TECHNICAL REPORT

The Reliability of the Interpolated Twitch Technique During Submaximal and Maximal Isometric Muscle Actions

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Abstract

Cooper, MA, Herda, TJ, Walter-Herda, AA, Costa, PB, Ryan, ED, and Cramer, JT. The reliability of the interpolated twitch technique during submaximal and maximal isometric muscle actions. *J Strength Cond Res* 27(10): 2909–2913, 2013—The purpose of this study was to examine the test-retest reliability of the percent voluntary activation (%VA) vs. force relationships. Fourteen healthy men (mean ± *SD* age = 21 ± 2.6 years) and 8 women (age = 21 ± 1.8 years) completed 4 maximal voluntary contractions (MVCs) and 9 randomly ordered submaximal isometric plantar flexions from 10 to 100% of the MVC. Transcutaneous electrical stimuli were delivered to the tibial nerve using a high-voltage constant-current stimulator (DS7AH; Digitimer, Herthfordshire, United Kingdom). The %VA was calculated for each maximal and submaximal MVC. Paired-samples *t*-tests were used to quantify systematic variability, whereas the intraclass correlation coefficients (ICCs), standard error of the mean (%SEM), and minimum differences (%MD; expressed as a percentage of the means) were used for test-retest reliability. Systematic variability was not present at any of the contraction intensities ($p >$ 0.05). The ICCs ranged from 0.52 to 0.84, whereas the %*SEM* ranged from 6.75 to 38.45%, and the %MD ranged from 18.71 to 106.58%. The ICCs were ≥0.74 at contraction intensities ranging from 40 to 100% MVC (6.75–16.78% *SEM*), whereas the ICCs were ≤0.65 (20.95–38.45% *SEM*) for the contraction intensities ≤30% MVC. Although not statistically tested, the ICCs tended to be higher, whereas the %*SEM*s lower for contractions ≥40% MVC. Future research using %VA during submaximal contraction intensities to predict a true maximal force may want to exclude contraction intensities <40% MVC. In addition, caution is warranted when interpreting the changes in the %VA during MVCs after an experimental intervention.

Key Words electromyography, voluntary activation, ITT, nerve stimulation

Introduction

The interpolated twitch technique (ITT) has been defined as a quantitative assessment of neural function (10) and has been used to monitor changes in muscle activation as a result of an experimental intervention or treatment (2,4,20). For example, Hartman et al. (12) reported significant decreases in ITT after a fatiguing exercise bout in untrained and resistance trained men. Although the technique is widely used in the strength and conditioning field to monitor acute and chronic neuromuscular adaptations to interventions and treatments, the amount of change in muscle activation that is required for that change to be deemed a real change is unknown. The ITT model involves an evoked stimulus to the peripheral nerve during a voluntary contraction, called the superimposed or interpolated twitch (5,16). During a voluntary contraction, the evoked twitch during a voluntary contraction will activate all motor units by superimposing a compound muscle action potential in motor units that are already voluntarily activated and those that are inactive (5,16). In theory, if any individual motor units are not recruited or firing fast enough to produce maximal force, then the superimposed action potential will evoke a subsequent and transient increase in force (13). Then you can calculate percent voluntary activation (%VA) by the comparison of the interpolated twitch force to the potentiated twitch force (2).

Numerous studies have used the ITT method during a maximal voluntary contraction (MVC) to detect changes in motor neuron excitability after an experimental intervention or treatment (6,12,23) with a smaller number of studies examining the use of the ITT method during submaximal contraction intensities to predict maximal force (3,4,7,14). The

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prediction of maximal force may be useful to diagnose certain medical conditions. For example, Norregaard et al. (17) reported that patients with fibromyalgia had significantly less leg extensor strength than matched healthy controls did; however, the fibromyalgia patients' predicted maximal force was not significantly different than that of the healthy controls. Previously, the ITT method applied during submaximal contraction intensities ≤40% MVC has resulted in large errors in predicting maximal force in comparison with using submaximal contractions >40% (4). It is plausible that poor repeatability at the lower contraction intensities may contribute to such large errors in predicting maximal force. Although the ITT method is often used, there is very little information available on the reliability of the technique (4,18). In addition, no studies have reported reliability statistics for the ITT method applied to submaximal contractions. For example, Behm et al. (4) reported the intraclass correlation coefficient (ICC) for the ITT method applied during a maximal contraction but did not report the reliability statistics for submaximal contractions. Oskouei et al. (18) examined the ITT method at 50 and 100% MVC, and like Behm et al. (4) did not report either the standard error of the mean (SEM) or minimal difference (MD). Therefore, there are no studies that have reported appropriate reliability statistics (3 levels) as described by Weir (24), such as a statistical test of the means across trials for the assessment of systematic error, ICC, *SEM*, and MD. Furthermore, a classically cited study (>240 citations) in the stretching literature, Behm et al. (3) reported a 2.8% decrease in the %VA as measured by the ITT method. The authors concluded that stretching decreased motor neuron excitability; however, to date, there is no information available to indicate if this change in the VA (i.e., motor neuron excitability) is meaningful (i.e., *SEM* and MD). Collectively, these measures all provide a comprehensive assessment of reliability. Therefore, the purpose of this study was to calculate the reliability statistics for the %VA derived from the ITT method applied during submaximal voluntary contraction and MVC. We hypothesize, referring to observations made by previous studies (3,4,18), that the reliability statistics will indicate better repeatability for the %VA at higher contraction intensities (>40% MVC).

