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ORIGINAL ARTICLE

Strength training with intermittent blood flow restriction improved strength without changes in neural aspects on quadriceps muscle

L'entraînement en force sous garrot intermittent accroît la force développée sans modifications de l'activité neuronale du muscle quadriceps

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KEYWORDS
Vascular occlusion;
Muscular strength;
Electromyography;
Neural adaptation

Summary
Objective. — The purpose of this study was to investigate the effects of low-intensity strength training with vascular occlusion on specific parameters of neural drive using amplitude and spectral analysis of surface electromyography.
Equipment and methods. — Twenty individuals were assigned to one of two groups (low-intensity strength training with or without vascular occlusion). The first group performed three sets of knee extension exercises until failure, with a 90 seconds interval between sets, while the second group performed three sets of the mean repetitions of the first group. Both groups performed the exercises with the load set at 20% of estimated 1 maximal repetition. To assess electromyographic parameters, sessions 1, 7 and 12 were evaluated, specifically from the first to third repetitions and the 3 final repetitions. One maximal repetition was measured in the same collection times.

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Results. — Our findings demonstrated that low-intensity strength training with vascular occlusion improved muscular strength; however, it did not affect the neural drive, since there were no differences in the investigated parameters between sessions.
Conclusion. — Low-intensity strength training with vascular occlusion is effective for producing muscular strength; however, it is not indicated for increases in neural activity.

MOTS CLÉS
Occlusion vasculaire ;
Force musculaire ;
Électromyographie ;
Adaptation neuronale

Résumé
Objectifs. — Le but de cette étude était d'évaluer les effets de l'entraînement en force de faible intensité avec occlusion vasculaire, sur les paramètres de l'activité neuronale, en utilisant l'amplitude et l'analyse spectrale du signal électromyographique de surface.
Matériel et méthodes. — Vingt sujets sains ont été assignés par randomisation à l'un des deux groupes expérimentaux suivants : entraînement de 6 semaines en force de faible intensité, avec ou sans occlusion vasculaire, à raison de 2 séances par semaine. Chaque séance comportait, pour le premier groupe (entraîné sous garrot), trois séries d'exercices de renforcement des extenseurs du genou jusqu'à épuisement, avec un intervalle de 90 secondes entre les séries. Le second groupe (entraîné sans garrot) effectuait trois séries de contractions dont le nombre et la fréquence étaient similaires à celles du premier groupe. Les deux groupes ont accompli les exercices de contraction avec une charge de 20 % d'une répétition maximum. Afin d'étudier l'évolution des paramètres électromyographiques dans les deux situations expérimentales, les signaux recueillis pendant les contractions 1, 7 et 12 ont été analysés pendant les trois premières répétitions, et les trois dernières. Une répétition maximum a été évaluée dans les mêmes périodes de la collecte.
Résultats. — Les résultats obtenus ont montré que l'entraînement en force de faible intensité avec occlusion vasculaire améliorait la force musculaire développée ; on n'a cependant pas pu mettre en évidence de corrélation entre l'amélioration des performances musculaires et les signaux représentatifs de l'activation neuronale.
Conclusion. — L'entraînement en force de faible intensité associé à une occlusion vasculaire permet d'améliorer la production de la force musculaire; néanmoins, ce gain de performance ne semble pas associé à une amélioration de l'activité neuronale.

1. Introduction

According to the current knowledge, muscular strength is influenced by skeletal muscle hypertrophy and/or changes in neural drive, among others factors [1]. The relationship between skeletal muscle cross-sectional area and strength is well established [2]. According to this relation, the larger the skeletal muscle cross-sectional area, the higher the strength levels generated. However, in some situations, e.g. the initial phases of strength training, increases in strength occur prior to significant hypertrophy, which suggests the influence of the neural drive, despite the enhancement of the cross-sectional area [3,4]. Moreover, in some sports in which gains in body weight are not desired, strength enhancement due to changes in neural activity can be obtained through a well-designed training schedule [1,5].

Changes in neural drive have been commonly evaluated by surface electromyography. Increases in the amplitude of surface electromyographic activity (SEMG) have been shown following strength training [4,6—9]. This has been interpreted as an increase in neural drive, which denotes the magnitude of efferent neural output from the central nervous system (CNS) to active muscle fibres [10]. Moreover, the electromyographic recording of muscle activity at the same absolute intensities is commonly reduced after strength training, however, may be higher at relative intensities [4]. Therefore, part of muscular strength gain is related to its output and is a result of neural adaptations after strength training [5].

In recent decades, strength training under conditions of vascular occlusion has been shown to be able to produce increases in muscular strength and hypertrophy [11—15]. This methodology consists of exercising the muscle groups at low-intensity using inflatable cuffs placed around the upper or lower limbs to restrict (partial occlusion) or inhibit (total occlusion) the arterial blood flow in the exercised muscle group or segment. Currently, there are several studies demonstrating higher acute SEMG activity during low-intensity strength training with vascular occlusion than resistance exercise using the same relative intensity without occlusion [16—20]. The hypothesis regarding this effect is that vascular occlusion produces a progressive or preferential recruitment of high threshold motor units due to the reduction in oxygen availability [21,22].

