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Knee angle-specific MVIC for triceps surae EMG signal normalization in weight and non weight-bearing conditions

Kim Hébert-Losier *, Hans-Christer Holmberg

Swedish Winter Sports Research Centre, Department of Health Sciences, Mid Sweden University, Kunskapens väg 8, Hus D, 83125 Östersund, Sweden

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ABSTRACT

Varying the degree of weight-bearing (WB) and/or knee flexion (KF) angle during a plantar-flexion maximal voluntary isometric contraction (MVIC) has been proposed to alter soleus and/or gastrocnemius medialis and lateralis activation. This study compared the surface EMG signals from the triceps surae of 27 men and 27 women during WB and non weight bearing (NWB) plantar-flexion MVICs performed at 0° and 45° of KF. The aim was to determine which condition was most effective at eliciting the greatest EMG signals from soleus, gastrocnemius medialis, and gastrocnemius lateralis, respectively, for subsequent use for the normalization of EMG signals. WB was more effective than NWB at eliciting the greatest signals from soleus ($p = 0.0021$), but there was no difference with respect to gastrocnemius medialis and lateralis ($p \geqslant 0.2482$). Although the greatest EMG signals during MVICs were more frequently elicited at 0° of KF from gastrocnemius medialis and lateralis, and at 45° from soleus ($p < 0.001$); neither angle consistently captured peak gastrocnemius medialis, gastrocnemius lateralis or soleus activity. The present findings encourage more consistent use of WB plantar flexion MVICs for soleus normalization; confirm that both WB and NWB procedures can elicit peak gastrocnemius activity; and emphasize the fact that no single KF angle consistently evokes selective maximal activity of any individual triceps surae muscle.

1. Introduction

It is standard in research to express electromyography (EMG) signals as a percentage of a reference value to quantify the relative level of muscle activity. One of the most common methods used in science is to normalize EMG signals to those associated with a maximal voluntary isometric contraction (MVIC). Such normalization reduces the between- and within-subject variability of EMG recordings, improves the accuracy and reproducibility of results, and allows valid and reliable comparison of data from different individuals and experimental conditions (Burden, 2010).

At the same time, several factors must be considered to optimize the amplitude, validity and specificity of EMG signals collected during an MVIC for normalization. These factors include the time of day (Castaingts et al., 2004; Guette et al., 2005), rate of force development (Ricard et al., 2005), lateralization (Ball and Scurr, 2011) and body position (Carlsson et al., 2001). One key factor is joint angles because these can significantly influence the amplitudes of EMG signals from an MVIC, as often reported in the case of the triceps surae muscles (Arampatzis et al., 2006; Arndt et al., 1998; Carlsson et al., 2001; Signorile et al., 2002).

Although these ankle plantar-flexors all insert distally into the posterior aspect of the calcaneus through the Achilles tendon, the muscles comprising the triceps surae group are considered to be anatomically and functionally distinct. For instance, the soleus is mono-articular and plays a role predominantly in postural stability and horizontal propulsion during gait; whereas the gastrocnemius is bi-articular, possesses medial and lateral heads, and is important in the generation and transmission of forces and power (Jacobs et al., 1996; Neptune et al., 2001). Therefore, selective MVIC procedures based primarily on different knee-joint angles, body positions and loading patterns have been proposed for the acquisition of normalization signals from the soleus (SOL), gastrocnemius medialis (GM) and gastrocnemius lateralis (GL) muscles.

All methods proposed for collecting MVIC signals from the triceps surae for normalization have specific advantages and drawbacks with respect to the level of muscle selectivity and signal amplitude. Hébert-Losier et al. (2011) reported that the amplitudes of SOL, GM and GL surface EMG signals during unilateral plantar-flexion MVICs were greater in weight-bearing and 0° or 45° of knee flexion (KF) than in non weight-bearing and 90° of KF, for all three triceps surae muscles. Overall, their findings support the use of both 0° and 45° of KF during collection of plantar-flexion MVIC for normalization of EMG signals from the triceps surae, while emphasizing that no single knee position is specific or selective to the respective maximal activation of the SOL or gastrocnemius muscles.

Since the late 1960s, isokinetic dynamometers demonstrated their practical value, utility and effectiveness in connection with

* Corresponding author. Tel.: +46 (0) 63 14 5632; fax: +46 (0) 63 16 5740.
E-mail address: kim.hebert-losier@miun.se (K. Hébert-Losier).

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muscle rehabilitation, training and testing in both research and clinical settings (Baltzopoulos and Brodie, 1989; Kraemer et al., 2006). Dynamometric investigations have improved our understanding of neuromuscular function (Duclay et al., 2009), adaptations to interventions (Alfredson et al., 1998b; Horstmann et al., 2012) and fluctuations in muscle performance as a function of time of day (Castaingts et al., 2004; Guette et al., 2005). In isometric, isokinetic or isotonic-based research studies, dynamometers are commonly employed to capture EMG signals during plantar-flexion MVIC trials for signal normalization of the triceps surae muscle group (Cresswell et al., 1995; Gerdle and Fugl-Meyer, 1992; Hubley-Kozey and Earl, 2000; Kay and Blazevich, 2009; Pinniger, 2003). This approach minimizes participant displacement and is convenient and time-efficient in laboratory settings, but does not necessarily provide the maximal activation of each individual triceps surae muscle (Ball and Scurr, 2010; Carlsson et al., 2001).

