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Reliability of absolute versus log-transformed regression models for examining the torque-related patterns of response for mechanomyographic amplitude

Trent J. Herda[a], Joseph P. Weir[b], Eric D. Ryan[a], Ashley A. Walter[a], Pablo B. Costa[a], Katherine M. Hoge[a], Travis W. Beck[a], Jeffrey R. Stout[a], Joel T. Cramer[a,*]

[a] Department of Health and Exercise Science, University of Oklahoma, Norman, OK 73019-6081, USA
[b] Program in Physical Therapy, Des Moines University - Osteopathic Medical Center, Des Moines, IA 50312, USA

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ABSTRACT

This study examined the test–retest reliability of the slopes (b) and y-intercepts (a) of the absolute and log-transformed regression models applied to the mechanomyographic amplitude (MMG_{RMS}) versus torque (TQ) relationship. Fifteen participants (mean ± SD age = 23 ± 4 yrs) performed two isometric maximal voluntary contractions (MVCs) and ten randomly ordered isometric leg extensions from 5% to 95% of their MVC during three separate trials. MMG_{RMS} was recorded from the vastus lateralis during each MVC. Intraclass correlation coefficients (ICCs) and standard errors of measurement (SEMs) were calculated for test–retest reliability. ICCs for the b and a terms were 0.89 and 0.90 for the log-transformed and 0.85 and 0.76 for the absolute relationships, respectively. The SEM values (expressed as a percentage of the mean) for the b and a terms were 9.7% and 16.4% for the log-transformed and 18.9% and 57.1% for the absolute relationships, respectively. These results indicated that the b and a terms from both the absolute linear and log-transformed MMG_{RMS} versus TQ relationships were relatively reliable (ICCs), however, the SEMs for the log-transformed relationships were lower than the absolute linear models. Furthermore, the b term from the log-transformed relationships may provide unique information regarding the nonlinear characteristics (plateau points) of the MMG_{RMS} versus TQ relationship, whereas the a term may indicate upward or downward shifts in MMG_{RMS} across the TQ spectrum. Thus, the log-transformed MMG_{RMS} versus TQ relationships may offer an attractive alternative method for reliably quantifying and tracking changes in the TQ-related patterns of response for MMG_{RMS} on a subject-by-subject basis.

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1. Introduction

Surface mechanomyography (MMG) has been defined as the recording of low-frequency lateral oscillations of muscle fibers that occur during a contraction (Barry and Cole, 1990; Orizio, 1993; Stokes and Dalton, 1993). Barry and Cole (1990) and Orizio (1993) have suggested that these oscillations are manifested through (a) the gross lateral movement of the muscle at the initiation of the contraction, (b) smaller subsequent lateral oscillations occurring at the resonant frequency of the muscle, and (c) dimensional changes in the active fibers. In addition, the amplitude of the MMG signal may be influenced by several factors including the active stiffness of the fibers modulated by the number of motor units recruited and the firing rates of the active motor units (Akataki et al., 2004; Orizio et al., 2003; Ryan et al., 2008b, 2007b), intramuscular pressure (Orizio et al., 1989), viscosity of the intra- and extra-cellular fluid surrounding the fibers (Barry and Cole, 1988), intramuscular temperature (Mitchell et al., 2008), and the thickness of subcutaneous fat between the MMG sensor and the surface of the muscle (Orizio et al., 1989). Consequently, it has been hypothesized that if MMG amplitude reflects the number of active motor units and their firing rates, then MMG amplitude should increase with the force output of the muscle (Akataki et al., 2004, 2003; Ebersole et al., 1998; Orizio et al., 2003; Shinohara et al., 1998). This relationship would be consistent with the well-established electromyographic (EMG) amplitude versus force relationship. However, MMG amplitude tends to plateau or decrease from 0% to 25% MVC, increase rapidly from 25% to 60–80% MVC, and then plateau or decrease to 100% MVC (Akataki et al., 2004; Orizio et al., 2003; Ryan et al., 2008b, 2007b). This "cubic" pattern that is often observed in the MMG–force relationship (Akataki et al., 2004; Akataki et al., 2003; Ebersole et al., 1998; Orizio et al., 2003; Shinohara et al., 1998) is much different from the patterns that are commonly observed in the EMG–force relationship (Akataki et al., 2004; Bilodeau et al., 1991; Ebersole et al., 1999; Maton et al., 1990; Ryan et al., 2008b). Since EMG amplitude increases either linearly or quadratically

