Original Article

EFFECTS OF EXERCISE INTENSITY ON EXCESS POST-EXERCISE OXYGEN CONSUMPTION AND SUBSTRATE USE AFTER RESISTANCE EXERCISE

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The purpose of this study was to compare the effects of equal work resistance exercise with different intensities on excess post-exercise oxygen consumption (EPOC) and substrate use after resistance exercise. In this study, 16 male university students performed resistance exercise of high intensity (HI; 3 sets of 10 repetitions at 75% of their one-repetition-maximum [1RM]) and low intensity (LO; 3 sets of 15 repetitions at 50% of their 1RM) respectively. During the post-exercise period, subject's heart rate (HR), ventilation volume ($\dot{V}E$), oxygen consumption ($\dot{V}O_2$), respiratory exchange ratio (RER) and body temperature (BT) were continuously monitored. Repeated *t* test was applied to test the difference in EPOC and substrate use between HI and LO. The results indicated that: (1) the EPOC of HI was significantly different from that of LO ($p < 0.05$); (2) HR, RER, $\dot{V}E$ and BT showed no significant differences between HI and LO ($p > 0.05$); and (3) post-exercise fat oxidation (0–20 minutes and 40–60 minutes) of HI was significantly greater than that of LO, but there were no significant differences between HI and LO in post-exercise carbohydrate oxidation. Thus, the results indicated that for resistance exercise with an equated work volume, HI produced higher EPOC and fat oxidation than LO. In conclusion, for resistance exercise bouts with an equated work volume, HI produces greater EPOC and fat use than LO.

Keywords: excess post-exercise oxygen consumption, resistance exercise, substrate

Introduction

For health benefits, exercise physiologists have always advocated aerobic exercise to expend energy. When performing aerobic exercise, more fat is used as the source of energy and energy expenditure is increased. Exercise-associated energy expenditure includes the energy that is expended during the exercise and during the recovery period. Post-exercise energy expenditure above the resting metabolic rate (RMR) is often referred to as excess post-exercise oxygen consumption (EPOC) (Gaesser & Brooks 1984). Some studies have shown that EPOC from intense exercise can last for several hours (Bahr 1992). Sedlock et al. (1989) indicated that intensity of exercise could affect the volume and duration of EPOC, but only duration of exercise could affect the duration of EPOC. Dawson et al. (1996) found that intensity of exercise was more important than duration of exercise for EPOC volume. Some studies also indicated

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that energy expenditure associated with anaerobic resistance exercise was higher than that associated with aerobic exercise, and that oxygen consumption during the recovery period was also greater after anaerobic resistance exercise than after aerobic exercise (Burleson et al. 1998; Elliot et al. 1992), but the workload between aerobic and anaerobic resistance exercise might have been unequal among these studies. Recently, a low-to-moderate-intensity regimen of resistance exercise has been commonly recommended (Feigenbaum & Pollock 1999). Moreover, long-term resistance exercise can enhance energy expenditure directly from the exercise, indirectly from increasing lean body mass, and from increasing post-exercise energy expenditure (Poehlman & Melby 1998).

Some studies indicated that high-intensity aerobic exercise could induce a greater EPOC response than low-intensity aerobic exercise (Phelain et al. 1997). Other studies have compared high- and low-intensity resistance exercise of equal work volume on EPOC (Thornton & Potteiger 2002; Olds & Abernethy 1993), but the results of these studies were diverse. Thus, the effect of resistance exercise intensity on EPOC is unclear. In addition, Tremblay et al. (1990) found that high-intensity intermittent exercise may favor increased lipid oxidation during recovery when compared with steady state exercise. Resistance exercise is considered to be intermittent exercise in nature; thus, it may induce a prolonged EPOC and a greater use of fat during the recovery period.

The intensity of resistance exercise that will produce the best overall effect on EPOC and fat oxidation needs to be determined. The purposes of this study were thus to: (1) compare the effects of equal work resistance exercise with different intensities on EPOC; and (2) analyze substrate oxidation in the 120 minutes after resistance exercise.

Methods

Subjects

Sixteen healthy male university students participated in this study. All subjects had at least 6 months of experience in performing resistance exercise (at least 3 days a week in the 6-month period prior to the start of the study), and were familiar with the exercises and equipment used in this study. The demographic characteristics of the subjects are presented in Table 1. Before participation in this study, all subjects signed an informed consent form and completed a health and exercise history questionnaire. All subjects were judged healthy according to the American College of Sport Medicine guidelines (ACSM 1998).

