

ACUTE EFFECTS OF FLEXI-BAR VS. SHAM-BAR EXERCISE ON MUSCLE ELECTROMYOGRAPHY ACTIVITY AND PERFORMANCE

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ABSTRACT

Mileva, KN, Kadr, M, Amin, N, and Bowtell, JL. Acute effects of flexi-bar vs. sham-bar exercise on muscle electromyography activity and performance. *J Strength Cond Res* 24(3): 737–748, 2010—This study was conducted to investigate whether the low-frequency (5-Hz) oscillatory vibration-like stimulus, purported to be delivered by exercising with Flexi-bar, acutely affects muscle activation and maximal voluntary contraction (MVC) force. Nine healthy men participated in 2 trials, separated by at least 1 week, during which 4 × 30-second sets of exercise were performed with either the Flexi bar or a Sham bar. Maximal voluntary contraction force for elbow flexion, elbow extension, and knee extension were measured before and after the exercise. Root-mean-square amplitude and median frequency of electromyography (EMG) signal were calculated for the first and last 10 seconds of each exercise set and during the MVCs from biceps brachii (BB), triceps brachii (TB), rectus femoris (RF), and vastus lateralis (VL) for each trial. Electromyography amplitude was significantly higher for all studied muscles during Flexi-bar than Sham-bar exercise (32–203%, $p < 0.05$). Median frequency of EMG power spectrum was significantly lower in arm (TB: $-40 \pm 13\%$, $p < 0.0001$; BB: $-32 \pm 25\%$, $p = 0.015$) but not in leg (RF: $-12 \pm 18\%$; VL: $+6 \pm 32\%$; $p > 0.05$) muscles during Flexi-bar compared with Sham-bar exercise. Knee extension MVC force significantly decreased after Flexi-bar exercise ($-3 \pm 7\%$, $p = 0.048$) in parallel with reduced RF EMG amplitude ($-8 \pm 5\%$, $p = 0.04$), but there were no acute residual effects on elbow flexion/extension MVC or arm and VL EMG muscle activity. Using Flexi bar during exercise provoked acute alterations in arm- and leg-muscle EMG parameters and maximum force-generating capacity, indicating greater fatigue development than when

exercising with the Sham bar. The results of this study indicate that Flexi bar may therefore be used to impose a stronger training stimulus on the muscle during submaximal exercise.

KEY WORDS human, MVC, training, leg and arm

INTRODUCTION

Experimental evidence suggests that mechanical vibration of low intensity (below 0.4 g) and low frequency (below 50 Hz) can be transmitted effectively through the human body (32). Thus, superimposition of such vibration to an active muscle has the potential to amplify the acute and chronic neuromuscular adaptations achieved during low-intensity exercise (26). Muscle vibration has been shown to induce acute residual (6,7,9,10,34), and chronic (5,13,33) increases in muscle strength, power, and flexibility. As a consequence, vibration training is gaining popularity as an adjunct warm-up and training modality for athletes and as a therapeutic tool for rehabilitation.

However, there is a wide variation across the literature in terms of direction and magnitude of the observed vibration-induced effects, with some studies finding no change or a reduction in muscle performance (12,15,27,29,35). These contradictory findings are related at least in part to the study designs employed, including variation in vibration stimuli (vibration frequency and amplitude [25]), exercise mode (static or dynamic [16]), postural conditions (joint angle and uni or bilateral exercise [1,31]), or mode of vibration delivery. The vibration stimulus can be delivered to the muscle in a number of ways: directly to the exercising muscle/tendon (e.g. [21,22,27]), or indirectly, via segmental (whole limb) vibration (e.g. [17,18,24,26]), or via whole body vibration platforms ([1,2,5–7,11,12,29,30,33–35]). A number of studies have investigated neuromuscular responses to vibration of different amplitude and frequency (7,21,26), applied during static or dynamic exercise (2,16) at sub or maximal muscle contractions (22,26), and different levels of muscle stretch (joint angle) (2,8,21,24), but there are as yet no universal recommendations for optimizing vibration training protocols for a desired response.

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Whatever the mode of vibration delivery or exercise, the intensity of the stimulus reaching the targeted muscle will be dependent on the transmission of the vibration stimulation through the human body (36). Therefore, in all vibration modalities, the proximity of vibration source to the target muscle is another important determinant of efficacy (22). To limit the impact of vibration damping, a number of training devices delivering direct or segmental low-frequency vibration have been developed. Flexi bar is 1 such device.

Because of its elastic properties and weighted construction, Flexi bar is designed to resonate with a frequency of 5 Hz when vigorously moved through small amplitudes of movement, which the user has to maintain whilst remaining physically stable. Flexi bar is claimed to target the core-stabilizing muscles, such as rectus abdominus, transverse abdominus, latissimus dorsi, and erector spinae. However, there are currently no peer-reviewed published studies available to support these claims. The purpose of this study therefore was to investigate the acute effects of the oscillatory vibration-like stimulus delivered by the Flexi bar on arm- and leg-muscle activation and performance during exercise in comparison to Sham-bar exercise. We hypothesize that the 5-Hz vibration induced by Flexi bar will result in greater muscle activation during Flexi- than during Sham-bar exercise and therefore induce a reduction in maximum force-generating capacity after exercise.

METHODS

Experimental Approach to the Problem

A repeated-measures sham-controlled study design was adopted to assess the effectiveness of using the Flexi bar to enhance arm- and leg-muscle activation (root-mean square [RMS] electromyography [EMG] amplitude and median frequency [MDF] of the EMG power spectrum) and performance level during and immediately after exercise (force production during maximal voluntary contraction [MVC]). A specially designed plastic bar (Sham bar) was used to complete the nonvibratory (control) trials in this study. After being familiarized and trained to perform arm exercise by shaking a bar, each subject completed 2 trials of static 1-legged squat exercise in a randomized order. Each trial consisted of 4 sets of exercise using the Flexi or the Sham bar lasting 30 seconds each with 90-second rest periods between the sets. Before and immediately after the exercise, the subject was tested for elbow joint flexion and extension, and knee joint extension MVC to assess the acute residual effects of the exercise on muscle force production (termed muscle performance). Electromyography activity was continuously recorded throughout the trials from 2 arm (biceps brachii [BB] and triceps brachii [TB]) and 2 leg (rectus femoris [RF] and vastus lateralis [VL]) muscles. The effects of Flexi-bar exercise on arm and leg muscles were compared with the results from the Sham-bar trials to determine the acute and acute residual effects of the Flexi-bar exercise.

