Effectiveness of low-frequency vibration recovery method on blood lactate removal, muscle contractile properties and on time to exhaustion during cycling at VO$_{2\text{max}}$ power output

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Abstract The aim of the study was to determine the effectiveness of low-frequency vibration recovery (LFV-rec) on blood lactate removal, muscle contractile properties, and on time to exhaustion during cycling at maximal oxygen uptake power output ($p$VO$_{2\text{max}}$). Twelve active males carried out three experimental sessions. In session 1, participants’ maximal oxygen uptake (VO$_{2\text{max}}$) and $p$VO$_{2\text{max}}$ were determined, and in sessions 2 and 3, the participants performed a fatiguing exercise (2 min of cycling at $p$VO$_{2\text{max}}$) and then a 15 min recovery period using one of two different methods: LFV-rec which consisted on sitting with feet on the vibratory platform (20 Hz; 4 mm) and passive recovery (P-rec), sitting without vibration stimulus. After that, participants performed an all-out exercise test on cycle ergometer at $p$VO$_{2\text{max}}$. In the recovery period, variables such as heart rate (HR), blood lactate concentration [Lac], and electromyographic parameters ($D_m$: maximal radial displacement; $T_c$: time of contraction maintenance, and $T_r$: relaxation time) were measured. In an all-out exercise test, mean time to exhaustion (TTE), total distance covered (TD), mean cycling velocity ($V_m$), and maximal HR (HR$_{\text{max}}$) were also assessed. The results showed no effect of recovery strategy on any of the assessed variables; nevertheless, higher values, although not significant, were observed in TTE, TD, and $V_m$ after LFV-rec intervention. In conclusion, LFV-rec strategy applied during 15 min after short and intense exercise does not seem to be effective on blood lactate removal, muscle contractile properties, and on time to exhaustion during cycling at $p$VO$_{2\text{max}}$.

Keywords Recovery · Low-frequency vibration · TMG · Lactate clearance · All-out exercise performance

Introduction

Muscle recovery after physical activity is very important, especially in sports competitions. In many sports events, athletes must exercise at high intensities (two or more times within the same competitive session and with limited rest periods between efforts. This may be the case of some qualification systems in sports where an athlete must complete several rounds during the same day. This often occurs in modalities in which athletes perform exercises lasting 2 min such as alpine skiing (downhill, super-combined), track and field (women 800 m), and speed skating (1,000–1,500 m inline/ice skating). Therefore, fast muscle recovery is needed in order to maintain or even increase performance in the subsequent efforts. In order to restore muscular function, a variety of postexercise intervention methods are often employed to improve recovery from training and competition bouts (Mika et al. 2007). It is proposed that the use of recovery strategies ensures performance in subsequent exercise sessions (training and/or competition) is not unduly compromised by lingering muscle soreness or decrements in power, flexibility, speed,
or agility (Dawson et al. 2005). Thus, an optimal balance between exercise load and recovery is required to maintain a high physical performance during subsequent exercise sessions.

For short intermittent exercises, performed under anaerobic conditions, it has been recommended to introduce active recovery between exercises rather than passive recovery in order to decrease blood lactate concentration ([Lac]) (Billat 2001; Billat et al. 2001). The lactate accumulation has been associated with a performance decline and hence lactate removal after effort seems to be important to improve the subsequent performance, mainly when the exercise is performed at high intensity (Ahmaid et al. 1996).

It has been suggested that active recovery methods improve muscle blood flow and blood velocity and enhance recovery by augmenting removal of [Lac] (Tiidus 1997; Begum et al. 2005; Suzuki et al. 2002; Steele and Duke 2003; Tiidus and Shoemaker 1995; Gupta et al. 1996; Monedero and Donne 2000). However, and although all seems to indicate that active recovery results in faster [Lac] removal than passive recovery, there are doubts about how these recovery types influence the performance of the subsequent exercise, probably due to methodological differences across studies, especially in relation with the task used as performance criterion (Francini et al. 2003). Indeed, performing active versus passive recovery between high-intensity cycling efforts has been reported to significantly impair performance (Haseler et al. 1999; Dupont et al. 2007; Spencer et al. 2006; Spencer et al. 2008), although other studies have found opposite results (Bogdanis et al. 1996; Dorado et al. 2004; Spierer et al. 2004). Taking into account these conflicting results, it is important to find alternative recovery methods that allow athletes to recover as soon as possible after short-term and intense efforts and to perform a subsequent exercise under the best conditions.