Table 1. Subject characteristics ($n = 16$)*

Age (yr)	20.2 ± 1.8
Height (cm)	172.9 ± 5.0
Body weight (kg)	68.1 ± 6.2
Body mass index (kg/m^2)	22.9 ± 1.4

*Data are presented as mean ± standard deviation.

Research design

Each subject visited the laboratory four times. During the first visit, subjects signed the informed consent form and completed the health and exercise history questionnaire, and their height and body weight were measured. During the second visit, subjects' maximal muscular strength was determined in order to calculate weight loads for the resistance exercise treatment sessions. In the following 3 days, the RMR and other resting physiologic responses were determined. Finally, all subjects had two exercise treatment sessions: low-intensity resistance exercise (LO) and high-intensity resistance exercise (HI). Subjects performed the two tests 3 days apart, and each test was performed at the same time of day. Furthermore, the two exercise treatment sessions were randomly assigned to subjects in a counterbalanced order. Each treatment session comprised three sets of eight exercises with an equal work volume but different exercise intensity. Subjects were instructed to be well hydrated in the 3 hours leading up to each session, to refrain from caffeine in the 24 hours before each session, and to avoid intense exercise in the 48 hours before each session.

Test of maximal muscular strength

Subjects had to perform warm-up and stretch activities for 10 minutes before the maximal muscular strength test. The weight loads set were according to the training records of each subject. During each test, if the subject successfully completed the weight loads more than two times, the tester would increase the weight load. The one-repetition-maximum (1RM) was defined as the weight load that the subject could successfully raise before the last weight load that he could not raise. During the test sessions, the exercises were performed in the following order: barbell arm curl, standing rowing, bench press, triceps press down, incline leg press, half squat, bent over rowing, leg extension.

Assessment of RMR

Subjects fasted during the 5 hours prior to RMR measurement. Then, each subject was instructed to lie down on the bench, resting for 30 minutes. The RMR and the resting values for heart rate (HR), ventilation volume ($\dot{V}E$), respiratory exchange ratio (RER) and body temperature (BT) during the 30 minutes were measuring using the K4b$_2$ metabolism analysis instrument (COSMED S.r.l., Rome, Italy). During the test, the laboratory was kept quiet, without any disturbances. The physiologic resting values of subjects are presented in Table 2.

Table 2. Physiologic resting values of subjects ($n = 16$)*

$\dot{V}E$ (L min^{-1})	7.8 ± 1.1
$\dot{V}O_2$ (mL kg^{-1} min^{-1})	4.3 ± 0.4
BT (°C)	36.5 ± 0.2
HR (beats min^{-1})	70 ± 4.0
RER	0.82 ± 0.1

*Data are presented as mean ± standard deviation. $\dot{V}E$ = ventilation volume; $\dot{V}O_2$ = oxygen consumption; BT = body temperature; HR = heart rate; RER = respiratory exchange ratio.

Resistance exercise sessions

All subjects performed high- and low-intensity resistance exercises. First, subjects sat quietly for 15 minutes to allow the metabolic rate to stabilize. Then, subjects performed high-intensity resistance exercises (3 sets, eight exercises of 10 repetitions at 75% of their 1RM) and low-intensity resistance exercises (3 sets, eight exercises of 15 repetitions at 50% of their 1RM). During the exercises, 2-minute rest periods between sets were enforced.

Determination of EPOC

Subjects sat on the bench immediately after completing all resistance exercise sessions. Then, subjects were instructed to rest quietly for 2 hours. During the rest period, subjects' oxygen consumption ($\dot{V}O_2$), HR, $\dot{V}E$ and RER were measured using the K4b$_2$ metabolism analysis instrument (COSMED S.r.l.). In addition, BT at 0, 20, 40, 60, 100 and 120 minutes during the rest period were recorded. Post-exercise oxygen consumption was measured for 2 hours (Figure 1). EPOC was calculated according to the formula: EPOC (L) = recovery $\dot{V}O_2$ − RMR.