* Corresponding author at: Biophysics Laboratory, Department of Health and Exercise Science, University of Oklahoma, 1401 Asp Avenue, Rm 12, Norman, OK 73019-6081, USA. Tel.: +1 405 325 5211; fax: +1 405 325 0594.
E-mail address: jcramer@ou.edu (J.T. Cramer).

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across the force spectrum (Akataki et al., 2004; Bilodeau et al., 1991; Ebersole et al., 1999; Maton et al., 1990; Ryan et al., 2008b), it has been hypothesized that the EMG–force relationship reflects the undistinguishable increases in both motor unit recruitment and the firing rates of the active motor units (Beck et al., 2009; Orizio et al., 2003, 1989). In contrast, the MMG–force relationship may be able to distinguish between these motor control strategies that are used synergistically to increase the force output of the muscle.

For example, the characteristic increases in MMG amplitude from 20–25% to 60–80% MVC are thought to reflect increases in motor unit recruitment with little change in the firing rates of the active motor units (Akataki et al., 2004; Orizio et al., 2003; Ryan et al., 2008b, 2007b). However, the characteristic plateau or decrease in MMG amplitude from 60–80% to 100% MVC may be attributed to "rate coding," or the fusion of motor unit twitches that stiffens the muscle and limits the lateral oscillations (Akataki et al., 2004; Orizio et al., 2003; Ryan et al., 2008b, 2007b). These motor control strategies have been established for both small (Akataki et al., 2003; Basmajian and Luca, 1985) and large (Akataki et al., 2003; Basmajian and Luca, 1985) skeletal muscles that rely on motor unit recruitment to increase force output to approximately 50–80% MVC (Akataki et al., 2003; Basmajian and Luca, 1985). From 50% to 80% (depending on the size of the muscle), there are increases in the firing rates of the active motor units (i.e., fusion of twitches) to increase force output to 100% MVC (Akataki et al., 2003; Basmajian and Luca, 1985). Therefore, it has been hypothesized that the patterns of response demonstrated during the MMG amplitude versus force relationship may be able to distinguish between the contributions of motor unit recruitment and rate coding as the motor control strategies that increase muscle force production (Beck et al., 2004, 2004b, 2006; Coburn et al., 2004, 2006; Ryan et al., 2008a, 2007a, 2007b).

Many studies have examined the *composite* (averaged across subjects) MMG amplitude versus force or torque (TQ) relationships to examine the motor control strategies of various muscles (Akataki et al., 2004; Beck et al., 2004; Coburn et al., 2004, 2005; Orizio et al., 2003; Ryan et al., 2008a, 2007a). In these cases, repeated measures analysis of variance (ANOVA) models can be applied to statistically examine changes in the average MMG amplitude values at discrete force levels (Akataki et al., 2004; Beck et al., 2004; Coburn et al., 2004, 2005; Orizio et al., 2003; Ryan et al., 2008b, 2007a). Moreover, Herda et al. (2008) have suggested that the MMG amplitude values at these discrete force levels demonstrate "acceptable" test–retest reliability. However, due to the relatively large amount of inter-individual variability among the MMG amplitude versus force or TQ relationships, several recent studies have suggested that these relationships should be examined on a subject-by-subject basis (Farina et al., 2004; Orizio et al., 1989; Zwarts and Keidel, 1991). Thus, polynomial regression analyses (i.e., linear, quadratic, and cubic models) have been used to describe the shapes of the MMG–force relationships for each subject (Beck et al., 2004, 2004b, 2006; Coburn et al., 2004, 2006; Ryan et al., 2008a, 2007a, 2007b). For example, Ryan et al. (2008a) reported that the MMG–force relationships for the vastus lateralis were linear for 58% of the subjects (11 of 19), quadratic for 26% (5 of 19), and cubic for 6% (2 of 19), yet only 6% of the individual subjects' patterns of response matched the composite relationship. However, in a test–retest reliability study, Herda et al. (2009) reported that only 33–55% of subjects were fit with the same polynomial models (ordinary and generalized least squares regression) across three separate trials. Together (Farina et al., 2004; Herda et al., 2009; Orizio et al., 1989; Ryan et al., 2008b, 2007a; Zwarts and Keidel, 1991), these findings suggested that polynomial regression analyses may not be consistently describing the individual force-related patterns of response for MMG amplitude. Thus, alternative methods to quantify these patterns may be needed.

