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Research article

Acute Effects of Short-Term Local Tendon Vibration on Plantar Flexor Torque, Muscle Contractile Properties, Neuromuscular and Brain Activity in Young Athletes

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Abstract
The purpose of this study was to examine the acute effects of short-term Achilles tendon vibration on plantar flexor torque, twitch contractile properties as well as muscle and cortical activity in young athletes. Eleven female elite soccer players aged 15.6 ± 0.5 years participated in this study. Three different conditions were applied in randomized order: Achilles tendon vibration (80 Hz) for 30 and 300 s, and a passive control condition (300 s). Tests at baseline and following conditions included the assessment of peak plantar flexor torque during maximum voluntary contraction, electrically evoked muscle twitches (e.g., potentiated twitch peak torque [PT]), and electromyographic (EMG) activity of the plantar flexors. Additionally, electroencephalographic (EEG) activity of the primary motor and somatosensory cortex were assessed during a submaximal dynamic concentric-eccentric plantar flexion exercise using an elastic rubber band. Large-sized main effects of condition were found for EEG absolute alpha-1 and beta-1 band power ($p \leq 0.011$; $1.5 \leq d \leq 2.6$). Post-hoc tests indicated that alpha-1 power was significantly lower at 30 and 300 s ($p = 0.009$; $d = 0.8$) and beta-1 power significantly lower at 300 s ($p < 0.001$; $d = 0.2$) compared to control condition. No significant effect of condition was found for peak plantar flexor torque, electrical evoked muscle twitches, and EMG activity. In conclusion, short-term local Achilles tendon vibration induced lower brain activity (i.e., alpha-1 and beta-1 band power) but did not affect lower limb peak torque, twitch contractile properties, and muscle activity. Lower brain activity following short-term local Achilles tendon vibration may indicate improved cortical function during a submaximal dynamic exercise in female young soccer players.

Key words Postactivation potentiation, electromyography, electroencephalography, maximum voluntary contraction, soccer.

Introduction

The performance of skeletal muscle is dependent on its contractile history where several activities can have a positive acute impact on contractile properties and/or performance (Bishop, 2003). In this regard, it has been postulated that vibration stimuli to motor nerves, muscle bellies, and/or tendons have the potential to induce short-term improvements in muscular performance (Cochrane, 2013; 2016b; Pamukoff et al., 2014). For instance, Cochrane (2016b) analyzed the acute effects of local vibration applied to the biceps brachii muscle for 10 min versus a control condition (i.e., no vibration) on mechanical power output during submaximal biceps curls (50% one-repetition maximum) in national-level master athletes (field hockey). Compared to the control condition, significant increases were found in power output immediately after local vibration. The authors suggested that the observed performance enhancements can be attributed to improved contractile properties following short-term local vibration (Cochrane, 2016b). In contrast, 10-15 min of local vibration of the biceps brachii and quadriceps femoris muscles were ineffective to improve maximum voluntary contraction (MVC) force, rate of force development and/or electrically evoked muscle twitch peak torque in trained males (Cochrane, 2016a; Souron et al., 2019). However, differences in training status (e.g., national-level vs. recreational) could be responsible for inconsistencies between these studies. In fact, training status is an important moderator variable for acute performance enhancements (e.g., muscle power) following activities with higher effects in athletes compared with trained individuals (Wilson et al., 2013). Further, findings from these studies can only partially be translated to young female athletes because physiology and proficiency in motor performance differ between female adolescent and male master athletes (Armstrong and McManus, 2011).

With regards to the underlying neuromuscular mechanisms, it has been shown that vibration stimuli to the neuromuscular system result in rapid changes of the muscle fiber length, thereby inducing muscle reflex activations on a spinal and supraspinal level (Cardinale and Bosco, 2003). Accordingly, vibration-related increases in muscular activity were observed in the stimulated muscles during isometric MVCs (Pamukoff et al., 2014; Souron et al., 2019). For instance, electromyographic (EMG) activity of the quadriceps femoris muscle during maximal isometric knee extensions was higher following 6 x 1 min of local tendon vibration compared with a passive control condition in recreationally active adults (Pamukoff et al., 2014). It was concluded that short-term local vibration appear to be efficient to increase central neural excitability and, thus, muscular performance (Pamukoff et al., 2014; Souron et al., 2019). Interestingly, Moraes Silva et al. (2015) showed that beta-band power increased in the contralateral primary motor cortex but decreased in the contralateral somatosensory cortex during an index finger task execution after 15 min of local vibration of the hand and forearm in healthy males and females. The authors suggested that local vibration could have concurrently increased cortical activity in the motor area and decreased muscle spindle afferent information during exercise (Moraes Silva et al., 2015). In particular regarding decreased cortical activity for a given motor task (e.g., index finger flexion-extension, cycling),

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lower motor cortex activity could be explained by more efficient processing in the cortical area (e.g., "neural efficiency" hypothesis) (Moraes Silva et al., 2015; Ludyga et al., 2016).

