Comparison of electromyographic activity during eccentrically versus concentrically loaded isometric contractions

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Abstract

Electromyographic (EMG) amplitude and mechanical tension are directly related during isometric contraction. Maximal voluntary isometric contractions are typically elicited through two different procedures: resisting a load, which is eccentric in nature, and contracting against an immovable object, which is concentric in nature. A wealth of literature exists indicating that EMG amplitude during concentric contractions is greater than that of eccentric contractions of the same magnitude. However, the effects of different methods to elicit isometric contraction on EMG amplitude have yet to be investigated. The purpose of this study was to compare EMG amplitudes under different loading configurations designed to elicit isometric muscle contraction. Twenty healthy volunteers (10 males and 10 females, age = 23 ± 2 yrs, height = 1.7 ± 0.09 m, mass = 69.9 ± 16.8 kg) performed a maximal voluntary plantarflexion effort for which the vertical ground reaction force (GRFv) sampled from a force plate and surface EMG of the soleus were recorded. Participants then performed isometric plantarflexion at 20%, 30%, 40%, and 50% GRFv max in a seated position, from a neutral ankle position, under two different counterbalanced isometric loading conditions (concentric and eccentric). For concentric loading conditions, the subject contracted against an immovable resistance to the specified %GRFv identified via visual and auditory feedback. For eccentric loading conditions, subjects contracted against an applied load placed on the distal anterior thigh that produced the specified %GRFv. This applied load had the tendency to force the ankle into dorsiflexion. Therefore, plantarflexion force, in an attempt to maintain the ankle in a neutral position, resisted lengthening of the plantarflexor musculature, thus representing eccentric loading during an isometric contraction. Mean EMG amplitude was compared across loading levels and types using a 2 (loading type: concentric, eccentric) × 4 (loading level: 20%, 30%, 40%, 50% GRFv) repeated-measures ANOVA. The main effect for loading level was significant (p = 0.007). However, the main effect for loading type, and the loading type × loading level interaction were non-significant (p > 0.05). The present findings provide evidence that isometric muscle contractions loaded in either concentric or eccentric manners elicit similar EMG amplitudes, and are therefore comparable in research settings.

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1. Introduction

It has long been recognized that mechanical tension and electromyographic (EMG) amplitude are directly related during isometric contraction (Basmajian, 1967; Bigland et al., 1953; Hof and van den Berg, 1977). Lippold and Bigland demonstrated that during a voluntary contraction, the tension is proportional to the measurable electrical activity under isometric contractions (Basmajian, 1967; Bigland and Lippold, 1954; Bigland et al., 1953; Lippold, 1952). Furthermore, Bigland and Lippold (1954) reported that graded increases in contractile force are predominantly a result of an increase in the number of active motor units.
Numerous studies have been conducted comparing EMG amplitude and motor unit activity during maximal and sub-maximal concentric (shortening) and eccentric (lengthening) contractions, with the bulk reporting lesser EMG amplitude and motor unit activation during eccentric contractions (Enoka, 1996; Grabiner and Owings, 2002; Grabiner et al., 1995; Kay et al., 2000; Madeleine et al., 2001; Moritani et al., 1987; Westing et al., 1991). For example, Moritani and colleagues reported greater mean motor unit activation in concentric biceps brachii contractions compared to eccentric biceps brachii muscle actions. Furthermore, in a comparison of EMG activity between concentric and eccentric maximal voluntary contractions of the knee extensors, Grabiner and Owings (2002) revealed the EMG of the eccentric contractions was significantly smaller than that of the corresponding concentric muscle contractions, supporting the research put forth by Westing et al. (1991) that showed greater EMG activity in a concentric contraction of the knee extensors.

There are two major theories regarding the origin of differences noted between concentric and eccentric muscle actions. The decreased EMG amplitude during eccentric muscle contractions is thought to be due to the greater overall musculotendinous force produced with lengthening contractions. Kossev and Christova (1998) as well as Laidlaw et al. (2000), both using indwelling electrodes, have shown that the number of motor units recruited is less and that the discharge rate is decreased in eccentric contractions compared to concentric contractions. This is thought to be a function of the greater passive force contributions of the parallel and series elastic components during lengthening contractions, thus necessitating a lesser requirement for motor unit activation from the central nervous system. Alternatively, research by Nardone and Schieppati (1988), Nardonne et al. (1989) has proposed that the differences in EMG amplitude between contraction types result from separate, distinct neural pathways for each type of muscle activation. This notion later gained some support with experimental evidence that suggests a reduced activation of muscle during maximum eccentric contractions (Allen et al., 1995; Nakazawa et al., 1993; Westing et al., 1990), different recruitment patterns during eccentric muscle actions (Howell et al., 1995; Kamen et al., 1995; Kay et al., 2000; Laidlaw et al., 2000; Laidlaw et al., 1994; McHugh et al., 2002), and a reduction in the size of the motor unit activation potentials of stimulations elicited during muscle lengthening actions (Aburzzese et al., 1994; Romano and Schieppati, 1987).

