Journal of Electromyography and Kinesiology 40 (2018) 88–94

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

The effect of epoch length on time and frequency domain parameters of electromyographic and mechanomyographic signals

Joshua L. Keller[a,*], Terry J. Housh[a], Clayton L. Camic[b], Haley C. Bergstrom[c], Doug B. Smith[d], Cory M. Smith[a], Ethan C. Hill[a], Richard J. Schmidt[a], Glen O. Johnson[a], Jorge M. Zuniga[e,f]

[a] University of Nebraska – Lincoln, United States
[b] Northern Illinois University, United States
[c] University of Kentucky, United States
[d] Oklahoma State University, United States
[e] University of Nebraska-Omaha, United States
[f] Facultad de Ciencias de la Salud, Universidad Autónoma de Chile, Chile

ARTICLE INFO

Keywords:
EMG
MMG
Epoch length

ABSTRACT

The selection of epoch lengths affects the time and frequency resolution of electromyographic (EMG) and mechanomyographic (MMG) signals, as well as decisions regarding the signal processing techniques to use for determining the power density spectrum. No previous studies, however, have examined the effects of epoch length on parameters of the MMG signal. The purpose of this study was to examine the differences between epoch lengths for EMG amplitude, EMG mean power frequency (MPF), MMG amplitude, and MMG MPF from the VL and VM muscles during MVIC muscle actions as well as at each 10% of the time to exhaustion (TTE) during a continuous isometric muscle action of the leg extensors at 50% of MVIC. During the MVIC trial, there were no significant ($p > 0.05$) differences between epoch lengths (0.25, 0.50, 1.00, and 2.00-s) for mean absolute values for any of the EMG or MMG parameters. During the submaximal, sustained muscle action, however, absolute MMG amplitude and MMG MPF were affected by the length of epoch. All epoch related differences were eliminated by normalizing the absolute values to MVIC. These findings supported normalizing EMG and MMG parameter values to MVIC and utilizing epoch lengths that ranged from 0.25 to 2.00-s.

1. Introduction

Physiological and nonphysiological factors influence the surface electromyographic (EMG) signal (Farina et al., 2004, 2014). The nonphysiological factors are related to anatomical, geometrical, and physical considerations of the muscles involved, while physiological factors are associated with fiber membrane and motor unit properties (Farina et al., 2004, 2014). In addition, signal processing methodologies including the algorithms used to calculate amplitude and frequency parameters, the windowing technique, the zero-padding applied, rectification, filtering, amplification, and epoch length can affect time and frequency domain parameters of the EMG signal. All these signal processing algorithms impact in the interpretation of the EMG data.

Mechanomyographic (MMG) signals are often measured simultaneously with EMG signals to make inferences regarding neural strategies during fatiguing and nonfatiguing muscle actions (Beck et al., 2005; Housh et al., 2000). Typically, the amplitude and frequency contents of the EMG and MMG signals are assessed over the same time period (epoch) to examine time-dependent, fatigue-related changes in neuromuscular responses (Beck et al., 2004; Farina and Gazzoni, 2003; Herda et al., 2008; Smith et al., 2016a, 2016b). The selection of epoch length affects the time and frequency resolution of both EMG and MMG signals (Merletti and Conte, 1997). Short epochs exhibit good time resolution, but poor frequency resolution, while longer epochs have the opposite effect (Beck et al., 2005). Furthermore, the power density spectra (PSD) of EMG and MMG signals are often determined using fast Fourier transform (FFT), which operates under the assumption that the signal is stationary with no change overtime in the mean or variance of the frequency content (Beck et al., 2005; Blanco et al., 1995). Because EMG and MMG signals during isometric and dynamic muscle actions are often non-stationary (Beck et al., 2004, 2010; Karlsson et al., 2000, 2001), short signal epochs are used which can be considered quasi-stationary (Farina and Merletti, 2000). Generally, epoch lengths range from approximately 0.25–2.00 s, although shorter (0.167-s) and longer epochs (10.00-s) are sometimes used (Beck et al., 2007; Farina and Gazzoni, 2003). Epochs shorter than 0.25-s, however, can result in a

* Corresponding author at: University of Nebraska – Lincoln, Department of Nutrition and Health Sciences, 110 Ruth Leverton Hall, Lincoln, NE 68583-0806, United States.
E-mail address: jkeller@unl.edu (J.L. Keller).

https://doi.org/10.1016/j.jelekin.2018.04.003
Received 14 December 2017; Received in revised form 10 April 2018; Accepted 14 April 2018
1050-6411/

high degree of random and systematic error variability for the estimation of frequency parameters from the PSD including the mean power frequency (MPF) and median power frequency (Farina and Merletti, 2000). Therefore, the SENIAM project (1999) has made recommendations for epoch lengths that consider both the EMG parameter that is being assessed (amplitude or frequency) and the intensity of muscle action. Comparable recommendations for MMG signals, however, do not exist (Herda et al., 2008) and no previous studies have examined the effects of epoch length on the time or frequency domain parameters of the MMG signal. Therefore, the purpose of the present study was to examine the differences between epoch lengths for EMG amplitude, EMG MPF, MMG amplitude, and MMG MPF from the vastus lateralis (VL) and vastus medialis (VM) muscles during MVIC muscle actions as well as at each 10% of the TTE during a continuous isometric muscle action of the leg extensors at 50% of MVIC. Based on previous studies of EMG signals (Georgakis et al., 2003; Waly et al., 1996; Xie and Wang, 2006), it was hypothesized that epoch length would have no effect on submaximal or maximal mean values for the neuromuscular parameters.