Subjects

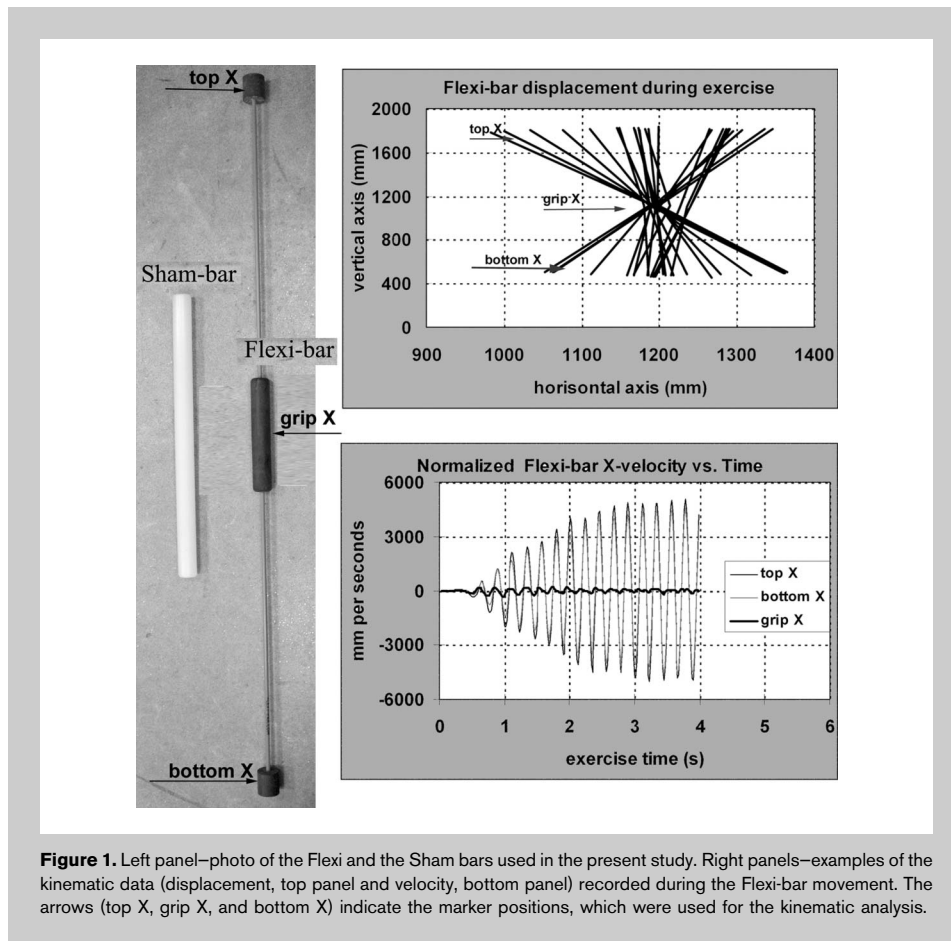
Nine healthy men (mean \pm SD; 20.6 \pm 0.5 years, 178.1 \pm 9.0 cm, and 78.3 \pm 12.7 kg) with no previous motor disorders or injuries to any limbs in the last 2 years gave written and informed consent to participate in this study. The subjects were recreational athletes recruited from the student population at the University, who carried out a combination of endurance (moderate intensity cycling and running) and strength training (high-intensity gym-based training) 3–4 times a week. The participants were naïve to the aims of this study and the efficacy of Flexi-bar exercise. The study protocol was approved by the Local University Ethics Committee, and it was performed according to the conditions from the Declaration of Helsinki.

Experimental Procedures

Exercise Equipment. The Flexi bar (Flexi-Sports, Bisley, Stroud, United Kingdom, 719 g weight, 1520-mm length) is an exercise tool designed by German physiotherapists. Its constituents are a flexible fiberglass pole with a rubber handle (17.9-cm girth) in the middle and weighted rubber at each end (Figure 1). The principle is that shaking the Flexi bar causes the rubber handle to vibrate with a 5-Hz frequency, which is then passed through the holding hand along the arm into the body although this has not previously been directly measured. A 605-mm-long solid plastic bar (Sham bar) with the same weight and girth as the Flexi bar was manufactured in the University workshop and used to complete the non-vibratory (control) trials in this study (Figure 1).

Experimental Protocol. Each subject completed 2 main trials (Flexi and Sham) after being familiarized with the equipment used and the experimental procedures. The trials were completed 6–7 days apart and in random order based on the rotational principle to counteract any learning effect. Subjects were asked to maintain a similar diet and exercise regime between the laboratory visits. The main trials were preceded by a familiarization visit, during which body anthropometrics, such as body weight and height, segmental length of arms and legs, were measured to adjust the measuring equipment to identical levels during both trials. All subjects in this study were right hand dominant. The Flexi bar requires coordination and correct technique. Therefore, during their preliminary visit, the subjects were trained to use the Flexi-bar equipment, and to perform MVC for each of the tested muscle groups (knee extension and elbow extension/flexion).

Experimental sessions began with a standardized 5-minute warm-up, consisting of light jogging on the spot and muscle stretching. After the warm-up, the subjects completed 4 sets of exercise using a bar (Flexi- or Sham-) lasting 30 seconds each with 90-second rest periods between the sets. Before and immediately after the exercise, the subject was tested for elbow joint flexion and extension, and knee joint extension MVC. Three MVC readings each lasting 3 seconds were taken consecutively for each tested joint, and movement direction



with a 90-second rest period was allowed between the MVC attempts (Figure 2A).

The force produced during the elbow joint MVCs was measured using 1 in-line force transducer (MCL, RDP Ltd., Wolverhampton, United Kingdom) incorporated into specifically designed equipment for testing isometric elbow contractions. The knee extension MVCs were tested on a leg extension machine (Technogym UK Ltd., Bracknell, United Kingdom). Before the initiation of the main trials, the force transducers were calibrated using standard weights. The force signals were recorded in parallel with muscle EMG activity (Figure 2C, D).

The EMG activities of 2 right arm (long heads of BB and of TB) and 2 right leg (RF and VL) muscles were simultaneously recorded during the study (Figure 2B). Electromyography surface bipolar electrodes (1-cm diameter, 2-cm interelectrode distance) were attached with adhesive medical tape above the distal half of the muscle belly. A common grounding electrode was attached to the ankle. The area of skin under each EMG electrode was shaved, then exfoliated with abrasive gel, and cleaned with alcohol (ethyl propanol) to minimize resistance between the electrode and the skin surface.

Knee and elbow flexion/extension joint angular displacements during the tests were recorded continuously with

2 preamplified electrogoniometers (Biometrics Ltd., Gwent, United Kingdom) attached with double-sided medical tape laterally at the right elbow and knee joints (Figure 2B). The elbow and knee angles were zero set at full joint extension (180° angle between the humerus and radius, and between the femur and fibula, respectively). During each trial, subjects were provided with continuous visual feedback on their knee and elbow angular position to keep constant posture. The exercising bar was held in the subject's dominant (right) hand away from their body to the side at a 20° elbow flexion angle while standing in a right leg squat position (knee flexed at a 20° angle). During the exercise sets, the subjects kept their nondominant (left) arm in a relaxed pronated position and the nondominant (left) knee flexed to ensure that their foot was not touching the ground.