Despite studies that demonstrate increases in SEMG during one bout of low-intensity strength training with vascular occlusion, there are few studies that have examined

the neural adaptations following a long period of training [13,16,23]. Moore et al. [16] did not find changes in motor unit activation during maximal voluntary isometric torque (MVC) of the elbow flexors following 8 weeks of unilateral elbow flexion at 50% of 1MVC with and without vascular occlusion using the twitch interpolation technique. Similar results using the same methodology were shown by Kubo et al. [23] after a 12-week unilateral isotonic training program on the knee extensors. However, Manimmanakorn et al. [13] demonstrated that 5 weeks of training with knee flexion and extension exercises at 20% 1RM, increased the SEMG amplitude in the low-intensity strength training with vascular occlusion group during both 3 s and 30 s MVC. These results allowed the authors to suggest that training caused neuromuscular adaptation due to increased SEMG amplitude. To our knowledge, different from previous research, which investigated neural response during MVC [13,16,23], there is no information about the responses of the neural drive in the same training situations. Moreover, according to the specificity principle of training, the more similar the evaluations are to the trained exercise, the greater the reliability of the results [24,25]. Therefore, the purpose of the present study was to examine the effects of low-intensity strength training with vascular occlusion on neural adaptations following a training period.

2. Equipment and methods

2.1. Subjects

Twenty healthy male volunteers with at least 6 months of experience in resistance training volunteered to participate in this study (23 ± 6.1 years; 1.76 ± 0.05 m height; 79.1 ± 10 kg body weight). The participants were informed about the experimental procedures and written informed consent was obtained prior to the beginning of the protocol. To ensure that the subjects were healthy, a physical activity readiness questionnaire (PAR-Q) was answered before beginning the study [26]. Moreover, the exclusion criteria adopted were:

- use of anabolic steroids or ergogenic aids that could affect the investigated variables;
- orthopaedic diseases or injuries which could prevent the subjects from performing the exercise;
- diseases not included in the other criteria but which have harmful effects for the individuals or results of the study.

The study was approved by the Ethics Committee of the Faculty of Philosophy, Sciences and Languages of Ribeirão Preto, University of São Paulo, Ribeirão Preto, Brazil.

2.2. Procedures

To examine the effects of low-intensity strength training with vascular occlusion on neural adaptations of skeletal muscle following a training programme, volunteers were randomly assigned to one of two groups:

- low-intensity resistance exercise with intermittent vascular occlusion (LIVO) ($n = 11$);
- low-intensity resistance exercise without vascular occlusion (LI) ($n = 9$).

The dependent variables investigated were: predicted 1RM knee extension, SEMG amplitude [root mean square (RMS)] and SEMG median frequency (MDF). Participants were instructed not to change their regular training routine. They participated in a familiarization session for the exercise used throughout the study (unilateral knee extension) 2 days before the beginning of the experimental protocol. The assessments were conducted at pre-training (week 1), after 3 weeks of training (week 5) and at the end of the protocol (week 9). The experimental protocol lasted 9 weeks composed of 3 weeks of assessments and 6 weeks of training, during which the subjects trained 2 days a week, performing 3 sets of unilateral knee extension exercises, with a 90″ interval between each set.

2.2.1. Maximal repetitions test and familiarization

Two days before the beginning of the experimental protocol, the volunteers participated in a familiarization session with the exercise machine (Extensor LFS, Lion Fitness, São Paulo, Brazil), performing 2 sets of 20 repetitions. The first set was performed in a free fashion while the second set was under the cadence of repetitions used during the protocol [27].

Prior to the test, subjects performed a 10 minute warm-up on a stationary bike at a low-to-moderate intensity (level 3—5 of the Borg scale) before the knee extension exercise. For the maximal repetitions test, the subjects performed as many repetitions as possible in one set of unilateral knee extensions with the estimated load which permitted the individuals to perform 6 to 10 repetitions for each leg. This procedure ensures greater reliability in the estimated 1RM through the Brzycki equation [28]. The test had a cadence of repetitions controlled by a metronome (software Metronome Plus 2.0.0.1.) set at 30 beats per minute (2″ for each concentric and eccentric phase). When the volunteer was not able to maintain the cadence or the range of motion (from 90 — start position — to 0 — full extension —) the test was interrupted. Finally, the data were inserted in the Brzycki equation to determine the one maximum repetition.

2.2.2. Surface electromyography

Assessment of SEMG activity was carried out during the 1st, 7th and 12th sessions using the TRIGNO™ wireless system (DELSYS®, Boston, USA). The skin preparation and locations of the electrodes were made according to the Surface ElectroMyoGraphy for the Noninvasive Assessment of Muscles (SENIAM) recommendations for the vastus medialis (VM) and vastus lateralis (VL) muscle groups respectively. The marked points of the skin were shaved, slightly abraded and cleaned with 70% ethanol and then the wireless EMG sensor was placed in the direction of the muscle fibres.

The electrical activity was obtained at 2000 Hz sampling rate, EMG bandwidth from 20 to 450 Hz and an effective EMG signal gain of 909 V/V ± 5%. Data were processed using software EMGworks 4.1.5 Analysis® (DELSYS®, Boston, USA). A 4th order *Butterworth* filter was used for filtering all raw EMG data with a band-pass filter from 10 to 500 Hz. The mean

values of root mean square (RMS) and median frequency (MDF) during the 3 first and 3 final repetitions (repetition zone) for each set were used to compare groups in the same sets, repetition zone and time points as well as between time points within a group in the same set and repetition zone. Moreover, analyses were conducted between sets in the same time point within each group for the same repetition zone.

2.2.3. Blood flow restriction

The occlusion pressure was determined with the assistance of a Doppler device (VersaLab®, Madison, WI, USA) prior to starting the experimental training protocol. To determine the occlusion pressure, a modified cuff (95 cm length × 15 cm width; JPJ®, São Paulo, Brazil) was positioned around the thigh immediately below the gluteal line, and the volunteer positioned in the prone position, allowing the evaluator to locate the popliteal artery using a 4 MHz Doppler sensor. The sensor was positioned with water soluble gel (Aquasonic®100) angled 45° in relation to the blood vessel, with a Doppler insonation angle opposite to the blood flow [29]. Then, the cuff was inflated until the sound of the Doppler device was not audible. This pressure was noted and the same procedure was conducted on the other lower limb. Measurements were performed 3 times in an alternate fashion [30]. The highest value obtained at the end of the assessments was used as the occlusion pressure during the training. The mean value of pressure applied to the lower limbs of the LIVO group was 140 ± 19 mmHg.