One possible alternative is to examine the MMG amplitude versus TQ relationships with linear regression models on a subject-by-subject basis. Like all analytical models, a certain degree of parsimony is sought to answer most research questions. In fact, Frank (1966) states that ". . . if a problem can be adequately characterized by a linear model, the appropriate analytical techniques are usually better documented, more easily interpreted, and more readily available . . ." (p. 248). Therefore, the slopes and *y*-intercepts from linear models may provide simple quantitative values by which to examine changes in the TQ-related patterns of response for MMG amplitude. However, since the MMG amplitude versus TQ relationships can be nonlinear (Akataki et al., 2004, 2003; Ebersole et al., 1998; Orizio et al., 2003; Shinohara et al., 1998), linear regression applied to nonlinear patterns may not accurately characterize the relationship between MMG amplitude and TQ. Consequently, a natural log-transform applied to both MMG amplitude and TQ may improve the linearity of these relationships (Frank, 1966). Furthermore, linear models applied to log-transformed relationships provide additional quantitative information about the linearity or nonlinearity of the original-scale relationships. For example, slope coefficients in log-transformed relationships that are greater than 1 indicate that the relationship "accelerates" upward in a nonlinear fashion, while slope coefficients that are less than 1 indicate that the relationship "decelerates" or plateaus. Considering that the MMG amplitude versus TQ relationship has been described as having a plateau or decrease from 60–80% to 100% of the MVC (Akataki et al., 2004; Orizio et al., 2003; Ryan et al., 2008b, 2007b), the slope coefficient from the log-transformed relationship should, in theory, indicate the presence of such a plateau. However, we are aware of no previous studies that have used log-transformed MMG amplitude versus TQ relationships. Therefore, the purpose of this study was to examine the test–retest reliability of the slopes and *y*-intercepts for both the absolute and log-transformed linear regression models that can be applied to the MMG amplitude versus TQ relationship.

2. Methods

Fifteen healthy participants (mean ± SD age = 23 ± 4 yrs; stature = 173 ± 10 cm; mass = 75 ± 14 kg) volunteered for this investigation. None of them reported any current or ongoing neuromuscular diseases or musculoskeletal injuries that involved the ankle, knee, or hip joints. This study was approved by the University of Oklahoma Institutional Review Board. All participants read and signed an informed consent form and completed a pre-exercise health status questionnaire.

2.1. Research design

Isometric strength for the right leg extensor muscles was measured using the analog TQ signal extracted from a calibrated Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY). The participants were seated with restraining straps over the pelvis, trunk, and contralateral thigh, and the lateral condyle of the femur was aligned with the input axis of the dynamometer in accordance with the Biodex User's Guide (Biodex Pro Manual, Applications/Operations. Biodex Medical Systems, Inc., Shirley, NY, 1998). All isometric TQ assessments were performed at a leg flexion angle of 120° (i.e., 60° below full extension).

Each participant visited the laboratory on four occasions, once for a familiarization trial followed by three separate experimental trials. During the familiarization trial, participants performed two 4-s isometric maximal voluntary contractions (MVCs) and several submaximal isometric step muscle actions at randomly ordered