J Musculoskelet Neuronal Interact 2022; 22(3):316-325

Journal of Musculoskeletal and Neuronal Interactions JMNI

Original Article

Decomposition of tensiomyogram and comparison with torque twitch responses after post-activation potentiation

Ensar Abazović[1], Armin Paravlić[2,3,4], Damir Zubac[3,5], Erol Kovačević[1], Boštjan Šimunič[3]

[1]Faculty of Sport and Physical Education, University of Sarajevo, Sarajevo, Bosnia and Herzegovina;
[2]Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia;
[3]Science and Research Centre Koper, Institute for Kinesiology Research, Koper, Slovenia;
[4]Faculty of Sports Studies, Masaryk University, Brno, Czech Republic;
[5]Faculty of Kinesiology, University of Split, Split, Croatia

Abstract

Objectives: This study evaluates the effect of post-activation potentiation (PAP) after 5x5s maximal voluntary isometric contractions (activation stimulus, AS) on tensiomyography (TMG) and torque twitch contractile parameters of vastus lateralis (VL) and medialis (VM), respectively. Further, we validated the decomposition of TMG response to separate responses of three fiber types. **Methods**: 15 healthy individuals participated in this study (40% women; age 19±2.3 years). A decomposition of VL TMG response was done after optimal fitting of three exponential curves. **Results**: We found main effects in contraction time (Tc) for muscle, method and time. Furthermore, we found interactions between muscle*method, method*time and muscle*method*time. Compared to PRE AS, we found shorter TMG Tc in VL and VM during the first two minutes after AS. Torque Tc remained unchanged in VL, while it increased in VM within 30 seconds after AS. A decomposition of VL TMG response confirmed PAP effects being present only in decomposed type IIb muscle fibers. **Conclusion**: The TMG is a sensitive method to detect PAP effects with a sensor mounted directly above the muscle belly. After the decomposition of the TMG signal to three separate muscle fiber phenotypes, we provided a non-invasive insight in the contribution of each muscle fiber phenotype to the PAP of the whole muscle.

Keywords: Decomposition, Fast-twitch Fibers, PAP, Skeletal Muscle, Tensiomyography

Introduction

The capability to maximize muscular strength and power is critical for sport success, especially in power sports such as track and field and its particular disciplines. Numerous studies showed that the post-activation potentiation (PAP) effect is a muscular phenomenon that can increase force output and enhance performance. The critical aspect of PAP protocols must consider an optimal dosage of prescribed exercise protocol to reach a point where the neuro-muscular system is potentiated, rather than fatigued[1]. Mainly, two proposed PAP mechanisms were described previously. The first one is represented through myosin regulatory light chains phosphorylation, which renders actin-myosin more sensitive to calcium released from the sarcoplasmic reticulum during subsequent muscle contractions[2]. As a result, the force of each successive twitch contraction is increased. The second is that PAP causes increased synaptic excitation within the spinal cord, which in turn results in increased post-synaptic potentials and subsequently increases force-generating capacity of the involved muscle groups[3]. It has been observed that muscle contractile characteristics may modulate the effects of prior conditioning on subsequent performance[4-6]. Previous studies have shown positive effects of PAP on the magnitude of neural activation[7,8] but also muscle contractile characteristics[7,9]. Thus, suggesting that the most important muscle characteristic affecting the magnitude of PAP is fiber type composition, with the greatest potential for enhanced PAP in muscles with a higher proportion of Type II fibers[7].

The authors have no conflict of interest.

Corresponding author: Ensar Abazović, Faculty of Sport and Physical Education, University of Sarajevo, BiH
E-mail: ensar.abazovic@fasto.unsa.ba

