Journal of Electromyography and Kinesiology 41 (2018) 1–8

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

Voluntary muscle activation and evoked volitional-wave responses as a function of torque

Robert E. Hight*, Alwyn T. Quarshie, Christopher D. Black

The Department of Health and Exercise Science, The University of Oklahoma, Norman, OK, United States

ARTICLE INFO

Keywords:
Twitch interpolation
H-reflex
Plantar flexor strength
Transcutaneous electrical
Nerve stimulation
Neuromuscular function
V-to-M ratio

ABSTRACT

Introduction: This study employed a unique stimulation paradigm which allowed for the simultaneous assessment of voluntary activation levels (VA) via twitch-interpolation, and the evoked V-wave responses of the plantar flexors during submaximal and maximal contractions. Test-retest reliability was also examined. *Methods:* Fourteen participants repeated a stimulation protocol over four visits to assess VA and evoked V-wave amplitude across torque levels ranging from 20% to 100% MVC. MVC torque and EMG amplitude were also measured. *Results:* VA increased nonlinearly with torque production and plateaued by 80% MVC. V-wave amplitude increased linearly from 20% to 100% MVC. There were no differences in any dependent variable across visits ($p > 0.05$). VA demonstrated moderate to substantial reliability across all torque levels (ICC = 0.76–0.91) while V-wave amplitude exhibited fair to moderate reliability from 40% to 100% (ICC = 0.48–0.74). *Discussion:* We were able to reliably collect VA and the V-wave simultaneously in the plantar flexors. Collection of VA and V-wave during the same contraction provides distinct information regarding the contribution of motor-unit recruitment and descending cortico-spinal drive/excitability to force production.

1. Introduction

The production of muscular force, a prerequisite for the performance of everyday tasks, is the result of interactions between signals from central and peripheral nervous system. Transmission failure at any point in the system results in incomplete skeletal muscle activation and a reduced net force output. Despite apparent maximal efforts, the ability to fully activate plantar flexor and knee extensor muscle groups is limited in healthy humans (Huber et al., 1998; Babault, 2001; Scaglioni, 2002; Shima, 2002) and especially under pathophysiological conditions such as fibromyalgia (Nørregaard, 1995), multiple sclerosis (Sheean, 1997), and osteoarthritis (Hurley, 1997). Given the importance of force generation to the performance of everyday tasks, several non-invasive tools have been developed to study nervous system function during force generation.

The interpolated twitch technique (ITT) is a common measurement whereby the completeness of skeletal muscle activation (i.e. voluntary activation; VA) is determined by delivering a supramaximal electrical stimulus to a peripheral nerve or skeletal muscle to evoke a twitch-like increment in torque production via the activation of motor-units that have not already been recruited or that are firing at sub-maximal rates [for review see (Shield and Zhou, 2004)]. The basis for this technique is founded upon the negative linear relationship between voluntary force and electrically evoked force which was first demonstrated by Merton (1954) and quantified in the linear equation: voluntary activation (percent) = [1 − (superimposed twitch/control twitch)] where a superimposed twitch is evoked during a voluntary contraction and a control twitch is evoked from relaxed muscle. Qualitatively, VA is perhaps best described as the amount of central drive to the motor neurons during a voluntary effort that is translated into force generation (Gandevia, 2001). In essence, VA quantifies a proportion of the muscle's maximum force generating capacity under given task constraints. However, VA does not provide information about the magnitude of central drive reaching the spinal motor neurons, whether they are firing at their maximal rates, or the multitude of factors that determine the net excitability of the motor neuron pool (Rekling, 2000).

The first volitional wave (V-wave) is evoked through the supramaximal stimulation of a peripheral mixed nerve during a voluntary effort (Upton et al., 1971). The evoked V-wave response involves similar spinal circuitry as the Hoffman reflex (H-reflex), which has frequently been described as the electrical analog to the stretch reflex, and is distinguished by a monosynaptic projection of group Ia afferents onto

---

Abbreviations: ANOVA, analysis of variance; EMG, electromyography; FCR, flexor carpi radialis; H-reflex, Hoffman reflex; ICC, intraclass correlation coefficient; ITT, interpolated twitch technique; M-wave, motor wave; MVC, maximal voluntary contraction; RMS, root-mean square; RTT, resting twitch torque; TENS, transcutaneous electrical nerve stimulation; V-wave, volitional wave; VA, voluntary activation

* Corresponding author.

E-mail address: robbyhight@ou.edu (R.E. Hight).

https://doi.org/10.1016/j.jelekin.2018.04.002
Received 7 September 2017; Received in revised form 28 February 2018; Accepted 14 April 2018
1050-6411/

the homonymous motor neurons of the spinal cord (Misiaszek, 2003). The amplitude of the V-wave, like the H-reflex, is influenced by intrinsic motor neuron excitability, pre-synaptic, and post-synaptic inhibition (Zehr, 2002). However, V-waves are evoked using supramaximal, rather than submaximal, stimulation and are typically recorded at high force levels, whereas H-reflexes are evoked during a low-force muscle contraction or at rest. Put another way, the V-wave amplitude is primarily determined by ongoing motor-unit output (i.e. supraspinal inputs) which reflects the level of descending drive to the motor neuron pool as efferent, orthodromic impulses cancel out and bypass antidromic flow to reach the muscle where they are recorded (Upton et al., 1971; Aagaard, 2002).

