Reliability and External Validity of Tensiomyography Measurements Following Strength Exercise

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Abstract: Tensiomyography (TMG) reliability and external validity using maximal voluntary isometric contraction (MVIC) following different strength training protocols (STP) were analysed. Twenty healthy male were tested two times over one week and TMG reliability was analysed in the muscles Rectus Femoris (RF), Biceps Femoris (BF), and Gastrocnemius Lateralis (GL), after an individual maximal and submaximal electrical stimulation. Moreover, TMG external validity was assessed through Pearson correlation between changes in TMG muscle mechanical properties in RF and changes in MVIC in squat exercise after five different lower-limb STPs. Maximal electrical stimulation showed the highest ICC scores for TMG muscle properties reliability in all muscles investigated. Significant Pearson correlation coefficients were found between changes in TMG mechanical properties and changes in MVIC after STPs characterized by high intensity, time under tension and eccentric overload. TMG is a valid and reliable method to assess muscle mechanical properties especially under maximal condition.

1 INTRODUCTION

Different methods and techniques have been used to assess neuromuscular function, such as torque recordings during voluntary or evoked contractions, mechanical power, surface electromyography, magnetic resonance imaging and ultrasound (Tous-Fajardo et al., 2010). In this context, a novel technique, tensiomyography (TMG), may have an additional advantage. TMG measures can be carried out quickly, are not producing additional fatigue and do not depend on voluntary motivation. It allows a non-invasive muscular function analysis, through the assessment of different specific muscle mechanical properties (Dahmane et al., 2001; García-Manso et al., 2012). Although the reliability of TMG was already reported (Rey et al., 2012), it is still unclear its reliability from submaximal electrical stimuli.

Despite many existing techniques to evaluate neuromuscular function, muscle force has been considered the best indicator of the ability of the muscle to perform (Jackman et al., 2010). Effective strength training programs can be performed with different ranges of load intensity, repetition number and rest period between sets, type of muscle action and time under tension (Kraemer and Ratamess, 2004). As far as we know, no study has correlated the acute strength performance changes with changes in TMG muscle properties after the execution of different strength training protocols used in the applied field.

Therefore, the purpose of the present study was to analyse the TMG reliability and external validity using maximal voluntary isometric contraction (MVIC). The reliability values were investigated within maximal and submaximal electrical stimuli. Changes in MVIC were assessed after five different lower-body strength training protocols. We hypothesized that TMG is a reliable method to assess muscular function within submaximal and maximal electrical stimuli and that changes in TMG muscle mechanical properties correlate with changes in MVIC values after different strength training protocols.

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2 METHODS

2.1 Experimental Design

The current study was organized in two different parts. In the first part of the study, it was analysed the reliability of the TMG mechanical properties. Twenty healthy male (age: 26.5 ± 6.7 years; body mass: 78.5 ± 6.8 kg; height: 181.0 ± 5.5 cm) were tested two times over one week period. Muscles analysed were rectus femoris (RF), biceps femoris (BF) and gastrocnemius lateralis (GL) left and right sides, after an individual maximal and a submaximal electrical stimulation (40 mA). Absolute reliability was assessed by the standard error of measurement (SEM) whereas the relative reliability by the intraclass correlation coefficient (ICC).

In the second part of the study, external validity of the most appropriate TMG mechanical properties verified in the first part of the current study from left and right muscle rectus femoris (RF) were assessed after the execution of five different lower-body strength training protocols in a randomized cross-over design with multiple repeated measures. Fourteen healthy male (age: 23.0 ± 1.9 years; body mass: 76.6 ± 7.8 kg; height: 179.4 ± 6.8 cm), experienced in strength training participated in this part of the study. All participants attended a familiarization session to introduce the testing and training procedures to minimize any learning effect. Average baseline values were collected on two occasions interspaced by one week including measures of body composition, TMG mechanical properties, one repetition maximum (1RM), and maximal voluntary isometric contraction (MVIC) for the parallel squat. The five different squat training protocols were randomly assigned for each participant and performed once per week, separated by six days in between, within 1.5 - 2 hours at the same time of the day throughout the study. It was told to the subjects not to exercise at the day before training, and to consume their last meal (caffeine-free) at least 2 hours before training and testing. TMG followed by MVIC measurements were conducted up to 0.5 hours after the end of each training protocol (post-train).

