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Immediate Effects Of Whole Body Vibration On Patellar Tendon Properties And Knee Extension Torque

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Abstract

Purpose: Reports about the immediate effects of whole body vibration (WBV) exposure upon torque production capacity are inconsistent. However, the changes in the torque-angle relationship observed by some authors after WBV may hinder the measurement of torque changes at a given angle. Acute changes in tendon mechanical properties do occur after certain types of exercise but this hypothesis has never been tested after a bout of WBV. The purpose of the present study was to investigate whether tendon compliance is altered immediately after WBV, effectively shifting the optimal angle of peak torque towards longer muscle length.

Methods: Twenty-eight subjects were randomly assigned to either a WBV (n = 14) or a squatting control group (n = 14). Patellar tendon CSA, stiffness and Young´s modulus and knee extension torque-angle relationship were measured using ultrasonography and dynamometry one day before and directly after the intervention. Tendon CSA was additionally measured 24 hours after the intervention to check for possible delayed onset of swelling.

Results: The vibration intervention had no effects on patellar tendon CSA, stiffness and Young´s modulus or the torque-angle relationship. Peak torque was produced at ~70° knee angle in both groups at pre- and post-test. Additionally, the knee extension torque globally remained unaffected with the exception of a small (-6%) reduction in isometric torque at a joint angle of 60°.

Conclusion: The present results indicate that a single bout of vibration exposure does not substantially alter patellar tendon properties or the torque-angle relationship of knee extensors.

Key words: mechanical properties, material properties, strength, length-tension relationship

Abbreviations

BF	Biceps femoris
CSA	Cross sectional area
EMG	Electromyographic activity
MTU	Muscle tendon unit
sCON	Static control
SD	Standard deviation
WBV	Whole body vibration

Introduction

During the last fifteen years, whole body vibration (WBV) has emerged as popular exercise and warm-up modality. Earlier studies have found increased muscular strength and power after a single bout of vibration exercise (Bosco et al. 1999; Bosco et al. 2000). However, discrepant findings have since been reported and the immediate effects of WBV on neuromuscular performance are still debated. For instance, authors observed gains in jump performance (Bosco et al. 2000; Colson and Petit 2013) and lower body strength (Mc Bride et al. 2010; Stewart et al. 2009; Torvinen et al. 2002) but others failed to see any improvement in muscular function (Kelly et al. 2010; Yeung et al. 2014) or even found reductions in maximum torque following a single WBV intervention (de Ruiter et al. 2003; Erskine et al. 2007; Jordan et al. 2010). These inconsistent findings are often explained by differences in vibration parameters or by the time elapsed between the WBV session and the measurements (Stewart et al. 2009; Torvinen et al. 2002). Whilst these hypotheses may hold true, another methodological pitfall may be related to the influence of vibration on musculotendinous mechanical properties. It has been reported that a single session of WBV alters the force-length relationship of plantarflexor muscles, leading to a shift in the optimal joint angle of torque production towards a longer muscle-tendon unit length (Kemertzis et al. 2008; Pellegrini et al. 2010). Such a shift may partially explain the ambiguous findings from studies where subjects were tested at a single joint angle. For instance, the increase in plantarflexion peak torque (+10.3Nm) observed by Kemertzis et al. (2008) following one session of WBV was achieved at more dorsi-flexed ankle positions (+7.1°). The authors attributed their results to an increased tissue compliance mediated by stretch-induced damage of musculotendinous structures. However, a few experiments have shown that muscle stiffness remains unchanged (triceps surae; Cronin et al. 2004; Siu et al. 2010) or is increased (rectus femoris; de Hoyo et al. 2013) following a single bout of WBV exercise, suggesting that the shift in peak torque angle observed by Kemertzis et al. (2008) and Pellegrini et al. (2010) could be related to changes in properties of series elastic elements.

Although tendon stiffness and sometimes cross sectional area (CSA) is increased after several weeks of resistance training (Wiesinger et al. 2015) a decrease in stiffness has been reported in Achilles (Burgess et al. 2009; Kay and Blazevich 2009; Kubo et al. 2002) and patellar tendons (Kubo et al. 2001a, b; Yin et al. 2014) after a single session of resistive and stretching exercises. One should note however, that tendon properties remained unaltered after single bouts of running (Peltonen et al. 2012) or submaximal isokinetic contractions (Ullrich et al. 2009; Mademli et al. 2008), suggesting a certain load-dependency. When they occurred, reductions in stiffness were nonetheless transient and possibly mediated by a concomitant decrease in tendon thickness (Grigg et al. 2009; Wearing et al. 2013).

We recently investigated the effects of an eight-week WBV training intervention on patellar tendon properties and knee torque-angle relation (Rieder et al. 2015). Despite an increase in tendon CSA, tendon stiffness remained unaltered after WBV, consistent with an unchanged torque-angle relation. These findings nevertheless confirm that regular exposure to WBV-induced stimuli can trigger metabolic responses in the patellar tendon and support the above questions regarding acute changes in mechanical properties. They also bring about the question of whether the increased tendon CSA, measured days (<7) after the end of WBV training without any change in mechanical properties, was truly caused by collagen anabolic processes or by any delayed onset of swelling.

