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Authors: Thomas Cattagni, Clément Billet, Christophe Cornu and Marc Jubeau

Affiliations: Laboratory “Movement, Interactions, Performance” EA 4334, University of Nantes, UFR STAPS, Nantes, France.

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No Alteration of the Neuromuscular Performance of Plantar-Flexor Muscles After Achilles Tendon Vibration

Thomas Cattagni, Clément Billet, Christophe Cornu and Marc Jubeau

Laboratory “Movement, Interactions, Performance” EA 4334, University of Nantes, UFR
STAPS, Nantes, France

Corresponding Author:

Thomas Cattagni, Ph.D.

UFR STAPS, Université de Nantes

Laboratoire "Motricité, Interactions, Performance" EA 4334

25 bis Boulevard Guy Mollet - BP 72206

44 322 Nantes cedex 3

France

E-mail: thomas.cattagni@univ-nantes.fr

Tel: (33) (0) 2 51 83 72 32

ABSTRACT

Context: The prolonged tendon vibration may induce muscle fatigue, as assessed by a decrease in maximal force production. It remains however unknown whether the decrease in muscle strength after prolonged Achilles tendon vibration is related to the vibration frequency.

Objective: This study aimed to assess the maximal capacity of plantar flexor neuromuscular function before and after prolonged Achilles tendon vibration at low and high frequencies generated using a portable device. **Design:** Pre- and post-test intervention with control. **Setting:** University laboratory. **Participants:** Ten healthy males (age 22.6 ± 4.0 yrs). **Intervention:** Each subject participated in three experimental sessions that were randomly distributed and separated by one week. During each experimental session, one of the following vibration protocols was applied for 30 minutes: i) 40 Hz vibration, ii) 100 Hz vibration, or iii) no vibration (control protocol). **Main Outcome Measures:** MVC torque, voluntary activation level, twitch torque, maximal electromyographic activity, and maximal M-wave of plantar flexor muscles (measured before and after each vibration or control protocol). **Results:** Statistical analysis exhibited no significant effect of vibration protocol on the measured variables. **Conclusions:** The current study demonstrates that 30 min of Achilles tendon vibration at a low or high frequency using a portable stimulator did not affect the neuromuscular performance of the plantar flexor muscles. These results emphasize the limits of tendon vibration, whatever the frequency applied, for inducing neuromuscular fatigue.

INTRODUCTION

Prolonged muscle or tendon vibration may induce fatigue, as assessed by a decrease in MVC strength¹⁻⁶ even though some investigations reported no fatigue effect^{7,8}. Ushiyama et al. (2005)³ found a significant decrease in plantar flexor (PF) MVC strength (-16.6%) after 30 min of Achilles tendon vibration at 100 Hz, using a fixed mechanical stimulator. These authors observed that the reduction in MVC strength was due to an attenuation of Ia afferent activity leading to a decrease in muscle activity that was more pronounced for the gastrocnemii than for the soleus (SOL) muscle³. Nevertheless, some questions related to this finding remain to be clarified. First, when vibration is applied to the quadriceps muscle during 30 min, the reduction in MVC strength is greater at low frequency (30 Hz) than at high frequency (120 Hz)². Roll et al. (1989)⁹ observed that muscle spindle primary afferents are stimulated, with a one-to-one discharge rate, by vibration frequencies up to 100 Hz, but frequencies above 100 Hz impaired the relationship. These authors showed that vibration frequency is optimal between 80 Hz and 100 Hz, i.e., high-frequency vibration, to activate the primary endings of muscle spindle while secondary endings can be recruited in the 20 Hz to 60 Hz vibration range, i.e., low-frequency vibration. Consequently, it remains unknown whether the decrease in muscle strength after prolonged Achilles tendon vibration is related to high- (i.e. involving Ia afferent activation) vs. low-vibration (i.e. involving both type Ia and II afferent activations) frequencies. Second, Ushiyama et al. (2005)³ linked the decrease in MVC strength with a reduction in raw muscle electromyographic (EMG) activity, but did not assess the voluntary activation level (VAL) during MVC. Herda et al. (2009)⁶ found no change in VAL after 20 min of Achilles tendon vibration (70 Hz), although they observed a 5% decrease in PF MVC torque. This outcome is surprising given that the vibration-related decrease in muscle force is generally attributed to the neural inhibitory mechanisms (i.e. inhibition of Ia afferent activity) reducing the rate of α -motoneurons recruitment^{3,10}. The

relationship between changes in MVC torque and VAL before and after tendon vibration therefore must be clarified.