Edited by: G. Lyritis
Accepted 8 March 2022

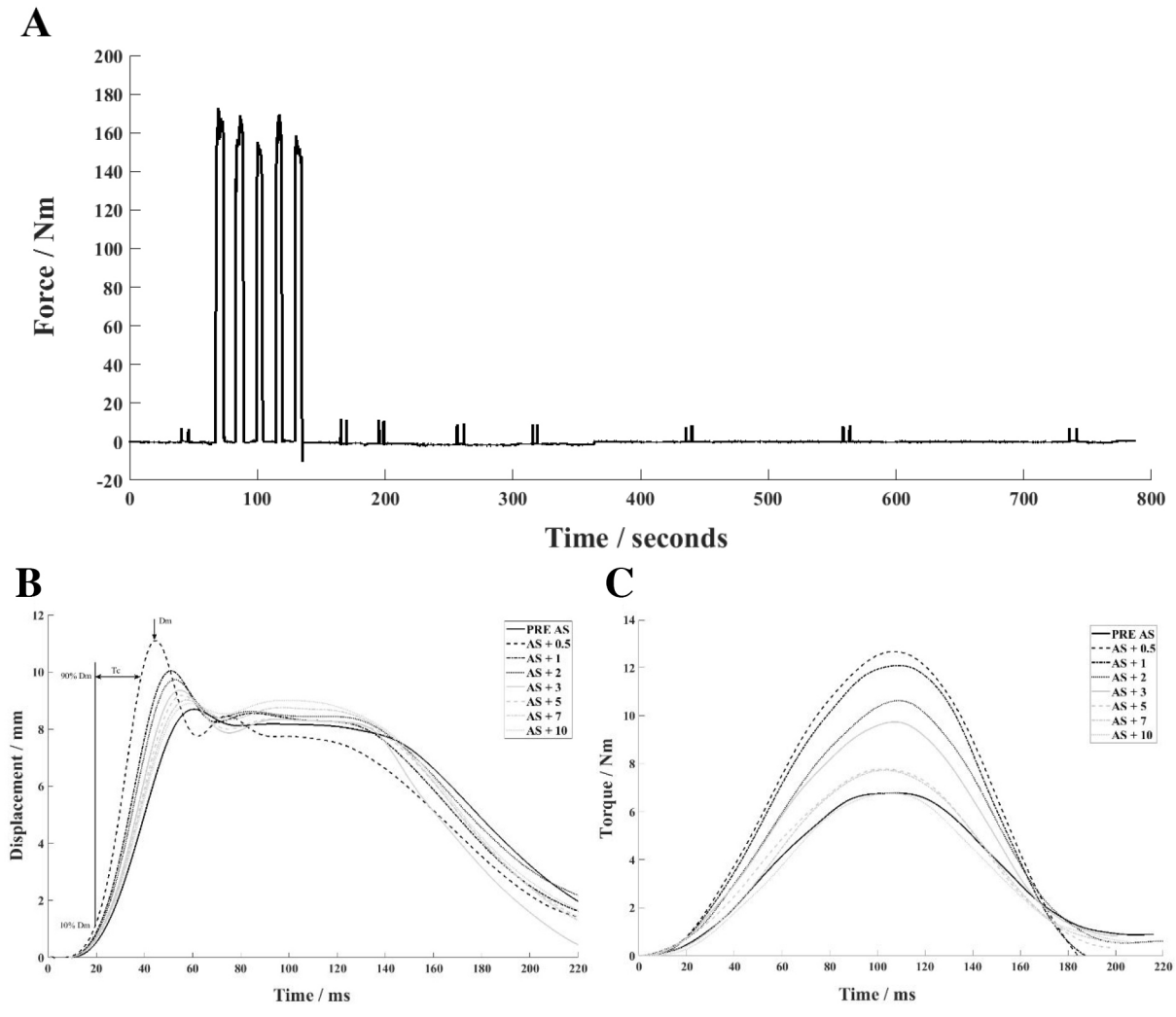

Figure 1. A representative VM torque trace curve with double twitch responses before and after AS (A). Stacked VM twitch responses assessed by tensiomyography (B) and torque (C) are also presented. An amplitude (Dm) and contraction time (Tc) calculation is presented only for AS + 0.5 TMG curve in Figure 1B.

Thus, according to existing literature, the PAP effect might be greater in muscles with the shorter twitch contraction time[7].

Skeletal muscle contractile properties have been evaluated for various purposes and mainly by estimating twitch torque response, but in recent literature, they have also been evaluated after maximal voluntary isometric contraction (MVIC). For example, twitch torque response after MVIC was investigated by utilizing a dynamometer[7,10], EMG[11,12] and functional performance by using different jumps[13]. To the authors' knowledge, only one study[14] noted PAP effect by using Tensiomyography (TMG). They initially aimed to detect mechanical fatigue induced by two different resistance exercises on *m.biceps brachii* but found acute PAP effects[14].

TMG is based on the non-invasive and selective assessment of skeletal muscle contractile properties using a displacement sensor mounted on the skin overlying individual muscle belly and was introduced in the early 90'[15]. From TMG response several parameters of muscle contraction could be derived, of which contraction time (Tc) and maximal displacement amplitude (Dm) were found to be the most reliable[16,17] and clinically relevant[18-20]. In recent years it has been extensively used to measure muscle adaptations following disuse, training processes and different rehabilitation protocols[18,20,21]. Previous work of Šimunič[22] and Koren[23] compared muscle twitch contractile parameters by simultaneously measuring TMG and dynamometry in human muscles whilst Šimunič[24] compared TMG and dynamometer muscle twitch response in isolated toad *m.gastrocnemius*. They found that skeletal muscle's TMG response reflects more intrinsic contractile properties as the TMG-derived Tc is ~40% shorter when

measured *in vivo*[22,23], however, comparable to dynamometry Tc when measured in isolated muscle[24].

TMG showed to be an accurate noninvasive predictor of the %MHC-I in a muscle[19], and since previous findings suggest that PAP effect are fiber type dependent, primarily greater in muscles with higher proportion of type II fibers[7,10], we aimed to evaluate contribution of different fiber types to overall muscle PAP. Therefore, we are presenting for the first time a TMG decomposition technique to show separate theoretical responses of type I, IIa and IIb muscle fibers and by using a known-difference evidence technique to show construct validity of such decomposition. It is well known that there are large differences in Tc of single fibers between different muscle fiber types, being <60 ms, <100 ms and >100 ms for type IIb, IIa and I, respectively[25-27], which were used for initial decomposition model.

The purpose of this study is threefold. Firstly, we aimed to evaluate the effect of repetitive short burst MVIC, as preconditioning activity, on TMG and torque twitch contractile parameters of *vastus lateralis* (VL) and *vastus medialis* (VM) and to investigate the differences between both assessment techniques. Finally, we decomposed raw VL TMG response to separate responses of type I, IIa and IIb fibers to evaluate different fiber type contribution to overall muscle response.