Hence, the aim of this study was three fold: i) to examine the acute effect of WBV on patellar tendon properties, ii) to investigate whether alterations in these parameters are consistent with a concomitant change in the torque-angle relationship of the quadriceps femoris muscle tendon unit (MTU), iii) to determine whether delayed onset swelling of the patellar tendon occurred after a single bout of WBV. We hypothesized that one bout of WBV would reduce patellar tendon stiffness and CSA leading to a shift of the joint angle of peak torque productions towards a longer muscle length. However, we did not expect any swelling of the tendon.

Methods

Subjects

Twenty-eight adults (20 males and 8 females; age 31 ± 5 years; mass 69 ± 13 kg; height 173 ± 9 cm) were recruited among students and employees of the Faculty of Sport Science of the University of Salzburg. All subjects were physically active and had no prior experience in WBV exercises. Exclusion criteria were pregnancy, diabetes, acute hernia, epilepsy, thrombosis, known cardiovascular disorders and orthopedic problems limiting testing of the right leg. Before the start of the study, subjects were informed about the intervention, the testing protocol and possible health related advert effects and signed a written declaration of consent. The study conformed to the requirements of the Declarations of Helsinki and was approved by the Ethics Committee of the University of Salzburg.

Experimental design

Subject were randomly assigned to a whole body vibration (WBV, n = 14) or a squatting control (sCON, n = 14) group. The intervention for both groups consisted in standing in a static position (knee angle 50°; 0° = fully extended) on a vibration platform (Nemes LCB; nemes bosco systems^{Tm}, Rome, Italy) for ten times 60 seconds, with a 60-second resting period between repetitions. Vibration was superimposed (frequency 30 Hz; amplitude 2 mm) the static squats for the WBV group only. The recorded acceleration (one-dimensional accelerometer placed in the middle of the platform, biovision, Wehrheim, Germany) for this setting was about 2 g. Subjects of the sCON group performed the same exercises on the platform without vibration. The 50° knee angle was chosen according to Rieder et al. (2015) since this position ensured a better transmission of vibration to the quadriceps femoris muscles. Strength and tendon parameters were assessed one day before the intervention and immediately after the intervention. Tendon

CSA was additionally measured 24 hours after the intervention to detect any delayed onset of swelling.

Torque-angle relationship

The torque-angle relationship of knee extensors was measured during isokinetic and isometric knee extensions. Both tests were performed to account for their respective limitations (e.g. influence of in series compliance, fatigue) and ascertain the validity of the obtained torque-angle relationship. Therefore, subjects were seated on an isokinetic dynamometer (IsoMed 2000 D&R Ferstl GmbH, Hemau, Germany) with a hip angle of 60° (0° corresponding to full extension) and strapped with safety belts. All tests were performed on the right leg. Subjects performed two isokinetic knee flexion-extension movements at 30°/s, between 30° and 100° of knee flexion with 60 seconds of rest between trials. Instructions for this test were to push as hard and fast as possible over the entire range of motion. The highest extension torque and the corresponding knee angle were recorded for further analyses.

To assess the isometric torque-angle relationship of knee extension, the maximum torque was measured at five knee joint angles: 50°, 60°, 70° 80°and 90°. The ascending or descending order of knee angles was randomly selected for each subject but remained identical on the second testing day. Subjects had two attempts for each angle, with a 30-second rest period between attempts and 60 seconds between angles. The highest torque value for each angle was retained for further analyses.

Tendon morphology and mechanical properties

At the start of each testing session, patellar tendon length and CSA were measured using ultrasonography (LA523, 10- to 15-MHz transducer, MyLab25, Esaote, Genoa, Italy) in the longitudinal and the transversal planes, respectively, at a knee angle of 90°. Tendon length was measured as the distance between the tibial insertion and the apex of the patella. Tendon CSA was measured proximally, below the apex of the patella, at mid-length and distally, above the tibial insertion. Analyses were performed offline by a single operator blinded to the subjects' identity with image analyzing software (ImageJ 1.41, NIH, Bethesda, USA).

To determine patellar tendon stiffness and Young´s modulus, tendon elongation was recorded using ultrasonography while subjects performed maximum isometric knee extensions (knee angle: 90°) with a given loading rate of 110 Nm/s (Kösters et al. 2014). Tendon elongation was measured offline as the displacement of the patellar apex relative to the tibial plateau (Tracker 4.8, cabrillo.edu/~dbrown/tracker/). Torque signals were synchronized with ultrasound recordings and electromyographic activity (EMG) of the biceps femoris (BF) muscle. To obtain the net extension torque, the antagonistic - flexion - torque was added to the measured knee extension torque. Antagonistic torque was estimated from agonist knee flexion torque and EMG activity and by assuming a linear relationship between these variables (Magnusson et al. 2001). Hence, activity of the BF muscle was recorded during isometric ramp contractions of the knee extensors and during two preceding maximum isometric voluntary knee flexions (knee angle: 90°). Standard procedures for skin preparation were followed (Hermens et al. 1999) and surface electrodes (Ag/AgCL; 120 dB, Input impedance: 1200 GOhm; 10 mm diameter, 22 mm spacing, Biovision, Wehrheim, Germany) were placed over the BF muscle. A reference electrode was placed on the lateral epicondyle of the femur. The signal was filtered offline using a second order butterworth filter with cut off frequencies of 10 and 300 Hz. The EMG amplitude was calculated as the root mean square of the signal over a 0.5 s period around the peak torque of knee flexion. Patellar tendon force was obtained by dividing the net extension torque by the tendon moment arm length, which was calculated individually from femur length (Visser et al. 1990).