On the other hand, the effectiveness of different recovery strategies applied after short and intense exercises can be evaluated using surface electromyographic signals (EMG) or muscle contractile properties. Several studies have analyzed the EMG power spectrum during dynamic exercise (Mika et al. 2007) finding reductions of the median frequency with the onset of muscle fatigue (Singh et al. 2007). However, muscle contractile properties during or after fatiguing exercise remain unclear, mainly due to a lack of an adequate assay system. In the last few years, measurements of contraction time by tensiomyography (TMG) have been successfully implemented on different muscle groups (Valencic and Knez 1997) to investigate endurance and fatigue among other muscular responses (Grabiljevec et al. 2005; Krizaj et al. 2008). By using TMG, fatigued muscle responses as well as the effects of different recovery methods on muscle contractile properties could be tested.

In any case, to find an effective recovery strategy after short and intense exercises which facilitates [Lac] removal, decreases muscle tone and improves the performance in subsequent efforts is a difficult task. Whilst contrast water therapy, stretching and massage have previously been widely investigated (Barnett 2006), the impact of low-frequency vibrations (LFV) on muscle recovery has not (Edge et al. 2009). In a recent study, Edge et al. (2009) found no benefit of whole body vibrations (WBV) on running performance recovery following high-intensity interval training. These authors used WBV at a frequency of 12 Hz, lower than that applied by Bakhtiari et al. (2007) who reported that administering 50 Hz of local vibration to each lower limb significantly reduced 24 h postexercise creatine kinase levels and increased the recovery of isometric force production. Moreover, Green and Stannard (2010) found no significant increases in intermittent isometric hand grip exercise capacity after local LFV compared with passive rest in trained and untrained climbers. Although LFV may act as a mechanical massage to accelerate the recovery process by increasing blood flow to and from the damaged muscle (Cochrane and Hawke 2007; Kerschan-Schindl et al. 2001; Yamada et al. 2005; Lohman et al. 2007), removing waste products, increasing muscle temperature and oxygenation recovery rate (Cochrane et al. 2008; Coza et al. 2010), and stimulate the muscle receptors to ease muscular tension (Cafarelli et al. 1990), different vibration stimulus used in the above mentioned investigations (local or whole body application, and different vibration characteristics) can lead to lack of consensus on the usefulness of LFV as recovery method, being important to clarify its recovery effects on metabolic and muscular systems after short and intense exercise. In this way, the purpose of this study was to evaluate the effectiveness of LFV as a recovery strategy on blood lactate removal, muscle contractile properties and on exercise performance after a short and intense cycling effort.

Methods

Participants

Twelve healthy male volunteers (mean ± SEM; age, 24.16 ± 0.62 years, height 172.02 ± 2.1 cm, body mass 71.84 ± 2.19 kg, BMI 24.42 ± 0.70 kg m⁻²) were recruited for this study. All were recreationally active who were not engaged in a systematic exercise program. Participants were asked to abstain from food and caffeine beverages for 2 h before testing and to not perform heavy exercise during the 24 h preceding the tests. After being fully informed about the purpose of the experiments, each participant signed an informed consent. The Local Research Ethical Committee...
approved the experimental protocol and the procedures involved.