Although numerous studies support the concept that eccentric contractions elicit lesser motor unit activation and, in turn, lower EMG amplitudes compared to concentric contractions, we are not aware of any studies that have compared different loading mechanisms for eliciting isometric contractions (i.e. concentrically loaded versus eccentrically loaded). For the purposes of this study, an isometric muscle contraction was defined as a contraction that produces no change in the joint angle, thus maintaining constant overall musculotendinous length. A concentrically loaded isometric muscle contraction (CONI) was defined as an isometric contraction during which the contractile apparatus attempted to shorten while joint motion was restricted. This type of contraction is similar to the use of an isokinetic dynamometer to elicit maximal voluntary isometric contraction (MVIC) (Blackburn and Mynark et al., 2006; Blackburn et al., 2006; Christou and Carlton, 2002; Grabiner and Owings, 2002; Kay et al., 2000). Conversely, an eccentrically loaded isometric contraction (ECCI) was defined as a contraction during which the musculotendinous unit was active in an attempt to maintain a specific joint position as it resisted the lengthening imposed by an external load. This type of contraction is similar to the use of manual muscle tests or hand held dynamometers to elicit MVIC such as during a clinical “break test” (Linnamo et al., 2003; McNair and Stanley, 1996; McNair et al., 1992; Nardonne et al., 1989). Though overwhelming evidence exists suggesting that eccentric muscle actions elicit a lower EMG amplitude than concentric muscle contractions for similar torque or force production, it is unclear if different types of loading mechanisms for isometric contractions produce the same relative EMG amplitudes. Due to the fact that the musculotendinous unit is resisting changes in its length during ECCI contractions, the potential for passive contributions from parallel and series elastic components may be enhanced relative to CONI contractions. As such, lesser neural input may be required during ECCI contractions as evidenced by lesser EMG amplitude. Therefore, the purpose of this study was to evaluate differences in EMG amplitude under different loading configurations to elicit isometric muscle contractions. We hypothesized that the eccentrically loaded isometric muscle contractions would produce a lower mean EMG amplitude than the concentrically loaded isometric muscle contractions. The data provide evidence regarding the validity of comparisons between investigations which utilize different methods to obtain MVIC.

2. Methods

2.1. Participants

The sample included 20 healthy volunteers (10 males and 10 females) (age = 22.5 ± 2.7 yrs, height = 1.7 ± 0.1 m, mass = 69.9 ± 16.8 kg) from the Auburn University Department of Health and Human Performance Student Population. All subjects were free of lower extremity injury, had no history of lower extremity surgery or current neuromuscular disorder, and gave their informed consent.

2.2. Project overview

Mean EMG amplitudes were obtained from the participants using a traditional MVIC setup. The participants were seated in the experimental apparatus and instructed to plantarflex maximally against an immovable device resting on their anterior thigh. They were then asked to plantarflex to designated percentages of their MVIC in two manners. One measure involved the same
setup as the MVIC, where the participant was isometrically plantarflexing against an immovable resistance. This setup was considered a concentrically loaded isometric muscle contraction (CONI). The second setup required the participant to isometrically plantarflex in an effort to resist a load placed on the anterior thigh which had the potential to lengthen the musculotendinous unit. This set up was considered an eccentrically loaded isometric muscle contraction (ECCI).

2.3. Procedures

A bipolar Ag/AgCl active surface EMG electrode configuration (model DE-2.1, Delsys Inc., Boston, MA) with a 1 cm inter-electrode distance was placed over the soleus muscle, slightly distal to the medial gastrocnemius muscle belly, and medial to the Achilles tendon. Proper electrode placement and minimal cross-talk were verified via manual muscle testing Hislop and Montgomery, 1995. A reference electrode was placed over the tibial tuberosity. To secure electrodes, pre-wrap was placed over the sites and anchored with athletic tape. EMGs were sampled at 1000 Hz over a bandwidth of 20–450 Hz using a hardwired EMG system (DelSys Bagnoli 8, DelSys Inc., Boston, MA; differential amplification, input impedance > 10^15/0.2 ohm/pF, CMRR = 92 dB @ 60 Hz, SNR = 65 dB, overall noise (RMS, RTI) <1.2 µV). An electromagnetic motion analysis system (Ascension Technology Corp., Burlington, VT) interfaced with a force plate (Bertec model 6040-NC, Bertec Corp., Columbus, OH) was used to monitor sagittal-plane ankle joint kinematics and plantarflexion force. Electromagnetic sensors were placed over the proximal tibia and the dorsum of the foot, and were sampled at 100 Hz, while force plate data were sampled at 1000 Hz.