Data Acquisition. Electromyography data were acquired continuously and simultaneously with the force and joint angle data throughout the tests via an analog-to-digital converter (ADC, 1401 power, CED, Cambridge, United Kingdom) using Spike2 data acquisition software (CED). The EMG signals were preamplified in the active electrodes ($\times 330$, B&L Engineering, Santa Ana, CA, USA) and further amplified in the conditioning system ($\times 3000$, 1902 CED). The signals from the electrogoniometers were preamplified in a subject unit mounted on a subject's belt and transferred online to the PC via the ADC. The sampling frequency used for the EMG signals was 2 kHz, 200 Hz for the electrogoniometry records (elbow and knee joints), and 200 Hz for the force. During elbow flexion and extension MVC testing, EMG traces were recorded only from the BB and TB muscles (Figure 2D) and during knee extension, MVC testing EMG traces were recorded only from RF and VL muscles (Figure 2C). During the exercise sets, muscle EMG activity was recorded simultaneously from all 4 studied muscles in parallel with the elbow and knee joint angular displacement (Figure 2B).

Data Analysis. Off-line data analysis was performed using a custom written script generated in Spike2 (CED). The muscle activation level during the tests was quantified by the

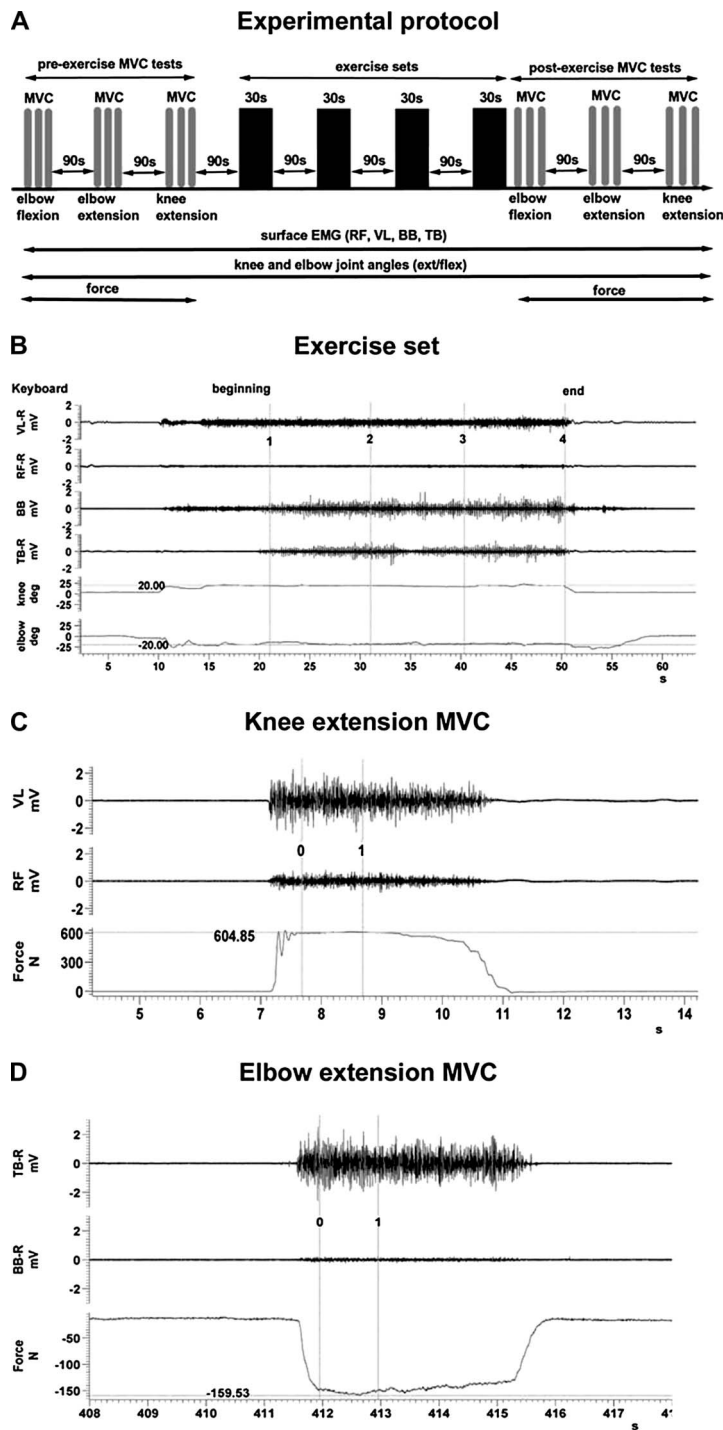
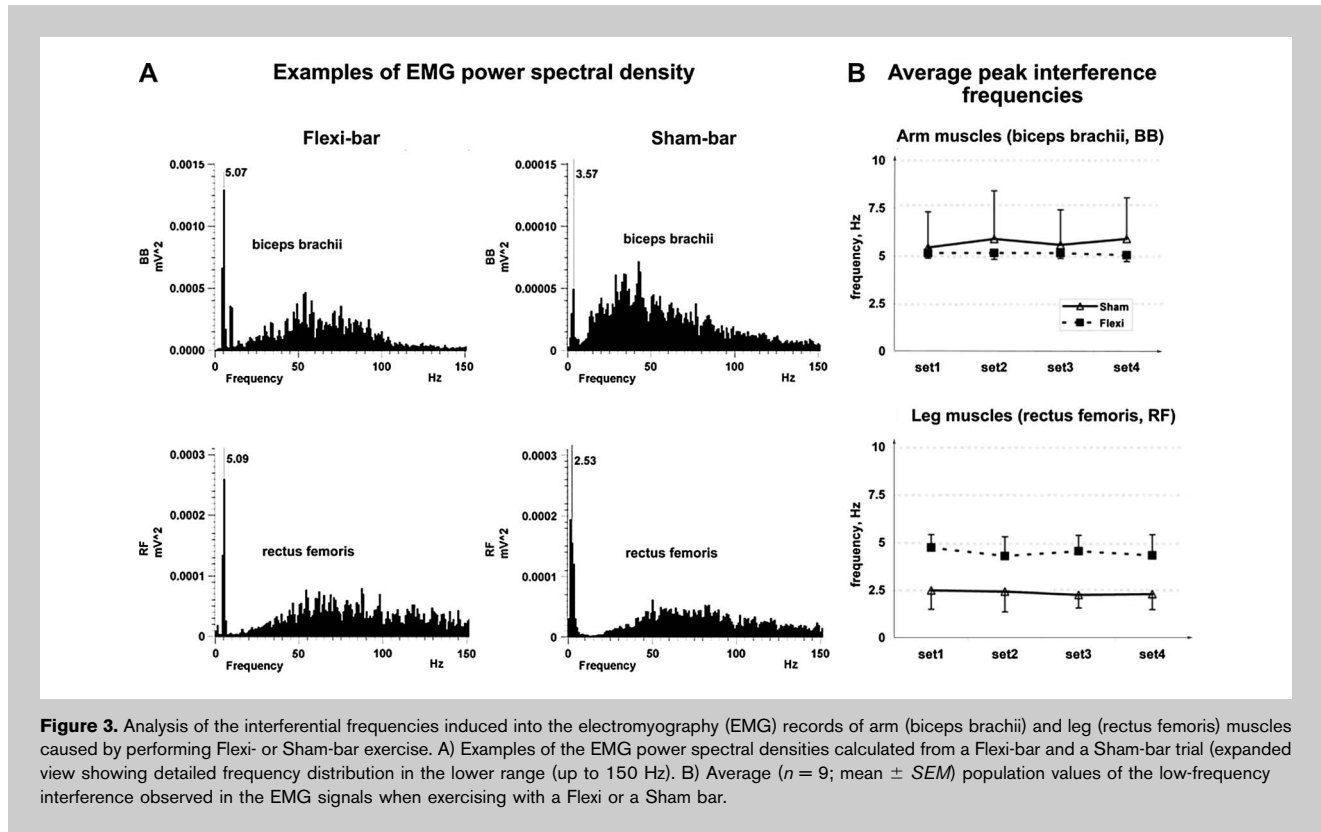