Methods

Experimental Approach to the Problem

To date, there is no indication in the literature regarding the necessary changes needed in the %VA values to be deemed meaningful as a result of treatments or interventions, such as resistance training, stretching, and fatigue. Therefore, this study was designed to examine the reliability of %VA derived from the ITT method during submaximal voluntary contraction and MVC of the plantar flexors. Reliability statistics calculated included the ICC, *SEM*, and MD. Therefore, the sensitivity of the %VA measurement will be assessed to determine the MD needed between trials for the change to be considered real. The participants will visit the laboratory on 3 occasions, the first visit being for familiarization, and the other 2 visits being experimental trials. Before each visit, the subject was asked to refrain from heavy exercise the day before and day of testing and to maintain their typical eating and sleeping routine throughout the study. During the experimental trials, the participants will complete isometric MVCs and isometric submaximal step muscle actions ranging from 10 to 90% MVC in random order with the ITT method applied during the muscle actions to assess the %VA.

Subjects

Fourteen healthy men (mean ± *SD* age = 21 ± 2.6 years, height = 180 ± 7.5 cm, weight = 69.5 ± 10 kg) and 8 women (age = 21 ± 1.8 years, height = 163 ± 6.5 cm, weight = 52 ± 5.6 kg) volunteered for this study. None of the participants reported any history of or current ongoing neuromuscular diseases or musculoskeletal injuries that involved the ankle, knee, or hip joints. Each participant completed a preexercise health questionnaire, which indicated that the individuals might be best classified as normal moderately active recreationally trained. All experimental trials were performed at the same time of the day (±2 hours). Furthermore, this study was conducted during the spring semester at the university. This study was approved by the Institutional Review Board for human subject research, and all the participants read and signed an informed consent form.

Procedures

Each participant was seated with restraining straps over the pelvis and thigh, with a knee flexion angle of 0° below the horizontal plane (full extension) on a custom-built apparatus equipped with a high accuracy load cell (Omegadyne, model LC402, range 0–500 lbs; Stamford, CT, USA) that was designed to isolate plantar flexor force production. Each participant visited the laboratory on 3 occasions, once for a familiarization trial followed by 2 experimental trials. During the familiarization trial, the participants performed multiple (2–6) 4-second isometric MVCs and several isometric step muscle actions at randomly ordered percentages of the MVC (10–90% of the MVC) with transcutaneous electrical stimulation. Within 2–5 days after the familiarization trial, the participants reported back to the laboratory for the first of 2 experimental trials. The subjects were instructed to refrain from lower body exercise the night before and day of testing. During each experimental trial, the participants performed 4 isometric MVCs followed by 9 randomly ordered submaximal isometric step contractions at 10, 20, 30, 40, 50, 60, 70, 80, and 90% MVC. During all submaximal trials and 2 of the MVCs, the ITT was used to determine the %VA. During each MVC trial, strong verbal encouragement was given. Submaximal isometric step contraction percentages were calculated from the highest of the 2 initial MVCs that were performed without the transcutaneous electrical stimuli (MVC). Transcutaneous electrical stimuli were delivered to the tibial nerve using a high-voltage (maximal voltage = 400 V) constant-current stimulator (DS7AH; Digitimer, Hertfordshire, United Kingdom). The stimuli were applied via bipolar surface electrodes that were placed in the popliteal space. Single stimuli were used to determine the optimal stimulation electrode location (20 mA) and the maximal compound muscle action potential (M-wave) with incremental amperage increases (2–100 mA). Once a plateau in the peak-to-peak (p-p) M-wave and peak twitch force was determined, despite amperage increases, 20% was added to the amperage that yielded the highest p-p M-wave and peak twitch force to ensure a supramaximal stimulus. A single stimulus was a 200-microsecond duration square wave impulse, whereas a doublet consisted of 2 single stimuli delivered successively at 100 Hz. Doublets were administered with the supramaximal stimulus intensity during 2 of the MVC trials (ITT MVC) and all submaximal trials to increase the signal-to-noise ratio and minimize the series elastic effects on force production (9). In accordance with the twitch interpolation procedure, a supramaximal doublet was administered 350–500 milliseconds after the start of the plateaus in force during the submaximal and ITT MVC (superimposed twitch) and then again 3–5 seconds after the submaximal and ITT MVC trial at rest (potentiated twitch). The %VA was calculated using the equation below (1):