Short-term vibration stimuli of ≤5 min appear to be most effective for acute performance enhancements in young adults (Issurin, 2005). In fact, there is compelling evidence that longer vibration exposure times of 20-30 min duration can decrease subsequent EMG activity and muscular performance in upper and lower limb muscles (Issurin, 2005; Souron et al., 2017). Thus, further studies are needed to determine the best parameters for local vibration stimuli (e.g., exposure times) to induce acute performance gains (Souron et al., 2019). To the best of our knowledge, there is no study available that examined the acute effects of short-term (i.e., ≤5 min) local vibration (e.g., of the Achilles tendon) on subsequent proxies of performance (e.g., MVC), (lower limb) twitch contractile properties, as well as muscle and brain activity in young athletes.

Thus, the purpose of this study was to examine the acute effects of short-term (i.e., ≤5 min) local vibration to the Achilles tendon on subsequent peak plantar flexor torque during isometric MVCs, twitch contractile properties (e.g., peak twitch torque), plantar flexor muscle activity, and brain activity in young female athletes. With reference to the relevant literature (Issurin, 2005; Wilson et al., 2013; Pamukoff et al., 2014; Moraes Silva et al., 2015; Cochrane, 2016b),), we hypothesized that the application of short-term local tendon vibration will acutely induce greater peak plantar flexor torque, twitch contractile properties, and muscle activity of the plantar flexors. Additionally, we expected modified brain activity of the motor cortex.

Methods

Participants

Eleven young and healthy female elite soccer players participated in this study (Table 1). With reference to Cochrane (2016b), an a priori power analysis (type I error rate: 0.05; statistical power 80%) was computed. The analysis indicated that ten young soccer players are sufficient to observe large-sized main effects (Cohen's d = 0.8) of condition on measures of plantar flexor torque (i.e., mechanical peak force). All participants were free of any musculoskeletal, neurological, or orthopedic disorders during the past three months prior to the start of the study. Leg dominance was determined according to the lateral preference inventory for foot preference (e.g., with which foot would you kick a ball to hit a target?) (Coren, 1993). Athletes and their related legal guardians provided written informed consent prior to the start of the study. All experimental procedures were approved by the local ethics committee (submission number: 8/2017) and all experimental procedures were in accordance with the latest version of the Declaration of Helsinki.

Protocol

A single group, randomized cross-over design was used to examine the acute effects of local Achilles tendon vibration on peak plantar flexor torque, twitch contractile properties, plantar flexor muscle activity, and brain activity (Kümmel et al., 2017; Prieske et al., 2018). To get accustomed to the experimental procedures (e.g., dynamometry, tendon vibration, muscle stimulation, electroencephalography [EEG]), one familiarization session was conducted seven days prior to the start of the study. During the familiarization session, participants' body height was assessed using a wall-mounted scale. In addition, body mass and percent body fat were quantified by means of a bioimpedance analysis system (InBody 720, BioSpace, Seoul, South Korea). Further, an isokinetic dynamometer (Isomed 2000, D&R Ferstl GmbH, Hemau, Germany) was individually adjusted with the participants lying in prone position with hip, knee, and ankle joints in neutral position (180°, 180°, and 90°, respectively). Extended knee positions (i.e., 180°) were used during testing to evoke more pronounced twitch torque measures of the plantar flexor muscles. The foot of the dominant leg was firmly attached to the lever arm of the dynamometer with its rotational axis at the level of the malleoli. In order to limit upper body contributions to torque production, straps/pads were applied at the hip and shoulder level. This fixed position on the dynamometer was maintained throughout the entire procedures during familiarization and experimental session. During the familiarization session, participants performed six to eight isometric MVCs with the dominant leg to get used to the electrical stimulation and the measurement of the voluntary activation. Additionally, participants performed one minute of concentric-eccentric plantarflexions against a standardized resistance of a rubber band with the non-dominant leg accustoming to the test for brain activity assessment.

Table 1. Mean (SD) demographic characteristics of participants.

Age, years	15.6 (.5)
Time from peak height velocity, year	+3.1 (.5)
Height, m	1.64 (.06)
Body mass [kg]	56.8 (5.8)
Fat mass [%]	17.3 (3.7)
Average soccer training volume, sessions per weeks	9.3 (.5)

The experimental session started by analyzing the maximal stimulus intensity for electrical muscle stimulation (Figure 1). In other words, the intensity that produced a plateau in twitch peak torque under relaxed condition. Single electrical pulses of increasing intensity which evoked torque in relation to stimulation were delivered. The stimulation intensity to torque data resulted in recruitment curves. Subsequently, a brief warm-up was conducted on the isokinetic dynamometer consisting of five submaximal isometric contractions of the dominant plantar flexors at 80% MVC (each lasting for 5 s). For the non-dominant leg, the warm-up involved 30 dynamic repetitions (duration: 60 s) of the plantar flexors against the resistance of an elastic rubber band. Thereafter, baseline-tests for peak plantar flexor torque during isometric MVCs, twitch contractile properties, and muscle activity of the plantar flexor muscles using the dominant leg were applied. Three trials with a rest of three minutes between trials were conducted. Subsequently, the baseline-test for brain activity was performed using dynamic concentric-eccentric plantar flexions for 60 s with the non-dominant leg.