EMG and vertical ground reaction force (GRFv) data were sampled during MVICs to serve as references to calculate standardized applied loads of 20%, 30%, 40%, and 50% MVIC. MVICs were assessed using a custom static loading device placed on the distal anterior thigh Blackburn and Mynark et al. (2006) (Fig. 1a). This loading device has been demonstrated to effectively elicit activity of the soleus in the absence of antagonist co-contraction Blackburn and Mynark et al. (2006). With subjects seated with the hip, knee, and ankle joints at 90°, this device was secured on the distal anterior thigh by a winch fixed to the ground. The metatarsal heads were placed over a plank that was rigidly fixed to the force plate, allowing plantarflexion force to be captured in the GRFv. A second plank of equal height was placed under the calcaneous, maintaining the ankle at 90°. Hip and knee joint positions were standardized by leveling the thigh segment parallel to the ground so that the knee was flexed to 90°. The winch securing the loading device was tightened until the subject could no longer lift the calcaneous off the second plank during active plantar flexion, thus making the contraction isometric. The subject was then instructed to maximally plantarflex against the device while EMG and GRFv data were sampled. Each subject performed one practice trial and three collection trials. The collection trials were sampled for 3 s, with mean GRFv of the three collection trials serving as the MVIC.

This same loading configuration was used for the CONI condition. A biofeedback module was employed using Motion Monitor software (Innovative Sports Training, Chicago, IL), allowing for verification and replication of a specified force output (i.e. 20%, 30%, 40%, and 50 ± 5% MVIC). Visual and audio biofeedback of the GRFv was provided to the subject such that he/she was able to produce the specified level of force. Once subjects attained the appropriate force level, EMG data were sampled over a 3 s interval. Five trials were sampled.

For the ECCI condition, the plank under the calcaneous and the winch restricting motion of the loading device were removed, allowing full plantarflexion range of motion. An arbitrary load was placed on the loading device, and the subject was instructed to plantarflex isometrically in an effort to support the applied load with the ankle in a neutral (i.e. 90°) position (Fig. 1b). The magnitude of the applied load was adjusted to produce the specified %MVIC, and visual and audio biofeedback was used to verify this value as well as the specified ankle position simultaneously. Once subjects contracted against the applied load to the appropriate ankle joint position, EMG data were recorded over a 3 s interval. Five trials were sampled.

2.4. Data reduction

After A/D conversion, EMG signals were corrected for DC bias, bandpass filtered at 20–350 Hz (2nd order Butterworth), and notch filtered at 59.5–60.5 Hz (2nd order Butterworth). In addition, EMG data were smoothed using a 100 ms time constant RMS sliding window function. Mean EMG amplitude was calculated as the mean over the entire 3 s contraction interval (see Table 1).

Fig. 1. (a) Experimental setup for concentrically loaded isometric contractions. Plantarflexion force was characterized in the vertical ground reaction force. Position of the loading device was fixed using a winch, maintaining the ankle at 90°, and making the contraction isometric. (b) Experimental setup for eccentrically loaded isometric contractions. The block placed under the calcaneous during the concentrically loaded trials was removed, and subjects were required to support the load, maintaining the ankle at 90°.
2.5. Statistical analyses

Mean EMG amplitude was analyzed using a 2 (load type: CONI and ECCI) x 4 (load level: 20%, 30%, 40%, 50% MVIC) within-subject repeated-measures ANOVA model. Statistical significance was established a priori at \( \alpha = 0.05 \). All statistical analyses were performed using SPSS version 12 statistical software package (SPSS Inc., Chicago, IL).

3. Results

As expected, a significant main effect for load on EMG amplitude was observed \((p = 0.007)\), with EMG amplitude increasing as a function of load level (Fig. 2). However, the main effect for load type was not significant \((p = 0.386)\). EMG amplitudes collapsed across loading levels for each load type produced the following mean ± SD EMG amplitudes: ECCI = 0.1124 ± 0.0531 mV, CONI = 0.1092 ± 0.0585 mV. Similarly, the load type x load level interaction was non-significant \((p = 0.635)\) (Fig. 2).