Methods

Participants

In the conceptualization phase of the study, we conducted a power analysis using the G*Power[28]. Based on previous studies with similar design we expected to find medium to large effects between PRE AS and AS+0.5 measurement points[29] (0.7) with power of 0.90 and α=0.05, two-tiled, which calculated a sample size of 14 participants. Therefore, fifteen healthy participants (9 males, 6 females; aged 19±2.3 years; body height 178.2±10.6 cm; and body mass 75±7.2 kg) with no history of neurological disorders or lower limbs musculoskeletal injuries in the previous six months, and a minimum one-year weight training experience gave written informed consent to participate in the current investigation. Participants' eligibility was determined by interview before a detailed explanation of the study protocol. Additionally, participants were informed to suspend alcohol and/or caffeine-based beverage consumption and participation in high-intensity exercises 48 h before the experiment. Water consumption was allowed during the experimental protocol. The study was approved by the Local Ethics Committee and conducted in accordance with the 1964 Declaration of Helsinki and its subsequent amendments.

Experimental design

After a detailed explanation of the protocol and the written consent agreement, a standardized warm-up protocol consisting of five minutes on a stepper and three-minute dynamic stretching was performed ensuring static stretching negative PAP effects avoidance[30]. The stretching tempo was controlled (1s:1s - concentric: eccentric) to minimize additional warm-up potentiation[31].

To reduce fatigue and PAP effects caused by warm-up[32], each participant was subjected to a 15-minutes supine washout period sufficient in residual PAP effects reduction[33]. Additionally, resting in the supine position before mechanomyographic, as TMG is, testing is a good practice resulting in better body fluids redistribution[34].

After a washout period, a baseline data assessment (PRE AS) was being followed by a 5x5 seconds MVIC with a ten-second pause between repetitions (Activation Stimulus – AS) to trigger PAP[35]. Following AS, an assessment of VL and VM was repeated in specific time points, 0.5, 1, 2, 3, 5, 7, 10 minutes for AS+0.5 - AS+10, respectively. At each time point, two TMG and torque twitch responses were obtained (Figure 1A) in VL and VM.

Measuring protocol

All measurements were performed unilaterally using the seated position, with an average angle of trunk and thighs of 85°. Stabilization straps were placed over the chest, hips and distal thigh at the dominant leg. Dominant leg was defined by the participants[36]. The knee angle was adjusted to 40° of knee flexion so that the leg position was optimal for PAP[37], and TMG measurement[38].

Electrical stimulation

We used a monophasic electrical stimulator (TMG ZD-1, TMG-BMC Ltd., Ljubljana, Slovenia). The supramaximal stimulation amplitudes were determined for each muscle at PRE and kept the same for the whole experiment. Initially, the stimulation current amplitude (stimulation voltage was constant at 30 V) was set just above the threshold at which a muscle twitch occurs and then gradually (every 10 s) increased until the amplitudes of TMG and torque twitch responses increase no further. Each participant received a total of 16 VL and 16 VM electrical stimulations, two at 8-time points. Each electrical stimulus lasted one millisecond and was brought to the muscle through two square self-adhesive electrodes (Compex Medical SA, Ecublens, Switzerland), 5cm distal (cathode) and 5cm proximal (anode) from the measuring point. A point of maximal muscle belly displacement during voluntary knee extension was selected as a measurement point as it was recommended by the manufacturer and previous authors[16,19,39].

Torque assessment

The twitch-torque response was measured using an isometric dynamometer (S2P, Ljubljana, Slovenia). An analog force transducer (TSD121C, BIOPAC Systems Inc., USA) was mounted 38.0±2.3 cm distally from the axis of the knee rotation on the tibia. Force analog output was sampled at a frequency of 2 kHz. The dynamometer axis of rotation was adjusted to correspond to the knee joint axis and the dynamometer lever was measured.

Table 1. Comparison of baseline contraction time (Tc) estimated from tensiomyographic and torque twitch responses in VM and VL.

	Tensiomyography	Torque	p-value
VM Tc / ms	24.1 (3.4)	44.4 (9.3)	<0.001
VL Tc / ms	20.7 (4.2)	63.7 (8.1)	<0.001
p-value	0.021	<0.001	

Abbreviations: VM – vastus medialis; VL – vastus lateralis; Tc- contraction time,