Figure 2. A) Experimental protocol B) and examples of the signals recorded during the exercise sets C,D) and during the pre- and postexercise tests for maximal voluntary contraction (MVC). B) Electromyography (EMG) activity from biceps brachii (BB), triceps brachii (TB), rectus femoris (RF), and vastus lateralis (VL) muscles was recorded simultaneously with the elbow and the knee joint angles during the exercise sets. Cursors 1 and 2 delineate the first 10 seconds (beginning) and cursors 3 and 4—the last 10 seconds (end) of an exercise set. C) During the pre- and postexercise performance tests the contraction force (N) was recorded in parallel with the RF and VL EMG activity when performing knee extension MVCs D), and with the BB and TB EMG activity when performing elbow MVCs in flexion and extension. Cursors 0 and 1 delineate the 1-second period used to calculate the MVC parameters.

RMS EMG amplitude, and the contributing factors to any change were assessed by the MDF of EMG power spectral density. Electromyography records were high pass filtered with a 20-Hz cut-off frequency to remove motion artefact before parameter calculations. The frequency distribution was calculated using Fast Fourier Transformation with a block size of 512 milliseconds using a Hanning window function and presented between 0 and 1,000 Hz in 256 bins at a resolution of 3.906 Hz.

During the MVC tests, the peak force was calculated as the average value over a 1-second period around the highest force achieved during the plateau level of each MVC attempt. This period did not include the first segment of the contraction (lasting about 0.5 seconds) to exclude from the measurement the period of developing force (Figure 2C, D). The EMG parameters were calculated for each muscle from the selected 1-second period for each of the 3 initial MVC tests (Figure 2C, D). The pre-exercise MVC test with the highest force registered during each action (elbow flexion, elbow extension, and knee extension) was accepted as the baseline MVC and used for subsequent analysis. The normalized ratio between the initial and the postexercise MVC parameters was calculated to quantify the acute residual changes of muscle activation (EMG) and performance (MVC force) induced by the exercise protocols.

During the exercise sets, the EMG parameters, average knee and elbow joint angles and peak-to-peak angular velocities, were calculated for the first 10 seconds (0–10 seconds, beginning) and for the last 10 seconds



(20–30 seconds, end) of each exercise set for both conditions (Flexi and Sham, Figure 2B). The knee and elbow joint angular velocities were calculated by applying a digital differentiator filter (Spike2, CED) to the joint angular displacement signals and plotted in parallel with the rest of the data. Knee and elbow joint angular displacement and velocity traces were smoothed with 0.05-millisecond time constant to remove the high-frequency noise interferences. The parameters were averaged for each time segment (beginning and end) across the 4 sets completed in a trial for each subject and condition and presented as population average (mean \pm SEM) values. The threshold for muscle activation during the exercise sets was established as greater than the mean \pm 2SD of the baseline of each EMG channel. Baseline activation was calculated from a 1-second period at the beginning of each trial, when the subjects kept their muscles fully relaxed.

To quantify the Flexi-bar motion, kinematic data of the bar movement were collected using an automated 2-dimensional motion analysis system (*Qualysis ProReflex*) operating at 60 Hz and Q-Trac software. An example of the data recorded during a 4-second-exercise (from movement initiation until stabilization) is presented in Figure 1. The kinematic model was based on the coordinate positions of 3 markers attached to the top, middle (hand grip), and bottom end of the bar. In addition, the vibration frequencies transmitted to the arm and leg muscles during the exercise sets completed with the

Flexi or the Sham bar were quantified and compared by analysis of the power spectral density of the raw BB and RF EMG signals (before applying high-pass filtering procedure). The frequency with the maximal power in the spectral distribution below 20 Hz was identified for each condition (Flexi or Sham) and time segment (beginning or end of set, Figure 3).

Statistical Analyses

The reliability of muscle strength (MVC force) and EMG (RMS and MDF) measures was tested using a 1-way random-effects single measure model [1,1] to calculate the intraclass correlation coefficients (ICCs) for the pre-exercise MVC data collected in both trials. Initially, 3-factor repeated-measures analysis of variance (ANOVA; condition [Flexi vs. Sham]; set [4 levels]; time [2 levels: beginning vs. end of set]) was applied on the EMG and kinematic parameters calculated during the exercise. However, there were no significant main or interaction effects involving the factor ‘set,’ and therefore the average parameter values from the 2 time points (beginning and end of set) were averaged across the sets. Hence, a 2-way repeated-measures ANOVA (time vs. condition) was applied separately on the data from the MVC tests (force and EMG parameters) and from the exercise sets (joint angles, joint angular velocities and EMG parameters). The statistical analyses of the EMG data were completed on the values normalized to the corresponding parameter value