Subjects were informed about all details of the experimental procedures and the associated risks and discomforts. All participants gave their written consent to participate in the study and were free to withdraw from the study at any time. The experimental protocol followed the world medical association's declaration of Helsinki on research with humans and was approved by the local Ethics Committee of the Ruhr-University Bochum.

2.2 Training Protocols

Multiple Sets (MS): A smith rack machine with a guided barbell was used for training (TechnoGym Multipower, Italy). The protocol consisted of 4 sets of 6RM (i.e., 85% 1RM) parallel squats (knees are flexed until the inguinal fold is in a straight horizontal line with the top of the knee musculature), intended explosive during the concentric phase and 2 seconds in eccentric phase, approximately 72 seconds of time under tension (TUT), and 3 minutes rest between sets (Drinkwater et al., 2005). A laser imager and an acoustic stimulus were used to standardize the range of motion (ROM) of approximately 110-120°.

Drop Sets (DS): Subjects performed DS with the same barbell machine and ROM as described for MS. 1 set of 6RM (i.e., 85% 1RM), 4 seconds in eccentric and 2 seconds in concentric phase respectively, and approximately 130-150 seconds TUT was conducted (Skurvydas et al., 2010). Immediately after the first set, the load was reduced for the next three sets (70%, 55% and 40% 1RM, respectively), so that the subjects continued to train until concentric failure for each load, which was defined as the point when the muscles involved can no longer produce force enough to sustain the given load (Yarrow et al., 2007).

Eccentric Overload (EO): This protocol combined concentric with enhanced eccentric muscle actions (Yarrow et al., 2007) with the same barbell machine and ROM as the two protocols described before. 4 sets of 6 repetitions at a load of 70% concentric and 100% eccentric of their individual 1RM, 3 minutes rest between sets, were performed during approximately 4 seconds each repetition (i.e., 2 seconds eccentric, 1 second isometric, and intended explosive in concentric phase), and approximately 96 seconds TUT. Two helpers organized the weight changes during the upright and lower position.

Flywheel (FW): A YoYo squat flywheel machine was used for training (YoYo Technology, Stockholm, Sweden). Subjects performed 4 sets of 6 maximal rep- etitions, approximately 96 seconds TUT, 3 minutes rest between sets. Besides 6 intended maximal repetitions, 2 previous repetitions were selected for initial movement acceleration. The squat movement was executed with a ROM of about 95-105°, starting the concentric action at approximately 60-70° until about 165° of internal knee angle, carefully controlled by an experienced supervisor (Norrbrand, 2010). Subjects were asked to perform each repetition with a maximum effort, accelerating the wheel in the concentric action and upon completion, decelerating the wheel by means of an eccentric action.

Plyometrics (PL): Subjects performed 4 sets of 15 drop jumps from a 60 cm-jump box, with 5 seconds rest between repetitions, and 3 minutes rest between sets (de Villarreal et al., 2009). The study participants were asked to land until the knees are flexed of about 90° followed by a simultaneous explosive knee extension and arms swing for maximum vertical jump height.