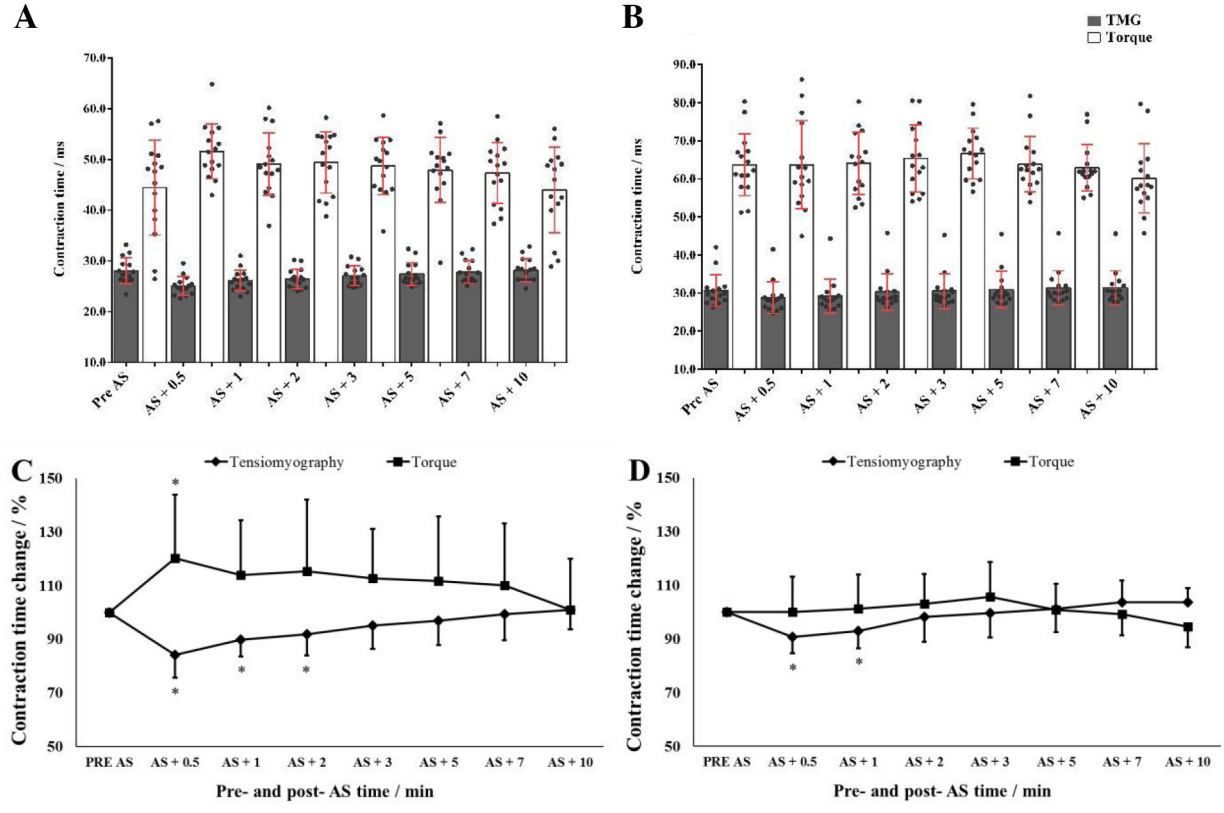

Figure 2. Absolute (A, B) and relative (C, D) changes in contraction time (Tc) after activation stimulus (AS) when compared to baseline values (PRE AS) in VM (A, C) and VL (B, D). * different from PRE AS at p<0.007.

TMG assessment

The TMG was used to assess skeletal muscle belly displacement in the transversal plane during electrically evoked contractions as described above. The measuring point was anatomically determined and the tip of the highly sensitive (1 μm) TMG displacement sensor (G40 digital-optical comparator, TMG-BMC Ltd., Ljubljana, Slovenia) was placed, perpendicular to the skin above the muscle belly with an initial pressure of 77 N/mm^2.

Data analysis

For each time point and muscle two TMG and torque curves were taken for further analysis. TMG curve needed no post-processing (Figure 1B). Each torque response was filtered (digital Butterworth filter, 50 Hz cut-off frequency) in Matlab software (function filtfilt) (Figure 1C). Dm and Tc were extracted from every TMG and torque twitch response (Figure 1B). The Dm was defined as the peak amplitude of the twitch response and the Tc was defined as the time twitch amplitude rises from 10% to 90% of the Dm[16,19]. An average Dm and Tc for TMG and torque responses were taken in further statistical analysis.