We propose in the present study to assess PF neuromuscular function by measuring torque, VAL and normalized EMG activity, both before and after 30 min of Achilles tendon vibration at low (40 Hz) and high (100 Hz) vibration frequencies. This vibration duration was chosen because this duration appears to be sufficient to observe changes in Ia-afferent activity and/or muscle activation^{6,8,11}. We hypothesized that the application of mechanical vibration to the Achilles tendon should decrease PF MVC strength due to reduced efferent neural drive, especially at low vibration frequency, involving both primary and secondary endings of muscle spindles.

METHODS

Ten healthy males (age 22.6 ± 4.0 years, height 171.5 ± 11.9 cm, mass 67.5 ± 13.4 kg) participated in three experimental sessions. Each experimental session consisted of the application of vibration to the Achilles tendon (amplitude: 0.2 mm) over 30 min using a portable tendon vibrator (Techno-Concept, VB 115) strapped to the right leg, above the malleolus. The frequency of vibration was 0 Hz (no vibration) for the first session, 40 Hz (low frequency) for the second session, and 100 Hz (high frequency) for the third session. The three sessions were randomly presented in a cross-over design and were separated by one week. Six and 1 min before (pre-tests) and immediately (0), 5 and 10 min after (post-tests) the vibration protocol, double-blind neuromuscular tests were performed.

Before each session, participants were familiarized with the procedure during a warm-up session in which they performed a total of nine plantar flexions at three different levels of their estimated MVC (25%, 50% and 90% MVC).

During each session, the subjects were seated with the knee joint at an angle of 160° flexion (180° = knee fully extended), a hip angle of 100° , and an ankle angle of 90° . EMG data were collected using pairs of surface electrodes (1 cm, ADInstrument Pty Ltd.) placed on the soleus (SOL) and medial gastrocnemius (MG) of the right leg, with reference electrodes on the patella of the left leg. The EMG signal was sampled at 2000 Hz (Gain=1000). Electrical stimulation was delivered using a Digitimer (model DS7, Hertfordshire, UK) at a high-voltage (maximal voltage 400 V, pulse duration: 1 ms). The posterior tibial nerve was stimulated using a surface electrode placed in the popliteal fossa, with the anode (5x10 cm, Medicomplex, Ecublens, Switzerland) on the anterior surface of the knee. The stimulation intensity was set at 120% of the optimal intensity.

Neuromuscular assessment was performed on the right leg. First, it consisted of a single stimulus evoked at rest to investigate the amplitude of the maximal motor response (M_{\max}) of the SOL and MG associated with the mechanical response. Then, 3 s after the single stimulus, the subjects were asked to perform a 4-5 s MVC on a Biodex dynamometer (Biodex Medical System Inc., New York, USA). Paired stimuli (100 Hz frequency) were evoked both during (superimposed doublet) and 4 s after (potentiated doublet) the MVC to investigate the contractile properties of the PF muscle and to estimate the VAL using the twitch interpolation technique¹². VAL was calculated using the method developed by Strojnik & Komi (1998)¹³. The maximal EMG during MVC was quantified as the root mean square value over a 0.5 s interval about the same interval of the MVC torque measurement normalized to the M_{\max} (EMG/M_{\max})¹⁴.

Two-factor ANOVA with repeated measures [vibration protocol (no vibration, 40 Hz and 100 Hz) x time (pre-test -6 min, pre-test -1 min, post-test 0 min, post-test +5 min and post-test +10 min)] were performed for each parameter (significance level: $P < 0.05$).

RESULTS

Statistical analysis revealed no significant effect or interaction, indicating that Achilles tendon vibration (high and/or low frequency) did not modify MVC torque, VAL, the peak torque of the twitch, M_{\max} , or EMG/ M_{\max} (Table 1).

DISCUSSION

Contrary to our hypothesis, the current study demonstrates that 30 min of Achilles tendon vibration at a low or high frequency using a portable stimulator did not affect the neuromuscular performance of the PF.