Testing procedures

All participants reported to laboratory for three visits. The first one was dedicated to determine participants’ VO2max and power associated with VO2max \( (pV02\text{max}) \); for that, the participants carried out a maximal graded test on a cycle ergometer. Then, on two separate sessions (48 h), and in a random order, they performed 2 min of cycling at \( pV02\text{max} \) (intense exercise) followed by 15 min of LFV (LFV-rec) or passive recovery (P-rec). After the recovery period participants performed an exercise test to exhaustion on a cycle ergometer at \( pV02\text{max} \) (Fig. 1). Heart rate, blood lactate concentrations and TMG measures were assessed in LFV-rec and P-rec. In order to avoid any interference of food ingestion on lactate response to exercise, participants were submitted to eat a known amount of carbohydrates (72%) during the previous 48 h to the experiments (sessions 2 and 3). All testing procedures were performed during the same period (between 9:00 and 11:00 am) in a room at an ambient temperature 22–24°C.

Maximal graded exercise test

After a standardized warm-up consisting of 5 min of pedaling on a cycle ergometer (Kettler Axiom P2, GmbH & Co.KG, Ense-Parsit, Germany) at a load of 50 W, participants performed a maximal graded exercise test. The initial load was 50 W and increased by 25 W every min until exhaustion with a pedaling frequency of 60 rpm. Gas analyses were performed using a breath-by-breath gas analyzer (VO2000 Portable Metabolic System, Medgraphics, St. Paul, MN), whose validity was previously proved by Byard and Dengel (2002). Before each test, VO2000 was manually calibrated according to the manufacturer’s guidelines. VO2max corresponded to the highest VO2 attained in two successive 15 s periods for the maximal graded test. In addition, HR was continuously monitored (Polar 800 CX, Polar Electro, Kempele, Finland). It was considered that participants had reached their VO2max when three or more of the following criteria were met: (a) a steady state of VO2 despite increasing load (changes in VO2 at VO2max ≤ 150 ml); (b) a final respiratory exchange ratio higher than 1:1; (c) visible exhaustion; (d) an HR at the end of the exercise \( (HR\text{max}) \) within the 10 bpm of the predicted maximum (220-age). In addition, \( pV02\text{max} \) was defined as power output (W) developed by the participants on the cycle ergometer when VO2max was reached.

Intense exercise

In sessions 2 and 3, and to avoid exercise time or intensity influence, the participants performed 2 min of cycling at \( pV02\text{max} \). These exercise characteristics were chosen taking into account previous studies with samples of well-trained athletes in which cycling TTE at the same relative intensity was between 2.9 ± 0.7 and 5.2 ± 2.4 min (Billat and Koralsztein 1996; Lepretre et al. 2004). Considering that our sample was only composed of healthy individuals (non-athletes), we decided to establish a duration of 2 min to ensure that participants could complete this fatigue protocol. The pedaling frequency was kept at 60 rpm and HR was continuously monitored during the exercise in order to determine HR\text{max} (HR\text{max}). Before each testing session ([Lac]pre), and just at the end of the intense exercise ([Lac]post), capillary blood samples were taken from the earlobe for blood lactate analyses (Dr. Lange Photometer LP 450, Konisburg, Germany).

Recovery period

Following intense exercise, participants were invited to rest during a 15 min recovery period using different recovery methods (LFV-rec or P-rec) that were applied in random order. This recovery period was applied since as previous studies reported, complete muscle recovery can be achieved with 10–15 min rest periods (Lariviere et al. 2003). In addition, P-rec strategies used for less than 10 min are insufficient to reproduce the maximal voluntary contraction (Esposito et al. 1998; Seiler and Hetlelid 2005). In LFV-rec, and in order to focus the vibratory stimulus on exercised muscles avoiding a weight-bearing effect (maintenance of isometric contraction typical of WBV), participants were seated with their feet on a vibratory platform (PhysioWave 700, Globus, Italy) keeping their thighs abducted and the knees and hips flexed 90°. Being...

![Fig. 1 Schematic illustration of testing protocol](image-url)
an oscillatory platform, and according to the manufacturer’s instructions, participants’ feet had to be separated from the central axis of the platform at the distance required to generate 4 mm of amplitude. Additionally, this position was already marked on the platform surface by the manufacturer and the feet were placed 30 cm apart. The participants then performed five sets of 2 min exercises with 1 min rest between sets at a frequency of 20 Hz. 