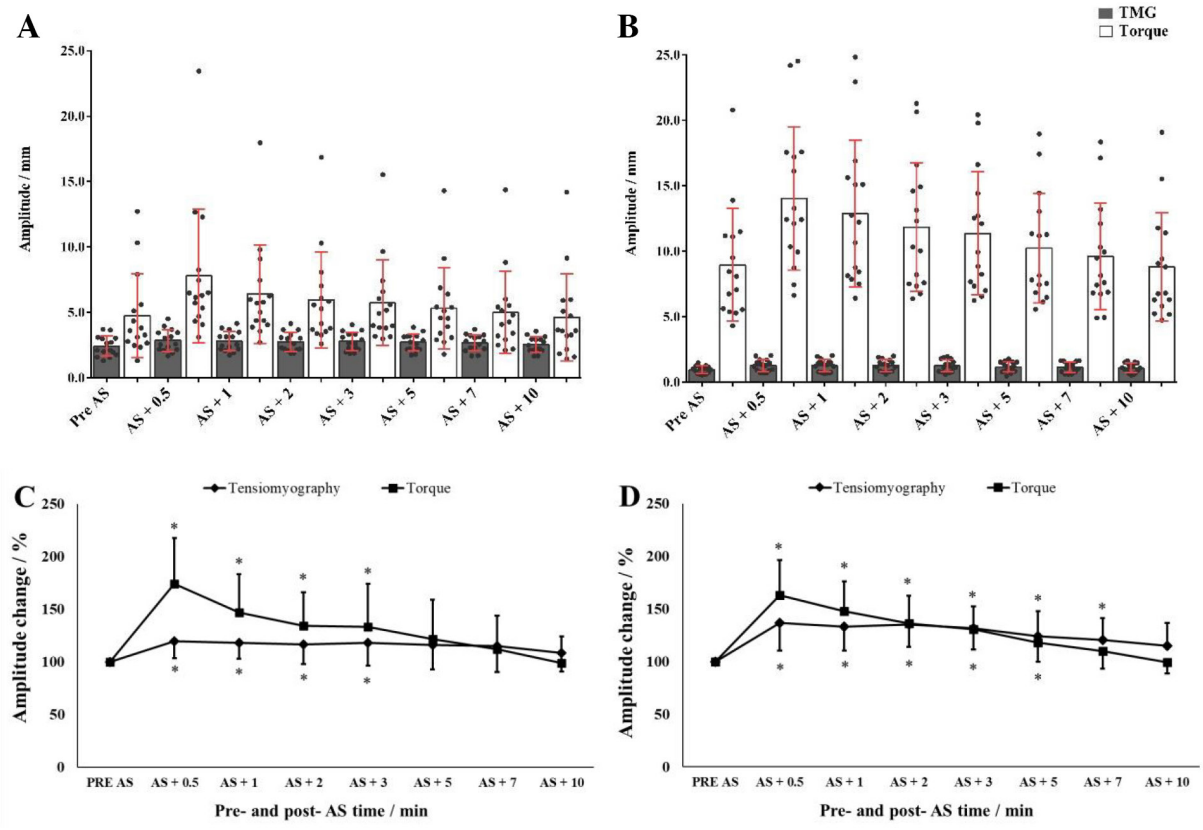

Figure 3. Absolute (A, B) and relative (C, D) changes in the amplitude after activation stimulus (AS) when compared to baseline values (PRE AS) in VM (A, C) and VL (B, D). * different from PRE AS at p<0.007.

Decomposition of TMG responses

Only VL TMG responses were decomposed in three theoretical responses of type I, Type IIa and Type IIb muscle fiber phenotypes. From the available literature, we obtained time to peak values (summated for the delay time) for the three most abundant skeletal muscle fiber phenotypes, being in the range from 82 to 168 milliseconds for type I, from 64 to 94 milliseconds for type IIa, and 43 to 60 milliseconds for type IIb[25-27]. Using a Matlab application (Curve fitting) we decompose TMG VL responses to three Gaussian functions (curves), each representing muscle fiber type phenotype (type I, IIa and IIb), optimizing the decomposition for minimal distance from a raw VL TMG curve, as shown in the Equation 1:

$$min\left(TMG_{raw} - \sum_{i=1}^{3} A_i \cdot exp^{-\left(\frac{x_i - B_i}{C_i}\right)^2}\right) \quad \text{Equation (1)}$$

where i represents three muscle fiber phenotypes, B_i represents the center of the curve peak, A_i the height of the curve, C_i the width of the curve and X_i represents the result of the decomposition – a theoretical curve representing the response of the homogenous group of fiber type phenotype. Before the decomposition, we limited the time position of the center of the peak (B) for each fiber type, as indicated above. The other two parameters (A and C) were not limited, being left to be calculated by the optimization routine. For each participant, we decomposed two VL responses and an average was taken for further statistical analysis. The quality of decomposition was assessed by the correlation coefficient and was found to be very high in all decompositions.

Statistical analysis

All statistical procedures were done in SPSS (version 24.0, IBM Ltd., USA). We presented means with standard deviations. After confirming normality (histogram with Q-Q plot, Shapiro-Wilk test) and equality of variances (Levene's test) we used parametric statistical methods. PRE AS Tc values were compared between the two methods and muscles by paired t-test and Pearson correlation coefficient. A three-way repeated-measures General linear model, with time (PRE AS - AS+10), method (TMG and Torque) and muscle (VL and VM) as within factors, was used for the evaluation of the time course of Tc and Dm. Time-pairwise comparison with PRE AS values was analyzed after Bonferroni correction