2.2.4. Training

The subjects underwent a period of training with (LIVO group) and without vascular occlusion (LI group) with 20% of the predicted 1RM. All individuals performed the same warm-up protocol used before the maximal repetitions test. Following, the subjects performed the unilateral knee extension with the right lower limb followed by the left lower limb. The range of motion was set at 0° to 90° and if the subject was unable to maintain the range of movement, the set was terminated. During rest periods, the cuff used for LIVO was deflated.

The cadence of movement was dictated by a metronome and, similar to range of motion, if the subject was unable to follow the cadence, the set was terminated. The LIVO group performed 3 sets until failure while the LI group performed the mean repetitions achieved by the LIVO group during each set in each session. This procedure was adopted to allow the LI group to perform a work-matched training protocol. After 3 weeks of training, 1 week of retests was carried out and the training load adjusted. Thereafter, there was a further 3 weeks of training followed by another final week of evaluations.

2.3. Statistical analyses

Statistical power was calculated from muscular strength data obtained in a pilot study and revealed a power of 0.94 for 10 volunteers in each group. Data were analysed using descriptive statistics (mean and standard deviation) and the Kolmogorov–Smirnov & Lilliefors test for normality, the Mauchley sphericity test, mixed ANOVA and Tukey test for comparison between and within groups. For the analysis of the RMS and MDF in the 3 first and 3 final repetitions within a session in different sets, one-way ANOVA was used. Results were considered significant when the differences presented values of $P < 0.05$. All data analyses were conducted using the software Statisitica 7.0.0 (StatSoft, Tulsa, USA).

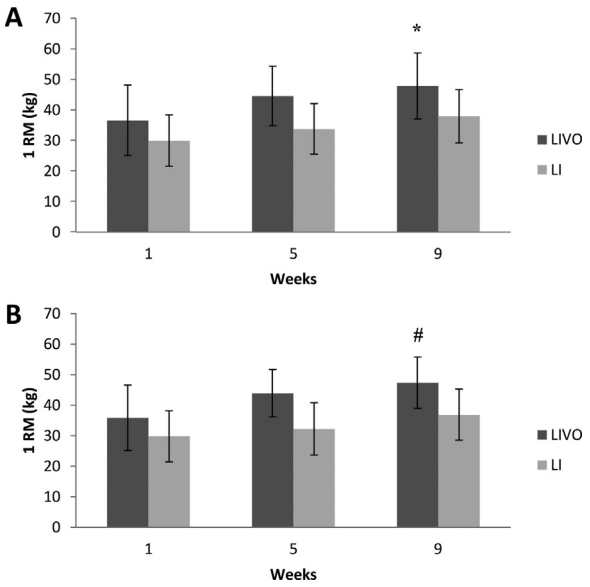

Figure 1 Predicted 1RM at three time points: before (week 1), mid (week 5) and after (week 9) the experimental protocol in the right lower limb (A) and left lower limb (B). * $P < 0.05$ from week 1 to 9 in the same group; # $P < 0.01$ from week 1 to 9 in the same group.

3. Results

3.1. Predicted one maximal repetition

LIVO group showed significant changes in the predicted 1RM in both right (from 36.54 ± 11.53 kg to 47.88 ± 10.81 kg, $P < 0.05$; Fig. 1A) and left (from 35.86 ± 10.68 kg to 47.35 ± 8.44 kg, $P < 0.01$; Fig. 1B) lower limbs across the protocol. No differences between groups in any session for both lower limbs were found. There were no statistical changes in the LI group (from 29.93 ± 8.41 kg to 37.91 ± 8.72 kg, $P > 0.05$ for the right lower limb and; from 29.81 ± 8.38 kg to 36.86 ± 8.34 kg, $P > 0.05$ for the left lower limb).

3.2. Electromyography

The right vastus medialis RMS of the LIVO group was higher than the LI group in the set 3 of the session 1 ($P < 0.05$) and in the sets 1 ($P < 0.05$), 2 ($P < 0.01$) and 3 ($P < 0.05$) of the session 12 for the 3 first repetitions. For the last 3 repetitions the RMS was higher in the LIVO group in the sets 1 ($P < 0.05$) and 2 ($P < 0.05$) of the session 1 and in the sets 1 ($P < 0.05$), 2 ($P < 0.05$) and 3 ($P < 0.05$) of the session 12 (Table 1).

For the 3 first repetitions, the right vastus lateralis RMS of the LIVO group was higher than the LI group in the sets 1 ($P < 0.01$), 2 ($P < 0.01$) and 3 ($P < 0.001$) of the session 1, in the sets 1 ($P < 0.01$), 2 ($P < 0.05$) and 3 ($P < 0.05$) of the session 7

Table 1 Root mean square (RMS) given in volts (V) for the right lower limb during sessions 1, 7, 12.