To obtain tendon stiffness, tendon force-elongation relationships were plotted and fitted with a second order polynomial function. Stiffness was determined for each subject as the ratio between changes in force and tendon deformation over the highest 10 % force interval. An average stiffness was calculated from several two-to-three attempts (trials with force-elongation relations with $R^2 < 0.97$ were discarded) for each subject and used for further analyses. Young's modulus was calculated as the product of stiffness and the ratio of tendon resting length to tendon CSA.

Reliability

Measurements published recently (Rieder et al. 2015) showed that isometric torque-angle relationship, patellar tendon CSA, stiffness, Young´s modulus and strain could be obtained with a satisfactory reliability when using the present methods . The reliability of the torque-angle relationship obtained from isokinetic measurement was measured separately, on two consecutive days, in a sample population of 24 students (13 males and 11 females; age 27 ± 3 years; mass 68 ± 11 kg; height 173 ± 8 cm). The typical error and the coefficient of variation (Hopkins 2000) for the peak torque were 15.4 Nm and 6 %, respectively, and 3.2° and 3%, respectively, for the angle of peak torque.

Statistics

Normality of the data distribution was tested using the Kolmogorov-Smirnov test. Baseline differences between groups were assessed for each variable using a Student`s t-test for independent samples. The effects of the intervention on each variable were tested with a two-way ANOVA for repeated measures [2 (groups) x 3 (times) for tendon CSA and 2 (groups) x 2 (times) for all other parameters]. When significant interaction effects were found, paired sample t-test with Bonferroni-adjusted *P*-values were performed within each group. Statistical analyses were performed using SPSS software (IBM SPSS Statistics 22; Armonk, USA) and GPower (Version

3.0.10, Heinrich Heine University; Düsseldorf, Germany). The level of significance was set at $\alpha = 0.05$ and $\alpha = 0.025$ for the Bonferroni adjustments. The effect size (f) was defined as small for $f > 0.1$, medium for $f > 0.25$, and large for $f > 0.4$ (Cohen 1988). Data are presented as means and standard deviations (SD). Figures were created using the graphpad prism 6 software (GraphPad Software Inc; La Jolla; USA).

Results

The baseline characteristics of the subjects did not differ significantly between groups (**Table 1)**.

Table 1. Subjects´ baseline characteristics

		WBV			sCON	
Subjects						
Men	n	=	10	n	=	10
Women	n	=	4	n	=	4
Age (years)	29	±	7	31	±	7
Body height (cm)	178	±	9	173	±	9
Body weight (kg)	74	±	10	69	±	14
Isokinetic measurements		±				
Extension peak torque (Nm)	242	±	76	194	±	49
Extension peak torque angle (°)	70	±	7	72	±	6
Isometric measurements						
Extension torque (Nm)						
90°	259	±	77	213	±	65
80°	299	±	91	252	±	79
70°	307	±	91	263	±	79
60°	279	±	81	241	±	67
50°	242	±	65	216		52
Patellar tendon parameters						
CSA proximal (mm^2)	98	±	21	104	±	27
CSA mid-length (mm^2)	97	±	17	101	±	24
CSA distal (mm^2)	118	±	23	121	±	27
Mean CSA (mm^2)	104	±	17	107	±	23
Stiffness (N/mm)	2650	±	940	2638	±	920
Young´s modulus (Gpa)	1.3	±	0.5	1.2	±	0.5
Strain (%)	7.1	±	1.2	7.1	±	1.9

Values are presented as mean ± SD; WBV = whole body vibration group; sCON = squatting control group; CSA = cross sectional area.

Patellar tendon CSA and properties

Measurements of patellar tendon CSA and properties are presented in **Figure 1 and Figure 2**.

There were no significant group x time effects for patellar tendon CSA (proximal: $P = 0.890$, $F_{(2,26)} = 0.12$, $f = 0.06$; mid-length: $P = 0.290$, $F_{(2,26)} = 1.27$, $f = 0.22$; distal: $P = 0.850$,

$F_{(2,26)} = 0.16$ $f = 0.08$; mean: $P = 0.506$, $F_{(2,26)} = 0.69$, $f = 0.16$), stiffness ($P = 0.338$, $F_{(1,26)} = 0.95$, $f = 0.19$) or Young´s modulus ($P = 0.770$, $F_{(1,26)} = 0.09$, $f = 0.05$). In addition, there were also no significant group x time effects for strain ($P = 0.390$, $F_{(1,26)} = 0.77$, $f = 0.17$). Strain values were 7.1 ± 1.2 % at pre- and 6.6 ± 1.1 % at post-test for the WBV group and 7.1 ± 1.9 % at pre- and 7.1 ± 1.7 % at post-test for the sCON group.