Brain activity during the entire 60 s time period was used as baseline measure. After baseline-tests and a rest of ten minutes, three different experimental conditions (30 s tendon vibration [V30], 300 s tendon vibration [V300], 300 s passive control [V0]) followed in randomized order. Each experimental condition was completed with two post-test trials immediately and 60 s after the experimental condition. During these tests, peak plantar flexor torque, twitch contractile properties, and muscle activity of the plantar flexor muscles were assessed. Immediately after the first trial, one post-test trial was conducted to assess brain activity. After the post tests, a wash-out phase of 10 minutes was provided because this time interval is sufficient to return peak torque and twitch torque values to baseline levels (Bishop, 2003; Kümmel et al., 2017; Prieske et al., 2018).

Figure 2. The set-up for the local vibration device with the electromyography on the shank. The foot was attached to the isokinetic device.

Experimental conditions

Local vibrations were applied to the Achilles tendon of the dominant and non-dominant leg using a small vibration apparatus (VB 115; Techno Concept, Mane, France). The vibration apparatus was strapped around the smallest circumference of the lower leg with an elastic Velcro fastener (Figure 2). To ensure similar pressure application for each condition, straps were attached by the same examiner and participants provided verbal feedback on the perceived pressure (Souron et al., 2018). During the vibration treatments (V30 or V300) and the passive control condition (i.e., the device was applied for 300 s but not activated), participants remained in prone position on the isokinetic dynamometer and the foot was detached from the lever arm of the dynamometer to allow recovery. Frequency of vibration was set at 80 Hz with a 1 mm amplitude (Lapole et al., 2015).

Assessment of peak plantar flexor torque

For the assessment of peak plantar flexor torque, isometric MVCs of the dominant leg were performed on the isokinetic dynamometer. During each peak torque trial, verbal encouragement was provided by the same examiner in the form of "contract the muscle as forcefully and as fast as possible". Trials with an identified initial countermovement were discarded after visual inspection of the torque-time curve. Peak torque and voluntary rate of torque development (RTD) were defined as peak torque and maximal slope of the torque-time curve. The mean of the two post-test trials was used for further analysis and torque data were normalized to the peak torque and voluntary RTD, respectively, of the baseline trials.

Assessment of twitch contractile properties

Plantar flexors' twitch contractile properties of the dominant leg were assessed using electrical muscle stimulation while the foot rested in an isokinetic dynamometer. Single stimuli were delivered transcutaneously to the plantar flexors of the dominant leg using two 5 × 10 cm rectangular self-adhesive surface electrodes (Compex®, DJO France/Division Compex Sport, Mouguerre, France). The anode was placed over the gastrocnemius muscle (~5 cm distal to the popliteal fossa) and the cathode over the soleus muscle (~10 cm proximal to the calcaneus).

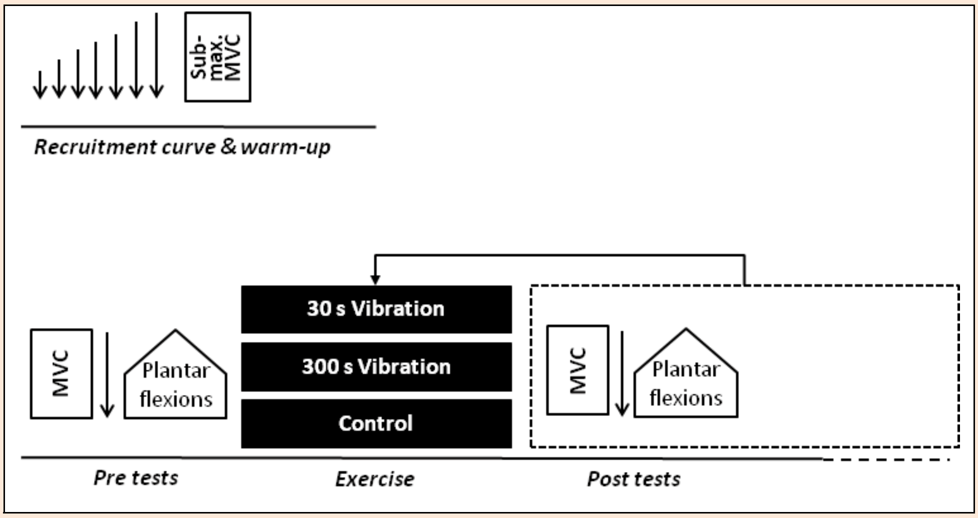

Figure 1. Experimental protocol. The order of experimental conditions (i.e., 30 s vibration, 300 s vibration, control) was randomized within the same session. Following each condition with post-tests, a wash-out phase of 10 min duration was provided.

