Journal of the Neurological Sciences 369 (2016) 368–374

Contents lists available at ScienceDirect

Journal of the Neurological Sciences

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

Reliability of the functional measures of the corticospinal pathways to dorsiflexor muscles during maximal voluntary contractions

Robin Souron [a], Adrien Farabet [a], Guillaume Y. Millet [b], Thomas Lapole [a,*]

[a] Univ Lyon, UJM-Saint-Etienne, LIBM, F-42023 Saint-Etienne, France
[b] Human Performance Laboratory, Faculty of Kinesiology, University of Calgary, Canada

ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 1 September 2016
Accepted 2 September 2016
Available online 4 September 2016

Keywords:
Transcranial magnetic stimulation
Tibialis anterior
Cortical voluntary activation
Corticospinal excitability
Boltzmann modelling

ABSTRACT

This study aimed to evaluate the intra- and inter-day reliability of transcranial magnetic stimulation (TMS)-related measurements recorded from the tibialis anterior (TA) muscle. Thirteen healthy young men and women (23 ± 4 years) performed 3 testing sessions to assess intra- (i.e., two sessions performed the same day) and inter-day (i.e. two sessions performed one week apart) reliability of (i) dorsiflexion cortical maximal voluntary activation level (VA_{TMS}), (ii) TA corticospinal excitability assessed through the amplitude of the motor evoked potentials (MEP) recorded during 100, 75 and 50% maximal voluntary contractions (MVC), and (iii) intracortical inhibition investigated via the cortical silent period (CSP) recorded at the same % MVC. Absolute (i.e., coefficient of variation (CV) and standard error of the mean (SEM)), and relative (i.e., intraclass correlation coefficients (ICC)) reliability parameters were calculated. VA_{TMS} demonstrated excellent intra- and inter-day reliabilities (ICC: 0.80 and 0.99; CV: 1.7 and 0.8%, respectively). MEPs and CSPs presented moderate to excellent intra- and inter-day reliabilities, while input-output curves extracted parameters presented highly variable outcomes. These results suggest that most TA corticospinal measurements during voluntary contractions can be used to quantify corticospinal adaptations after acute (e.g. fatigue) or long term (e.g. training) interventions.

1. Introduction

It is well established that training, and especially strength training, induces several adaptations to the central nervous system leading, *in fine*, to an augmentation of maximal voluntary contraction (MVC) force. The investigation of maximal voluntary activation is critical to assess neural adaptations. Voluntary activation refers to the neural drive delivered to a muscle during a voluntary contraction. The most common way to estimate maximal voluntary activation is to use the interpolated twitch technique [1], where a supramaximal stimulus is delivered over a motor nerve during an MVC to measure the extra force evoked by the stimulation. Using this method, changes in neural drive can be identified as at or above the site of stimulation of the motor axons, without distinction between spinal and supraspinal mechanisms [2]. Since training may induce both spinal [3] and supraspinal adaptations [4], transcranial magnetic stimulation (TMS) has been proposed as an alternative technique to ascertain whether adaptations occur throughout the corticospinal pathway [5]. Indeed, the evocation of a superimposed twitch elicited by TMS during MVC has been suggested to highlight a suboptimal drive from the motor cortex [5–7], although the cause of VA_{TMS} reduction can be due to modulation at any level of the corticospinal network (i.e. through reduced spinal and/or motoneuronal excitability).

The assessment of cortical voluntary activation using TMS (i.e., VA_{TMS}) cannot be performed for all muscles since some criteria must be met, especially having strong corticomotoneuronal projections [8]. VA_{TMS} has been shown to be reliable for the elbow flexors [9] or the knee extensors [8], but not in dorsiflexor muscles thus far, despite the functional role of these muscles in particular during locomotion [10,11]. The tibialis anterior (TA), contributing to almost half of the voluntary torque produced in ankle dorsiflexion (the remainder presumably being provided by the long extensors of the toes) [12], is known to have the strongest corticospinal projections among lower limb muscles [13]. Even though dorsiflexor muscles VA_{TMS} has already been assessed