Calculation of energy expenditure and substrate use

In this study, energy expenditure during recovery was calculated by multiplying the $\dot{V}O_2$ values by the caloric equivalents of 5.00 kcal L^{-1} because resistance exercise greatly influences blood pH. An increased exhaling of CO$_2$ and buffering reactions, to help normalize

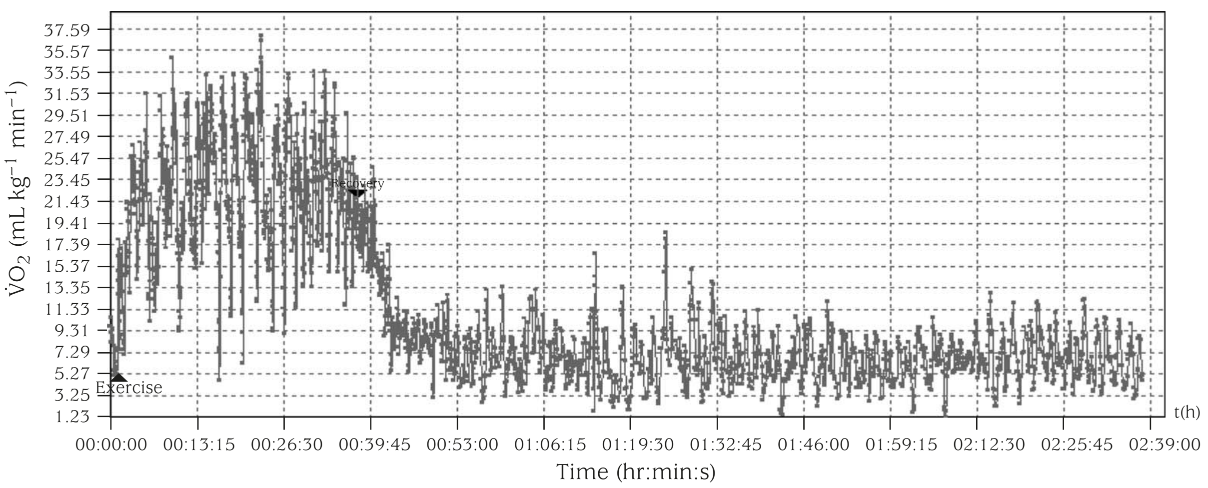

Fig. 1 Post-exercise oxygen consumption, $\dot{V}O_2$ (mL kg^{-1} min^{-1}), over the 2-hour resting period.

acid-base balance, will affect accurate interpretation of the RER (Haltom et al. 1999). Thus, we did not use RER values to compute energy expenditure. However, we did use RER values to compute percent of metabolic substrate use during recovery (substrate oxidation estimation was a limitation in this study).

Statistical analysis

Data were summarized as group means with variance presented as standard deviation. Descriptive statistics of demographic data were evaluated to determine sample homogeneity. Repeated *t* test was applied to compare EPOC, substrate oxidation and physiologic responses ($\dot{V}E$, RER, HR, BT) between HI and LO. The level of significance for all tests was set at $p < 0.05$. All data were analyzed using SPSS version 10.0 (SPSS Inc., Chicago, IL, USA).

Results

EPOC

The $\dot{V}O_2$ of the post-exercise recovery period (0–20 minutes, 40–60 minutes, and 100–120 minutes) and EPOC from HI were significantly greater than those from LO ($p < 0.05$). Furthermore, energy expenditure in the recovery period (0–20 minutes, 40–60 minutes, and 100–120 minutes) after HI was significantly greater than that after LO ($p < 0.05$) (Figure 2).

Substrate oxidation

No significant difference was found between HI and LO in post-exercise RER, HR, BT and $\dot{V}E$ ($p > 0.05$) (Figure 3). However, at 0–20 minutes and 40–60 minutes after exercise, fat oxidation from HI was significantly greater than from LO ($p < 0.05$). There was no significant difference in post-exercise carbohydrate oxidation between HI and LO ($p > 0.05$) (Figure 4).

Discussion

EPOC was greater after HI than after LO when the two sessions were equal in work volume. EPOC from HI was significantly greater than from LO for each post-exercise time period. Also, post-exercise $\dot{V}O_2$ in both HI and LO conditions remained significantly elevated above resting level for at least 2 hours.