Rectangular wave pulses (200 µs duration) were generated at a high-voltage (max 400 V) constant-current stimulator (Digitimer DS7AH, Hertfordshire, UK). For the twitch torque recruitment curve, the stimulator current was progressively increased in steps of 10-20 mA starting from 50 mA until no further increase in twitch torque was observed. A rest of 10 seconds was provided between stimulations. Finally, the stimulator current at maximum torque was set at 130% to ensure supramaximal muscle stimulation. During baseline- and post-tests, superimposed twitches (i.e., twitches on the plateau of the torque-time curve during peak torque trials) and potentiated twitches (i.e., twitches at rest two seconds after peak torque trials) were evoked. The torque signal of the dynamometer was analog-to-digital converted (TeleMyo 2400R G2 Analog Output Receiver, Noraxon®, Scottsdale, AZ, USA), sampled at 3,000 Hz, and stored on a computer running MyoResearch XP Master Edition software (version 1.08.17, Noraxon®, Scottsdale, AZ, USA). Outcomes of twitch peak torque (twitch PT) and twitch rate of torque development (twitch RTD) were determined as peak torque and maximal slope of the twitch torque-time curve after stimulation induced onset of torque. Additionally, voluntary activation (VA) was calculated using the following formula: VA = (1- superimposed twitch PT / potentiated twitch PT) x 100 (Allen et al., 1995). The mean of the two post-test trials was used for further analysis and twitch torque data were normalized to the twitch peak torque, twitch RTD, and VA, respectively, of the baseline trials.

Assessment of muscle activity

Bipolar surface electromyography (EMG) (TeleMyo 2400R G2, Noraxon, Scottsdale, AZ, USA) was applied to the following lower limb muscles of the dominant leg during peak torque trials: m. gastrocnemius medialis (GM), lateralis (GL), m. soleus (SL), m. tibialis anterior (TA) of the dominant leg. After skin preparation (shaving, abraded and disinfecting), self-adhering dual Ag-AgCl electrodes (center-to-center distance: 2.5 cm; Dual EMG Electrode, Noraxon, Scottsdale, AZ, USA) were placed over the muscle bellies according to SENIAM recommendations (Hermens et al., 1999). A single reference electrode was attached to the tibia head. Torque and EMG data were sampled at 3 kHz and synchronized on the same I/O board (TeleMyo 2400R Analog Output Receiver, Noraxon, Scottsdale, AZ, USA). After application of a 5-500 Hz bandpass filter, the EMG signals were smoothed using a moving root mean square (window: 50 ms) and then averaged for the last 100 ms before the instant of peak torque. EMG data were normalized to the EMG of the highest baseline peak torque (Prieske et al., 2016).

Assessment of brain activity

Brain activity was assessed during a dynamic concentric-eccentric plantar flexion exercise for 60 s with the non-dominant leg using the elastic rubber band. The resistance of the rubber band was individually adjusted (i.e., level 3 on a 1-10 scale of perceived exertion) by using different combinations of elastic rubber band colors (Andersen et al., 2017). During exercise, participants were lying on the isokinetic device in prone position with hip and knee joints in neutral position. Eyes were kept open. Additionally, the dominant leg was in a relaxed position. According to an electronic metronome, every single movement-cycle of concentric-eccentric plantar flexions lasted two seconds. One second for plantar flexions and one second for dorsi extensions.

EEG was continuously recorded from 64 passive electrodes, using an elastic cap (Advanced Neuro Technology B.V., Enschede, Netherlands) with electrodes placed in accordance to the international 10-20 system (Klem et al., 1999) (Figure 2). All leads were recorded with an average reference and AFz serving as ground electrode. Electrode impedances were kept <5 kΩ to obtain a low signal-to-noise ratio. EEG data were amplified with an analog amplifier (eego, Advanced Neuro Technology B.V., Enschede, Netherlands), band limited between 0.01 and 100 Hz, and recorded with sampling frequency of 1024 Hz using the eego™ software (ANT Neuro eego™, Version 1.6, Neuro Technology B.V., Enschede, Netherlands).

The acquired EEG data were processed offline using MATLAB (Mathworks Inc., Natick, MA, USA) and the EEGLAB 14.1.0b toolbox (Delorme and Makeig, 2004). For further analysis, the physiological signals were band pass filtered with a finite impulse response filter between 1 and 50 Hz and down-sampled to 256 Hz after removing line noise with the help of the CleanLine plugin (Mullen, 2012). Channels with major non-stereotypical artefacts or high-frequency noise were manually removed and EEG data was then re-referenced to common average. Continuous data were visually inspected, and non-stereotypical artefacts were removed from the data set. An adaptive mixture independent component analysis (AMICA) was performed on the remaining data to separate functional activity from stereotypical artefacts (Palmer et al., 2008). Components, displaying electro-oculographic activities (i.e., eye blinks) assessed by electrode-oculograms (electrode placement below and above the left eye as well as at the outer canthi) as well as muscle electromyographic activities and other stereotypical artefacts, were manually identified and segregated by visual inspection of the scalp topographic maps, time courses, and activation spectra (Onton and Makeig, 2006). Finally, 30 s of the concentric-eccentric plantar flexion exercise (5-35 s after onset of task) at baseline- and post-tests were used for the spectral power analysis of selected electrodes (i.e., Fc1, FcZ, Fc2, C1, Cz, C2, Cp1, CpZ, Cp2) which were averaged to build the region of interest and representing the cortical area of the foot (Pfurtscheller, 2001). Alpha-1 band was defined from 7.0 - 9.5 Hz, alpha-2 from 9.6 - 12.5 Hz, beta-1 from 12.6 - 18 Hz and beta-2 from 18.1 - 30 Hz (Neuper and Pfurtscheller, 2001). In accordance to EMG procedures, EEG data were normalized to the EEG of the highest baseline value for further analysis.