2. Methods

2.1. Subjects

Nine recreationally active subjects (7 men and 2 women, mean ± SD age = 22.4 ± 2.3 yrs, weight 76.9 ± 10.3 kg, height 177.1 ± 8.0 cm) volunteered to participate in the current study. The subjects regularly participated in physical activities, such as running, bicycling, and resistance training. These subjects were from our series of previous EMG linear array papers (Herda et al., 2013, 2015; Smith et al., 2015, 2016a, 2016b, 2017). The Institutional Review Board for Human Subjects at the University of Nebraska-Lincoln (IRB #20100110521FB) approved the study, and prior to participation the subjects completed a health history questionnaire and gave written informed consent.

2.2. Orientation session

Each subject's innervation zones (IZ) and pennation angles for VL and VM muscle fibers were determined. After skin preparations, two 8-channel silver bar electrodes (5 mm × 1 mm, 10 mm interelectrode distance, OT Bioelettronica, Torino, Italy) were placed on the muscle bellies of the VL and VM. The probe on the VL was oriented at a 20° angle related to the reference line between the anterior superior iliac spine and superior border of the patella. The probe on the VM was oriented at a 50° angle related to the reference line between the anterior superior iliac spine and anterior border of the medial ligament (Rainoldi et al., 2000). Reference electrodes were placed around the subject's wrist and the subject was instructed to perform a submaximal isometric leg extension muscle action on a calibrated Cybex II dynamometer (Cybex International INC., Medway, MA). The IZ for the VL and VM were identified by the EMG channel with the minimal amplitude and phase reversal (Merletti et al., 1990). The probe was then moved along the reference lines until the IZ were in the center of the electrode arrays. The pennation angle was then determined by rotating the probe around the IZ until the slopes of the two lines connecting the EMG waveforms from the channels above and below the IZ were approximately equal (EMG16 User Manual, 2006). After both the IZ and pennation angles were identified, a marker was used to outline the probe so that proper placement and alignment were identified for the subsequent session.

2.3. Warm-up

The warm-up consisted of 5, 6-s submaximal isometric leg extension muscle actions, and subjects were instructed to warm-up at a perceived moderate intensity (~50% of maximum effort). The subject's dominant leg (based on kicking preference) was used for all testing on the calibrated Cybex II dynamometer with a knee joint angle of 120° (180° full leg extension).

2.4. Maximum voluntary isometric contraction (MVIC)

Following the warm-up, each subject completed 2, 6-s MVICs separated by 2-min of rest. Strong verbal encouragement was provided during each MVIC trial. The MVIC value was calculated for a 2-s time period, corresponding to the middle 33% of each 6-s trial. The highest torque value of the two MVIC trials was used to calculate each subject's 50% MVIC torque value for the subsequent sustained isometric task. During the MVIC trial, neuromuscular parameters were determined by utilizing each individual epoch length (0.25, 0.50, 1.00, or 2.00-s) and each utilized a uniform center timepoint at the 3-s timepoint. These neuromuscular values were then used for subsequent normalization procedures.

2.5. Sustained isometric task

Each subject performed a sustained isometric leg extension muscle action at 50% of MVIC with a knee joint angle of 120° (180° full leg extension) until exhaustion (mean ± SD: 103.8 ± 17.7-s) was reached. Exhaustion was defined as the subject being unable to maintain torque production within ± 5% of their 50% of MVIC value despite strong verbal encouragement. The real-time digitized torque signal was displayed on a computer monitor so that the subjects could visually track their torque production.

2.6. EMG measurements and signal processing

Surface EMG and MMG signals were simultaneously recorded on the VL and VM muscles of the dominant leg with 8-channel linear electrode arrays and an EMG 16 data acquisition system (EMG 16, LISiN-Prima Biomedical & Sport, Treviso, Italy). Before securing the linear EMG electrode arrays with double-sided adhesive strips on the VL and VM, the skin was carefully abraded and cleaned with rubbing alcohol (70% v/v isopropyl alcohol, CareTouch, Westminster, CO). The adhesive strips had small holes for each silver bar electrode and each hole was filled with 30 μL of conductive gel with a gel dispenser (AG22331, Eppendorf, Hamburg, Germany) (EMG16 User Manual, 2006). The probes were set so that channel 1 was the most proximal and channel 8 was the most distal electrode.

The raw EMG signals from each electrode of the array were recorded in a monopolar signal acquisition mode (gain x 500) and analog filtered (fourth-order Bessel, bandwidth = 10–500 Hz) with the surface EMG 16 data acquisition system. The monopolar signals were converted to a digital form with a 12-bit analog-to-digital converter with a sampling frequency of 2048 Hz. The digital signals were then stored on a personal computer for analysis. Fast Fourier transform was used to estimate the PSD and zero-padding was not applied.

Channels 7 and 8 (10 mm interelectrode distance, 30 mm distal to the IZ) of the VL and VM probes were used for the bipolar electrode configuration, which were in accordance with locations recommended by SENIAM (Hermens et al., 1999). The EMG signals were zero-meaned, and digitally bandpass filtered (fourth-order Butterworth) at 10–500 Hz. The EMG amplitude was estimated by calculating the root mean square and MPF values were calculated for each MVIC trial for each epoch length (0.25, 0.50, 1.00, and 2.00-s) with the 3-s timepoint used as the center for each epoch. During the isometric task, the subjects reached their 50% MVIC torque value approximately within 1-s. The TTE was defined from the initial timepoint that the subject reached 50% of MVIC until torque production could not be maintained within ± 5% of 50% of MVIC value. Following the sustained isometric task, the EMG amplitude and MPF values were calculated offline at the