Effect of resistance exercise intensity on EPOC

The results of this study indicated that EPOC during the recovery period (120 minutes) after HI was significantly greater than after LO. A few studies have compared EPOC of equal work volume but different exercise intensity (Thornton & Potteiger 2002; Olds & Abernethy 1993), but the results have been diverse. Olds & Abernethy

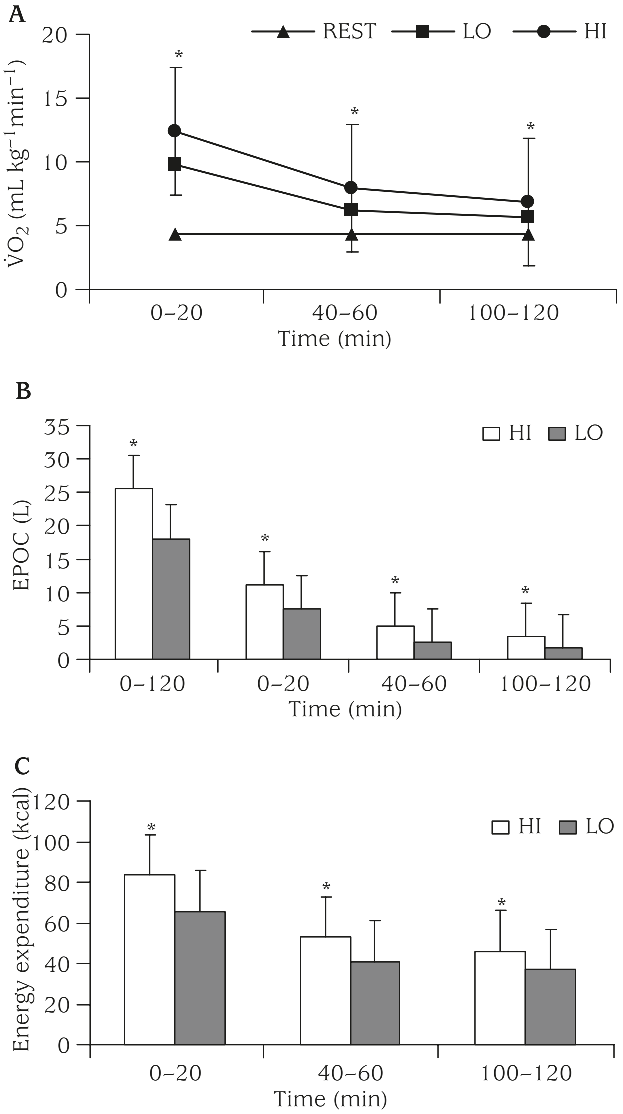

Fig. 2 (A) Oxygen consumption, $\dot{V}O_2$; (B) excess post-exercise oxygen consumption (EPOC); and (C) energy expenditure post high-intensity (HI) and low-intensity (LO) resistance exercise sessions in 16 male subjects. *HI significantly greater than LO. Data are presented as mean ± standard deviation.