Statistical analyses

Descriptive data are presented as group mean values and standard deviations (SD). Normal distribution was examined using the Shapiro-Wilk test. In accordance with previous studies on the acute effects of conditioning activities on muscular performance and/or contractile properties (Kümmel et al., 2017; Prieske et al., 2018), a one-way repeated measures ANOVA with the factor *condition* (baseline, V30, V300, control for peak plantar flexor torque and twitch contractile properties; V30, V300, control for muscle and brain activity) was used. The significance level was set at $p < 0.05$. Post-hoc tests with the Bonferroni-adjusted α of the pairwise comparisons were calculated to identify the comparisons that were statistically significant. Additionally, effect sizes were determined by converting partial eta-squared to Cohen's *d* to indicate whether a statistically significant difference is a difference of practical concern. In accordance with Cohen (1988), effect sizes were classified as small ($0.2 \leq d < 0.5$), medium ($0.5 \leq d < 0.8$), and large ($d \geq 0.8$). Statistical analyses were performed using IBM Statistical Package for Social Sciences (SPSS Version 25, SPSS Inc., Chicago, IL, USA).

Results

Peak plantar flexor torque

Descriptive data for peak plantar flexor torque and voluntary RTD during isometric MVC trials are presented in Table 2. Our analysis revealed non-significant and medium-sized effects of condition for peak torque ($p = 0.508$; $d = 0.5$). Additionally, a non-significant and small-sized main effect of condition was found for voluntary RTD ($p = 0.532$; $d = 0.5$).

Twitch contractile properties

Descriptive data for twitch peak torque, twitch RTD, and voluntary activation are presented in Table 2. A non-significant and small-sized main effect of condition was found for potentiated twitch PT ($p = 0.920$; $d = 0.2$). Additionally, a non-significant and small-sized main effect of condition was observed for potentiated twitch RTD ($p = 0.609$; $d = 0.5$). Further, our analysis revealed a non-significant but large-sized main effect of condition for voluntary activation ($p = 0.065169$; $d = 0.9$).

Muscle activity

For EMG activity, non-significant and small-to-medium-sized main effects of condition were identified for GM ($p = 0.544$; $d = 0.4$), GL ($p = 0.329$; $d = 0.6$), and SL activity ($p = 0.297$; $d = 0.7$). Additionally, the analysis revealed non-significant, medium-sized main effects of condition for antagonistic muscles (i.e, TA) ($p = 0.332$; $d = 0.6$). Muscle specific EMG activities for all experimental conditions are presented in Figure 3.

Table 2. Peak plantar flexor torque (PT) and rate of torque development (RTD) during maximum voluntary contractions and potentiated twitches following 30 s (V30) and 300 s (V300) of local vibration.

Performance measure	Baseline	Control		V30		V300		Main effect of condition p value (d)
		absolute	% Baseline	absolute	% Baseline	absolute	% Baseline	
Strength performance								
Plantar flexor PT [Nm]	125.0 ± 14.8	118.7 ± 12.6	95.6	114.0 ± 15.7	93.2	117.3 ± 14.6	94.1	.508 (.53)
Voluntary RTD [Nm/s]	434.2 ± 93.9	398.5 ± 95.6	92.8	386.1 ± 68.8	90.5	397.6 ± 83.2	92.9	.532 (.45)
Twitch contractile properties								
Twitch PT [Nm]	21.9 ± 2.7	21.2 ± 3.3	97.3	21.0 ± 3.0	96.7	21.1 ± 3.2	96.5	.920 (.18)
Twitch RTD [Nm/s]	745.0 ± 103.8	748.3±100.5	99.4	731.6 ± 85.7	99.0	730.0 ± 101.5	97.3	.609 (.45)
Voluntary activation [%]	93.3 ± 4.9	93.2± 5.7	102.3	92.7 ± 6.1	99.0	91.4 ± 6.4	109.2	.169 (.92)

Values are presented in means ± standard deviation; *d*: effect size (Cohen's d).

