. Staude et al. later presented an overview of different techniques based upon thresholds and statistical optimal decision methods [13]. Due to non-stationary nature of the EMG signal, wavelet transforms are also used by some authors for the purpose of detecting of muscle activations [14,15], but again these methods suffer from implementation complexity. Solnik et al. used the Teager–Kaiser Operator to improve the detection accuracy but used the algorithms proposed by [10,12,16].

There has been considerable work on finding the mathematical/statistical relation between the movement being performed and the resulting EMG signal. Bobet and Norman [17] used least-squares fitting to find a dynamic relationship between EMG and joint moments for making joint movement predictions. Furthermore, some algorithms have been proposed to find a relationship between EMG signal and the specific movement being performed [18]. Moreover, modeling efforts have been done using fractional derivatives [19]. A majority of the literature examining these methods of muscle activity detection apply these to human gait. Whether these methods of determining muscle activation during gait will similarly work for the STS and STST movements has not been investigated.

In this study we aim to detect muscle activation periods in the myoelectric signals recorded from multiple sites during STS and STST movements. We use a previously established double threshold [10] detection scheme, and we propose another scheme based upon the Neyman–Pearson detector formulation for stochastic signals buried in noise, called the energy detectors. A exhaustive literature review did not reveal any previous studies which applied the energy detectors to myoelectric signals. We compare ROC curves of both detection schemes to determine which of them more precisely identifies the onset and duration of muscle activation.

2. Methods

The study received prior approval from Institutional Review Board (IRB) of University of Arkansas at Little Rock (UALR) under protocol 12-054 and all participants provided written informed consent. Eighteen healthy individuals, three males and fifteen females, volunteered for the study. The participants mean ($\pm$ S.D.) age, height, and body mass were 21.94 ± 5.05 years, 1.70 ± 0.04 m, and 66.76 ± 4.32 kg respectively. All participants were free from current or pre-existing injuries that would influence their execution of the STS or STST movements.

2.1. Protocol

Numerous factors give rise to variability in the performance of the STS and STST movements [20]. These factors can be termed as determinants of the STS and STST transfers. Relevant determinants which were controlled during this study are:

1. Each individual's seat height was set equal to his/hers knee height as measured from the lateral epicondyle of the femur to the floor without shoes. All trials were performed barefoot.
2. The seat used in this study, which was a common adjustable height chair, did not have a backrest or armrests. The chair was placed comfortably in front of dual force plates for measuring the ground reaction forces (GRF) under each foot, which were recorded but not presented here.