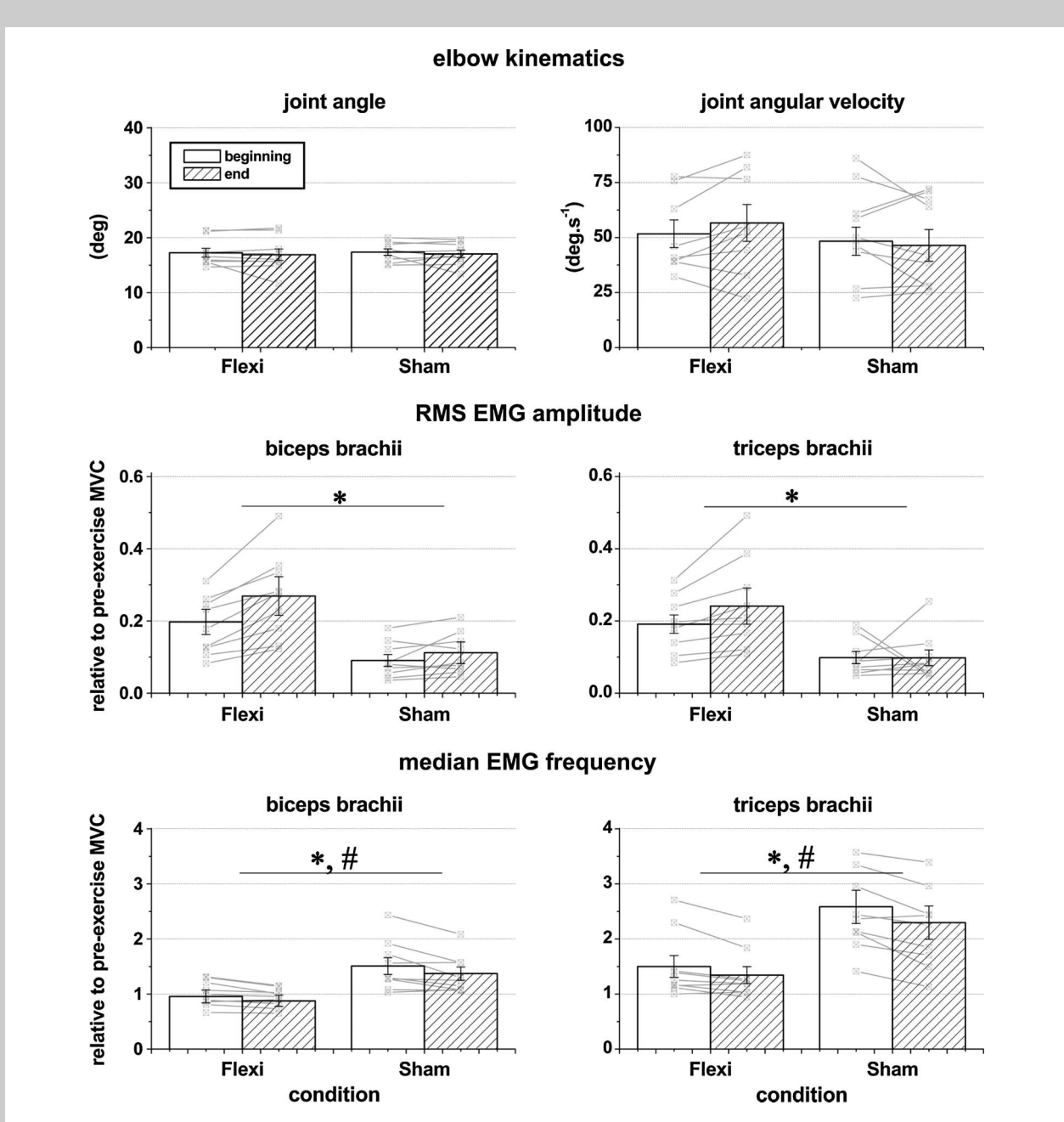


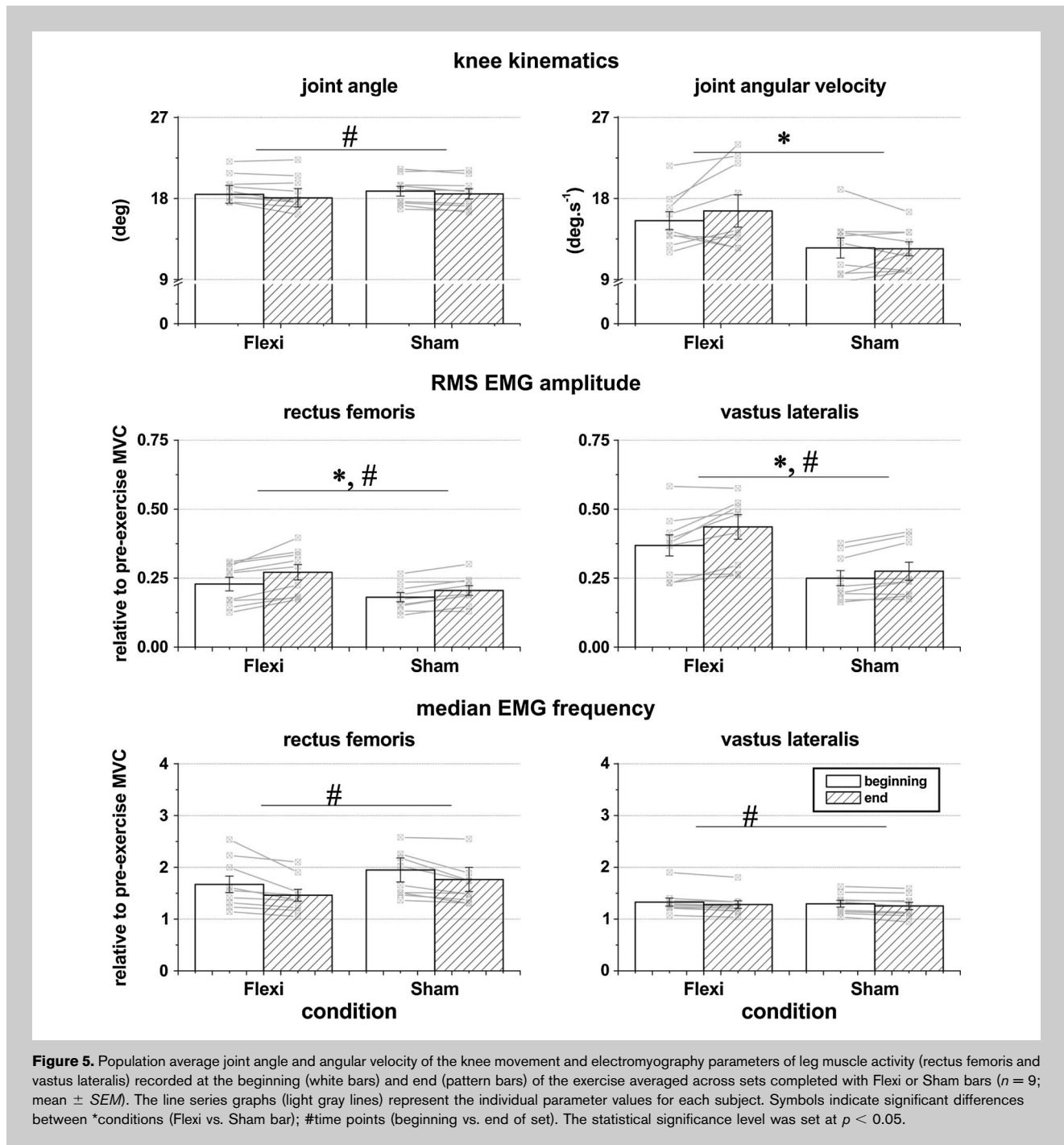
Figure 4. Population average kinematic characteristics of the elbow joint movement (joint angle and angular velocity) and electromyography parameters of arm muscle activity (biceps brachii and triceps brachii) recorded at the beginning (white bars) and end (pattern bars) of the exercise averaged across sets completed with Flexi or Sham bars ($n = 9$; mean \pm SEM). The line series graphs (light gray lines) represent the individual parameter values for each subject. Symbols indicate significant differences between: *conditions (Flexi vs. Sham bar); #time points (beginning vs. end of set). The statistical significance level was set at $p < 0.05$.

from the initial (pre-exercise) MVC test. The statistical significance level was set at $p \leq 0.05$.