$$\%\text{VA} = \left[1 - \left(\frac{\text{superimposed twitch}}{\text{potentiated twitch}}\right)\right] \times 100.$$

During the submaximal isometric step muscle actions, the participants were required to track their force production on a computer monitor placed in front of them that displayed the real-time digitized force signal overlaid onto a programmed template. The stimulation was administered once the subject consistently traced the line for 2–3 seconds based on the investigator's (T.J.H.) judgment. The same investigator administered all the stimulations, as to measure test-retest reliability of the measurement. All software programs were custom written with LabVIEW v 8.5 (National Instruments, Austin, TX, USA).

Electromyography

Preamplified, bipolar surface electromyography (EMG) electrodes (EL254S, Biopac Systems Inc., Santa Barbara, CA, USA) with a fixed center-to-center interelectrode distance of 20-mm, built-in differential amplifier with a gain of 350 (nominal), input impedance of 100 MΩ, and common mode rejection ratio of 95 dB (nominal) were taped over the soleus (SOL) muscle of the right leg. The electrodes were placed along the longitudinal axis of the tibia at 66% of the distance between the medial condyle of the femur and the medial malleolus (15). A single pregelled, disposable electrode (Ag–AgCl, Quinton Quick Prep, Quinton Instruments Co., Bothell, WA) was placed on the spinous process of the seventh cervical vertebrae to serve as a reference electrode. To reduce interelectrode impedance and increase the signal-to-noise ratio, local areas of the skin were shaved and cleaned with isopropyl alcohol before placement of the electrodes.

Signal Processing

The EMG (microvolts) and force (newtons) signals were recorded simultaneously with a Biopac data acquisition system (MP150WSW, Biopac Systems, Inc.) during each assessment. The force signal from the load cell and the EMG signals from the SOL muscle were sampled at 2 kHz using a 16-bit analog-to-digital converter (DHQCard-6036E, National Instruments) interfaced with a laptop computer (Inspiron 8200, Dell Inc., Round Rock, TX, USA). The force signal was low-pass filtered with a 10-Hz cutoff (second-order Butterworth filter). The force value was calculated during a 0.25-second epoch immediately before the stimulation for all submaximal and the 2 MVC (ITT MVC) trials. For the 2 MVCs without stimulation (MVC), force was recorded from the highest consecutive 0.25-second epoch during the contraction. All the signals were recorded, stored, and processed off-line with custom-written software (LabVIEW v 8.5, National Instruments). The EMG signals from the SOL were band passed filtered at 10–500 HZ (fourth-order Butterworth filter), and the M-waves from the SOL during the superimposed stimulations were expressed as p-p amplitude values (millivolts). The p-p M-wave values were monitored during each trial and contraction to ensure a maximal stimulus was delivered for every muscle action. A 2-way analysis of variance (trial × %MVC) was performed on the M-waves and indicated no 2-interaction ($p = 0.437$) or main effects for trial ($p = 0.457$) or %MVC ($p = 0.318$), and thus, a consistent maximal stimulus was delivered during each muscle action. These data are not reported in the Statistical Analyses or Results section.

Statistical Analyses

The ICCs and %*SEM*s (expressed as a percentage of the mean), and %MDs (expressed as a percentage of the mean) were used for test-retest reliability, whereas paired-samples *t*-tests were used to quantify systematic variability. Model "2,1" from Shrout and Fleiss (21) was used to calculate the ICCs. Reliability statistics were calculated for the %VA from all submaximal and ITT MVCs. The ICC is unitless, and can "theoretically vary between 0 and 1.0, where an ICC of 0 indicates no reliability and an ICC of 1.0 indicates perfect reliability (24)." The *SEM* gives an indication on the precision of the measurement and, therefore, can provide an index of the expected trial-to-trial noise for the variable being examined (24). Furthermore, the *SEM* allows one to construct confidence intervals for the scores and can be used to define the difference needed between separate measures on a subject for that change in score to be considered real (MD). Although there are no specific values to describe a "good" *SEM*, researchers and practitioners can use the *SEM* (and MD) for the interpretation of change scores from individuals. An alpha level of $p \le 0.05$ was considered statistically significant for all comparisons. All statistical analyses were performed using Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA).