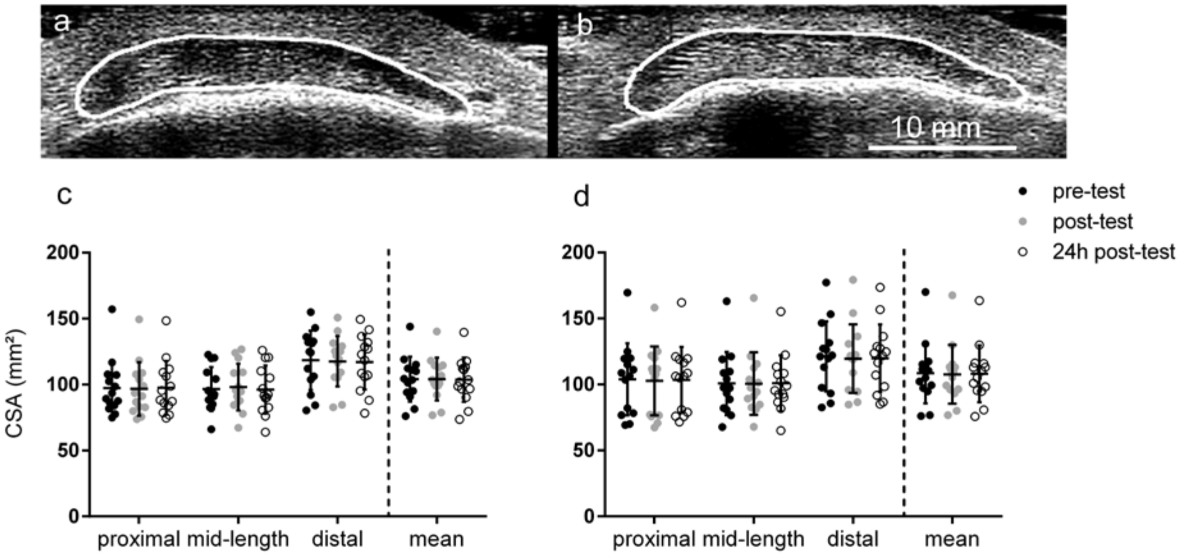

Fig1. Top row: Representative ultrasound scans of the distal patellar tendon cross-sectional area (CSA) of one subject before (a) and after (b) the vibration intervention. Bottom row: Patellar tendon CSA measurements obtained in the whole-body vibration (c) and the control (d) groups

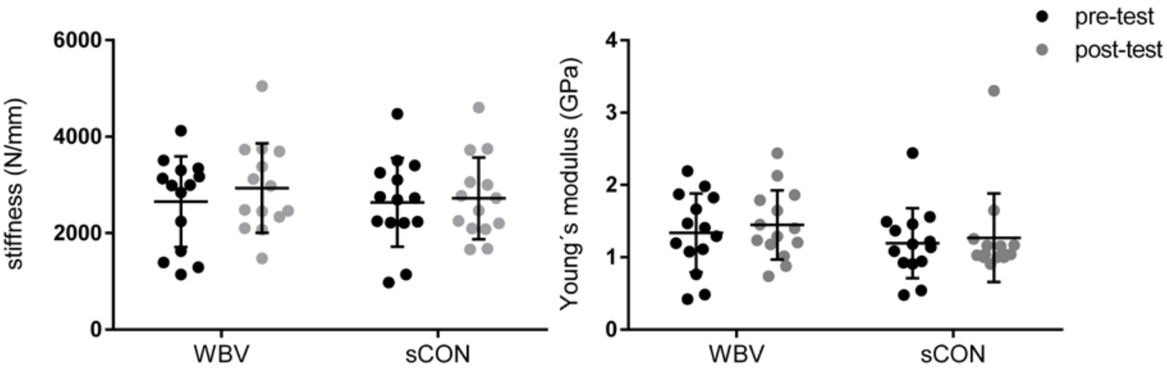

Fig2. Patellar tendon stiffness and Young's modulus before and after the intervention in the whole-body vibration (WBV) and the squatting control (sCON) groups

Torque- angle relationship

There was a significant group x time interaction for isometric knee extension torque at 60° knee angle (*P* = 0.031; $F_{(1,26)} = 5.21$; *f* = 0.45). Post-hoc tests revealed that the isometric torque decreased in the WBV group (-6.1 %; *P* = 0.009) while there were no changes for the sCON group (0.8 %; *P* = 0.882*)*. There were no further significant group x time effects for the remaining knee angles (90°: *P* = 0.262, $F_{(1,26)} = 1.31$, *f* = 0.22; 80°: *P* = 0.637, $F_{(1,26)} = 0.23$, *f* = 0.10; 70°: *P* = 0.223, $F_{(1,26)} = 1.56$, *f* = 0.24; 50°: *P* = 0.348; $F_{(1,26)} = 0.91$, *f* = 0.19). Peak isometric knee extension torque was produced at 70° knee angle in both groups at pre- and post-test (**Figure 3)**.