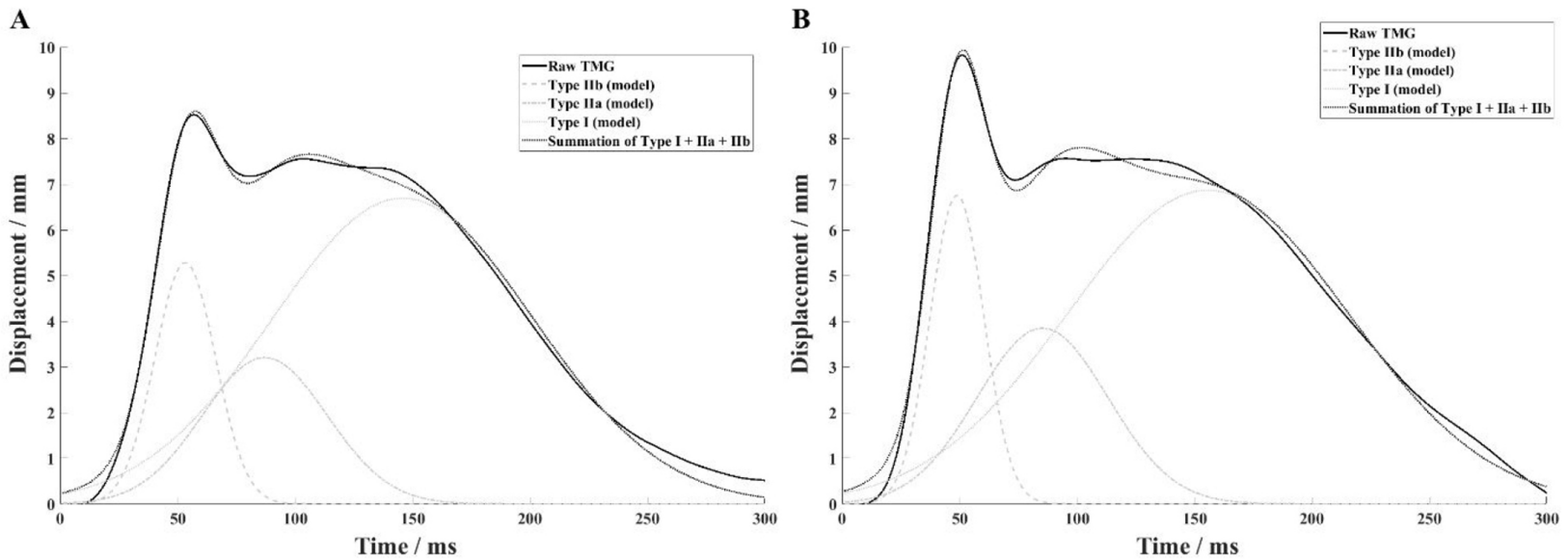

Figure 4. A representative decomposition model of VL response before (A) and 30 seconds after AS (B). Raw data are compared with a summation of modeled type I, IIa and IIb muscle fiber responses.

Table 2. Raw VL TMG response decomposition parameters representing different fiber types and their changes after activation stimulus (AS).

	PRE AS	AS + 0.5	AS + 1	AS + 2	AS + 3	AS + 5	AS + 7	AS + 10	p-value (η^2)
Type I									
A / ms	5.47 (2.09)	5.15 (1.39)	5.58 (1.32)	5.87 (1.29)	6.19 (1.47)	6.47 (1.83)	6.39 (1.70)	6.40 (1.54)	p=0.041 (0.328)
B / ms	157 (10.1)	163 (11.0)	166 (9.47)	164 (10.4)	164 (7.28)	161 (8.59)	157 (8.90)	157 (10.2)	p=0.074
C / ms	78.1 (7.39)	84.5 (9.13)	83.2 (6.65)	82.5 (7.96)	82.9 (4.73)	80.5 (6.53)	78.0 (7.44)	80.5 (5.92)	p=0.056
Type IIa									
A / ms	4.06 (1.70)	4.29 (1.51)	4.69 (1.78)	4.69 (1.73)	4.70 (1.70)	4.65 (1.50)	4.39 (1.46)	4.20 (1.52)	p=0.039 (0.334)
B / ms	86.4 (6.18)	82.3 (6.63)	86.1 (6.93)	85.5 (6.45)	87.0 (7.12)	86.7 (8.06)	86.1 (7.38)	85.8 (5.7)	p=0.001 (0.260)
C / ms	39.9 (4.57)	39.9 (4.56)	41.8 (4.11)	41.2 (4.55)	41.9 (4.68)	40.8 (5.26)	39.3 (4.22)	39.0 (3.79)	p<0.001 (0.297)
Type IIb									
A / ms	4.19 (1.46)	5.82 (2.22)*	5.46 (1.82)*	5.36 (1.79)*	5.33 (1.71)*	5.00 (1.58)*	4.86 (1.60)	4.57 (1.39)	p=0.002 (0.613)
B / ms	50.4 (4.01)	45.9 (3.34)*	47.9 (3.83)	48.1 (3.72)	49.1 (4.03)	49.8 (4.34)	51.0 (4.57)	51.0 (3.58)	p=0.001 (0.645)
C / ms	18.3 (2.85)	15.6 (2.28)*	16.5 (2.61)*	16.8 (2.52)	17.1 (2.72)	17.8 (2.85)	18.2 (3.12)	18.0 (2.51)	p=0.003 (0.579)
r^2	0.994 (0.004)	0.990 (0.006)	0.992 (0.003)	0.993 (0.003)	0.992 (0.004)	0.994 (0.003)	0.993 (0.003)	0.994 (0.002)	p=0.068

PRE - before; AS - activation stimulus; Type I - slow twitch fibers; Type IIa - fast twitch oxidative fibers; Type IIb - fast twitch glycolytic fibers; A - the height of the curve; B - the center of the curve peak; C - the width of the curve; r^2 - a coefficient of determination; different from PRE AS at p<0.007.*

of the p-value (p=0.05/7=0.007). A three-way repeated-measures General linear model, with time (from PRE AS to AS+10), decomposition Gaussian parameters (A, B and C) and fiber type (types I, IIa and IIb) as within factors, was used to evaluate time trends in decomposition parameters. Time-pairwise comparison with PRE AS values was analyzed after Bonferroni correction of the p-value (p=0.05/7=0.007). The level of statistical significance was set to p<0.05. If significant effects were found a partial eta-squared (η^2) was reported. Data are presented as mean (SD).