	Sessions	Groups	RMS (V)					
			3 first repetitions			3 final repetitions		
			1st set	2nd set	3rd set	1st set	2nd set	3rd set
Right vastus medialis	1	LIVO	1.55 ± 1.11E-4	1.47 ± 1.13E-4	1.76 ± 1.32E-4[a]	2.34 ± 1.42E-4[a]	2.51 ± 1.53E-4[a]	2.35 ± 1.49E-4
		LI	0.81 ± 0.33E-4	0.62 ± 0.17E-4	0.73 ± 0.23E-4	0.87 ± 0.22E-4	1.01 ± 0.3E-4	1.18 ± 0.38E-4
	7	LIVO	1.18 ± 0.75E-4	1.11 ± 0.66E-4	1.24 ± 0.71E-4	1.47 ± 0.91E-4	1.67 ± 1E-4	1.7 ± 0.92E-4
		LI	0.64 ± 0.27E-4	0.59 ± 0.18E-4	0.7 ± 0.24E-4	0.79 ± 0.21E-4	0.9 ± 0.24E-4	1.06 ± 0.41E-4
	12	LIVO	1.67 ± 1.24E-4[a]	1.73 ± 1.39E-4[b]	1.77 ± 1.14E-4[a]	2.21 ± 1.76E-4[a]	2.19 ± 1.63E-4[a]	2.23 ± 1.55E-4[a]
		LI	0.61 ± 0.19E-4	0.54 ± 0.19E-4	0.63 ± 0.18E-4	0.81 ± 0.22E-4	0.84 ± 0.18E-4	0.87 ± 0.18E-4
Right vastus lateralis	1	LIVO	1.11 ± 0.48E-4[b]	1.07 ± 0.5E-4[b]	1.27 ± 0.58E-4[c]	1.48 ± 0.75E-4[b]	1.61 ± 0.61E-4[c]	1.68 ± 0.63E-4[b]
		LI	0.63 ± 0.29E-4	0.49 ± 0.14E-4	0.59 ± 0.17E-4	0.68 ± 0.21E-4	0.81 ± 0.23E-4	0.94 ± 0.3E-4
	7	LIVO	1.17 ± 0.59E-4[b]	1.10 ± 0.60E-4[a]	1.21 ± 0.61E-4[a]	1.42 ± 0.82E-4	1.53 ± 0.78E-4[a]	1.65 ± 0.84E-4[a]
		LI	0.51 ± 0.14E-4	0.49 ± 0.11E-4	0.59 ± 0.17E-4	0.68 ± 0.13E-4	0.76 ± 0.16E-4	0.89 ± 0.25E-4
	12	LIVO	1.16 ± 0.5E-4[b]	1.15 ± 0.63E-4[c]	1.19 ± 0.55E-4[b]	1.4 ± 0.8E-4[a]	1.53 ± 0.75E-4[b]	1.55 ± 0.76E-4[a]
		LI	0.56 ± 0.18E-4	0.53 ± 0.18E-4	0.64 ± 0.24E-4	0.73 ± 0.25E-4	0.86 ± 0.24E-4	0.93 ± 0.32E-4

The data are given as mean ± standard deviation.
[a] $P < 0.05$ between groups in the same session.
[b] $P < 0.01$ between groups in the same session.
[c] $P < 0.001$ between groups in the same session.

and in the sets 1 ($P < 0.01$), 2 ($p < 0.001$) and 3 ($P < 0.01$) of the session 12. Also, RMS was higher in the LIVO group for the 3 last repetitions in the sets 1 ($P < 0.01$), 2 ($P < 0.001$) and 3 ($P < 0.01$) of the session 1, in the sets 2 ($P < 0.05$) and 3 ($P < 0.05$) of the session 7 and in the sets 1 ($P < 0.05$), 2 ($P < 0.01$), 3 ($P < 0.05$) of the session 12 (Table 1).

Left vastus medialis RMS of the LIVO group was greater than the LI group for the 3 first repetitions in the sets 1 ($P < 0.05$), 2 ($P < 0.05$) and 3 ($P < 0.01$) of the session 1, in the set 3 of the session 7 ($P < 0.05$) and in the sets 2 ($P < 0.05$) and 3 ($P < 0.05$) of the session 12. Moreover, RMS of the LIVO group was higher for the 3 final repetitions in sets 1 ($P < 0.05$), 2 ($P < 0.05$) and 3 ($P < 0.05$) of the session 1 and in the set 3 of the session 7 ($P < 0.05$) (Table 2).

Left vastus lateralis RMS was different between groups in the sets 1 ($P < 0.01$), 2 ($P < 0.01$) and 3 ($P < 0.01$) of the session 1 and in the sets 1 ($P < 0.01$), 2 ($P < 0.01$) and 3 ($P < 0.05$) of the session 12 for the 3 first repetitions. Similarly, RMS for the 3 final repetitions was higher in the LIVO group in the sets 1 ($P < 0.05$), 2 ($P < 0.01$) and 3 ($P < 0.05$) of the session 1 and in the sets 1 ($P < 0.05$), 2 ($P < 0.05$) and 3 ($P < 0.05$) of the session 12 (Table 2).

Right vastus medialis MDF differences were found between groups in the sets 1 ($P < 0.05$), 2 ($P < 0.05$) and 3 ($P < 0.05$) of the session 7 for the 3 first repetitions. Likewise, MDF was greater in the LIVO group for the 3 final repetitions in the sets 1 ($P < 0.01$), 2 ($P < 0.05$) and 3 ($P < 0.05$) in the session 7. No differences between groups were found for right vastus lateralis MDF (Table 3).

Left vastus medialis MDF was different between groups only for the 3 first repetitions in the set 1 of the session 12 ($P < 0.01$). No differences between groups in the 3 final repetitions were found. Left vastus lateralis MDF were higher in the LIVO group for the 3 first repetitions in the set 1 of the session 1 ($P < 0.01$) and in the sets 1 ($P < 0.01$) and 2 ($P < 0.01$) of the session 7. Again, no differences between groups for the 3 final repetitions were found (Table 4).

Both LIVO and LI groups did not show any RMS (Tables 1 and 2) or MDF (Tables 3 and 4) difference between sets for the same repetition zone in any session as well as between sessions for the same set and repetition zone.

4. Discussion

The main finding of this study was the increase in muscular strength without a specific change in neural activity following LIVO. Some studies have examined the effects of low-intensity training with vascular occlusion on neural adaptations and found ambiguous results [13,16,23]. While some studies did not find neural adaptations [16,23] others found improved neural function [13]. However, to our knowledge, this is the first study to investigate specific neural adaptations in a determined pattern of motion during a 6-week training programme.