Results

Table 1 contains the mean ± *SD* values for %VA and the reliability and measurement variability statistics for %VA from the submaximal voluntary contraction and MVC. Systematic

Table 1. Mean ± *SD* %VA values and reliability and measurement variability statistics for %VA from the submaximal and maximal voluntary activation.*

	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
%VA	11.6 ± 6.6	18.6 ± 8.3	29.4 ± 10.1	37.7 ± 12.1	49.4 ± 12.9	60.4 ± 14.2	71.3 ± 16.1	81.0 ± 16.3	87.6 ± 14.3	84.2 ± 14.2
p-Value	0.092	0.508	0.268	0.917	0.602	0.166	0.345	0.060	0.281	0.197
$ICC_{2,1}$	0.514	0.652	0.630	0.744	0.767	0.839	0.809	0.826	0.770	0.837
% SEM	38.45	26.67	20.95	16.78	12.89	9.31	9.99	7.98	7.86	6.75
% MD	106.58	73.92	58.08	46.52	35.75	25.81	27.71	22.12	21.79	18.71

*%VA = percent voluntary activation; ICC = intraclass correlation coefficient; % *SEM* = standard errors of measurements; % MD = minimum differences.

variability for %VA was not present at any of the contraction intensities ($p > 0.05$). The ICCs ranged from 0.52 to 0.84, whereas the %*SEM* ranged from 6.75 to 38.45%, and the % MD ranged from 18.71 to 106.58%. The ICCs were ≥0.74 at contraction intensities ranging from 40 to 100% MVC, whereas the ICCs were ≤0.65 for the contraction intensities ≤30% MVC. For the *SEM*, the values ranged from 6.75 to 9.31% for contraction intensities ranging from 60 to 100% MVC, whereas the *SEM* ranged from 12.90 to 38.45% for contraction intensities ≤50% MVC.

Discussion

Previous studies have suggested that the ITT method applied to contraction intensities of <40% of MVC may be unreliable when used to assess %VA. (4,7,22); however, the authors never reported ICCs or other reliability statistics for the lower contraction intensities. The poor reliability at these contraction intensities may be because of a number of factors. For example, Behm et al. (4) indicated at a contraction intensity of 20% MVC, there were disproportionately large superimposed twitches compared with the potentiated twitches. Belanger and McComas (5) hypothesized that the reduction in the slack of the series elastic component with a weak contraction would contribute to a larger superimposed twitch than potentiating twitch. The larger superimposed twitch results in an underestimation of muscle activation at lower intensities and may account for the large error in MVC prediction that has been previously reported (4,14). Therefore, the larger superimposed twitch at lower contraction intensities in comparison with the potentiated twitch that must overcome the series elastic component may reduce the repeatability of the measurement. It has been previously suggested that %VA calculated at lower contraction intensities (<40% MVC) may be unreliable (4); however, this is the first study to support this hypothesis with appropriate statistics.

Numerous studies have used the ITT method during an MVC to detect changes in motor neuron excitability after an experimental treatment or intervention (3,8,11,19). The % *SEM* and %MD values reported in this study indicated that there is a considerable amount of noise (i.e., lower precision in the score) in the %VA calculated from the ITT measurement. The amount of change needed to indicate a real change for % VA is much larger than what would be reasonable to expect in an experimental setting based on the %*SEM* and %MD values (3,8,11,19). Understanding the real change needed for %VA is important for investigators and practitioners to provide a complete interpretation of the efficacy of strength training, stretching, vibration, and other interventions of interest to the strength and conditioning field. Therefore, caution is warranted when interpreting the changes in the %VA (or lack thereof) after an experimental intervention. Monitoring the %VA on a subject-by-subject basis may be necessary to conclude any changes in motor neuron excitability as a result of an experimental treatment or intervention. Researchers may explore the possibility of increasing the number of evoked potentials (>doublet stimulus) during the ITT method to improve the repeatability of %VA; however, subject discomfort would also increase with such a change.

Practical Applications

Referring to Table 1, you would need to observe a change >20% in the VA to be considered a real change at contraction intensities >70% MVC. This is, however, an unreasonable amount of change to expect from many treatments or interventions and, therefore, clinicians and coaches need to exercise caution when interpreting changes in muscle activation as measured by %VA. Furthermore, when attempting to predict a theoretical true force, we recommend that researchers use the ITT method during muscle actions >40% MVC because of poorer reliability at the lower contraction intensities.

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