4. Discussion

The purpose of the current study was to compare EMG amplitudes of the soleus under different loading configurations of isometric contraction. The present findings provide evidence that isometric contractions loaded in either a concentric or eccentric manner elicit similar EMG amplitudes and are comparable in research settings. These data suggest that the use of either concentric or eccentric loading mechanisms to elicit isometric contraction for use as an EMG standardization criterion is warranted, as the resulting amplitudes are comparable. However, future research is necessary to determine if these results are applicable to musculature other than the soleus.

In previous research, methods of obtaining maximal or sub-maximal isometric muscle contractions have differed (Blackburn and Mynark et al., 2006; Carpentier et al., 1998; Moritani et al., 1987; Westing et al., 1991) potentially confounding the comparability of the studies as a whole. The results of this study suggest that varying methodologies of obtaining MVICs are not a source of error or dissimilarity. In fact, these findings allow direct comparison between studies, as the concentrically and eccentrically loaded isometric muscle contractions were found to be similar. As a consequence, the use of either CONI or ECCI mechanisms to derive an EMG amplitude standardization criterion is warranted.

Obtaining MVIC using ECCI methods is far more complex from an experimental perspective, and presents several more limitations than CONI. During CONI contractions, the MVIC value is readily obtainable due to the fact that the participant simply maximally contracts against an immovable resistance. During ECCI, however, the subject resists an applied load, the magnitude of which is not readily available. The magnitude of the applied load must be incrementally increased in an effort to identify the exact maximal load that can be resisted by the particular muscle or muscle group. For example, McNair and Stanley, 1996 loaded subjects in an ECCI manner until they could no longer support the applied load, and considered the final load increment as the MVIC. This means that unlike CONI protocols, ECCI protocols require multiple trials to determine the appropriate maximal load value. This method has two major limitations. Firstly, fatigue may result from the

<table>
<thead>
<tr>
<th>CONI</th>
<th>ECCI</th>
<th>Collapsed</th>
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<tbody>
<tr>
<td>Load level (%)</td>
<td>Mean ± SD</td>
<td>Load level (%)</td>
</tr>
<tr>
<td>20</td>
<td>0.079 ± 0.085</td>
<td>20</td>
</tr>
<tr>
<td>30</td>
<td>0.099 ± 0.108</td>
<td>30</td>
</tr>
<tr>
<td>40</td>
<td>0.120 ± 0.144</td>
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<tr>
<td>50</td>
<td>0.137 ± 0.173</td>
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Fig. 2. Mean soleus EMG amplitude versus load level.
multiple trials needed to “fine tune” the applied load. As fatigue has direct implications for EMG amplitude (Hortobagyi et al., 1996; Moritani et al., 1982), its presence during identification of an amplitude standardization criterion should be avoided. Secondly, each increment in the applied load with ECCI methods places increasing tensile loads on parallel and series elastic components, potentially decreasing their force contributions to resisting lengthening of the activated musculature via changes in viscoelastic properties (McNair and Stanley, 1996). This potential decrease in passive force contributions would necessarily require an increase in neural contributions to produce a given force output, thus directly affecting EMG amplitude. For these reasons, we recommend the use of CONI to derive MVIC.

This investigation involved several limitations. Power analysis of mean EMG amplitude data indicated that a sample of 118 subjects would have been required for a statistical power of 0.80 given the observed effect size of 0.024 between loading types. This small observed effect size supports the notion that the type of loading used to elicit isometric contraction does not have a substantial effect on EMG amplitude. Furthermore, the requirement of a large sample size to achieve statistical significance associated with this small effect size suggests that the mean difference between loading types likely has little clinical or physiological significance. This, in turn, suggests that our study was not limited by power, but that the two loading types do, in fact, produce similar results from a physiological perspective.

There were also limitations involving the load applied to the custom static loading device. Loads higher than 50%MVIC were too high to comfortably place over a subject’s anterior thigh. It is difficult to determine if the results would have changed had loads greater than 50%MVIC been tested. Due to the limitation that only 40% of the MVIC load spectrum was tested (i.e., 20–50% MVIC), we were unable to determine if the same results persist at higher levels of loading.

4.1. Conclusions

This study revealed that there are no differences in EMG amplitudes associated with isometric contractions during which the muscle is attempting to shorten (CONI) versus isometric contractions during which the muscle is attempting to resist lengthening (ECCI). These results suggest that the type of isometric loading does not have a significant effect on the EMG amplitude of the muscle of interest. As such, either method appears to be appropriate for deriving MVIC for use as an EMG amplitude standardization criterion.

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