These vibratory characteristics were chosen according to the conclusions of previous studies in which a frequency of 12 Hz and 6 mm of amplitude (peak to peak) were not sufficient to increase blood flow, muscle temperature, and other neurogenic changes required for enhancing recovery (Edge et al. 2009), and based on the assumption that resonance effects appear when frequencies between 2.5 and 16 Hz are used (Goel et al. 1994; Randall et al. 1997). In P-rec, participants kept the same position on the vibratory platform, but no vibratory stimulus was applied. 

In both protocols, LFV-rec and P-rec, HR was continuously recorded (HRrec) and capillary blood samples were taken from the earlobe at minutes 2 ([Lac]rec2), 5 ([Lac]rec5), 8 ([Lac]rec8), 11 ([Lac]rec11), and 14 ([Lac]rec14) of the recovery period. 

**TMG measures**

TMG is a measuring method for detection of skeletal muscles’ contractile properties based on a muscle contraction characteristic: when a muscle contracts, its belly enlarges. With a displacement sensor, the radial enlargement of the muscle belly can be measured. Displacement-time curve recordings allow muscle contractile properties to be assessed, obtaining different parameters which can inform about muscle tone (Valencic and Knez 1997) (Fig. 2).

The main muscle contraction parameters are: maximal radial displacement (Dm), time from the onset of electrical stimulus to 10% of Dm (Tc), time from 10 to 90% of Dm in the ascending curve (Tc), time between 50% of Dm on both sides of the curve (Tc), and time from 90 to 50% of Dm on the descending curve (Tr). Recently, reliability of TMG has been established (Tous et al. 2010). 

In our study, before session 1 (TMGrec), after intense exercise (TMGrec) and after recovery period (TMGrec), tensiomyography analysis of rectus femoris (RF) of the right leg was performed. Radial displacements were measured under static and relaxed conditions, with the participants in the supine position and the knee joint fixed at a 120° angle (180° corresponding to full extension of the knee). The measured limb was positioned on a triangular wedge foam cushion to keep a fixed knee angle. A digital displacement transducer (DK 40, Panoptik d.o.o., Ljubljana, Slovenia), which incorporates a spring of 0.17 mm−1, was set perpendicular to the muscle belly to acquire RF radial displacement. Sensor location was determined anatomically according to Delagi et al. (1975) and marked with a dermatological pen. Two square (5 × 5 cm) 2 mm thick self-adhesive electrodes (Compend Medical SA, Ecbulens, Switzerland) were placed symmetrically 5 cm (±5 cm) distal and proximal to the sensor tip. A TMG-S1 (EMF-Furlan and Co. d.o.o., Ljubljana, Slovenia) stimulator was used.

Regarding electrical stimulation procedures, pulse duration was 1 ms and the initial current amplitude was 30 mA. For each of the TMG assessment, current amplitude was progressively increased by 10 mA increments until there was no further increase in Dm or maximal stimulator output (110 mA). Rest periods of 15 s were interspersed between consecutive measurements to minimize the effects of fatigue and potentiation. For each participant, two consecutive measurements were performed at the highest current amplitude, and they were recorded and averaged for subsequent analyses (mean amplitude used was 98.89 ± 4.60 mA). In any case, none of the participants reported discomfort during electrical stimulation.

In the present study, Dm, Tr, and Tc were registered in each testing session; therefore, these parameters seem to show largest influence to muscle fatigue rate and are also expected to be the best measure of the fatigue rate (Kriza et al. 2008).

**Exercise test to exhaustion**

Following the recovery period and once TMG assessment was completed, participants performed an exercise test to exhaustion (ETEX) on the cycle ergometer at pVO2max maintaining a pedaling frequency of 60 rpm. This type of exercise test has been widely used to investigate the effectiveness of both warm-up and recovery strategies (Wittekind and Bence 2009; Miladi et al. 2010). HR was
monitored during the effort. The test finished when participants were unable to maintain the frequency of pedaling for more than 15 s. The variables selected were HRR \(_{\text{max}}\) (a-oHRR \(_{\text{max}}\)), time to exhaustion (TTE), mean velocity (\(V_m\)), and total distance covered (TD).