The LIVO group produced increases in muscular strength, whereas the levels of strength in the LI group did not change significantly (Fig. 1A and B). These results are in accordance with other studies, which demonstrated increments in leg extension strength after low-intensity strength training with vascular occlusion [11,12,14,15]. It has been proposed that these enhancements in muscular strength could be, among other factors, due to the higher recruitment of motor units, mainly the high threshold motor units which unnerve fast-twitch fibres that have greater hypertrophic potential [21,22]. In fact, our results demonstrated higher LIVO group EMG amplitude (RMS) than the LI group during training sessions (Tables 1 and 2) which corroborate the findings of other studies [16—20,31] where low-intensity strength training with vascular occlusion caused an acute increase in EMG amplitude suggesting higher recruitment of motor units. So, this mechanism might lead to a larger hypertrophic response which could be responsible for the increases in muscular strength seen in this work.

Differences in RMS were shown only between conditions in the same session (Tables 1 and 2). The LIVO group RMS values were frequently higher than the LI group in the 3 first repetitions. It is well established that muscle spindles and Golgi tendon organs are structures that affect neuromuscular activity through inhibitory or excitatory signals, modulating the force production [2]. These structures supply the CNS with peripheral information, which is crucial to modulate strength. However, the pressure applied during complete occlusion might disturb these feedback mechanisms, impairing the sensory function of muscles and causing a reduction in the reflex inhibition of alpha motoneurons leading to greater motor unit recruitment [32]. Therefore, it is possible that this lack of sensory feedback may increase the RMS, suggesting greater motor unit recruitment during sets in the LIVO group.

After strength training, the amplitude of SEMG has been shown to be lower at the same absolute force, indicating an increased recruitment and synchronously-contracting motor units, but higher activity at the same relative force [4]. If low-intensity strength training with vascular occlusion caused neural adaptations after a period of training, similar responses would be expected to be seen. However, our results did not demonstrate changes between the same sets in the same repetition zones at different time points, demonstrating that there were no neural adaptations. These results contradict the results of Manimmanakorn et al. [13], who presented a tendency for lower RMS signals compared to the values pre-training during a free blood flow set until exhaustion at 20% of 1RM. However, we utilized the same protocol as that used for the training while the latter study used a different set. In this way and as mentioned earlier, the pressure caused by the cuff may have influenced the motor unit recruitment making difficult to detect any difference. Still, the results found in this study pointed out the lack of specific neural adaptation. According to the specificity principle of training, if a specific neural adaptation occurs after low-intensity strength training with vascular occlusion, it is more likely to be found in the same setting in which training was performed [24,25] what was not the case.

There were no differences between RMS in the repetition zones at the same time point but different sets for either group. Some studies [16,33] have demonstrated higher amplitude of SEMG in subsequent sets during low-intensity strength training with vascular occlusion. One possible explanation for these differences is related to the impact of the methodological design on fatigue. During repetitive bouts of exercise interspersed with incomplete recovery, the fatigue effects become more pronounced depending on how the rest is performed (occluded or not),

Table 2 Root mean square (RMS) given in volts (V) for the left lower limb during sessions 1, 7, 12.

	Sessions	Groups	RMS (V)					
			3 first repetitions			3 final repetitions		
			1st set	2nd set	3rd set	1st set	2nd set	3rd set
Left vastus medialis	1	LIVO	1.38 ± 1.29E-4[a]	1.26 ± 1.09E-4[a]	1.45 ± 1.08E-4[b]	1.66 ± 1.27E-4[a]	1.66 ± 1.33E-4[a]	1.95 ± 1.36E-4[a]
		LI	0.62 ± 0.36E-4	0.5 ± 0.26E-4	0.57 ± 0.28E-4	0.72 ± 0.33E-4	0.76 ± 0.33E-4	0.87 ± 0.35E-4
	7	LIVO	1.43 ± 0.86E-4	1.27 ± 0.69E-4	1.56 ± 0.89E-4[a]	1.63 ± 1E-4	1.82 ± 1.14E-4	2.01 ± 1.16E-4[a]
		LI	0.51 ± 0.14E-4	0.43 ± 0.08E-4	0.53 ± 0.09E-4	0.63 ± 0.1E-4	0.73 ± 0.17E-4	0.83 ± 0.21E-4
	12	LIVO	1.09 ± 0.73E-4	1.12 ± 0.85E-4[a]	1.27 ± 1E-4[a]	1.43 ± 1.12E-4	1.46 ± 0.94E-4	1.56 ± 1.03E-4
		LI	0.44 ± 0.14E-4	0.4 ± 0.1E-4	0.47 ± 0.11E-4	0.67 ± 0.27E-4	0.64 ± 0.11E-4	0.67 ± 0.12E-4
Left vastus lateralis	1	LIVO	1.23 ± 0.67E-4[b]	1.15 ± 0.65E-4[b]	1.53 ± 1.16E-4[b]	1.41 ± 0.89E-4[a]	1.55 ± 0.86E-4[b]	1.68 ± 0.93E-4[a]
		LI	0.76 ± 0.33E-4	0.6 ± 0.25E-4	0.64 ± 0.22E-4	0.78 ± 0.27E-4	0.87 ± 0.33E-4	0.97 ± 0.35E-4
	7	LIVO	1.23 ± 0.51E-4	1.13 ± 0.46E-4	1.34 ± 0.54E-4	1.47 ± 0.72E-4	1.6 ± 0.72E-4	1.69 ± 0.63E-4
		LI	0.65 ± 0.23E-4	0.55 ± 0.16E-4	0.66 ± 0.17E-4	0.78 ± 0.2E-4	0.87 ± 0.23E-4	0.94 ± 0.2E-4
	12	LIVO	1.25 ± 0.63E-4[b]	1.27 ± 0.65E-4[b]	1.43 ± 0.74E-4[a]	1.57 ± 0.89E-4[a]	1.62 ± 0.81E-4[a]	1.76 ± 0.82E-4[a]
		LI	0.58 ± 0.18E-4	0.54 ± 0.16E-4	0.6 ± 0.16E-4	0.77 ± 0.2E-4	0.85 ± 0.23E-4	0.88 ± 0.2E-4

The data are given as mean ± standard deviation.
[a] $P < 0.05$ between groups in the same session.
[b] $P < 0.01$ between groups in the same session.