Results

Baseline VL and VM Tc were 45% and 68% shorter (p<0.001) when estimated from TMG response in comparison to torque response, respectively (Table 1). Tc was shorter in VL than in VM, regardless of the method. There were no correlations between TMG Tc and torque twitch responses, neither in VL (p=0.154) or VM (p=0.093).

A VM torque trace of a representative participant is shown in Figure 1A. After stacking torque and TMG twitch responses a shift to the left in TMG responses (Figure 1B) or shift to the right in torque responses (Figure 1C) are evident after AS. This already indicated different responses after the same stimulus between both methods.

For Tc we found muscle (p<0.001; η^2=0.677), method (p<0.001; η^2=0.974) and time (p=0.032; η^2=0.142) effects. Furthermore, we found interactions between muscle*method (p<0.001; η^2=0.810), method*time (p<0.001; η^2=0.424) and muscle*method*time (p=0.010; η^2=0.169), but not in muscle*time (p=0.328). A post hoc analysis of TMG Tc confirmed the time effect (p<0.001; η^2=0.704) in VM with Tc being lower during two minutes after AS, when compared to PRE AS (Figure 2C). Similarly, the time effect was also confirmed in VL (p<0.001; η^2=0.525) with TMG Tc being lower during the first minute after AS, when compared to PRE AS (Figure 2D). A post hoc analysis of Torque Tc revealed different results. Time effect was confirmed only in VM Tc (p<0.001; η^2=0.259) with Tc being higher during 30 seconds after AS, when compared to PRE AS (Figure 2C).

For amplitudes we found method (p=0.032; η^2=0.289) and time (p<0.001; η^2=0.738) effects. Furthermore, we also found interactions between muscle*method (p<0.001; η^2=0.896), muscle*time (p<0.001; η^2=0.386), method*time (p<0.001; η^2=0.574) and muscle*method*time (p<0.001; η^2=0.553). A post hoc analysis of TMG amplitude confirmed the time effect (p<0.001; η^2=0.383) in VM with amplitude being higher during three minutes after AS, when compared to PRE AS (Figure 3C). Similarly, the time effect was also confirmed in VL (p<0.001; η^2=0.524) with TMG amplitude being higher seven minutes after AS, when compared to PRE AS (Figure 3D). A post hoc analysis of torque amplitude confirmed similar results. Time effect was found in VM (p<0.001; η^2=0.558) with amplitude being higher during three minutes after AS, when compared to PRE AS (Figure 3C). Similarly, the time effect was also confirmed in VL (p<0.001; η^2=0.738) with torque amplitude being higher during five minutes after AS, when compared to PRE AS (Figure 3D).

After decomposition of each VL TMG raw response into three separate responses of type I, IIa and IIb muscle fiber composition groups (Figure 4) we found a trend towards time effect (p=0.067), time*decomposition coefficients interaction (p=0.046; η^2=0.139), time*muscle fiber types interaction (p<0.001; η^2=0.369) and time*decomposition coefficients*muscle fiber type interaction (p<0.001; η^2=0.427). A post hoc analysis (Table 2) revealed the largest changes after AS in coefficients of type IIb fibers, then in type IIa fibers and no changes in type I fibers. Specifically, in type IIb fibers A increased in AS+0.5 to AS+5, B decreased only in AS+0.5, while C decreased in AS+0.5 and AS+1. All three coefficients in type IIa fibers changed significantly, too; although, no changes could be identified from PRE AS values. In type I fibers only A changed with no deviation from PRE AS values could be identified.

Discussion

The present study aimed to evaluate the effect of PAP after 5x5 MVICs on TMG and torque twitch contractile parameters of VL and VM. Further, we validated the decomposition of TMG response to separate responses of three fiber types. We found altered TMG- and torque-derived contractile properties (Tc and Dm) after AS. However, the Tc response, estimated from both methods, was not similar nor in the same direction. A decomposition of raw VL TMG response to separate responses of type I, IIa and IIb muscle fibers confirmed PAP effects being present only in type IIb muscle fibers.

Tc was 45.7% and 67.5% shorter when estimated from TMG response, in comparison to torque response, of VL and VM, respectively. This is in line with previous findings of Koren[23] for VL (42.7%) and by Šimunič[22] in biceps brachii (40.4%). They explained this delay in Tc with lower effects of viscoelastic properties of muscle and tendons as well as joint mechanics examined through TMG response compared to torque response, as the TMG sensor is positioned directly on the muscle belly, whereas the torque sensor is positioned on a distal limb. Consequently, a torque sensor captures a delayed muscular response transferred from the muscle through all knee joint structures. To confirm that, Šimunič[24] demonstrated there is no difference in Tc when it is estimated *in vivo* from TMG or force twitch response of isolated toad muscle. AS induced a decrease in the TMG-derived Tc with the highest relative decrease at AS+0.5 being 15.8% (VM) and 9.2% (VL). VM Tc recovered to PRE AS values 3 minutes after AS, whereas 2 minutes were needed for VL. Oppositely, VM Torque Tc increased by 20.3% at AS+0.5 and recovered to PRE AS values after 1 minute. There was no torque Tc change after AS in VL. As this is the first report of the potentiation of TMG Tc, several findings reported decreased torque Tc or time to peak torque after AS[7,40]. However, similar to the current study, their findings were not consistent for all muscles and populations assessed. Specifically, higher AS