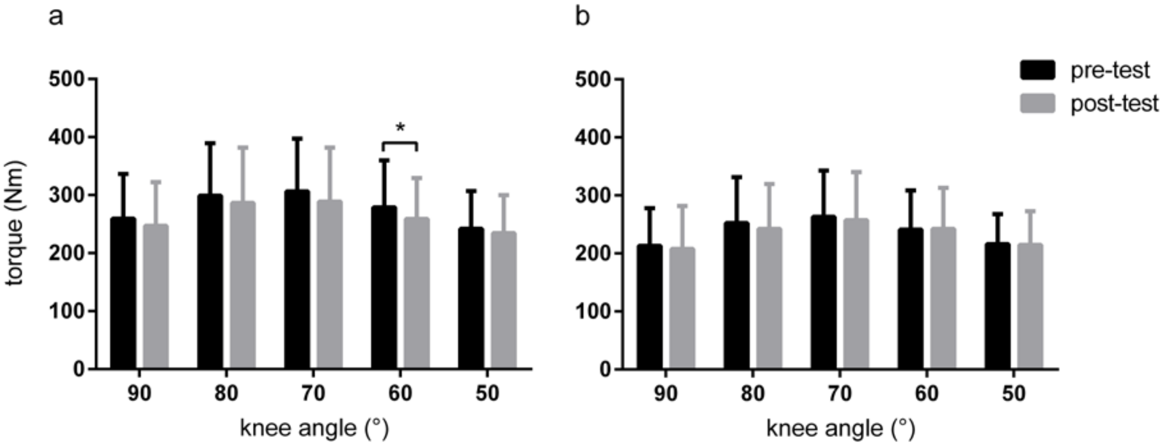

Fig3. Isometric knee extension torque before and after the intervention in the whole body vibration (a) and the squatting control groups (b). * = significant change. Values are presented as mean ± SD

In line with isometric tests, the isokinetic measurements showed no significant group x time effects for angle of peak torque production (*P* = 0.268; $F_{(1,26)}$ = 1.28, *f* = 0.22) or peak torque (*P* = 0.076, $F_{(1,26)}$ = 3.41, *f* = 0.36). These measurements are presented in **Figure 4**.

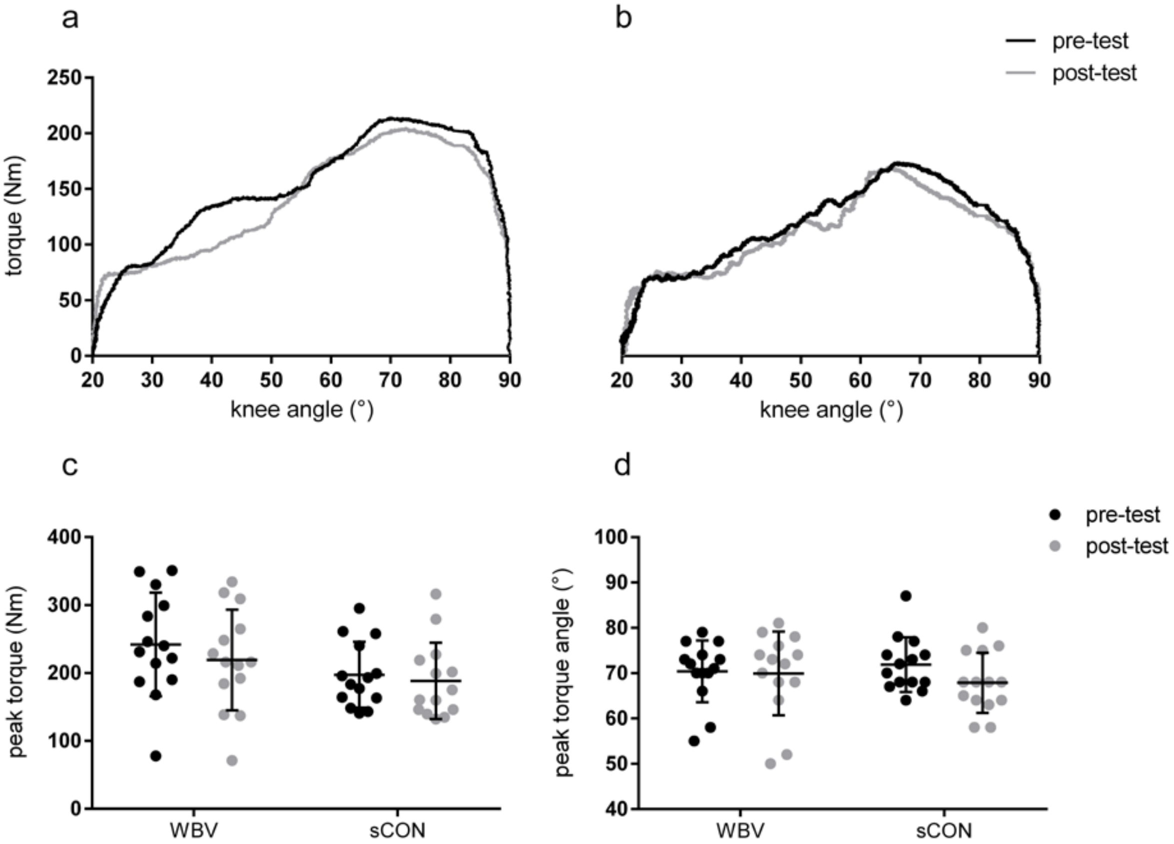

Fig4. Top row: Representative isokinetic torque traces obtained during knee extension in a WBV (a) and a control (b) subject. Bottom row: Isokinetic peak torque (c) and joint angle of peak torque production (d)

Discussion

In contrast to our hypothesis, the present findings indicate that a single bout of WBV was not sufficient to induce changes in patellar tendon properties. Consistently with the unaltered tendon stiffness, a shift in optimal angle of knee extension torque production was not observed. In fact, the torque-angle relation remained similar globally, with a marginal (- 6%) decrease in isometric torque at 60° of knee joint angle.