Table 3 Median frequency (MDF) given in hertz (Hz) for the right lower limb during sessions 1, 7, 12.

	Sessions	Groups	MDF (Hz)					
			3 first repetitions			3 final repetitions		
			1st set	2nd set	3rd set	1st set	2nd set	3rd set
Right vastus medialis	1	LIVO	95.35 ± 22.94	92.61 ± 16.99	90.94 ± 15.85	70.8 ± 19.3	79.43 ± 16.55	80.64 ± 18.78
		LI	74.83 ± 13.36	76.28 ± 11.89	75.64 ± 13.14	68.09 ± 10.91	71.48 ± 12.27	73.15 ± 14.25
	7	LIVO	107.21 ± 31.45[a]	103.49 ± 25.56[a]	101.25 ± 23.75[a]	88.88 ± 18.83[b]	95 ± 27.27[a]	100.95 ± 27.89[a]
		LI	75.62 ± 14.7	74.55 ± 13.13	75.44 ± 14.37	66.19 ± 14.34	71.07 ± 16.22	73.61 ± 15.42
	12	LIVO	103.54 ± 25.33	95.56 ± 21.31	94.02 ± 17.56	81.06 ± 11.81	85.65 ± 16.47	88.68 ± 14.17
		LI	83.59 ± 10.81	84.6 ± 13.52	83.72 ± 11.9	76.7 ± 12.26	82.07 ± 12.84	83.69 ± 12.4
Right vastus lateralis	1	LIVO	84.06 ± 18.9	80.67 ± 15.41	79.29 ± 15.44	67.49 ± 11.36	73.45 ± 16.11	73.05 ± 13.56
		LI	70.17 ± 8.7	70.18 ± 8.79	69.11 ± 8.7	64.39 ± 9.38	66.01 ± 9.4	65.46 ± 10.49
	7	LIVO	86.63 ± 18.9	82.5 ± 12.34	83 ± 10.7	76.4 ± 15.15	78.26 ± 13.42	82.67 ± 12.72
		LI	73.37 ± 10.42	71.4 ± 7.86	71.21 ± 9.63	67.08 ± 10.38	68.64 ± 11.3	69.75 ± 11.17
	12	LIVO	83.86 ± 16.54	80.49 ± 13.51	78.75 ± 16.09	68.77 ± 9.84	71.59 ± 14.91	75.4 ± 14.84
		LI	72.99 ± 8.26	70.29 ± 9.25	70.45 ± 9.72	67.36 ± 10	67.62 ± 9.93	69.5 ± 10.45

The data are given as mean ± standard deviation.
[a] $P < 0.05$ between groups in the same session.
[b] $P < 0.01$ between groups in the same session.

Table 4 Median frequency (MDF) given in hertz (Hz) for the left lower limb during sessions 1, 7, 12.

	Sessions	Groups	MDF (Hz)					
			3 first repetitions			3 last repetitions		
			1st set	2nd set	3rd set	1st set	2nd set	3rd set
Left vastus medialis	1	LIVO	97.95 ± 17.23	93.1 ± 9.67	91.47 ± 10.15	78.21 ± 6.14	84.87 ± 8.19	86.24 ± 10.38
		LI	82.7 ± 16.8	82.35 ± 18.57	82.76 ± 19.35	75.27 ± 16.18	82.1 ± 19.8	85.11 ± 20.73
	7	LIVO	91.52 ± 15.48	92.9 ± 17.59	88.03 ± 12.4	77.57 ± 10.99	86.18 ± 14.19	83.99 ± 12.65
		LI	75.25 ± 16.74	75.31 ± 16.39	76.66 ± 17.05	68.7 ± 16.04	72.24 ± 17.43	74.11 ± 18.93
	12	LIVO	101.08 ± 22.94[a]	94.39 ± 18.2	91.78 ± 16.99	80.82 ± 20.76	86.79 ± 23.05	87.02 ± 24.84
		LI	75.74 ± 24.02	77.36 ± 20.05	76.8 ± 19.22	73.52 ± 23.4	76.58 ± 20.57	77.81 ± 21.48
Left vastus lateralis	1	LIVO	82.92 ± 12.21[a]	78.52 ± 6.72	74.97 ± 7.73	69.07 ± 7.79	72.24 ± 12.88	74.04 ± 15.89
		LI	68.4 ± 7.78	69.43 ± 7.74	69.29 ± 7.07	63.94 ± 6.44	66.86 ± 6.33	67.54 ± 7.4
	7	LIVO	88.6 ± 16.84[a]	87.09 ± 18.54[a]	83.61 ± 16.06	75.15 ± 15.34	80.05 ± 16.87	76.99 ± 15.28
		LI	69.47 ± 7.87	69.53 ± 8.66	70.65 ± 9.26	62.07 ± 3.75	66.26 ± 6.78	67.08 ± 7.97
	12	LIVO	84.26 ± 17.47	77.24 ± 16.61	76.12 ± 15.54	70.46 ± 17.62	72.37 ± 17.82	73.16 ± 17.94
		LI	74.24 ± 11.8	73.95 ± 12.54	74.42 ± 11.61	69.44 ± 12.31	72.41 ± 11.8	73.74 ± 12.74

The data are given as mean ± standard deviation.
[a] $P < 0.01$ between groups in the same session.

the length of the rest interval, the level of effort achieved during the sets and the number of sets performed. Therefore, it is difficult to make a comparison between studies because of the large variety of occluded training protocols. Even so, it is possible that the results obtained in the present study could be attributed to the intermittent occlusion and length of the rest interval, minimizing the accumulation of fatiguing metabolites, e.g. H^+ ions from the active muscle, compared to continuous occlusion [16].

