



Original Article

## Influence of repeated bouts of eccentric exercise on high-intensity aerobic performance

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**Abstract.** [Purpose] It is believed that eccentric high-intensity exercise can decrease performance in subsequent exercise. However, with repetition, the deleterious effects can be minimized. Thus, this study evaluated the influence of repeated bouts of eccentric exercise on subsequent high-intensity aerobic performance. [Subjects and Methods] Seven healthy and sedentary male volunteers were recruited. a) Visit 1: determination of maximum oxygen uptake ( $VO_{2max}$ ) and speed associated with maximum oxygen uptake ( $vVO_{2max}$ ) in incremental treadmill testing; b) Visit 2: run to exhaustion at  $vVO_{2max}$  (Tlim control); c) Visit 3: 10 sets of 10 depth jumps, followed by a run to exhaustion at  $vVO_{2max}$  (Tlim 1); d) Visit 4: after 6 weeks without any physical training, the volunteers carried out the same procedures as on the third visit (Tlim 2). Data were analyzed using one-way analysis of variance (ANOVA) with the post-hoc Tukey test. [Results] Significant differences were found between Tlim control and Tlim 1 ( $283.4 \pm 47.7$  s vs.  $125.2 \pm 64.1$  s, respectively), these were not different from Tlim 2. [Conclusion] Eccentric exercise showed deleterious effects on subsequent high-intensity aerobic performance. These effects were minimized after the exercise protocol was repeated 6 weeks after the first event.

**Key words:** Fatigue, Time to exhaustion, Repeated bout effect

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### INTRODUCTION

Muscle damage and delayed onset muscle soreness (DOMS) may occur at different levels depending on the type of contraction (concentric or eccentric), type of exercise (plyometric jumps, resistance training, downhill runs, long-term runs, etc.), movement speed (high or low angular velocity), time interval between sets, and trainability of the individual (sedentary, physically active, or trained)<sup>1)</sup>. For a given muscle power, it is known that there is less recruitment of motor units for eccentric contraction than for concentric contraction<sup>2)</sup>. This higher strength/activation ratio exerts high stress on the tissues involved, and is considered the main factor in structural damage of muscle fibers. Additionally, the connective tissue is stretched, causing greater passive strain on the cytoskeleton. These two factors together are responsible for a higher incidence of muscle damage and consequent reduction in contractile capacity, also known as fatigue<sup>3)</sup>.

It has recently been postulated that muscle damage caused by eccentric or any other physical activity may be minimized by performing the same type of exercise a few weeks after the initial training. This adaptation is called a “repeated bout effect”<sup>4)</sup>. The protective mechanism of the repeated bout effect appears to be due to an increase in the recruitment of slow contraction

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motor units, activation of a large number of motor units (neural adaptation), increased dynamic and passive muscular endurance (mechanical adaptation), longitudinal addition of sarcomeres, adaptation to the inflammatory response, and adaptation to maintain muscle excitation-contraction coupling (cellular adaptation)<sup>5</sup>.

However, most studies that investigated the repeated bout effect observed a decrease in the ability of muscle to generate strength and power. Few studies have verified the repeated bout effect or the effect of repetition of eccentric exercise on subsequent aerobic performance. Previous articles reported that both oxygen consumption kinetics and running economy are negatively affected when a prior eccentric exercise is performed<sup>6, 7</sup>.

Therefore, the present study aimed to evaluate the influence of repeated bouts of eccentric exercise on subsequent high-intensity aerobic performance. It is believed that severe neuromuscular fatigue develops after eccentric high-intensity exercise. However, an analysis of the literature suggests that the harmful effects may be minimized by performing the same activity several weeks later, which could induce favorable adjustments to offset these effects on subsequent aerobic performance.

## SUBJECTS AND METHODS

The subject population was a convenience sample comprised of 7 healthy male volunteers, sedentary for at least 3 months, and with no experience in resistance training. Demographic data for the sample were as follows (mean  $\pm$  standard deviation [SD]): age ( $21.7 \pm 3.4$  years); body mass ( $67.2 \pm 9.9$  kg); height ( $171.5 \pm 0.0$  cm); fat percentage ( $15.4 \pm 7.1\%$ ) and maximum oxygen consumption ( $44.1 \pm 2.8$  ml $\cdot$ kg<sup>-1</sup> $\cdot$ min<sup>-1</sup>). Each volunteer was informed about the investigational procedures and their implications, and provided signed informed consent to take part in the study. The study was approved by the Human Research Ethics Committee of UNISALESIANO, protocol number: 292/09.