While ITT has been widely used, the evoked V-wave response has been employed less frequently to examine potential changes in neural drive during contractions and in response to training, detraining, and other interventions (Lee et al., 2009; Lee et al., 2009). As would be expected, V-wave amplitude has been shown to increase as contraction force increases (Butler et al., 1993; El Bouse et al., 2013; Pensini and Martin, 2004) although it is unclear whether this increase is linear or best modeled with a polynomial. Additionally, V-wave amplitude has been shown to increase following short and long term resistance training (Aagaard, 2002; Aagaard, 2003; Fimland, 2009; Ekblom, 2010; Colomer-Poveda, 2017; Vila-Chã, 2012; Del Balso and Cafarelli, 2007; Duclay, 2008). Interestingly, no changes were found in V wave amplitude despite significant reductions in strength following 24-days of unilateral lower limb suspension (Seynnes, 2010). Although they assess distinct aspects of neural drive to skeletal muscle (motor-unit recruitment/activation for VA and descending cortio-spinal drive for V-wave) several studies have collected both VA and V-wave amplitude in response to a similar intervention (Ekblom, 2010; Seynnes, 2010) and noted, as expected, similar changes for both variables. A potential limitation of these studies was that they collected VA and V-wave measures during different contractions. The simultaneous measurement of VA and the evoked V-wave amplitude may provide greater and more precise insights into neural drive to skeletal muscle and how this drive results in motor-unit recruitment and torque production. To our knowledge no studies have assessed VA and evoked soleus V-wave amplitude simultaneously in the plantar flexors from the same voluntary effort. Thus, the primary aim of this investigation was two-fold: (1) to examine the pattern of change in ITT-assessed VA and evoked V-wave amplitude across contractions of increasing torque production and (2) to establish the day-to-day reliability of VA and evoked V-wave amplitude during maximal voluntary isometric contractions.

2. Methods

2.1. Participants

Sixteen college-aged men and women who were recreationally active, but had no history of lower leg injury volunteered to participate in this study. Two participants withdrew from the study due to discomfort during electrical stimulation and thus analyses were performed on a sample of fourteen (8 men, 6 women) with a mean age of 24.4 ± 3.0 years, mean height of 175.1 ± 7.3 cm, and mean weight of 77.4 ± 16.6 kg. This study was approved by the local university Institutional Review Board and all study procedures were carried out in accordance with the approved guidelines. All participants provided written informed consent and completed routine medical screening forms to identify potential contraindications to exercise prior to testing.

2.2. Study design

Two familiarization and two experimental testing sessions were completed at least 24-hours apart for a total of 4 visits performed over 8–14 days. During the familiarization sessions participants practiced all experimental procedures, including maximal voluntary isometric contractions, submaximal isometric contractions at 20, 40, 60, and 80% of MVC and were familiarized with the transcutaneous electrical nerve stimulation (ES) protocol used to assess voluntary muscle activation (via ITT) and descending drive (normalized V-wave amplitude) during maximal efforts. During experimental visits 3 and 4 the stimulation was applied and VA and V-wave amplitude were assessed during all contractions (20–100%).

2.3. Instrumentation

All measurements were made in the dominant plantar flexors (determined by kicking preference) while participants lay supine in an isokinetic dynamometer (KinCom, Chattanooga, TN). The hip, knee, and ankle joints were positioned at 90°, 90°, and 90° of flexion, respectively, with the foot strapped into a force plate mounted to the dynamometer. The non-dominant leg was fixed at ~30–60° of flexion with the foot resting flat against the chair base of the dynamometer. Participants were instructed to find a comfortable position they could maintain throughout testing. The position of each participant was recorded and care was taken to replicate each individual's position among visits. Isometric plantar flexor torque low-pass filtered at 10 Hz (Acknowledge v4.3, Biopac Systems Inc., Goleta, CA) and displayed in real-time on a computer monitor positioned at eye-level to provide biofeedback for each participant.

2.3.1. Surface EMG

EMG signals were recorded from the soleus muscle in accordance with SENIAM recommendations (Hermens, 1999) with a pair of bipolar Ag-AgCl electrodes (interelectrode distance: 20 mm) using a BioNomadix dual-channel wireless EMG system (Biopac Systems Inc., Goleta, CA). A ground electrode was fixed over the lateral malleolus of the ankle. EMG signals were sampled at 2000 Hz, amplified, band-pass filtered from 10 to 500 Hz (AcqKnowledge v4.3; Biopac Systems Inc.) and saved on a desktop computer for offline analyses.

2.3.2. Electrical stimulation

The common posterior tibial nerve of the dominant leg was stimulated using a 3.2 cm diameter circular cathode placed over the popliteal fossa and a 5 cm × 5 cm square anode located proximal to the patella. Optimal cathode placement over the tibial nerve was identified visually using a handheld 15 mm diameter pencil electrode (Mettler Electronics Corp., Anaheim, CA) to locate the site that elicited the greatest plantar flexor response to a minimal current intensity (~15–25 mA). A constant-current linear isolated stimulator (STMISOLA; Biopac Systems Inc.) was used to deliver a single, square, 1-ms pulses to evoke M, and V-waves in the soleus muscle and resting and interpolated twitches from the torque signal.

2.4. Experimental procedures

Prior to the performance of isometric contractions, the current intensity necessary to elicit a maximal motor response (M-wave) was determined by progressively increasing the current intensity in 5 mA increments until peak-to-peak resting twitch torque (RTT) and M-wave amplitude plateaued. During subsequent procedures, a supramaximal stimulus (150% of the current needed to evoke the maximal M-wave) was used to evoke M-waves, V-waves, interpolated and resting twitches according to recommendations by Zehr (2002) and Racinais et al. (2013).

2.4.1. Maximal voluntary contractions

Following a brief warm-up of the plantar-flexors (3–4 reps at ~50% MVC), participants performed a total of three consecutive MVCs with each lasting 3-seconds in duration and separated by 3-minutes of rest. Participants were signaled when to contract and relax via a timed audio file that was synced with the stimulator and were verbally encouraged