effects were found in knee extensors and plantar flexors while no effect was found in *m.tibialis anterior*. Pääsuke[41] reported no AS effect on knee extensors torque Tc in three different populations (power-, endurance-trained and untrained females). On the other hand, Hamada[10] reported a higher AS effect (22%) on torque Tc in participants with higher (71.8%) and lower AS effect (15%) in participants with lower type II fibers proportion (38.6%). Our results, indicating no change of VL torque Tc after AS, are in line with findings of Requena[29] and Pääsuke[41], whilst the 22% increase in VM torque Tc after AS is in line with Hamada[10]. Indeed, TMG Tc is positively correlated with muscle fiber type distribution, with shorter Tc reflecting a higher proportion of type II fibers[19]. Consequently, the AS effect is greater in type II fibers[7,8,10], which showed to have a lower basal Ca^{2+} sensitivity[42] and greater Myosin light chain kinase activity compared to type I fibers[8]. TMG amplitude increased more in VL (36.5%) than in VM (19.6%). It is most likely due to initially shorter TMG Tc in VL, that is a higher proportion of type II muscle fibers in VL compared to VM, as it was confirmed by Johnson et al[43]. TMG amplitude returned to PRE AS values 5 and 7 minutes post AS in VM and VL, respectively.

This is the first systematical study reporting TMG amplitude increase after AS. Torque amplitude increased more than TMG amplitude, reaching 74.4% and 63% in VM and VL, respectively, and returned to PRE AS values 2 minutes before TMG amplitude. A previous study by Hamada[10] showed torque amplitude increased values, ranged from 34 to 114% (70.6±22.5%) at 10th second post 10s MVIC and then rapidly declined but was still elevated ~12% after 5 min. Further on, Behm[44] recorded an increase of 55.6% at 5-minute post AS which lasted 15 min (53.1%) but found no effects in the first post AS (1 min) timepoint while using twitch voltage 100-150V and 3x10 sec MVIC (AS) while Pääsuke[41] found immediate (2s) post-MVC, torque amplitude potentiation by 51, 44, and 30% for power-trained, untrained, and endurance-trained women, respectively. Significant potentiation was present until 1 min (13%) post AS for endurance-trained, while power-trained and untrained women PAP effects lasted for 5 min (14 and 13%, respectively).

This is the first study reporting raw TMG mechanical response decomposition to three separate responses of type I, IIa and IIb muscle fibers. Although we did not perform invasive muscle composition analysis, we considered available Tc of single fibers from the literature[25-27]. Available Tc of single fibers were obtained by *in vitro* dynamometry assessment. However, Tc values from single fibers are much shorter than those obtained by vivo dynamometric assessment. However, they are comparable to *in vivo* TMG assessed values. Therefore, we decided to do decomposition on TMG mechanical response curves instead on dynamometric response curves. To support this, it was confirmed that TMG response curve (and its parameters) assimilates those of single fibers[19,22-24]. Gaussian curves used for the composition mimics muscle twitch contraction with three adjustable parameters for curve fitting: the height (A), width (C) and center of the curve peak (B). We limited B, with the available physiological data and left A and C parameters to the optimization procedure to be adjusted. The quality of the fit between a raw curve and a sum of three decomposed curves was excellent in all assessments. After AS we found that only type IIb Gaussian curve parameters changed. The height of curve A was increased until AS+5, while width C decreased until AS+1 and position of the center B until AS+0.5. This could be interpreted that the Tc of type IIb fibers is quicker and more synchronized (≤AS+1) and more type IIb fibers are activated (≤AS+5). And indeed literature confirms a higher-order motor units recruitment after AS[45]. During twitch contractions, increased neural activity may occur through the recruitment of more motor units and better motor unit synchronization. The phosphorylation (addition of a phosphate for the production of ATP) of myosin regulatory light chains allows the actin and myosin binding to be more responsive to the Ca^{2+} ions released, triggering a cascade of events leading to enhanced muscle force production at the structural level of muscle[7]. As a result, faster contraction rates and faster rates of tension development occur[45].

Conclusion

This study suggests that the TMG sensor is a sensitive tool to monitor PAP effects, and showed that Tc, estimated from the TMG response, is shorter during the PAP, while it is not when estimated from torque twitch response. Furthermore, differences between TMG and torque twitch Tc responses during PAP in two vastii muscles support claims from previous studies that TMG is very sensitive to assess intrinsic muscle properties. To support this, by decomposition of the TMG signal to three separate muscle fiber phenotypes, we confirmed a construct validity of TMG assessment being sensitive to demonstrate PAP effect only in type II muscle fibers.

Acknowledgments

The authors would like to thank the participants enrolled in the study.

Funding

This work was supported by the Slovenian Research Agency project: "L7-9421 Decomposition of skeletal muscle tensiomyogram with identification of contractile parameters for sensitive monitoring of muscle adaptation".

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