All procedures were performed over 9 weeks. In the first week, anthropometric and cardiorespiratory measurements were obtained. Anthropometric data included body mass (BM), height (H), and the percentage of body fat from skinfold measurements<sup>8</sup>. Subjects performed incremental treadmill testing until volitional exhaustion to determine  $VO_{2max}$  and the intensity associated with the achievement of  $VO_{2max}$  ( $vVO_{2max}$ ). This test started at 8 km $\cdot$ h<sup>-1</sup>, with increases of 1 km $\cdot$ h<sup>-1</sup> at each stage. Using a metabolic analyzer (Cortex Metalyser 3B<sup>®</sup>, Leipzig, Germany), each subject was encouraged to give maximum effort. The test completion was determined by volitional exhaustion or when one of the following criteria was reached<sup>9</sup>: (1) peak heart rate (HR) at least equal to 90% of the age-predicted maximum; (2) respiratory exchange ratio (RER) greater than 1.1; and (3) increased intensity with stable oxygen consumption. The  $VO_{2max}$  was defined by the higher average value of oxygen consumption ( $VO_2$ ) found during the last 30 s of each stage. The exercise intensity at which  $VO_{2max}$  occurred was considered the  $vVO_{2max}$ <sup>10</sup>. The subjects returned to the laboratory the following week to determine the time limit to  $vVO_{2max}$  (Tlim Control), which was characterized by treadmill running at  $vVO_{2max}$  until voluntary exhaustion; the HR and lactate concentration (Yellow Springs -1500 Sport<sup>®</sup>, Ohio, USA) were measured before and after Tlim.

A plyometric activity was performed in the third week, consisting of 10 sets of 10 depth jumps, with a 1-min interval between each set, in which subjects jumped from a high level (0.6 m). After landing, the subjects were asked to perform the strongest possible vertical jump, to land on another higher plane placed 1 m in front of the first. They performed this procedure in succession until the completion of all jumps<sup>4</sup>. After 15 min, they performed another time limit activity (Tlim 1).

After 6 weeks of limited physical activity, volunteers returned to the laboratory to perform the same procedures as in the third week, with a plyometric activity followed by treadmill running at  $vVO_{2max}$  (Tlim 2). For at least 24 h before the experiments, volunteers were advised to avoid any strenuous physical activity and alcoholic or caffeinated drinks, with a night of proper rest and the last meal at least 2 h prior to the test. To avoid any effects of a circadian cycle, all procedures were performed during the same period and time of day for each subject.

Statistical analysis was performed using SPSS version 20.0 (Chicago, IL, USA) Prior to any analysis, a Shapiro-Wilk normality test was applied. Before the confirmation of normality, one-way analysis of variance (ANOVA) was applied with a post-hoc Tukey test to compare data for Tlim (Control, 1, and 2) and physiological variables related to performance times (blood lactate and HR). Student's t-test was used for paired data for the same physiological variables before and after the plyometric activity. In all analyses, a significance level of  $p \leq 0.05$  was adopted.

## RESULTS

Table 1 shows the initial data of the sample, including the cardiorespiratory variables ( $VO_{2max}$  and  $vVO_{2max}$ ) related to the initial level of physical fitness, as an inclusion criterion.

Table 2 shows Tlim (Control, 1, and 2). There was a significant difference between Tlim 1 and Tlim Control, suggesting the deleterious effect of previous eccentric exercise. However, after 6 weeks of limited activity, Tlim Control and Tlim 2 showed no statistically significant differences, demonstrating the repeated bout effect on subsequent aerobic performance.

Tables 3 and 4 show the HR and concentrations of lactate after Tlim and following the depth jumps, respectively. Table 3 shows no statistically significant differences for the 2 variables after 3 time limits. Table 4 shows the same results after depth jumps.

**Table 1.** Characteristics of volunteers

	Mean	SD
Age (years)	21.7	3.4
Body weight (kg)	67.2	9.9
Height (cm)	171.5	0.0
Fat percentage (%)	15.4	7.1
VO <sub>2max</sub> (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	44.1	2.8
vVO <sub>2max</sub> (km·h <sup>-1</sup> )	12.7	1.7

VO<sub>2max</sub>: maximum oxygen uptake; vVO<sub>2max</sub>: speed associated with maximum oxygen uptake

**Table 3.** Mean values and standard deviation (SD) of physiological responses (blood lactate concentrations –[Lac], and maximum heart rate –HR<sub>max</sub>) after Tlim

	Mean	SD
[Lac] Tlim Control (mmol/l)	11.68	4.43
[Lac] Tlim 1 (mmol/l)	9.08	3.75
[Lac] Tlim 2 (mmol/l)	9.84	3.38
HR <sub>max</sub> Tlim Control (bpm)	198.4	10.6
HR <sub>max</sub> Tlim 1 (bpm)	192.2	12.6
HR <sub>max</sub> Tlim 2 (bpm)	198.1	10.6

**Table 2.** Permanence time at vVO<sub>2max</sub> in control situations (Tlim Control) and after the first and second session of depth jumps (Tlim 1 and Tlim 2)

	Tlim Control (s.)	Tlim 1 (s.)	Tlim 2 (s.)
Mean	283.4	125.2 <sup>a</sup>	192.7
SD	47.7	64.1	71.9