2.3 Measurements

Tensiomyography (TMG): TMG measurements were conducted using a specific electrical stimulator (TMG-S2), the TMG-OK 3.0 software, as well as a displacement sensor tip with a prefixed tension of 0.17 N m-1, which was positioned perpendicular to the selected muscle belly (TMG-BMC, Ljubljana, Slovenia). Mechanical properties under submaximal (40 mA) and individual maximal conditions were obtained after a single 1 ms electrical stimuli. Maximal electrical stimulation and maximal muscle belly displacement were found by progressively increasing the electric current by 20 mA for each stimuli. An average from two consecutive stimuli from both legs was taken and a rest period of 10 s was interspersed between the measurements. The measuring point for each muscle was carefully determined as a point of maximal muscle belly displacement during voluntary contraction. The measurements were performed in the lower limbs in a supine position and a knee joint angle of 120° was kept by using supporting pads. The electrodes (5 x 5 cm) were placed five cm distally and five cm proximally to the sensor. The positions of electrodes and sensor were marked and kept constant during the complete experimental period. All the measurement procedures were accomplished according Rey et al. (2012). Maximal radial muscle displacement (Dm), time contraction (Tc), determined from 10% to 90% Dm, delay time (Td), determined from onset of electrical stimulus to 10% Dm, sustain time (Ts), determined as time between 50% Dm during muscle contraction and relaxation, relaxation time (Tr), determined from time of fall from 90% to 50% Dm, mean contraction velocity until 10% Dm (V_{10}) and mean contraction velocity until 90% Dm (V_{90}) were analysed.

One Repetition Maximum (1RM): The hypothetical one repetition maximum (1RM) for each participant in a smith rack machine (TechnoGym Multipower, Italy) was assessed by the formula proposed by Brzycki (1993). Subjects were instructed to position into a shoulder bride stand and the barbell was placed on the trapezius muscle and posterior deltoid muscle. In the parallel squat, the knees are flexed until the inguinal fold is in a straight horizontal line with the top of the knee musculature. A laser imager and an acoustic stimulus served to standardize the ROM of approximately 105-110°. Subjects started with two warm-up sets consisting of five repetitions with an intensity of 50% of the individual body weight with two minutes pause. After that, a work set including five repetitions with an intensity of 80 to 85% of the individual body weight was performed. Finally, after five minutes, the test supervisor asked to increase the weight for estimating the 1RM. The test was stopped when subjects were unable to raise the barbell with a proper technique or without the help of the supervisor. If subjects exceeded the limit of ten repetitions, the supervisor stopped the test and the intensity was increased. The test ended when subjects achieved five to ten maximum repetitions and the 1RM was estimated in kg.

Maximal Voluntary Isometric Contraction (MVIC): MVIC was measured in a half squat isometric exercise using a Multitrainer 7812-000 (Kettler Profiline, Germany) and analogous user software (DigiMax Version 7.X). The subjects were directed to position under the shoulder upholstery into a shoulder bride stand. Subsequently the subject was set up into a testing position up to a knee-joint angle of 90° using a custom made goniometer. Without moving explosively, but low rate of force development they were asked to produce a maximal voluntary isometric contraction over a 3 second time interval, as recommended by Blazevich et al. (2002). All subjects performed two MVICs with 2 min rest in between and the mean of both attempts was recorded.

2.4 Statistical Analyses

Data are presented as the mean ± standard deviation (SD). These data were analysed using the Statistical Package for the Social Sciences 18.0 Software (SPSS Inc., USA). The Kolmogorov-Smirnov test was used to check the normality of the data distribution. In the first part of the study, absolute reliability was assessed by the standard error of measurement (SEM) whereas the relative reliability by the intraclass correlation coefficient (ICC). After the calculation of the changes in TMG parameters and MVIC from each protocol from baseline to post-train, Pearson correlation coefficient between those

Table 1: Intraclass correlation coefficient (ICC) and standard error of measure (SEM) for TMG parameters under maximal stimulation for the muscles RF, BF and GL (* $p < 0.01$).