RESULTS

The range of the ICC calculated for MVC force (ICC = 0.80–0.87), EMG RMS amplitude (ICC = 0.64–0.81) and MDF (ICC = 0.56–0.77) indicated fair-to-good reproducibility of the measures employed in the study (20).

The analysis of the Flexi-bar motion revealed that after a movement initiation period lasting for about 3–5 seconds, the Flexi-bar movement remained stable for the rest of the exercise set (30 seconds in total). The range of the Flexi-bar ends displacement along the X-axis was between +20 and –20 cm resulting in an average peak movement velocity of about $5 \text{ m}\cdot\text{s}^{-1}$ (top X and bottom X, Figure 1). The displacement and the movement velocity of the marker



attached at the grip point of the Flexi-bar (grip X) were negligible. The plot of the X-velocity also illustrates the 5-Hz repetition rate of the Flexi-bar movement ($5 \text{ cycles}\cdot\text{s}^{-1}$).

Figure 2B provides an example of the signals (elbow and knee angles and EMG) recorded from a representative subject during 1 exercise set completed with the Flexi bar. The interferential frequency induced into the EMG signals by shaking the bar during the exercise sets was identical

between conditions for the arm muscle EMG activity (5.12 ± 0.05 vs. 5.70 ± 0.11 Hz, Flexi vs. Sham, $p > 0.05$, Figure 3) but significantly different for the leg muscles (4.49 ± 0.10 vs. 2.39 ± 0.05 Hz, Flexi vs. Sham, $p < 0.0001$, Figure 3).

The average elbow flexion joint angles ($17.3 \pm 0.8^\circ$ vs. $17.4 \pm 0.6^\circ$) and angular velocities ($52 \pm 6^\circ\cdot\text{s}^{-1}$ vs. $48 \pm 6^\circ\cdot\text{s}^{-1}$) registered throughout the exercise sets were well matched between the conditions (Flexi vs. Sham, $p > 0.05$, Figure 4).

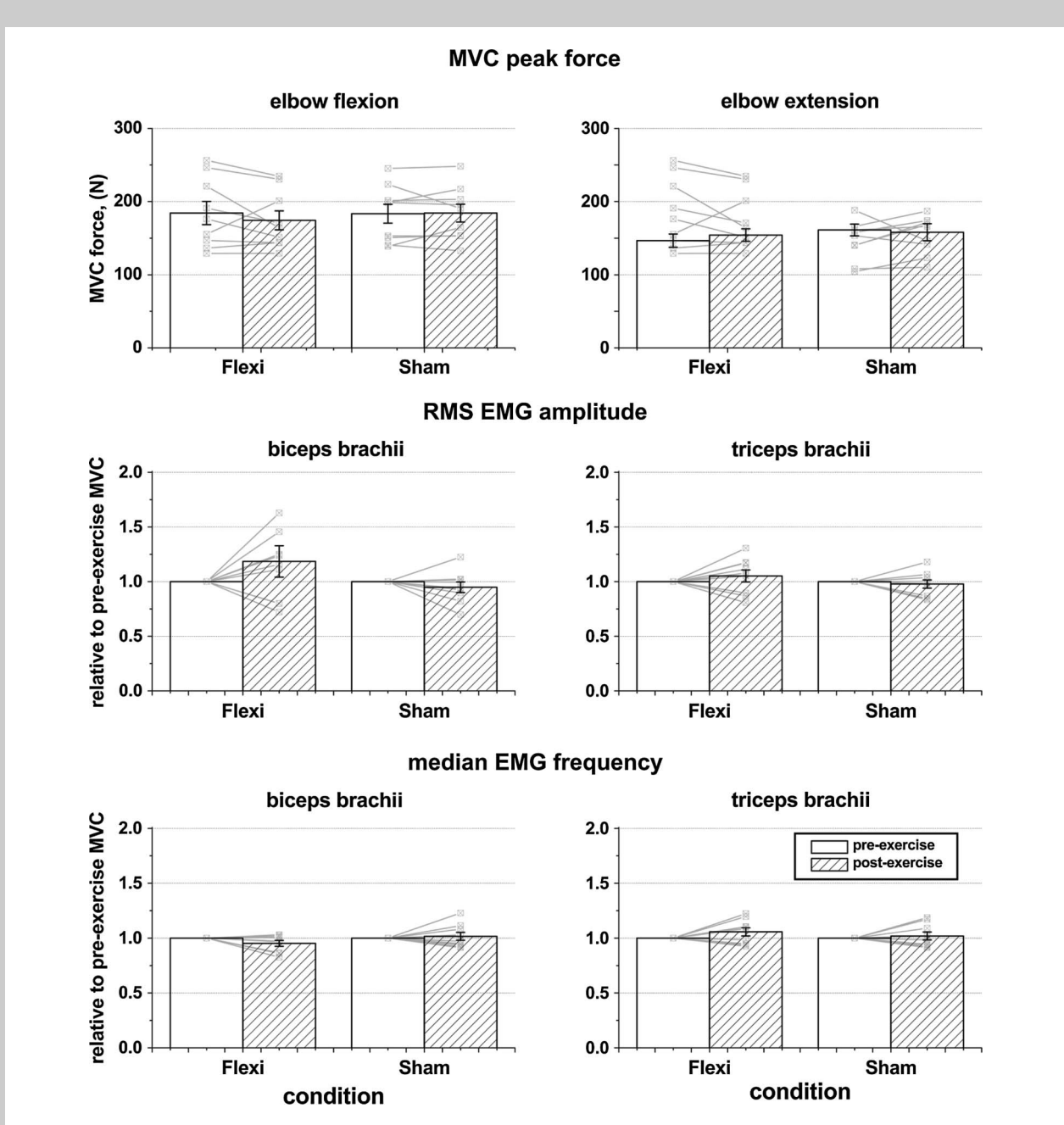


Figure 6. Average ($n = 9$; mean \pm SEM) peak force and normalized changes in EMG parameters of arm muscle activity (biceps brachii and triceps brachii) calculated from the tests for maximal voluntary isometric contraction in elbow flexion and extension completed pre- (white bars) and immediately post (pattern bars) 4 sets of 30-second exercise using Flexi or Sham bar. The line series graphs (light gray lines) represent the individual parameter values for each subject. There were no significant differences for any of the calculated parameters between the conditions (Flexi vs. Sham bar) and/or the time points (beginning vs. end of set). The statistical significance level was set at $p < 0.05$.