In fact, more pronounced activation of the triceps surae during plantar-flexion contractions has been observed in connection with a weight-bearing (WB) standing position than a non weight-bearing (NWB) sitting or supine position (Carlsson et al., 2001; Perry et al., 1981). Consequently, unless configuration of the isokinetic dynamometer permits positioning in an upright stance, the traditional approach use to collect plantar-flexion MVIC values for EMG signal normalization using isokinetic devices may not elicit the same level of triceps surae muscle activity as the unipedal standing heel-raise MVIC method. Clearly, the greatest EMG signal recorded during an MVIC from any given muscle should be utilized in subsequent EMG signal normalization (Winter, 1991).

The present investigation compares the surface EMG recordings from the three triceps surae muscles during WB and NWB plantar-flexion MVICs at both 0° and 45° of KF. The primary purpose was to determine the condition that elicited the greatest signal during plantar-flexion MVICs from SOL, GM and GL, respectively, for EMG signal normalization. Our hypotheses were that WB would elicit the greatest EMG signal more frequently than NWB from all muscles; and that no single knee position would specifically or consistently capture peak SOL, GM or GL activity. However, on the basis of a previous investigation (Hébert-Losier et al., 2011), we speculated that 0° of KF would elicit the greatest EMG signal amplitudes from the GM and GL in approximately 70% of the study group, and the greatest amplitude from the SOL in about 40%. A secondary aim was to document the plantar-flexion torque and force values associated with the various MVIC trials. Because of the positive relationship between generation of force and muscle length (Arndt et al., 1998), it was assumed that 0° of KF would elicit higher plantar-flexion output than 45° both with and without weight-bearing.

2. Methods

2.1. Experimental design

This study used a repeated-measures design (Fig. 1) that required each participant to attend a single experimental session at the muscle performance laboratory of the Swedish Winter Sports Research Centre. The project was pre-approved by the Regional Ethical Review Board (2011-385-31M, Umeå, Sweden) and adhered to the latest amendment of the *Declaration of Helsinki*.

2.2. Participants

After providing verbal and written informed consent, 54 volunteers purposefully recruited to balance the cohort with respect to sex and age completed this study. Accordingly, half of the participants were men (mean ± SD; age: 39 ± 11 years; height: 181 ± 7 cm; mass: 81 ± 9 kg; body mass index: 25 ± 2 kg m^{-2}), the other half were women (age: 41 ± 11 years; height: 169 ± 8 cm; mass: 68 ± 8 kg; body mass index: 24 ± 3 kg m^{-2}), and the number of participants within each 5-year age group from 20 to 60 years was equal. Inclusion criteria were good self-reported general health, with no current or recent (<3 months) musculoskeletal injuries, joint pathologies or medical conditions that might limit plantar-flexion MVIC performance. Exclusion criteria were elite level athletes and, in women, the possibility of pregnancy. The participants were asked to refrain from strenuous physical activity and lower-body training for the 24-h period prior to testing, as well as from the ingestion of caffeine on the day of testing.

2.3. Procedures

In a single session, each participant was familiarized with the experimental protocol and then tested with the knee straight (0° of KF) and bent (45° of KF) in the WB and NWB condition. Accordingly, the four different experimental conditions were (1) weight-bearing at 0° of KF ($WB_{0°}$), (2) weight-bearing at 45° of KF ($WB_{45°}$), (3) non weight-bearing at 0° of KF ($NWB_{0°}$), and (4) non weight-bearing at 45° of KF ($NWB_{45°}$). Before testing, the Dunedin Footedness Inventory (Schneiders et al., 2010) was used to determine lower-extremity dominance and showed right foot dominance in 49 individuals and left in the remaining 5. In summary, the inventory required an individual to perform 4 skilled tasks using either the right or left leg: kick a ball, stamp out a simulated fire, pick up a marble and trace a shape. The lower-extremity that was used most often to perform these tasks defined lower-extremity dominance, with the foot used to kick a ball determining dominancy in the case of an equal right to left repartition within the 4 tasks. For testing, triceps surae EMG signals were collected from the dominant lower-extremity, only.

2.4. The two non weight-bearing (NWB) conditions

For the two NWB conditions, the participant was positioned on the IsoMed2000-dynamometer (D. & R. Ferstl GmbH, DE), which recorded plantar-flexion torque during MVIC trials using the IsoMed2000® Software 2008.1.2RV1. Calibration of the IsoMed2000-dynamometer was certified and verified each day before data collection.

While lying supine, the participant's dominant foot was attached firmly to an adapter using three Velcro straps. One strap applied pressure on the distal aspect of the foot and the other two on its proximal aspect, just distal to the ankle-joint line (Fig. 2A). This positioning was adjusted to align the axes of rotation of the ankle-joint and dynamometer, orient the foot in a position that felt natural to the individual [i.e. with about 8–10° of toeing out (Gross et al., 2011)], and place the ankle in the neutral position (i.e. with the 5th metatarsal and fibula bones perpendicular to one another, Fig. 2B). A thigh support was used to secure the knee at either 0° (the straight knee position with the femoral and tibial bones in alignment, Fig. 2C) or 45° (the knee bent position, Fig. 2D). The investigator confirmed the proper positioning of the knee- and ankle-joints using an extendable goniometer (Model 01135, Lafayette Instrument Europe, UK) following standard clinical guidelines (Reese and Bandy, 2009). Proper stabilization of the knee and ankle was verified and adjusted to prevent superior displacement and misalignment of the axes of rotation of the ankle and dynamometer during maximal plantar-flexion efforts.

Finally, two shoulder pads and a broad pelvic belt were used to minimize extraneous movements while on the IsoMed2000-dynamometer. The participant was permitted to grasp the shoulder pads of the dynamometer for additional upper body stabilization during MVIC testing.