These results were in agreement with previous studies reporting no effect of tendon vibration on maximal force production^{7,8}. Indeed, Ekblom and Thorstensson (2011)⁸ reported no change in PF force during dynamic contractions following 30 min Achilles tendon vibration at 100 Hz. In addition Fry and Folland (2014)⁷ observed no effect of prolonged infrapatellar tendon vibration at 80 Hz on quadriceps maximal force production. In contrast with these results, most authors observed a decrease in maximal force production after one session of prolonged tendon vibration^{1,3,5,10}. For instance, Ushiyama et al. (2005)³ reported a greater decrease (~17%) for PF MVC strength after 30 min of Achilles tendon vibration.

We assume that this difference lies in the fact that in our study, the vibration was generated using a portable device that induced a low vibration amplitude and for which the force applied to the Achilles tendon was most likely lower compared with the parameters used in the study of Ushiyama et al. (2005)³. Indeed, these authors controlled the force applied by the stimulator device to the tendon (~15 N) and used a larger vibration amplitude (0.75 vs. 0.2 mm) that could have had a greater impact on neuromuscular function. It is likely that the vibration amplitude and the force applied to the tendon by the device are as important as vibration frequency for inducing neuromuscular fatigue.

A potential limitation of the present study was the lack of control in the effects of tendon vibration on Ia afferent efficacy to activate α -motoneurons, which could have been witnessed by the recordings of Hoffmann reflex⁸.

In light of our results, we conclude that Achilles tendon vibration does not induce PF neuromuscular fatigue in healthy young subjects, whatever the vibration frequency used.

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Table 1. The mean values of neuromuscular assessments before and after 30 minutes of Achilles tendon vibration.

		Pre-test -6 min	Pre-test -1 min	Post-test +0 min	Post-test +5 min	Post-test +10 min
MVC torque (Nm)	<i>No-vib</i>	167.4 ± 47.6	168.8 ± 48.9	165.9 ± 47.3	165.9 ± 51.8	171.3 ± 56.4
	40 Hz	162.5 ± 47.6	168.8 ± 52.3	164.6 ± 51.0	164.6 ± 39.5	170.8 ± 45.6
	100 Hz	172.1 ± 61.1	173.4 ± 56.3	158.8 ± 47.0	174.9 ± 52.1	179.6 ± 52.7
VAL (%)	<i>No-vib</i>	94.1 ± 6.5	96.0 ± 5.5	94.4 ± 4.0	92.0 ± 10.7	91.2 ± 10.2
	40 Hz	93.8 ± 5.2	91.0 ± 11.4	92.2 ± 7.9	91.4 ± 6.8	94.5 ± 6.2
	100 Hz	91.8 ± 10.0	92.7 ± 12.3	89.6 ± 12.1	94.6 ± 6.3	92.9 ± 7.2
Twitch torque (Nm)	<i>No-vib</i>	20.3 ± 4.8	21.3 ± 5.2	19.3 ± 3.9	20.5 ± 4.2	21.6 ± 4.4
	40 Hz	19.9 ± 4.2	21.2 ± 5.2	18.8 ± 4.4	21.4 ± 5.6	20.8 ± 4.2
	100 Hz	19.3 ± 4.6	20.4 ± 3.7	18.1 ± 2.7	20.6 ± 3.5	20.9 ± 3.1
SOL EMG/M_{max}	<i>No-vib</i>	3.7 ± 1.7	3.6 ± 1.9	3.6 ± 1.6	3.6 ± 2.3	3.7 ± 2.1
	40 Hz	3.3 ± 1.5	3.1 ± 1.2	3.1 ± 0.9	3.1 ± 1.3	3.3 ± 1.3
	100 Hz	3.4 ± 1.7	3.6 ± 1.7	3.4 ± 1.6	3.3 ± 1.1	3.5 ± 1.2
MG EMG/M_{max}	<i>No-vib</i>	5.1 ± 2.5	4.9 ± 2.5	5.8 ± 3.3	5.5 ± 3.3	5.5 ± 3.3
	40 Hz	4.9 ± 2.2	4.8 ± 2.1	5.0 ± 2.0	4.2 ± 1.5	4.7 ± 1.9
	100 Hz	5.0 ± 2.9	4.8 ± 2.4	4.4 ± 2.4	4.5 ± 2.6	4.9 ± 2.7

MVC: maximal voluntary contraction; VAL: voluntary activation level; SOL: soleus; MG: medial gastrocnemius; EMG: electromyographic activity; M_{max}: maximal motor potential; No-vib: no vibration; 40 Hz: low vibration frequency; 100 Hz: high vibration frequency. The vertical grey dashed line separates pre- (left side of the line) and post-test (right side of the line)