The EMG activity of the arm muscles had significantly higher RMS amplitudes (BB: $203 \pm 227\%$, $p = 0.029$; TB: $177 \pm 234\%$, $p = 0.012$) and significantly lower median spectral frequency (BB: $-32 \pm 25\%$, $p = 0.015$; TB: $-40 \pm 13\%$, $p < 0.001$) during Flexi- than Sham-bar exercise (main condition effect, Figure 4). Also, median EMG frequency

was significantly lower during the last 10 seconds than the first 10 seconds of the sets for both tested arm muscles (BB, $-8 \pm 9\%$, $p = 0.015$; TB, $-11 \pm 9\%$, $p = 0.001$), but the EMG amplitude did not change significantly over time in TB muscle and only tended to be higher ($37 \pm 75\%$, $p = 0.057$) in BB muscle by the end of the exercise sets (Figure 4).

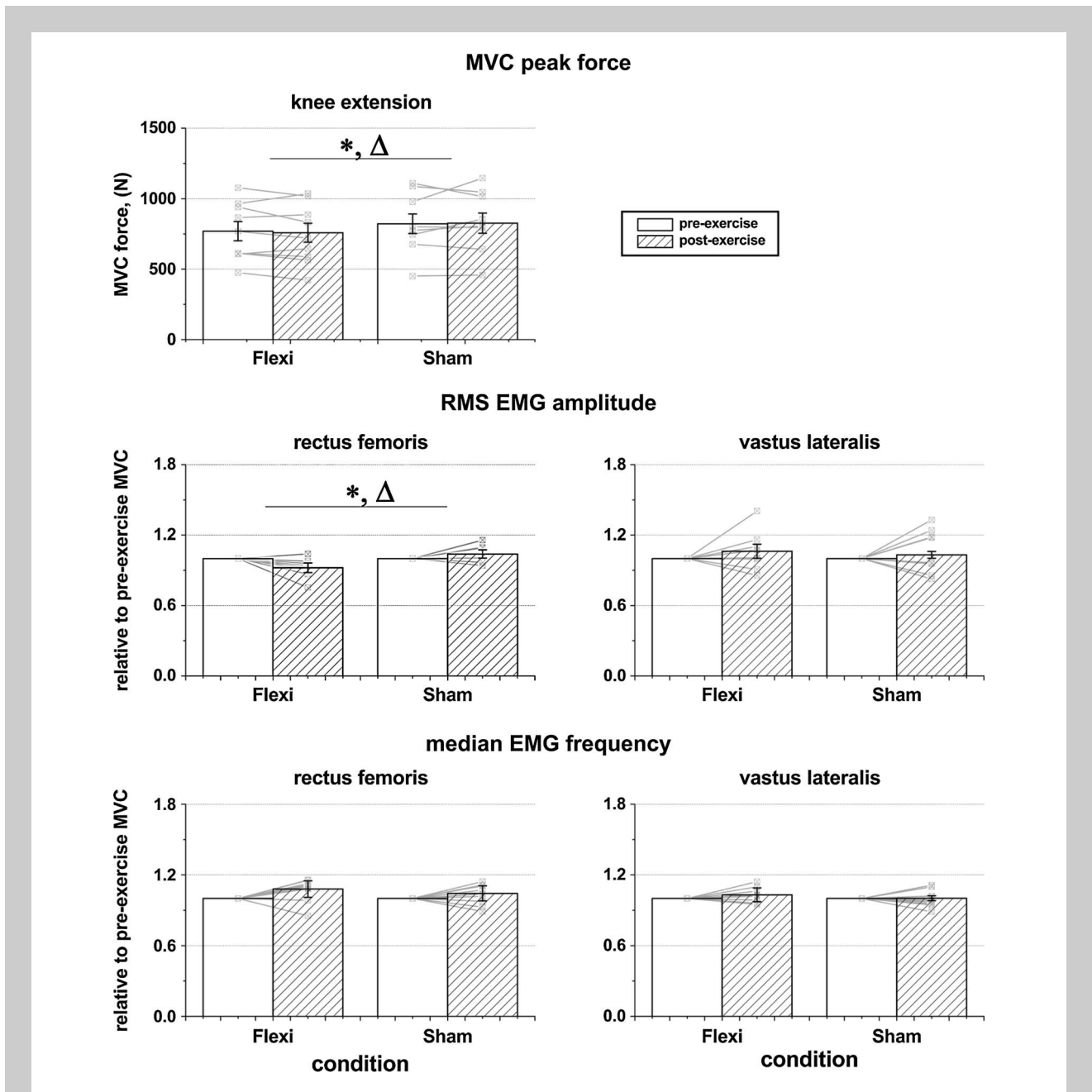


Figure 7. Average ($n = 9$; mean \pm SEM) maximal voluntary contraction (MVC) peak force and normalized changes in electromyography parameters of leg muscles (rectus femoris and vastus lateralis) calculated from the tests for knee extension MVC completed pre- (white bars) and immediately post (pattern bars) 4 sets of 30-second exercise using Flexi or Sham bar. The line series graphs (light gray lines) represent the individual parameter values for each subject. Symbols indicate: *significant differences between conditions (Flexi vs. Sham bar); Δ significant time vs. condition interaction effect. The statistical significance level was set at $p < 0.05$.

The average knee flexion joint angles ($18.5 \pm 1.0^\circ$ vs. $18.8 \pm 0.5^\circ$) were not different between trials (main condition effect, Flexi vs. Sham, $p > 0.05$, Figure 5), but the knee angular velocity was significantly higher throughout Flexi-bar compared with Sham-bar exercise trials ($15.5 \pm 1^\circ \cdot s^{-1}$ vs. $12.5 \pm 1^\circ \cdot s^{-1}$, Flexi vs. Sham, $p = 0.024$, Figure 5). Also, a small but significant decrease in knee joint flexion angle was

observed by the end of the sets in both conditions ($-2 \pm 1\%$ vs. $-1.7 \pm 0.5\%$, Flexi vs. Sham, $p = 0.007$, Figure 5). In parallel, significantly higher RMS amplitudes of the leg muscle EMG activity were registered during Flexi- vs. Sham-bar exercise (main condition effect; RF: $32 \pm 36\%$; VL: $57 \pm 37\%$, $p = 0.001$, $p = 0.03$), but the median EMG frequencies were not different between trials ($p > 0.05$, Figure 5). There was also

a significant main time effect of exercise on both RMS EMG amplitude (RF: $17 \pm 11\%$, $p < 0.001$; VL: $14 \pm 15\%$, $p = 0.011$) and median EMG frequency (RF: $-10 \pm 7\%$, $p = 0.001$; VL: $-4 \pm 2\%$, $p = 0.008$) for both leg muscles (Figure 5).