Tendon mechanical and morphological properties

The main hypothesis of the present work was that a single bout of WBV would induce changes in tendon compliance, which would in turn alter the muscle torque-angle relation. In spite of tendon stiffness being unchanged after weeks of WBV training (Rieder et al. 2015), we expected a transient decrease in this variable, in agreement with observations following a single session of other types of interventions (Kubo et al. 2001a, b; Yin et al. 2014). However, patellar tendon stiffness was unaffected by WBV. Immediate alterations in tendon properties after exercise are not uniformly reported in the literature. Decreases in tendon stiffness or Young´s modulus measured after resistive or stretching exercises were for instance not observed following stretch-shortening reliant interventions, such as hopping or running (Obst et al. 2013). This dichotomy between intervention types suggests that certain loading patterns and/or thresholds may be required to instantly alter tendon mechanical properties. Ultrasound recordings during WBV indicate that tensile loading does occur within the gastrocnemius muscle-tendon unit (Cochrane et al. 2009). However, the small tendon strain induced with this type of intervention (Cochrane et al. 2009) may represent a fraction of the strain values reached with resistive or stretching exercises. An alternative explanation to the present findings may be related to the training status of the subjects. It was recently demonstrated that reductions in patellar tendon stiffness occurred in trained athletes at higher training volumes than required in untrained controls after one bout of eccentric exercises (Yin et al. 2014). The subjects of the present study regularly engaged in sporting activities and one cannot dismiss the possibility of the WBV intervention being more effective in less physically active individuals.

Consistent with there being no change in mechanical properties, the cross-sectional area and Young's modulus of the patellar tendon remained unaltered after WBV exposure. Decreases in Achilles (Grigg et al. 2009) and patellar tendon thickness (Wearing et al. 2013) immediately after high load exercises have been documented in previous studies and are generally attributed to the ejection of fluids caused by hydrostatic pressure during tensile loading. We expected that cyclic loading induced by vibration would bring about similar fluid dynamics, thereby reducing tendon CSA. However, neither regional nor mean tendon CSAs were altered immediately after and 24h after the WBV session (Figure 1).

Two methodological considerations should be taken into account in the interpretation of these results. Firstly, ultrasound-based measurements of tendon morphology (Brushoj et al. 2006; Ekizos et al. 2013) have been shown to have a lesser reliability than other techniques (i.e. magnetic resonance) providing a better contrast between different tissues. In our hands, test-retest coefficients of variation ranging from 0.6 to 1.4% were obtained for this measure (Rieder et al. 2015), indicating that changes lower than 2% may have gone undetected. Secondarily, one should note that immediate effects of exercise on patellar tendon morphology have hitherto only been assessed via thickness measurements (Wearing et al. 2013). Fluids distribution towards other tendon areas than the sagittal plane cannot be excluded and may limit the comparison between these studies and the present one. Nonetheless, assuming that certain exercise modalities do reduce tendon thickness and CSA, the loading parameters produced by our WBV protocol may have simply been inadequate to induce a similar effect. These aspects are further discussed in the “Torque-angle relationship” section bellow. In addition, the small effect sizes for tendon CSA, stiffness and Young´s modulus (ranging from $f = 0.05$ to 0.22) support these assumptions.

Interestingly, the unchanged tendon CSA, up to 24h after exposure to WBV, bears indirect significance for the understanding of tendon adaptations to this type of training. An increase in patellar tendon CSA after weeks of WBV training has indeed been recently measured (Rieder et al. 2015). However, the lack of concomitant changes in stiffness and the relatively late timing of CSA measurements (one week post-training) raised the question of the origin of WBV-induced hypertrophy. The present results do not inform the exact nature of these changes but they indicate that WBV does not cause tendon swelling, up to 24h post exposure. They hereby support the hypothesis of anabolic processes underpinning tendon hypertrophy after weeks of WBV training (Rieder et al. 2015).

Torque-angle relationship

In line with unaltered tendon compliance, the torque-angle relationship of the knee extensor muscles did not change after a single bout of WBV. Isometric peak torque was produced at a knee angle of 70° in both groups at pre- and post-test, which was congruous with isokinetic peak torque angle. The discrepancy between tested and internal knee joint angle (Arampatzis et al. 2004; Tsaopoulos et al. 2011) probably affected the accuracy of the optimal joint angle estimation. However, the lack of change in torque suggests that this artifact had a limited impact on the similar torque-angle relationship measured after intervention. These findings contrast with reports from Kemertzis et al. (2008) and Pellegrini et al. (2010) showing a shift in plantarflexor peak torque angle towards a longer muscle length after a single session of WBV. Regardless of mechanisms explaining this shift, these studies indicate that WBV constitutes a sufficient stimulus to alter the torque-angle relation in plantarflexor muscles. The reasons why similar results were not obtained in the knee extensors remain unclear but are arguably related to the relatively less potent effect of WBV on this muscle group. This assumption is in line with previous work showing similar neuromuscular fatigue outcomes after static squatting with or without superimposed WBV (Maffiuletti et al. 2013).