Abbreviations: CSP, cortical silent period; CSP_{50}, cortical silent period during a 50% MVC submaximal contraction; CSP_{75}, cortical silent period during a 75% MVC submaximal contraction; CSP_{MVC}, cortical silent period during a MVC; CV, coefficient of variation; EMG, electromyographic; ERT, estimated resting twitch amplitude; I_{50}, stimulus intensity required to obtain a MEP of half the size of the plateau; ICC, intraclass correlation coefficient; k, the slope parameter of the Boltzmann modelling; M_{MVC}, M-wave amplitude during a MVC; MEP, motor evoked potential; MEP_{50}, motor evoked potential amplitude during a 50% MVC submaximal contraction; MEP_{75}, motor evoked potential amplitude during a 75% MVC submaximal contraction; MEP_{MVC}, motor evoked potential amplitude during a MVC; MVC, maximal voluntary contraction; P, the function plateau of Boltzmann modelling; RMS, root mean square; SEM, standard error of the mean; SIT, superimposed twitch amplitude; SIT_{MVC}, superimposed twitch amplitude during a maximal voluntary contraction; TA, tibialis anterior; TMS, transcranial magnetic stimulation; VA_{TMS}, voluntary activation assessed with TMS.

* Corresponding author at: Laboratoire Interuniversitaire de Biologie de la Motricité, Bâtiment IRMIS, 10 rue de la Marandière, 42270 Saint Priest en Jarez, France.
E-mail address: thomas.lapole@univ-st-etienne.fr (T. Lapole).

http://dx.doi.org/10.1016/j.jns.2016.09.003
0022-510X/

in fatigue studies [14,15], no study has yet investigated VA_{TMS} reliability for this muscle group. Such an approach is necessary since the constant oscillation in the elements of the central nervous system and methodological factors (e.g. subject population, muscle considered, position for magnetic stimulation) are two main sources that may affect the stability of TMS measurements [16]. Indeed, motor-evoked potential (MEP) elicited by TMS, which is known to represent the excitability of cortical neurons and/or motoneuron pools of the stimulated muscles [17], are inherently variable. For instance, MEP amplitude may be influenced by circadian variation [18]. To reduce variability, MEP amplitude is commonly expressed as ratio to M-wave to rise above the membrane excitability and conductivity influence. MEPs should also be measured during a stable voluntary contraction to further reduce variability [16,19]. Among the studies that investigated TA MEP reliability [14,16,20], only one met these last two criteria and reported high inter-day reliability for MEPs measured during submaximal lengthening and shortening contractions [16]. During maximal isometric contraction, absolute MEP was also reported to be reliable [14], as it was at rest [14,20]. Hence, intra-day and inter-day reliability of normalized TA MEPs during submaximal and maximal isometric contractions has yet to be determined. Moreover, although input-output curves (i.e. the relation between TMS intensity and MEP amplitude) [19,21] are recognized as a more sensitive measure of corticospinal excitability [22,23], its reliability for the TA muscle has only been proven during a relaxed condition [20].

Although several studies have investigated the reliability of TA TMS-related parameters [14,16,20], this topic needs further investigation. Specifically, dorsiflexor VA_{TMS} must be examined to better understand short- and long-term adaptations within the central nervous system during acute and long term interventions. This would provide complementary knowledge with regard to previous TMS studies demonstrating changes in TA corticospinal excitability after strength training [24,25].

Therefore, the present study is intended to evaluate the intra- and inter-day reliability of VA_{TMS} and associated corticospinal functional properties (e.g., MEP amplitude) for dorsiflexor muscles.

2. Material and methods

2.1. Participants

Thirteen young, healthy young subjects (9 men and 4 women, 23 ± 4 years; height: 177 ± 8 cm; body mass: 69 ± 10 kg) participated in this study. The subjects' level of weekly physical activity was reported to be between 0 and 5 h per week. Written, informed consent was obtained from all subjects prior to their participation and this study conformed to the standards from latest revision of the Helsinki Declaration and was approved by the local ethics committee. All subjects were free of lower-limb injury during the previous three months, contraindications to TMS, acute and chronic neurological disorders, and trauma. Before testing, each subject was informed about the nature and the aim of this study, as well as risks and discomfort associated with electrical and magnetic stimulation. They were instructed to abstain from caffeine for a minimum of 12 h before each session.