Statistical analyses

Means and standard errors of the mean were calculated for each variable. Normality assumption was checked using the Kolmogorov–Smirnov test and all variables were normally distributed. A 2 \(\times\) 7 analysis of variance (ANOVA) for repeated measures was used to compare [Lac] values across recovery method (LFV-rec, P-rec) and time (before and after intense exercise, and min 2, 5, 8, 11, and 14 of recovery period). A 2 \(\times\) 6 analysis of variance (ANOVA) for repeated measures was used to compare HR values across recovery method (LFV-rec, P-rec) and time (after intense exercise, and min 2, 5, 8, 11, and 14 of recovery period). Intra-class correlation coefficient of TMG parameters was assessed using two measures of each one during session 1. Furthermore, a 2 \(\times\) 3 ANOVA for repeated measures was performed to compare TMG parameters across recovery method (LFV-rec, P-rec) and time (before session 1, after intense exercise, and after recovery period). Moreover, one-way ANOVA was performed to analyze the effects of recovery method (LFV-rec and P-rec) on ETEX variables. Eta-squared (\(\eta^2\)) was used for the calculation of effect size. Statistical significance was set at \(p < 0.05\).

Results

In session 1, mean \(\text{VO}_{2\text{max}}\) measured during maximal graded exercise test was 53.44 ± 2.67 ml kg\(^{-1}\) min\(^{-1}\), reaching a mean \(\nu\text{VO}_{2\text{max}}\) of 270.83 ± 8.61 W.

In sessions 2 and 3, physiological responses to intense exercise performed before LFV-rec and P-rec showed no statistical differences in terms of \([\text{Lac}]_{\text{pre}}\) (1.46 ± 0.07 mmol l\(^{-1}\) vs. 1.36 ± 0.07 mmol l\(^{-1}\), respectively; \(F = 0.867, p = 0.362\)), \([\text{Lac}]_0\) (5.85 ± 0.31 vs. 5.84 ± 0.51 mmol l\(^{-1}\); \(F = 0.001, p = 0.989\)), and \(fHRR_{\text{max}}\) (166.3 ± 2.1 bpm vs. 163.2 ± 2.6 bpm, respectively; \(F = 0.851, p = 0.366\)).

During recovery period, a similar trend was observed in [Lac] dynamics in both LFV-rec and P-rec strategies (Fig. 3). [Lac] peak was reached 2 min after intense exercise (8.90 ± 0.54 mmol l\(^{-1}\) and 8.84 ± 0.70 mmol l\(^{-1}\), respectively), dropping to levels of 5.68 ± 0.39 mmol l\(^{-1}\) and 6.18 ± 0.55 mmol l\(^{-1}\), respectively, at min 14 of recovery period. No significant differences were found at each time point for [Lac] during LFV-rec and P-rec (\(F = 0.372; p = 0.715\)), although towards the end of recovery period [Lac] removal in LFV-rec was slightly higher than that observed in P-rec.

As occurred with recovery [Lac], no significant differences were found in HR values during the recovery period when LFV-rec and P-rec were contrasted (\(F = 0.165; p = 0.884\)). In both cases, HR values showed an important drop during the first 2 min into recovery period; after that, the rate of HR decline was lower, although HR values in LFV-rec remained slightly higher than that measured in P-rec (Fig. 4).