Although vibration is unequivocally transmitted to the quadriceps with the present protocol (Rieder et al. 2015), the vibratory stimulus transmitted to the more distal triceps surae is stronger. One may speculate that increasing the intensity of the stimulus transmitted to the quadriceps, by altering vibration parameters, would have yielded similar results to that of Kemertzis et al. (2008) and Pellegrini et al. (2010). Furthermore, the patellar tendon was selected for the present experiment in accordance with our previous report about WBV training. The morphological and functional dissimilarities between the patellar and Achilles tendons may affect their susceptibility to the vibratory stimulus differently. For instance, the Achilles tendon is slenderer than the patellar tendon and may undergo higher stresses, relative to its ultimate stress. A higher safety factor may therefore shield the patellar tendon - more than the Achilles tendon - against mechanical stimuli. An adaptive specificity does not clearly appear with other forms of training (Wiesinger et al. 2015) but additional studies focusing on the triceps surae and Achilles tendon are required to refute this hypothesis.

In addition to keeping a similar angle of torque production, the individuals subjected to WBV did not experience any substantial loss in isokinetic or isometric knee extension torque. A small decrease in isometric torque was observed at knee angle of 60° in the WBV group and suggests that a certain fatigue was caused by vibration. This is further supported by other publications with comparable vibration settings (3-to-10 times 60-second periods of isometric squatting at 70-to-50° of knee flexion; vibration frequency: 30 Hz; vibration amplitude: 4-8 mm), reporting decreases in muscular strength after a single session of WBV (de Ruiter et al. 2003; Erskine et al. 2007; Jordan et al. 2010) Conversely, some authors have reported strength increases immediately after WBV (Bosco et al. 1999; Bosco et al. 2000; Mc Bride et al. 2010). However, this phenomenon only seems ephemeral, as suggested by its disappearance after a few minutes (Stewart et al. 2009; Torvinen et al. 2002). This brief increase is often ascribed to post-activation potentiation and seems short-lived after exercise (Güllich and Schmidtbleicher 1996). The time elapsed between the WBV protocol and the strength tests was not measured in this study. A time interval exceeding the force-enhancing time window can therefore not be excluded and may explain the unchanged peak torque.

Conclusion

A single bout of the present WBV protocol does not seem to induce alterations in patellar tendon properties and in quadriceps torque-angle relationship. The hypothesis of a causal relation between vibration, the compliance of series elastic elements and optimal angle of torque output is hereby disproved.

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical approval: “All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.”

Informed consent: “Informed consent was obtained from all individual participants included in the study.”

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New figures: Fig1 + Fig4

Editor comments:
The manuscript is suitable for publication, but I would like authors to consider the possibility of reorganizing the figures as follows:

- merge Fig. 1 and Fig. 2 (the current Fig.2 would be the new Fig. 1A and B, while the current Fig. 1 would be Fig.1 C and D).
- merge Fig. 5 and Fig. 6 (the current Fig.6 would be the new Fig.4A and B and the current Fig. 5 would be the new Fig. 4 C and D.

That would be more logical for the reader.