<sup>a</sup>significant difference from Tlim Control; p<0.05

**Table 4.** Mean values and standard deviation (SD) of physiological responses (blood lactate concentrations –[Lac], and maximum heart rate –HR<sub>max</sub>) after the depth jump (DJ)

	Mean	SD
[Lac] JD 1 (mmol/l)	7.57	3.21
[Lac] JD 2 (mmol/l)	5.91	2.36
HR <sub>max</sub> JD 1 (bpm)	177.8	7.1
HR <sub>max</sub> JD 2 (bpm)	178.0	10.3

## DISCUSSION

The purpose of this research was to investigate the influence of the repeated bout effect of eccentric exercise on subsequent high-intensity aerobic performance. The primary finding was that eccentric exercise decreases aerobic performance after the first time limit, but deleterious effects are minimized after performing the same exercises (jumps) a few weeks later. This adaptation is called the “repeated bout effect”<sup>11, 12</sup>.

In the current study, the effect of repeated exercise was assessed in sedentary individuals. Thus, one of the criteria used to determine the cardiorespiratory level of subjects was obtained in an incremental ergometry test. Cardiorespiratory level is reportedly closely related to VO<sub>2max</sub>. In sedentary males, this value is about 45 mL·kg<sup>-1</sup>·min<sup>-1</sup><sup>13</sup>. Thus, the volunteers were considered sedentary, because of their average values for VO<sub>2max</sub> (44 mL/kg/min).

According to the present investigation and previous studies that also used depth jump exercises to generate muscle damage, low (10 jumps) and high volumes (45–50 jumps), provided the same protective effect against muscle damage induced by the first exposure. However, a larger volume of eccentric movements induces muscle damage as compared to a lower volume<sup>5, 14</sup>. Muscle damage is closely related to decreased muscle contractile capacity; in physiological terms, the greater the damage, the greater the muscle fatigue<sup>15</sup>.

The protective mechanism of the repeated bout effect appears to be due to an increase in the recruitment of slow contraction motor units, activation of a large number of motor units (neural adaptation), increased dynamic and passive muscular endurance (mechanical adjustments), longitudinal addition of sarcomeres, adaptation to the inflammatory response, and adaptation to maintain muscle excitation-contraction coupling (cellular adaptation)<sup>5, 14</sup>. However, there is little information about the repeated bout effect of eccentric exercise on subsequent aerobic performance. The effect of repeated bouts of eccentric exercise on running economy<sup>16, 17</sup> and VO<sub>2</sub> kinetics during cycloergometric exercise performance<sup>7</sup> was verified by some authors. The effect of eccentric exercise on running economy seems to be intensity dependent; at moderate intensities (55–75% of VO<sub>2max</sub>), running economy is not affected, but is only influenced at high intensities (up to 90% of VO<sub>2max</sub>). This is due to prior fatigue of type II fibers that are additionally recruited at high aerobic exercise intensities<sup>18</sup>.

Moreover, Byrne, Twist, and Eston<sup>19</sup> reported that the performance of eccentric exercise at high intensity prior to aerobic activities can lead to reduction in contractile ability of the quadriceps muscles and reduced muscle force development ratio (fatigue), thus increasing the contact time with the ground during running and decreasing efficiency of the exercise. According to Billat et al.<sup>20</sup>, the determination of vVO<sub>2max</sub> is dependent on factors that are not related solely to anaerobic participation in the aerobic component, especially with regard to the slow component of oxygen uptake kinetics. Eccentric exercise performed prior to aerobic exercise decreases the recruitment level of type II fibers, thus decreasing the amplitude of the slow component in determining VO<sub>2max</sub>, and interfering with the time to exhaustion at vVO<sub>2max</sub><sup>20, 21</sup>.

Thus, the adaptations to the repetition of exercise cited by Miyama and Nosaka<sup>5</sup> can improve the level of muscle fiber recruitment after the performance of the second eccentric exercise, which could explain the statistically similar times between Tlim Control and Tlim 2. For the limit time exercise at vVO<sub>2max</sub> (Tlim Control, Tlim 1 and Tlim 2), and the depth

jump performed by the volunteers, physiologic stress apparently was no different between the moments before and after six weeks without exercise, since the HR values and lactate concentrations were statistically similar. However, the lactate concentrations after Tlim 1 and Tlim 2 tended to be lower than in Tlim Control. This lower concentration can be explained by lower lactate removal capacity after exercises with high-intensity eccentric contractions<sup>22</sup>).

Thus, it can be concluded that the “repeated bout effect” exerts a positive influence on  $v\dot{V}O_{2max}$ , possibly resulting in less deleterious effects on the permanence time after 6 weeks of limited physical activity. However, methodological limitations of this study suggest the need for further research. Due to the great variability of the Tlim, a larger sample would increase the statistical power. In addition, the kinetic measurement of oxygen uptake, and even electromyographic evaluation of the muscles involved, could help explain the repeated bout effect on subsequent high-intensity aerobic activity, as well as variables related to muscle damage; these findings could help explain the damage caused by eccentric high-intensity activities.

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