Figure 5a–d shows ETEX results. TD, \(V_m\), a-oHRR \(_{\text{max}}\), and TTE showed no statistical differences when LFV-rec and P-rec were contrasted. However, data from LFV-rec are higher than those observed in P-rec; indeed, the mean total distances covered by participants after the recovery period was 1.71 ± 0.16 km and 1.56 ± 0.21 km for LFV-rec and P-rec strategies, respectively (\(F = 0.344; p = 0.563\)) (Fig. 5a). Mean \(V_m\) was 22.70 ± 0.39 km h\(^{-1}\) after LFV-rec and 22.28 ± 0.39 km h\(^{-1}\) after P-rec (\(F = 0.550; p = 0.466\)). In addition, mean a-oHRR \(_{\text{max}}\) values measured in
ETEX were 186.2 ± 2.8 beats min⁻¹ and 184.0 ± 2.9 beats min⁻¹ for LFV-rec and P-rec, respectively (F = 0.287; p = 0.598), whereas mean TTE was also slightly higher in LFV-rec compared to P-rec (248.00 ± 22.64 and 239.91 ± 28.01 s, respectively; F = 0.050, p = 0.825).

As shown in Table 1, ICC scores (95% CI) for TMG variables obtained in the current study reached an acceptable level, being comparable to those reported by Tous-Fajardo et al. (2010). Finally, Table 2 shows TMG data obtained at different time points of the experimental testing. It is important to note that there were no statistical differences in TMGₚₑᵩ, TMGₚₑᵮ, and TMGₑᵩ variables measured on RF of the right leg. However, significant differences were observed for Dₑᵩ and Tₑᵩ between time points when the recovery method was not considered as a factor. Dₑᵩ dropped remarkably from TMGₚₑᵩ to TMGₑᵩ (p < 0.001), and then increased at TMGₑᵩ (p < 0.001), reaching values that were significantly lower than those found in TMGₑᵩ (p = 0.002). Tₑᵩ showed no significant increase from TMGₚₑᵩ to TMGₑᵩ (p = 0.130) and a significant decrease from TMGₑᵩ to TMGₑᵩ was observed (p = 0.005), reaching values that were also significantly lower than those found in TMGₑᵩ.

Table 1 ICC scores of tensionomyographic variables

<table>
<thead>
<tr>
<th>TMG variables</th>
<th>ICC test–retest (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tous-Fajardo et al. (2010)</td>
</tr>
<tr>
<td>Dₑᵩ (nm)</td>
<td>0.97 (0.92–0.99)</td>
</tr>
<tr>
<td>Tₑᵩ (ms)</td>
<td>0.92 (0.81–0.97)</td>
</tr>
<tr>
<td>Tₑᵩ (ms)</td>
<td>0.86 (0.86–0.95)</td>
</tr>
<tr>
<td>Tₑᵩ (ms)</td>
<td>0.77 (0.49–0.91)</td>
</tr>
<tr>
<td>Tₑᵩ (ms)</td>
<td>0.96 (0.90–0.99)</td>
</tr>
</tbody>
</table>

ICC intra-class correlation coefficient, CI confidence interval

Discussion

The ability to recover following intense training or competitive bouts is important so that performance can be maintained during subsequent efforts. Different recovery strategies have been compared to determine their effectiveness on physiological and exercise performance responses. Several of these studies showed that during maximal and supramaximal exercises, active recovery results in a decrease in performance when considered as the TTE (Dupont et al. 2003; Dupont et al. 2004; Buchheit et al. 2005).
Table 2 TMG measurements