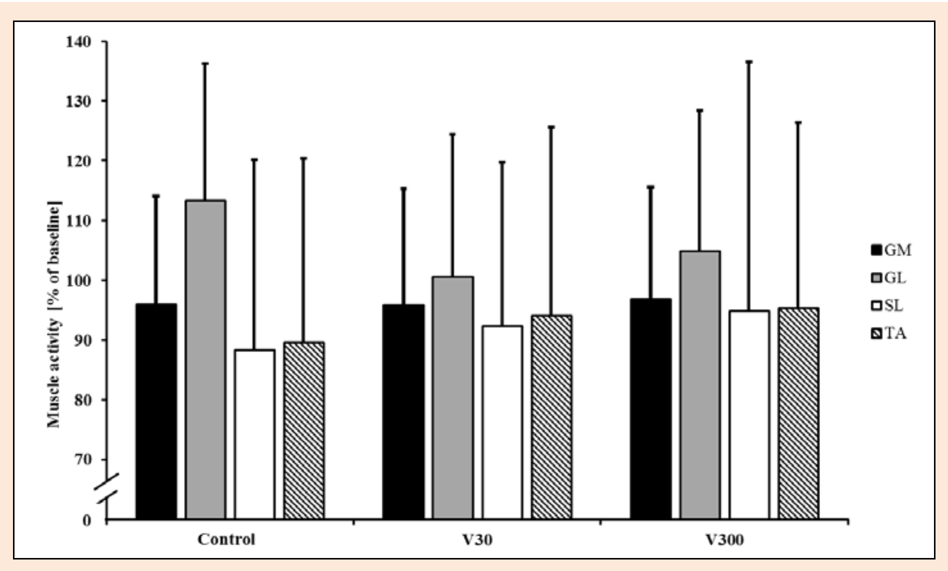

Figure 3. Electromyographic muscle activity during the different conditions relative to baseline. GM: m. gastrocnemius medialis; GL: m. gastrocnemius lateralis; SL: m. soleus, TA: m. tibialis anterior.

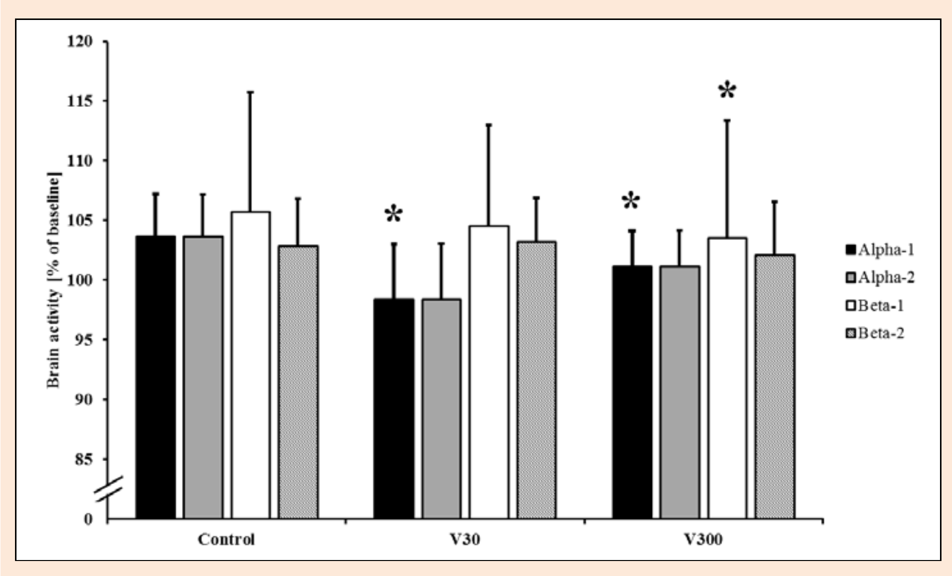

Figure 4. Electroencephalographic brain activity during the different conditions relative to baseline. V30 refers to 30 s and V300 to 300 s of local vibration. * indicates significant difference from the same cortical power spectrum during control condition ($p < 0.05$).

Brain activity

Statistically significant and large-sized main effects of condition were observed for alpha-1 band power ($p < 0.001$; d =2.6). Post-hoc analysis showed vibration-induced lower alpha-1 band activity after V30 ($p < 0.001$; $d = 1.4$; 98.4 ± 4.6%) and V300 ($p = 0.009$; $d = 0.8$; 101.1 ± 3.1%) compared with control condition (103.7 ± 3.5%). Non-significant and small-sized main effects of condition were identified for the alpha-2 band ($p = 0.202$; $d = 0.9$). Additionally, for beta-1 band, statistically significant and large-sized main effects of condition were observed ($p = 0.011$; d = 1.5). Post-hoc analyses revealed vibration-induced lower beta-1 band activity after V300 ($p < 0.001$; $d = 0.2$; 103.5 ± 9.8%) compared with control condition (105.7 ± 10%). The beta-2 frequency band showed non-significant main effects of condition ($p = 0.183$; $d = 0.9$). Band-specific EEG activities for all experimental conditions are presented in Figure 4.

Discussion

This is the first study to examine the acute effects of short-term local vibration (i.e., ≤5 min) of the Achilles tendon on peak plantar flexor torque under voluntary contraction, twitch contractile properties, muscle activity of the plantar flexors, and brain activity in young female athletes. The main findings of this study were that i) brain activity in the alpa-1 and beta-1 band were significantly lower after V30 and/or V300 condition compared with control condition, and ii) local tendon vibration did not significantly affect lower limb peak torque, twitch contractile properties, and EMG activity.