MDF normally exhibit the same pattern between the conditions in the same set and repetition zone for the same time point. Other results have demonstrated either no acute significant difference [33] or statistical differences [31] in mean power frequency between groups with and without vascular occlusion. One possible explanation for these differences may be related to skin and thickness of subcutaneous fat of the limb [34]. Karabulut and Perez [34] found that a decrease in median frequency during knee extensions with vascular occlusion is dependent on skin and subcutaneous fat thickness, which can influence initial restrictive pressure. This might also explain our findings since the physical characteristics of the volunteers in the present study were similar to those of the subjects in Karabulut et al.'s study [33]. Due to the MDF having been used as an index of alterations in electrical conduction frequency through the active motor units [35,36] and a decrease being expected during a fatiguing exercise [37], it is possible that the fatiguing effects, at least from a neural fatigue aspect, are similar during the exercise with and without vascular occlusion [33].

There were no changes in MDF for the same repetition zone and set but different time points for either the LIVO or LI. To our knowledge, this is the first chronic study to evaluate if low-intensity strength training with vascular occlusion affects frequency parameters. It is known that resistance exercise may increase maximal frequency of muscle fibre action potentials [38]. As MDF is often used to detect changes in electrical conduction frequency an increment in maximal frequency of muscle fibre action could increase the MDF while better synchronization would decrease the MDF [37]. Nevertheless, the lack of changes in MDF along with RMS between time points suggests that there was no specific neural adaptation.

MDF did not demonstrate significant changes between sets in the same repetition zone and time point for either group. Other findings have shown a decrease between sets during vascular occlusion [31]. However, this study used a continuous and complete occlusion, while in the present study intermittent occlusion was utilized. This fact could soften the imbalance between the energy demand (increased muscle activation) and energy supply (blood flow), unlike continuous occlusion [31].

Taken together, the lack of neural adaptation either during maximal effort [16,23] or during a specific pattern of motion (our results) and enhancements in strength support the hypothesis proposed by Loenneke et al. [39], that this training methodology, at least during the beginning of training, is primarily influenced by hypertrophy. This is opposite to what occurs during the initial stages of strength training. Furthermore, Kubo et al. [23] and Takarada et al. [40] found enhancements in muscular strength following low-intensity resistance training with vascular occlusion but no changes in the relationship between force and muscle cross-sectional area. These data suggest that low-intensity strength training with vascular occlusion increases strength through hypertrophy. Despite hypertrophy not being measured in this research, the lack of evidence of neural adaptations make it possible that increases in muscular strength could have been caused by hypertrophy.

5. Conclusions

Low-intensity strength training with intermittent vascular occlusion is capable to produce increases in muscular strength. However, specific neural adaptations to a pattern of motion appear not occur. So, the results of this study can be useful for utilization of this method of training in a practice view. The most important aspect of training is the transference of gains from the training to the real situations of practice. If this transference does not occur, or is limited, the training will not improve performance satisfactorily. Although muscular strength is an important physical capacity in sports, hypertrophy is not always desirable. Since hypertrophy is possibly the main factor to account for muscular strength in this technique, in sports or situations where strength, but not hypertrophy, is desired, high-intensity strength training continues to be the most appropriate training. However, if the goal is hypertrophy low-intensity strength training with vascular occlusion deserves consideration.

Disclosure of interest

The authors declare that they have no competing interest.

References

[1] American College of Sports Medicine. Position stand: progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009;41(3):687—708.
[2] McArdle WD, Katch FI, Katch VL. Fisiologia do exercício: Energia, Nutrição e Desempenho Humano. 5a ed. Rio de Janeiro: Editora Guanabara Koogan; 2003.
[3] Narici MV, Roi GS, Landoni L, Minetti AE, Cerretelli P. Changes in force, cross-sectional area and neural activation during strength training and detraining of the human quadriceps. Eur J Appl Physiol 1989;59:310—9.
[4] Häkkinen K, Komi PV. Electromyographic changes during strength training and detraining. Med Sci Sports Exerc 1983;15(6):455—60.
[5] Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc 2004;36(4):678—88.
[6] Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J Appl Physiol 2002;93(4):1318—26.
[7] Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Halkjaer-Kristensen J, Dyhre-Poulsen P. Neural inhibition during maximal eccentric and concentric quadriceps contraction: effects of resistance training. J Appl Physiol 2000;89(6):2249—57.
[8] Higbie EJ, Cureton KJ, Warren 3rd GL, Prior BM. Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. J Appl Physiol 1996;81(5):2173—81.