<table>
<thead>
<tr>
<th></th>
<th>TMG&lt;sub&gt;rec&lt;/sub&gt;</th>
<th>TMG&lt;sub&gt;post&lt;/sub&gt;</th>
<th>TMG&lt;sub&gt;rec&lt;/sub&gt;</th>
<th>F</th>
<th>sig</th>
<th>η&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>D&lt;sub&gt;m&lt;/sub&gt; (mm)</td>
<td>LFV-rec</td>
<td>7.57 ± 0.92</td>
<td>4.37 ± 0.67</td>
<td>6.64 ± 0.65</td>
<td>1.004</td>
<td>0.375</td>
</tr>
<tr>
<td></td>
<td>P-rec</td>
<td>7.86 ± 0.43</td>
<td>4.57 ± 0.58</td>
<td>5.80 ± 0.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T&lt;sub&gt;s&lt;/sub&gt; (ms)</td>
<td>LFV-rec</td>
<td>141.06 ± 18.01</td>
<td>165.32 ± 20.79</td>
<td>124.72 ± 20.79</td>
<td>0.341</td>
<td>0.713</td>
</tr>
<tr>
<td></td>
<td>P-rec</td>
<td>132.3 ± 13.59</td>
<td>178.68 ± 27.88</td>
<td>130.12 ± 16.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T&lt;sub&gt;r&lt;/sub&gt; (ms)</td>
<td>LFV-rec</td>
<td>54.84 ± 6.37</td>
<td>52.73 ± 8.28</td>
<td>50.13 ± 8.06</td>
<td>0.396</td>
<td>0.675</td>
</tr>
<tr>
<td></td>
<td>P-rec</td>
<td>74.54 ± 11.84</td>
<td>73.44 ± 9.23</td>
<td>59.0 ± 7.42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SEM. TMG<sub>rec</sub> before session 1, TMG<sub>post</sub> after fatiguing exercise; TMG<sub>rec</sub> after recovery period. F sig. and η<sup>2</sup> values are related to time × recovery method intersection. In all cases, sphericity was assumed (Mauchly’s W > 0.05).

An innovation of the present study is the local administration of LFV-rec evaluating its effect on blood lactate clearance, muscular contractile properties, and TTE in maximal cycling exercise. To our knowledge, and with the exception of the study conducted by Edge et al. (2009), the LFV-rec method applied here is quite different from WBV used in prior studies since the participants sat in front of the platform with their feet on it focusing the vibratory effect only on their lower extremities. In any case, these recovery methods are based on the mechanical massage effect of LFV, which could accelerate the recovery process by increasing blood flow to and from the damaged muscle, remove metabolites in muscle that inhibit tissue repair and stimulate the muscle receptors to ease muscular tension (Cafarelli et al. 1990). However, it does not seem that both WBV and local LFV-rec strategies lead to induce recovery effects on fatigued muscles. The results of this study indicate that LFV-rec strategy applied after short and intense exercise have similar efficacy than P-rec on [Lac] removal, muscle contractile properties and on TTE during cycling at pVO₂max.

Although there are several differences, related to experimental protocol (vibratory characteristics, duration of recovery periods, and fatiguing exercises) our results are consistent with those of previous studies in which WBV or local vibrations were tested as recovery methods. In one of these investigations, the effect of acute WBV (12 Hz) on recovery following a 3 km time trial and high-intensity interval training was examined (Edge et al. 2009). Neither metabolic nor performance variables showed differences after WBV recovery period (15 min) when these data were compared to those of P-rec. In addition, in a recent study in which the effectiveness of two recovery strategies (shaking the hand vigorously and grasping a handheld vibration device) applied on fatigued forearm and hand muscles was compared in trained and untrained climbers, neither shaking nor LFV-rec significantly improved intermittent isometric handgrip exercise capacity compared with P-rec (Green and Stannard 2010). However, Bakhtiari et al. (2007) reported that administering 50 Hz of local vibration to each lower limb significantly increased the recovery of isometric force production.

Nevertheless, vibration stimulus has been shown to increase peripheral circulation (Kersch-Schindl et al. 2001), muscle blood flow (Lohman et al. 2007), and muscle temperature (Cochrane et al. 2008). These circulatory effects could facilitate blood lactate clearance during recovery period allowing higher performance on a subsequent exercise. However, our results demonstrate that LFV-rec has no positive effect on [Lac] removal since no statistical differences between LFV-rec and P-rec were observed in any of the recovery time point analyzed. Yet under the LFV-rec condition, [Lac] removal was slightly higher during the last minutes of the recovery period, such trend that can be explained by the higher HR levels for most of the recovery periods under LFV-rec intervention. In fact, previous studies reported higher HR values during active recoveries, increasing blood flow to the fatigued muscles and enhancing the removal of metabolites (Bogdanis et al. 1996; Ahmadi et al. 1996; Draper et al. 2006). However, although HR shows an increase following active recovery, it does not seem to indicate a subsequent reduction in [Lac] (King and Duffield 2009). The lack of effect of LFV-rec on [Lac] removal observed in our study corresponds with the findings of previous research (Edge et al. 2009; Green and Stannard 2010).