Exercise-induced muscle performance changes were quantified by post- vs. pre-exercise comparison of MVC parameters for elbow flexion and extension and for knee extension. Figure 2 provides examples of the force and EMG signals recorded from a representative subject during testing for MVC in knee extension (Figure 2C) and elbow extension (Figure 2D). No time- and condition-dependent differences were observed in EMG and force parameters quantifying arm muscle activity and performance during the MVC tests (Figure 6). However, significant main condition and time vs. condition interaction effects were found when comparing post to pre-exercise values for the knee extension MVC force ($p = 0.048$) and RF EMG amplitude ($p = 0.039$, Figure 7). In contrast to the Sham-bar trials, in the Flexi-bar trials, both these measures were lower post than pre-exercise (MVC: $-3 \pm 7\%$ vs. $+3 \pm 9\%$, $p = 0.048$; RF RMS: $-8 \pm 5\%$ vs. $+4 \pm 9\%$, $p = 0.039$; Flexi vs. Sham; Figure 7). The VL EMG activity during the MVCs was not significantly affected either by condition or by time ($p > 0.05$, Figure 7).

DISCUSSION

The main finding of this study was that Flexi-bar exercise performed in a 1-leg squat position provoked specific acute adaptations in the activity of the muscles directly involved in the exercise. Significantly higher EMG amplitude and lower EMG median spectral frequency were evident during Flexi-bar exercise in the activity of the muscles close to the Flexi-bar (i.e., in the arm holding the bar) compared with the control trial completed with the Sham bar. The amplitude of the EMG activity in the studied leg muscles (RF and VL) was also significantly elevated when using the Flexi bar, but the EMG power spectrum was not significantly different between conditions. Also, significant time-dependent changes (elevated EMG amplitude and reduced MDF by the end of exercise sets) were observed in the activity of both arm and leg muscles. This pattern of change over time was not significantly different between the conditions suggesting that the observed time effects are most likely because of adaptation of muscle activation to prolonged exercise or initiation of fatigue effects.

There was no change in isometric elbow flexion or extension strength after Flexi-bar exercise, which implies that the Flexi-bar stimulus alone was not strong enough and/or the duration of the exercise was not long enough to result in significant residual changes in the postexercise performance of the arm muscles. However, a significant postexercise reduction in knee extension isometric strength was observed. It seems that the combination of unstable posture induced by the 1-legged squat and Flexi-bar exercise was sufficient to induce acute residual changes in leg muscle activation and performance.

Knee and elbow joint angles and the elbow angular velocity were not different between trials, demonstrating that the kinematic conditions of the Flexi-bar exercise were well reproduced in the Sham-bar exercise. The ICC values for the force and EMG measures, calculated from the data collected during the pre-exercise MVC tests in both trials, demonstrated fair-to-good reliability in line with previously reported reliability measures for peak torque and EMG during dynamic and isometric contractions (20). Therefore, the differences observed in MVC force and muscle activation parameters (EMG amplitude and MDF) between different conditions cannot be attributed to differences in postural characteristics or to data variability.

The Flexi bar is purported to deliver a very low-frequency vibration-like stimulus (5 Hz) through the point of contact (hand) to the rest of the body, although until now this has not been directly quantified. Mechanical vibration is known to induce interference within the EMG signal at the frequency of the vibration imparted (2). In the present study, analysis of the power spectra of the EMG signals before removal of the movement artefacts, revealed frequency peaks at about 5 Hz in the arm- and leg-muscle activity in the Flexi-bar trials and in the arm muscle activity in the Sham-bar trials although of considerably lower magnitude (Figure 3). Interference spectral peaks at 2.4 ± 0.1 Hz were registered in the leg muscle activity in the Sham-bar trials. This suggests that the Flexi-bar exercise successfully imparted 5-Hz vibration in arm muscles, which was effectively transmitted from hand, through the arm and trunk to the leg muscles, at least when in 1-leg squat position. Direct measurements of the acceleration reaching the muscles will be necessary to quantify the transmission of vibration induced by Flexi bar.

Abercromby et al. recently quantified vibration transmission through the body while standing on a whole-body vibration platform (1). The musculoskeletal system relies upon a number of passive mechanisms to attenuate the amplitude and frequency content of a continuous sinusoidal vibration. Bone and soft-tissue are 2 notable biological materials capable of preventing the propagation of such a stimulus. However, when subjected to prolonged vibration, these passive mechanisms alone will be unable to successfully damp the resulting energy (14) and require the influence of active mechanisms, including muscle activation and changes in segmental geometry, to prevent injurious consequences at more proximal segments of the body (19).

The present results showed significantly higher EMG amplitudes (all studied muscles) and lower MDF (arm muscles) of the EMG power spectrum when using the Flexi bar compared with the Sham bar. Because the kinematic data are well matched between trials these differences may be related to Flexi bar-induced vibration (5 Hz). However, it is not possible to determine whether the observed differences in muscle activation and performance between the conditions and their changes over time are due to the bar per se or the postural sway induced by using the Flexi bar. Increased EMG

amplitude is indicative of increased muscle activation (rate coding and motor unit recruitment). Median frequency decrease is reflective of peripheral (reduction in muscle fiber action potential conduction velocity) and central (synchronous firing of recruited motor units and recruitment of new motor units) changes (3,28). It is unlikely that such differences are because of fatigue within the first 10 seconds of the exercise sets. The observed lower MDF values in the Flexi-bar trials are most likely because of vibration-induced increased motor unit synchronization as previously suggested (23).

RMS EMG amplitude significantly increased over time (last 10 seconds compared with the first 10 seconds of the sets) in BB, RF, and VL muscles. In parallel, a significant decrease over time was observed in the MDF values in all studied muscles indicating muscle fatigue development in both experimental conditions (4,21). Most likely, the larger time-dependent changes in the EMG activity of leg muscles (RF and VL) are rather because of the increased demand for postural stability when performing 1-legged squat exercise than to the imposed disturbance by the vibration stimulus (2,7). It was previously shown that whole-body vibration applied during 1-legged squat produced significantly greater muscle EMG amplitudes than 2-legged squats (31), which conform to the results from the present study. In the Flexi-bar trials, these myoelectric manifestations of muscular fatigue were followed by a small (significant for knee extension and nonsignificant for elbow flexion) decrease in postexercise MVC force suggesting augmented muscle fatigue compared with the Sham-bar trials.

PRACTICAL APPLICATIONS

The potential for Flexi bar to impose a stronger training stimulus on the muscle during submaximal exercise appears promising. Shaking the Flexi bar introduced very low-frequency vibration either directly through the bar movement or indirectly by increasing postural sway. This potentiated the muscle activation levels during Flexi-bar exercise. As a result, an augmented fatigue development was achieved (lower maximum isometric knee extension force production), which could potentially increase the efficiency of training protocols particularly during rehabilitation or for frail individuals when only low-intensity or short duration training is possible. Further investigations are required to determine whether a longitudinal program of Flexi-bar exercise may be an effective training technique.

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