	Tc (ms)	Td (ms)	Tr (ms)	Dm (mm)	Ts (ms)	V_{10} ($mm.s^{-1}$)	V_{90} ($mm.s^{-1}$)
ICC	0.91*-0.94*	0.87*-0.92*	0.70*-0.93*	0.92*-0.95*	0.85*-0.88*	0.92*-0.94*	0.92*-0.95*
SEM	1.9-6.8	0.8-1.3	8.1-26.9	0.9-1.0	13.3-29.0	3.2-4.0	10.1-17.9

Table 2: Pearson correlation coefficients for changes from baseline to post-train, between Dm, V_{10}, V_{90}, and MVIC (* $p < 0.05$; ** $p < 0.01$).

	MS	DS	EO	FW	PL
Dm	0.21	0.61*	0.72**	0.17	0.14
V_{10}	0.25	0.62*	0.76**	0.18	0.04
V_{90}	0.25	0.63*	0.66**	0.08	-0.04

changes was used to establish TMG external validity. Moreover, it was established at baseline the correlation between TMG parameters. Statistical significance was set at $p < 0.05$.

3 RESULTS

Maximal electrical stimulation showed the highest ICC significant values for TMG reliability in all the muscles investigated (Table 1). Regarding submaximal condition, not all TMG muscle properties exhibited sufficient reliability. Tc, Td, Dm, V_{10}, and V_{90} showed significant ICC scores (0.66-0.92; 0.65-0.92; 0.81-0.96; 0.85-0.94; 0.85-0.93) in the different muscles respectively.

It was found a high significant Pearson correlation ($r > 0.9$; $p < 0.001$) between TMG muscle properties Dm, V_{10}, and V_{90}. Pearson correlation coefficients from each protocol between MVIC changes and respective changes of Dm, V_{10}, and V_{90}, are presented in Table 2.

4 DISCUSSION

Maximal electrical stimulation has demonstrated higher reliability in comparison with submaximal condition. In some muscles, under submaximal stimuli, Tr and Ts have not been repeatable. As the higher reliability scores were found after maximal stimulation and not all TMG muscle properties were repeatable, in the second part of the study, maximal stimuli and muscle properties Dm, V_{10}, and V_{90} were used.

Dm has been considered as a measure of muscle belly radial stiffness, and an increasing in such variable indicates smaller muscle belly radial stiffness, whereas its decreasing means greater muscle belly radial stiffness (García-Manso et al., 2012; Hunter et al., 2012; Rey et al., 2012). However, because of a high positive Pearson correlation coefficients found between the TMG muscle properties Dm, V_{10}, and V_{90} ($r > 0.90$; $p < 0.001$), Dm might also indicate the capacity to perform fast muscle contractions, under the conditions of the present study.

It was observed a significant correlation between changes in Dm, muscle contraction velocities, and changes in MVIC after the execution of DS and EO (r range between 0.61 and 0.76). These results are in accordance with Hunter al. (2012), which demonstrated a positive correlation between changes in strength performance and changes in TMG muscle properties after eccentric muscle actions. The association between changes in TMG muscle properties and changes in MVIC might be explained by some specific characteristics of DS and EO, possibly related to fatigue. The number of repetitions at a high workload performed in DS led to the highest TUT, compared to the other protocols. Moreover, it has been shown greater fatigue levels after drop-set strength protocols (Willardson, 2007), as additional higher threshold motor units are recruited and subsequently fatigued. Regarding EO, because of a greater eccentric muscle activation and higher exercise-induced muscle damage (Norrbrand, 2010; Schoenfeld, 2012), this protocol may have a special effect on fatigue. Eccentric muscle actions have been shown to produce a greater amount of force than isometric or concentric actions despite a decreased motor units recruitment (Tesch et al., 2004). The result is a higher tension produced per cross-bridge and progressive sarcomere over-stretching, predisposing to destruction of contractile proteins and damage in cellular structures (Proske and Allen, 2005; Tesch et al., 2004).

TMG is a valid and reliable method to assess muscle mechanical properties especially under maximal conditions. Based on our results, we advise researches that analyse the relationship between TMG muscle properties and muscle fatigue after the execution of strength training exercises.