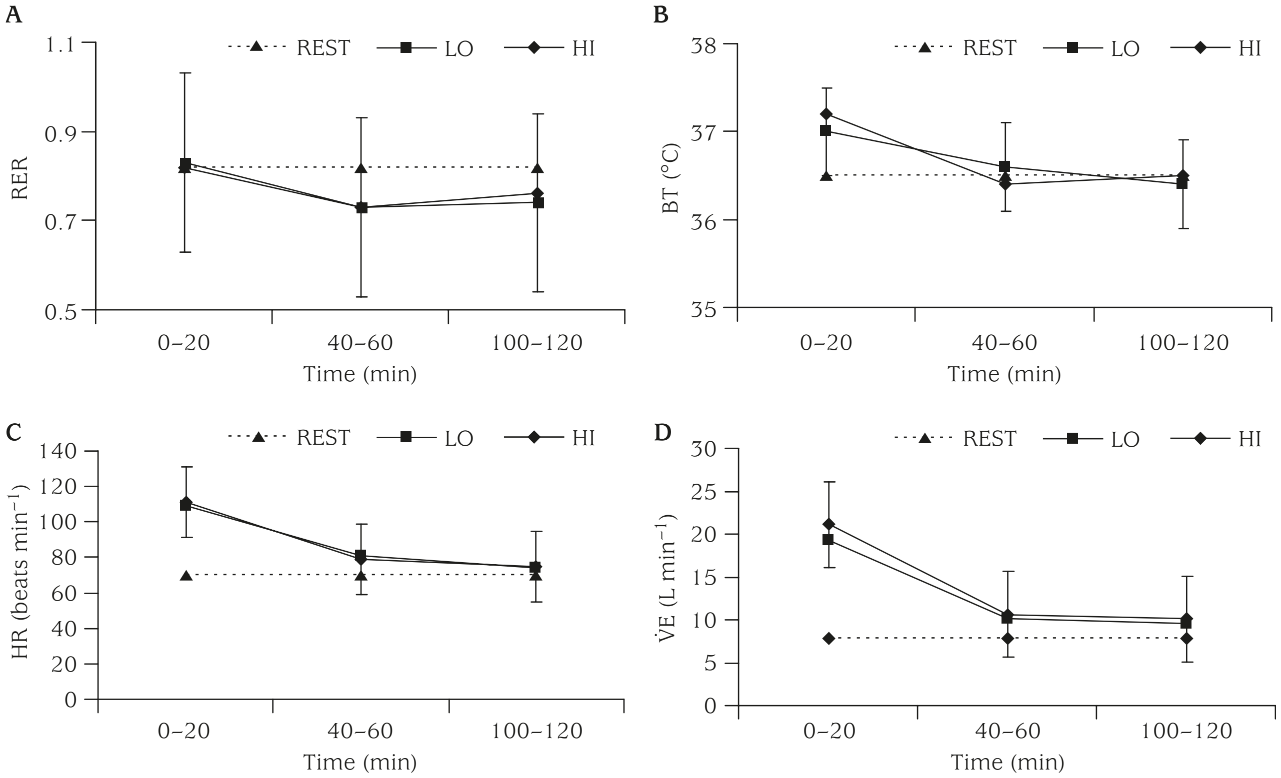

Fig. 3 (A) Respiratory exchange ratio (RER); (B) body temperature (BT); (C) heart rate (HR); and (D) ventilation volume ($\dot{V}E$) post high-intensity (HI) and low-intensity (LO) resistance exercise sessions in 16 male subjects. No significant differences were observed between HI and LO for any of these parameters. Data are presented as mean ± standard deviation.

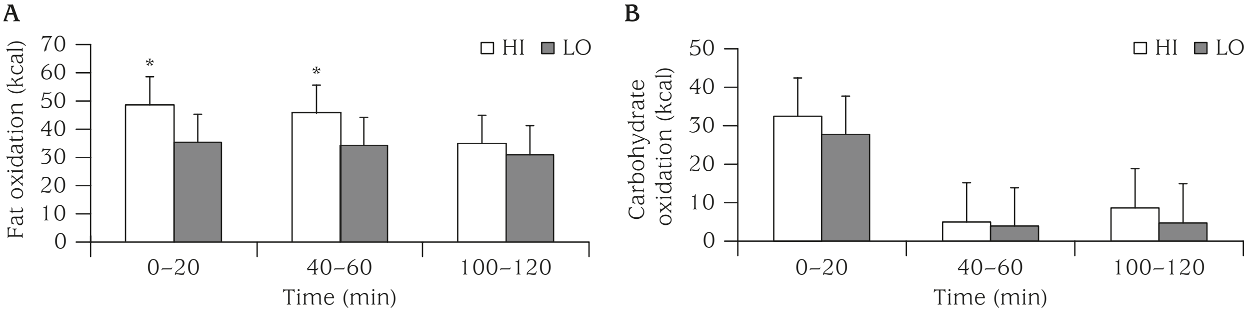

Fig. 4 (A) Fat oxidation; and (B) carbohydrate oxidation post high-intensity (HI) and low-intensity (LO) resistance exercise sessions in 16 male subjects. *HI significantly greater than LO. Data are presented as mean ± standard deviation.

(1993) compared equal work volume resistance exercise with different intensity (2 sets of 12 repetitions at 75% of 1RM and 2 sets of 15 repetitions at 60% of 1RM) and found no significant difference between HI and LO. However, the difference between the two intensities was narrow and may not have been large enough to induce a treatment effect. Thornton & Potteiger (2002) performed a similar study (2 sets of 15 repetitions at 45% of 8RM and 2 sets of 8 repetitions at 85% of 8RM) and concluded that EPOC of HI was significantly greater than EPOC of LO. The results of this study support the results of Thorton & Potteiger (2002). Some studies also indicated that EPOC of resistance exercise was greater than EPOC of aerobic exercise (Burleson et al. 1998; Elliot et al. 1992). However, the present study measured oxygen consumption during a recovery period of only

2 hours, and could not identify EPOC duration of resistance exercise accurately. Williamson & Kirwan (1997) and Dolezal et al. (2000) found that EPOC of moderate-to-high-intensity resistance exercise lasted for 48 hours. In this study, the EPOC of HI and LO lasted throughout the 2 hours that was studied. However, Melby et al. (1992) and Binzen et al. (2001) indicated that the EPOC of LO was less than 2 hours; the results of this study were different from theirs, but the differences may be due to differences in exercise intensity, exercises performed, and number of sets and repetitions.