2.2. Design of the study

Subjects came for three visits to the laboratory at the same time of the day with a 1-week interval between visits. The first visit was a familiarization session of the entire experimental protocol. In order to assess the inter-day reliability, the same protocol was performed during the second and third visits, i.e., session 1 (S1) and session 3 (S3), respectively. Except for the TMS recruitment curve and the peripheral nerve stimulation setup (see below), the whole experimental protocol was performed twice with a 30-min resting period between measurement sessions during one of these visits (randomly designed), allowing the assessment of intra-day reliability (S1 and session 2 (S2)) (Fig. 1). The 30 minute resting period began at the end of S1 and finished at the beginning of S2. Hence, subjects were invited to stay in a sitting position on the custom-built chair during the 30-min period.

2.3. Torque and electromyographic recordings

Dorsiflexion torque was measured during voluntary contractions by a calibrated, instrumented pedal (CS1060 300 Nm, FGP Sensors, Les Clayes Sous Bois, France). Subjects were seated upright in a custom-built chair with a hip, knee, and ankle angle of 90, 120, and 90°, respectively. The foot was securely attached to the pedal with a custom designed hook and loop fastener. Electromyographic (EMG) activity of the right TA and soleus (SOL) was recorded with pairs of self-adhesive surface electrodes (Meditrace 100, Covidien, Mansfield, USA) in bipolar configuration with a 30-mm interelectrode distance and the reference on the medial malleolus. SOL electrodes were placed 2 cm inferior to the insertion of the gastrocnemii on the Achilles tendon. TA electrodes were placed on the muscle belly parallel to the longitudinal axis of the muscle at one-third of the distance between the head of the fibula and the tip of the medial malleolus, according to SENIAM recommendations [26]. Skin impedance was measured using a classic impedance analyser (Fluke 87 V Ex, Fluke, Wallisellen, Switzerland) and low impedance (<5 kΩ) between electrodes was obtained by shaving, gently abrading the skin and then cleaning it with isopropyl alcohol. Signals were amplified with an octal bio-amplifier (ML138, ADInstruments; common mode rejection ratio = 85 dB, gain = 500), bandpass filtered (5–500 Hz), and analogue-to-digitally converted at a sampling rate of 2000 Hz by PowerLab system (16/30-ML880/P, ADInstruments, Bella Vista, Australia). All data was analysed offline using Labchart 7 software (ADInstruments).

2.4. Stimulation

Two types of stimulation were used. Specifically, electrical stimulation of the tibialis anterior motor nerve (i.e., peroneal nerve) and transcranial magnetic stimulation (TMS) over the motor hotspot for the TA muscle. For stimulation of the tibialis anterior motor nerve, a bipolar bar stimulating electrode with 30-mm anode-cathode spacing (Bipolar Felt Pad Stimulating Electrode Part number E.SB020/4mm, Digitimer) was positioned next to the fibular head. Single rectangular pulses with 0.5 ms duration and 400 V maximal output voltage were delivered to the right peroneal nerve via a constant-current stimulator (DS7A, Digitimer, Welwyn Garden City, Hertfordshire, UK). The optimal site of stimulation was determined as the location eliciting the greatest TA

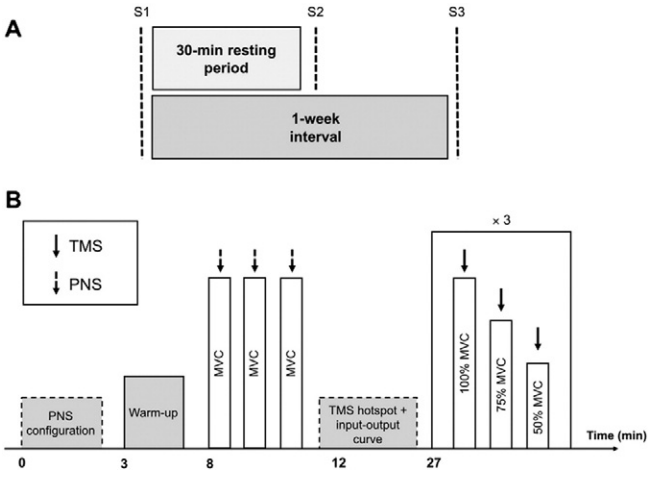

Fig. 1. Overview of the experimental design of the study (A) and the neuromuscular testing protocol (B). The measurements were performed during session 1 (S1), session 2 (S2) and session 3 (S3) except for peripheral nerve stimulation (PNS) and transcranial magnetic stimulation (TMS) setup which were performed only for S1 and S3.