[9] Seynnes OR, De Boer M, Narici MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. J Appl Physiol 2007;102:368—73.
[10] Gabriel DA, Kamen G, Frost G. Neural adaptations to resistive exercise: mechanisms and recommendations for training practises. Sport Med 2006;36(2):133—49.
[11] Laurentino GC, Ugrinowitsch C, Roschel H, Aoki MS, Soares AG, Neves Jr M, et al. Strength training with blood flow restriction diminishes myostatin gene expression. Med Sci Sports Exerc 2012;44(3):406—12.
[12] Madarame H, Neya M, Ochi E, Nakazato K, Sato Y, Ishii N. Cross-transfer effects of resistance training with blood flow restriction. Med Sci Sports Exerc 2008;40(2):258—63.
[13] Manimmanakorn A, Manimmanakorn N, Taylor R, Draper N, Billaut F, Shearman JP, et al. Effects of resistance training combined with vascular occlusion or hypoxia on neuromuscular function in athletes. Eur J Appl Physiol 2013;113(7):1767—74.
[14] Martín-Hernández J, Marín PJ, Menéndez H, Ferrero C, Loenneke JP, Herrero AJ. Muscular adaptations after two different volumes of blood flow-restricted training. Scand J Med Sci Sports 2013;23:e114—20.
[15] Takarada Y, Sato Y, Ishii N. Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. Eur J Appl Physiol 2002;86:308—14.
[16] Moore DR, Burgomaster KA, Schofield LM, Gibala MJ, Sale DG, Phillips SM. Neuromuscular adaptations in human muscle following low-intensity resistance training with vascular occlusion. Eur J Appl Physiol 2004;92:399—406.
[17] Moritani T, Sherman WM, Shibata M, Matsumoto T, Shinohara M. Oxygen availability and motor unit activity in humans. Eur J Appl Physiol 1992;64:552—6.
[18] Takarada Y, Nakamura Y, Aruga S, Onda T, Miyazaki S, Ishii N. Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. J Appl Physiol 2000;88:61—5.
[19] Takarada Y, Takazawa H, Sato Y, Takebayashy S, Tanaka Y, Ishii N. Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. J Appl Physiol 2000;88:2097—106.
[20] Yasuda T, Brechue WF, Fujita T, Sato Y, Abe T. Muscle activation during low-intensity muscle contractions with varying levels of external limb compression. J Sports Sci Med 2008;7:467—74.
[21] Loenneke JP, Wilson GJ, Wilson JM. A mechanistic approach to blood flow occlusion. Int J Sports Med 2010;31:1—4.
[22] Pope ZK, Willardson JM, Schoenfeld BJ. Exercise and blood flow restriction. J Strength Cond Res 2013;27(10):2914—26.
[23] Kubo K, Komuro T, Ishiguro N, Tsunoda N, Sato Y, Ishii N, et al. Effects of low-load resistance training with vascular occlusion on the mechanical properties of muscle and tendon. J Appl Biomech 2006;22:112—9.
[24] Behm DG. Neuromuscular implications and applications of resistance training. J Strength Cond Res 1995;9(4):264—74.
[25] Fry AC, Newton RU. Uma breve história do treinamento de força, princípios básicos e conceitos. In: Kraemer WJ, Häkkinen K, editors. Treinamento de força para o esporte. Porto Alegre: Artmed; 2004. p. 15—32.
[26] Carvalho T, Nóbrega ACL, Lazzoli JK, Magni JRT, Rezende L, Drummond FA, et al. Posição oficial da Sociedade Brasileira de Medicina do Esporte: atividade física e saúde. Rev Bras Med Esport 1996;2(4):79—81.
[27] American College of Sports Medicine. ACSM'S Guidelines for exercise testing and prescription. 9th ed. Philadelphia: Lippincott Willians & Wilkins; 2014.
[28] Lesuer DA, Mccormick JH, Mayhew JL, Wasserstein RL, Arnold MD. The accuracy of prediction equations for estimating 1RM performance in the bench press, squat and deadlift. J Strength and Cond Res 1997;11(4):211—3.
[29] Yao JST. Noninvasive studies of peripheral vascular disease. Vascular surgery: principles and practice. 3rd ed. New York: Marcell Deckker; 2004. p. 113—22.
[30] Guirro ECO, Guirro RRJ, Filho AVD, Montezuma T, Vaz MMOLL. Decrease in talocrural joint mobility is related to alteration of the arterial blood flow velocity in the lower limb in diabetic. J Phys Ther Sci 2014;26(4):553—6.
[31] Yasuda T, Brechue WF, Fujita T, Shirakawa J, Sato Y, Abe T. Muscle activation during low-intensity muscle contractions with restricted blood flow. J Sports Sci 2009;27(5):479—89.
[32] Leonard CT, Kane J, Perdaems J, Frank C, Graetzer DG, Moritani T. Neural modulation of muscle contractile properties during fatigue: afferent feedback dependence. Electroencephalogr Clin Neurophysiol 1994;93:209—17.
[33] Karabulut M, Cramer JT, Abe T, Sato Y, Bembem MG. Neuromuscular fatigue following low-intensity dynamic exercise with externally applied vascular restriction. J Electromyo Kinesiol 2010;20:440—7.
[34] Karabulut M, Perez G. Neuromuscular response to varying pressures created by tightness of restriction cuff. J Electromyo Kinesiol 2013;23:1494—8.
[35] Cochrane KC, Coburn JW, Brown LE, Judelson DA. Effects of diverting activity on strength, electromyographic, and mechanomyographic signals. J Strength Cond Res 2014;28(5):1203—11.
[36] Farina D, Merletti R, Enoka RM. The extraction of neural strategies from the surface EMG. J Appl Physiol 2004;96(4):1486—95.
[37] Hermens HJ, van Bruggen TAM, Baten CTM, Rutten WLC, Boom HBK. The median frequency of the surface EMG power spectrum in relation to motor unit firing and action potential properties. J Electromyo Kinesiol 1992;2(1):15—25.
[38] Aagaard P. Training-induced changes in neural function. Exerc Sport Sci Rev 2003;31(2):61—7.
[39] Loenneke JP, Wilson JM, Marín PJ, Zourdos MC, Bemben MG. Low-intensity blood flow restriction training: a meta-analysis. Eur J Appl Physiol 2012;112(5):1849—59.
[40] Takarada Y, Tsuruta T, Ishii N. Cooperative effects of exercise and occlusive stimuli on muscular function in low-intensity resistance exercise with moderate vascular occlusion. Jpn J Physiol 2004;54:585—92.