During the recovery period following exercise, physiologic activities such as HR, breathing, BT and circulating hormones remain elevated above resting levels and require additional oxygen above resting levels. Although the reasons for this response are unclear, the contributing factors include: restoration of muscle ATP-CP system; replenishment of oxygen stores in blood and muscles; repair of damaged muscle tissue; and lactate removal (Brooks et al. 2000). Harris et al. (1976) indicated that restoration of phosphorylcreatine and oxygen stores in muscle is completed within the first 2–3 minutes of the recovery period. In addition, no significant difference was found between HI and LO in post-exercise HR, $\dot{V}E$, RER and BT in the present study. However, hormone concentration in blood may be an important factor contributing to the EPOC of HI and LO. Viru (1985) indicated that exercise intensity has to reach a threshold in order to produce significant hormonal responses. Thus, HI would induce high levels of epinephrine or norepinephrine and result in increased oxygen consumption after exercise compared to LO. However, both of these hormones are rapidly removed from the blood following exercise and, therefore, may not exist long enough to have any significant impact on EPOC. Thus, there are other factors that affect EPOC from resistance exercise of different intensities. Further study of this issue is required.

Effect of resistance exercise intensity on substrate use

Mean recovery period (120 minutes) RER of HI and LO were 0.75±0.02 and 0.75±0.03, respectively. The main fuel in the recovery period after HI and LO was fat (Figure 5). Melby et al. (1992) and Binzen et al. (2001) also found that RER of the recovery period was lower than resting state. The results of this study revealed that fat oxidation in the recovery period (0–20 minutes and 40–60 minutes) after HI was significantly greater than after LO. However, there was no significant difference between HI and LO for post-exercise carbohydrate oxidation, meaning that a similar amount of carbohydrate was used as fuel in the recovery periods after HI and LO. However, recovery period (0–20 minutes and 40–60 minutes) after HI used additional fat as fuel. The possible mechanisms accounting for this are uncertain. It is known that as exercise intensity elevates, the contribution of fat as a fuel source decreases, resulting in a greater increase in carbohydrate utilization during exercise (Gaesser & Brooks 1984). Thus, people who perform high-intensity resistance exercise, which depends on the anaerobic metabolism of phosphorylcreatine and glycogen for energy, will experience a depletion of glycogen stores (Pascoe et al. 1993). During the recovery period after HI that results in glycogen depletion, lipid becomes the main fuel, indicating a shift toward elevated fat oxidation while sparing carbohydrate for glycogen resynthesis (Brooks & Mercier 1994). This shift toward greater fat utilization during recovery may represent a counter regulatory mechanism that increases fat utilization to spare carbohydrates. HI also uses more carbohydrate as fuel than LO during exercise. Thus, HI may lead to greater lipid oxidation in the post-exercise state than LO. In addition, the process of increased lipid oxidation requires more oxygen, which may explain the higher EPOC of HI.

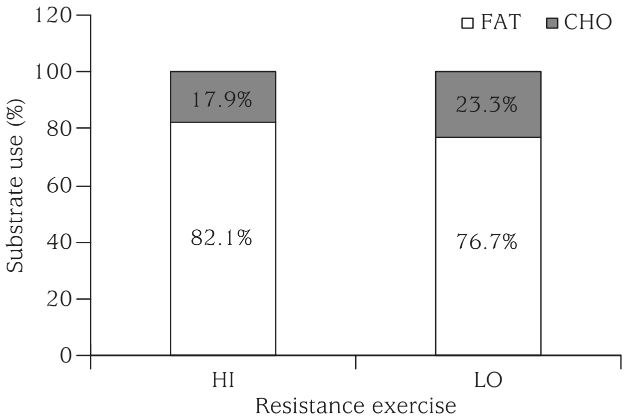

Fig. 5 Percentage of substrate use (fat [FAT] and carbohydrate [CHO]) 120 minutes post high-intensity (HI) and low-intensity (LO) resistance exercise sessions in 16 male subjects.

Conclusion

This study demonstrated that EPOC and fat oxidation after HI were higher than after LO, and energy expenditure in the recovery period after HI was also greater than after LO. Thus, we conclude that high-intensity resistance exercise is a better choice in weight control programs for energy expenditure.

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