Peak plantar flexor torque

Our results showed that peak plantar flexor torque during isometric MVC trials was not affected by vibration stimuli when compared with control condition. Interestingly, previous research reported significant performance gains (Cochrane, 2016b) or no changes in muscular performance (Pamukoff et al., 2014; Cochrane, 2016a; Souron et al., 2019) following short-term local vibration in adults. For instance, Pamukoff et al. (2014) investigated the effects of local quadriceps tendon vibration with 30 or 60 Hz in comparison to a control condition (i.e., no vibration) on quadriceps MVC peak torque and voluntary RTD in healthy males and females. Local vibration was applied during an isometric squatting position. The authors found no changes for MVC peak torque and voluntary RTD values following vibration condition (Pamukoff et al., 2014). Further, Cochrane (2016a) reported non-significant but moderate-to-large-sized enhancements in peak and mean force during concentric biceps curls after 10 min of local vibration of the biceps brachii muscle (frequency range: 0-170 Hz) compared to a control condition (i.e., no vibration) in healthy trained males. In another study, however, Cochrane (2016b) detected significant increases in power output during concentric dynamic biceps curls after 10 minutes of local biceps brachii vibration (frequency range: 0-170 Hz) compared to a control condition (i.e., no vibration) in master field hockey players. The author concluded that vibration-induced enhancements in contractile properties (i.e., postactivation potentiation) following short-term local vibration may have contributed to performance enhancements. In fact, some adult studies indicate that enhanced twitch contractile properties (e.g., twitch PT) induced by submaximal and maximal contractions partly contributed to acute performance gains (e.g., increased jump height) (Mitchell and Sale, 2011; Requena et al., 2011; Fukutani et al., 2014b). For instance, the studies of Mitchell and Sale (2011) and Fukutani et al. (2014b) reported concomitant increases in knee extensor twitch PT (11–40%) and countermovement jump height (3–11%) following submaximal squat exercise in trained men. However, statistical associations between pre-to-post-exercise changes of twitch contractile properties and muscular performance are inconsistent in the literature. In fact, a number of studies reported small-to-large sized correlation coefficients ($0.24 \leq r \leq 0.61$) in male rugby and soccer players (Mitchell and Sale, 2011; Requena et al., 2011) and trivial-to-large sized correlations ($-0.61 \leq r \leq 0.35$) in female elite young soccer players (Prieske et al., 2018). These findings indicate that individuals with greater acute enhancements in contractile properties are not necessarily those showing the greatest performance improvements following acute exercise. Further, methodological differences between studies may explain the overall inconsistent findings on the effects of short-term local vibration on muscular performance (e.g., force/torque output). For instance, in particular higher frequencies (150 Hz) during direct vibrations have been reported to induce a reflex contraction of the stimulated muscle (i.e., tonic vibration reflex) (Bongiovanni and Hagbarth, 1990). In this regards, masses of muscles that can be affected by vibration stimuli are substantially larger in males compared with females (Shephard, 2000). Additionally, training status has been discussed as a potential moderator variable for the effects of local tendon vibration (Souron et al., 2017). Thus, methodological differences in vibration frequency, training status, and/or sex may explain the observed discrepancies between the literature using high vibration frequencies (≤170 Hz) in male master athletes (Cochrane, 2016b) and our findings using lower frequencies (80 Hz) in female young athletes on the effects of local vibration on muscle performance.

Twitch contractile properties

It is well-documented that the contractile history of the skeletal muscle directly affects its performance characteristics (Bishop, 2003). Two antagonistic physiological processes take place following muscular contraction. On the one hand, sustained muscle contractions (whether dynamic or isometric) gradually induce muscle fatigue as indicated by decrements in performance output (Enoka and Duchateau, 2008). On the other hand, specific muscle contractions, whether voluntary or electrically evoked, can increase twitch contractile properties (i.e., postactivation potentiation). The net effect of fatigue and increased twitch contractile properties in favor of the latter may result in enhanced strength- and power-related performance output (Bishop, 2003). For twitch contractile properties, findings of the present study revealed that contractile properties (i.e., potentiated twitch PT) in the plantar flexors were not significantly affected by short-term local vibration applied to the Achilles tendon. To the best of our knowledge, this is the first study that examined the acute effects of short-term local vibration (i.e., 30-300 s) on muscle contractile properties such as potentiated twitch PT/RTD in female young athletes. Specifically, our study extends the existing literature on the acute effects of long-term local vibration (i.e., ≥20 min) on twitch contractile properties (Ushiyama et al., 2005; Fry and Folland, 2014; Cattagni et al., 2017). For instance, Cattagni et al. (2017) studied the effects of 30 min local Achilles tendon vibration with 0 (i.e., control condition), 40, and 100 Hz on twitch PT in healthy men. In their study, Achilles tendon vibration with both 40 and 100 Hz had no effects on twitch PT in comparison to the control condition (Cattagni et al., 2017). This is well in-line with the results of our study (i.e., unchanged twitch PT after 30 and 300 s of local Achilles tendon vibration). Moreover, Lapole and Pérot (2010) reported unchanged twitch PT even after 14 days of local vibration in healthy active men that consisted of daily vibration of the Achilles tendon at 50 Hz and 60 min of duration. Thus, it can be stated that neither short-term nor long-term local vibrations affect contractile properties of the stimulated muscle. One possible explanation could be a relatively low reflex contraction induced by the tendon vibration. In fact, potentiation effects on plantar flexor twitch PT progressively increase with higher contraction intensities as indicated by force/torque output relative to MVC during active plantar flexions (Fukutani et al., 2014a). However, vibration-induced force/torque outputs of stimulated lower limb muscles do not necessarily reach highest MVC levels (Bongiovanni and Hagbarth, 1990).