Another innovation of the present study is the use of TMG to evaluate the effects of LFV-rec and P-rec on contractile properties of fatigued muscles. From all TMG parameters, D<sub>m</sub>, T<sub>s</sub>, and T<sub>r</sub> seem to provide the most useful information in evaluation of muscle fatigue (Krizaj et al. 2008). D<sub>m</sub>, which could be equated to electrically evoked peak twitch torque, is determined by both the number and the type of muscle fibers recruited by the electrical stimulus, being considered as a measure of muscle belly stiffness (Pišt et al. 2008). Contraction time parameters such as T<sub>s</sub> (time between 50% of D<sub>m</sub> on both sides of the curve) and T<sub>r</sub> (time from 90 to 50% of D<sub>m</sub> on the descending curve) show largest influence to muscle fatigue rate (Krizaj et al. 2008). In the present study, TMG analysis of RF of the right leg was performed before session 1 (rest condition), after intense exercise, and after recovery period in both LFV-rec and P-rec interventions. There were no
statistical differences in TMG data when time × recovery
method intersection analysis was performed. These results
indicate that there was no recovery effect of LFV on the
fatigued RF since its contractile properties after P-rec
intervention were similar. However, when the recovery
method was not taken into account as a factor, we observed
a non-significant decrease in $D_m$ values after intense
exercise indicating a lower contractile capacity due to a
fatigue state. In addition, $T_s$ values increased after intense
exercise as a consequence of muscular fatigue and then
decreased after the recovery period reaching values below
those measured before session 1; in any case, no statistical
differences were observed. On the other hand, no changes
were observed in $T_r$ along experimental time points. These
results seem to define a general contractile response to
muscular fatigue, independently of the recovery strategy
applied, and they could also be explained by the duration of
recovery period. As previous studies reported, complete
muscle recovery can be achieved with 10–15 min rest
periods (Lariviére et al. 2003) since P-rec strategies used
for less than 10 min are insufficient to reproduce the
maximal voluntary contraction (Esposito et al. 1998; Seiler
and Hetlelid 2005). In the present study the recovery period
was 15 min, which could explain that $T_s$ and $T_r$ values
would revert to their initial levels after LFV-rec or P-rec
period. Unlike $T_r$ and $D_m$ values remained below their
initial levels after recovery period, a result that could
indicate lack of muscle recovery. In any case, future
research on TMG is needed to clarify the dynamics of
TMG parameters during fatigue and recovery status.

Finally, no statistical differences were obtained when
LFV-rec and P-rec were contrasted in terms of TTE during
cycling at $pVO_{2\text{max}}$. In addition, neither mean TD, nor
a-oHRmax nor $V_m$ showed statistical differences between
LFV-rec and P-rec strategies, although higher values in
these variables (TTE included) were observed under LFV-
rec intervention. These results indicate that LFV-rec seems
to have a small but no significative beneficial effect on
subsequent maximal exercises. Although previous studies
have shown that cycling performance during repeated
sprints is enhanced after active compared with passive
recovery (Bogdanis et al. 1996; Dorado et al. 2004; Spierer
et al. 2004), other authors have found contradictory results
(Buchheit et al. 2009), especially when performance was
evaluated through TTE (Dupont et al. 2003; Dupont et al.
2004). Based on aforementioned results LFV may be used
as recovery method if intense exercise must be repeated
after short periods of time since a slight increase (and no
decreases) in exercise performance can be achieved.

In conclusion, LFV-rec strategy applied during 15 min
after short and intense exercise does not seem to be
effective on blood lactate removal, muscle contractile
properties and on time to exhaustion during cycling at

$pVO_{2\text{max}}$. Future studies are needed in order to define
the optimal vibration stimulus attending to factors such as
position on the platform, frequency, or amplitude.

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

**References**