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REFERENCES

Blazevich, A. J., Gill, N., and Newton, R. U. Reliability and validity of two isometric squat tests. J Strength Cond Res 16: 298–304, 2002.

Brzycki, M. Strength testing: predicting a one-rep max from repetitions to fatigue. *J Physical Education 64: 88–90, 1993.*

Dahmane, R, Valencic, V, and Erzen, NK. Evaluation of the ability to make non- invasive estimation of muscle contractile properties on the basis of the muscle belly response. *Med Biol Eng Comput 39: 51–55, 2001.*

Drinkwater, EJ, Lawton, TW, Lindsell, RP, Pyne, D, Hunt, PH, and McKenna, MJ. Training leading to repetition failure enhances bench press strength gains in elite junior athletes. *J Strength Cond Res 19: 382–388, 2005.*

García-Manso, J. M., Rodríguez-Matoso, D., Sarmiento, S., de Saa, Y., Vaamonde, D., and Rodríguez-Ruiz, D. Effect of high-load and high-volume resistance exercise on the tensiomyographic twitch response of biceps brachii. *J Electromyogr Kinesiol 22: 612–619, 2012.*

Hunter, A. M, Galloway, S. D., Smith, I. J., Tallent, J., Ditroilo, M., and Fairweather, M. M. Assessment of eccentric exercise-induced muscle damage of the elbow flexors by tensiomyography. *J Elektromyogr Kinesiol 22: 334–341, 2012.*

Jackman, S. R., Witard, O. C., Jeukendrup, A. E., and Tipton, K. D. Branched-chain amino acid ingestion can ameliorate soreness from eccentric exercise. *Med Sci Sports Exerc 42: 962–970, 2010.*

Kraemer, W. J., and Ratamess, N. A. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc 36: 674–688, 2004.*

Norrbrand, L. P. Flywheel resistance training calls for greater eccentric muscle activation than weight training. *Eur J Appl Physio 110: 997–1005, 2010.*

Proske, U, and Allen, T. J. Damage to skeletal muscle from eccentric exercise. *Exerc Sport Sci Rev 33: 98–104, 2005.*

Rey, E., Lago-Pen˜as, C., and Lago-Ballesteros, J. Tensiomyography of selected lower-limb muscles in professional soccer players. *J Electromyogr Kinesiol 22: 866–872, 2012.*

Schoenfeld, B. Does exercise-induced muscle damage play a role in skeletal muscle hypertrophy*? J Strength Cond Research 26: 1441–1453, 2012.*

Skurvydas, A, Streckis, V, Brazaitis, M, and Rudas, E. The effect of plyometric training on central and peripheral fatigue in boys. Int J Sports Med 31: 1–7, 2010.

Tesch, PA, Ekberg, A, Lindquist, DM, and Trieschmann, JT. Muscle hypertrophy following 5-week resistance training using a nongravity-dependent exercise system. Acta Physiol Scand 180: 89–98, 2004.

Tous-Fajardo, J., Moras, G., Rodriguez-Jimenez, S., Usach, R., Doutres, D. M., Maffiuletti, N. A. Inter-rater reliability of muscle contractile property measurements using non-invasive tensiomyography. *J Electromyogr Kinesiol 20: 761–766, 2010.*

de Villarreal, E. S., Kellis, E., Kraemer, W. J., and Izquierdo, M. Determining variables of plyometric training for improving vertical jump height performance: a meta- analysis. *J Strength Cond Res 23: 495–506, 2009.*

Willardson, J. M. The application of training to failure in periodized multiple-set resistance exercise programs. *J Strength Cond Res 21: 628–631, 2007.*

Yarrow, J. F., Borsa, P. A., Borst, S. E., Sitren, H. S., Stevens, B. R., and White, L. J. Neu- roendocrine responses to an acute bout of eccentric-enhanced resistance exercise. *Med Sci Sports Exerc 39: 941–972, 2007.*