Muscle activity

In consistency with the findings on peak plantar flexor torque, plantar flexor EMG activity was not affected by local Achilles tendon vibration. Similarly, Cochrane (2016b) did not find changes in normalized EMG during concentric biceps curls after 10 min of local biceps vibration in comparison to a control condition (i.e., no vibration). Moreover, VA was not significantly affected by local vibration in the present study. Similar findings were also shown by Cattagni et al. (2017) who reported unchanged VA of the plantar flexors even after long-term local vibration (30 min; 40 and 100 Hz). Interestingly, Pamukoff et al. (2014) found acutely enhanced EMG activity following short-term local vibration (i.e., 6 min) applied to the knee extensors (Pamukoff et al., 2014). This specific finding may be explained by the application of vibration to voluntarily activated muscles (i.e., isometric squat position) compared with relaxed muscles in our study and the studies of Cochrane (2016b) and Cattagni et al. (2017).

Brain activity

Alpha-1 and beta-1 band power during a dynamic concentric-eccentric plantar flexion exercise were significantly lower after V300 and in the alpha-1 band after V30 in comparison to the control condition. This behavior is only partly in agreement with Moraes Silva et al. (2015) who reported lower beta band power over the contralateral somatosensory cortex but higher beta band power over the contralateral primary motor cortex during an index finger task execution after 15 min prolonged local vibration of the right hand and forearm. The lower beta and alpha band power in the present study may be a result of the increased sensory information processing induced by the local tendon vibration as well as of the execution of the motor processes during vibration (Neuper and Pfurtscheller, 1996). Lower power in frequency bands is the consequence of a desynchronization of the underlying neuronal populations (Pfurtscheller and Lopes da Silva, 1999). Of note, alpha desynchronization is obtained in response to almost any type of motor tasks, in which beta desynchronization is followed by sensory-motor tasks (Pfurtscheller and Lopes da Silva, 1999). Functionally, lower motor cortex activity may be associated with more efficient processing in the cortical area (Moraes Silva et al., 2015). For instance, local vibration can induce subsequent increments in cortical excitability as assessed through motor-evoked potentials with shorter (15 min) compared with longer (30 min) exposure times (Smith and Brouwer, 2005). Higher cortical excitability implies that lower cortical activity is needed for the same absolute performance output. Similarly, our findings indicate that lower cortical activity is needed for the same performance. (i.e., dynamic concentric-eccentric plantar flexion exercise using an elastic rubber band; rate of perceived exertion during exercise: level 3 out of 10).

Limitations

One potential limitation of the present study is the lack of single pre-tests before each experimental condition. However, 10 min of passive rest following muscular activities have previously been shown to be efficient to return muscular performance (e.g., peak torque, power) and twitch contractile properties to baseline levels (Wilson et al., 2013; Kümmel et al., 2017; Prieske et al., 2018). Additionally, a randomized cross-over design was used and a passive control condition was included to minimize systematic bias. As another limitation it has to be acknowledged that VA and EMG may not be sensitive enough to detect small changes (Kalmar and Cafarelli, 1999). Thus, the role of neuromuscular activation during short-term local vibration on subsequent muscular performance has to be interpreted with caution. Moreover, future studies may apply EEG and EMG during the same submaximal dynamic motor task to connect electrophysiological recordings from the cerebral cortex to muscle activity allowing e.g., corticomuscular coherence analyses (Enders and Nigg, 2016).

Conclusion

It has previously been shown that short-term local vibration – if acutely applied to specific muscle bellies and/or tendons – has the potential to enhance muscle performance and/or neuromuscular activity in healthy adults (Pamukoff et al., 2014; Cochrane, 2016b). The present study is the first to examine the acute effects of short-term local vibration on peak plantar flexor torque, twitch contractile properties, muscle activity, and brain activity in young female athletes. In summary, lower brain activity (i.e., alpha-1 and beta-1 band power) was observed following short-term local Achilles tendon vibration, whereas lower limb peak torque, twitch contractile properties, and muscle activity were not affected. It appears that local Achilles tendon vibration lasting 30 to 300 s improved cortical function during submaximal motor tasks (i.e., dynamic concentric-eccentric plantar flexion exercise using an elastic rubber band) in female young soccer players. In contrast, methodological reasons such as frequency of vibration, activity of the muscles during application, and/or subjects' specific characteristics may explain that performance, twitch contractile properties, and muscle activity were not modified by Achilles tendon vibration.

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Key points

- Short-term local Achilles tendon vibration induced lower brain activity (i.e., alpha-1 and beta-1 band power) during a submaximal dynamic exercise, whereas lower limb peak torque, twitch contractile properties, and muscle activity were not affected in young female athletes.
- Lower brain activity may indicate improved cortical function during a submaximal dynamic exercise following short-term local Achilles tendon vibration in young female athletes.
- In terms of performance measures related to lower limb maximal strength, short-term local Achilles tendon vibration cannot specifically be recommended as an activity to acutely improve performance in young female athletes.

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