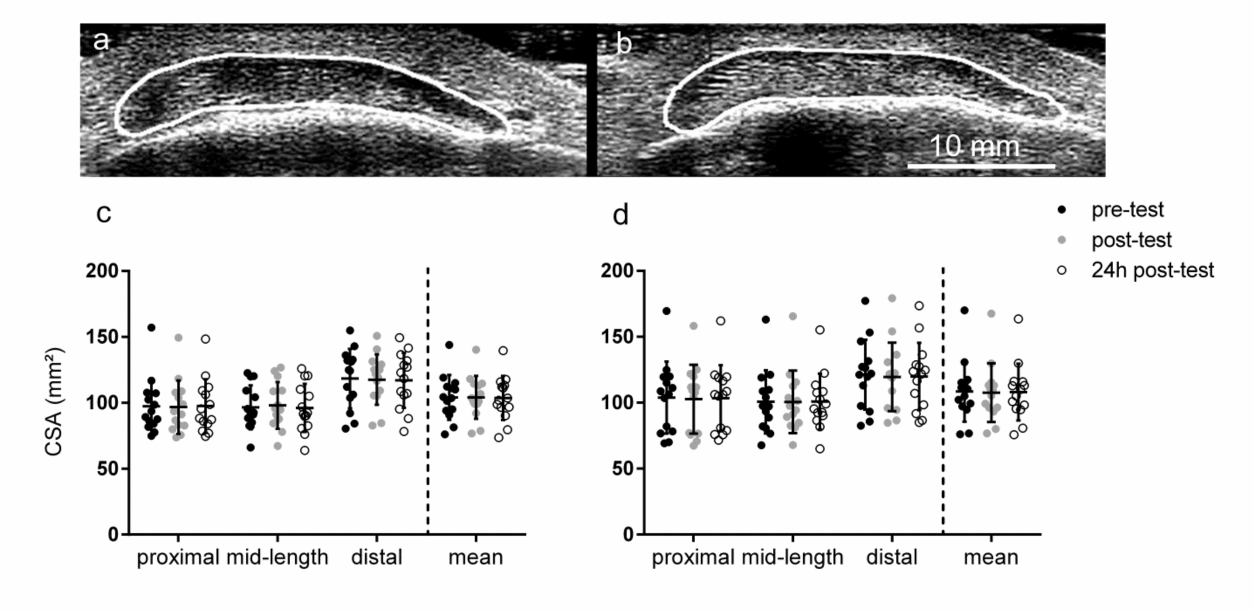

Fig1. Top row: Representative ultrasound scans of the distal patellar tendon cross-sectional area (CSA) of one subject before (a) and after (b) the vibration intervention. Bottom row: Patellar tendon CSA mesurements obtained in the whole-body vibration (c) and the control (d) groups.

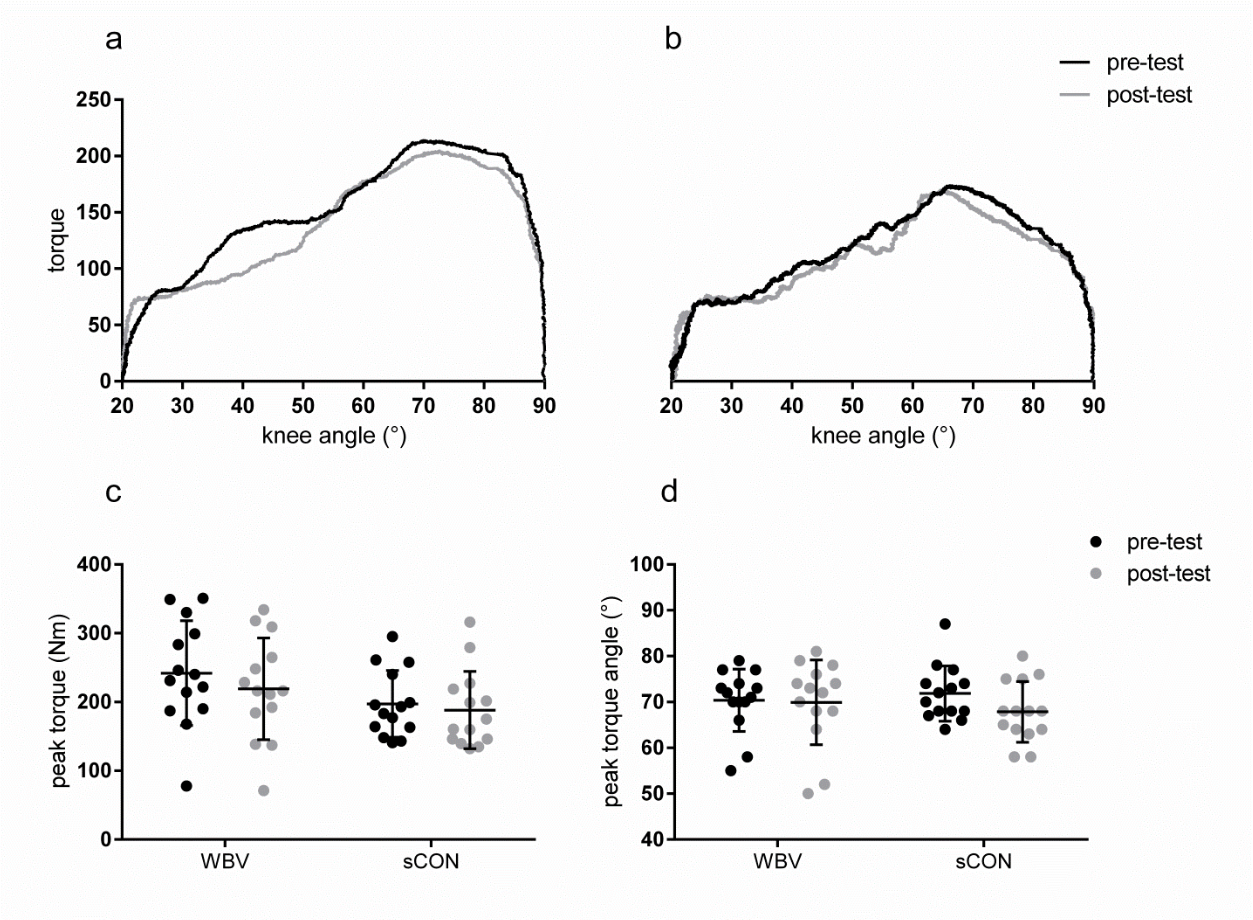

Fig4. Top row: Representative isokinetic torque traces obtained during knee extension in a WBV (a) and a control (b) subject. Bottom row: Isokinetic peak torque (c) and joint angle of peak torque production (d).