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ORIGINAL ARTICLE

Effect of preceding resistance exercise on metabolism during subsequent aerobic session

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Abstract The present study was undertaken to evaluate the acute effect of prior resistance training of varying intensities on energy expenditure and substrate utilization during subsequent aerobic exercise. Eleven males and 21 females completed three experimental trials consisting of (1) aerobic exercise only (C), (2) aerobic exercise preceded by a high-intensity resistance training (HI), and (3) aerobic exercise preceded by a low-intensity resistance training (LO). Resistance training produced an equal volume between HI and LO and consisted of six exercises with each performed for three sets of eight repetitions at 90% of 8-RM in HI and three sets of 12 repetitions at 60% of 8-RM in LO. Aerobic exercise was performed on a cycle ergometer at 50% VO_2peak for 20 min in all trials. Oxygen uptake (VO_2), and carbohydrate and fat oxidation were determined throughout each aerobic exercise session. Fat oxidation rate was higher ($P < 0.05$) in HI than either LO or C in both males and females. VO_2 was also higher ($P < 0.05$) in HI than either LO or C in females. In males, although between-trial differences in VO_2 did not reach statistical significance, they were consistent with the trend seen in females. No differences in carbohydrate oxidation rates were observed across the three trials in either gender group. It appears that in training that combines both aerobic and resistance exercises, performing a comparatively higher intensity resistance exercise first would augment fat utilization and energy expenditure during subsequent aerobic exercise.

Keywords Resistance exercise · Aerobic exercise · Exercise order · Fat utilization · Energy expenditure

Introduction

Aerobic and resistance exercises are the two forms of exercise commonly chosen in physical conditioning. Each modality has its unique advantages. Aerobic exercise is effective in improving one's cardiorespiratory fitness and in promoting energy expenditure and fat utilization. Resistance exercise can serve as a potent stimulus to the musculoskeletal system necessary to bring about gains in muscle size and strength. It is recommended that a training routine combine both aerobic and resistance exercises because improvements in both cardiorespiratory and musculoskeletal function can allow individuals to not only reduce health risks and symptoms associated with physical inactivity, but also perform activities of daily living comfortably and safely (American College of Sports Medicine 1988; Feigenbaum and Pollock 1999).

Although performing aerobic and resistance exercises in a single training session is common, considerably less information is available with regard to the desired order of this combined approach to optimize the effect of each type of exercise. Performing aerobic exercise first seems to be safer because it can serve as a sufficient warm-up of muscle prior to the start of resistance exercise. However, this sequence of exercise was found to attenuate the growth hormone response to resistance exercise (Goto et al. 2005). On the other hand, when administering resistance exercise prior to an aerobic workout, Goto et al. (2007b) observed a greater increase in lipolysis during subsequent aerobic exercise, suggesting that this exercise sequence may be more beneficial metabolically. In this same study, higher

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concentrations of plasma epinephrine, norepinephrine, and growth hormone and a lower concentration of plasma insulin were also noticed at the onset of aerobic exercise. Indeed, the circulating catecholamine and growth hormone levels in combination with a low insulin concentration are considered a major stimulus for lipolysis (Stallknecht et al. 2001; Lange et al. 2002).

It should be noted that the resistance exercise protocol used by Goto et al. (2007b) was quite vigorous. The protocol consisted of six exercises, each being performed at 75% 1-RM for three to four sets with 1 min rest interval between sets. This type of protocol has been typically used as a method for inducing muscular hypertrophy (Kraemer et al. 1987, 1990). A question is raised as to whether resistance exercise of milder intensity will produce similar effects. Secretion of the lipolytic hormones mentioned earlier has been found to be intensity dependent. For example, an increase in intensity of running or cycling was found to be associated with a corresponding increase in circulating catecholamine (Pritzlaff et al. 2000; Mora-Rodriguez and Coyle 2000). A direct relationship between exercise intensity and secretion of growth hormone was also reported by Vanhelder et al. (1984) who found that leg press at 85% of 7-RM elicited an increase in growth hormone, whereas no such change was observed following the same exercise of equal volume performed at 28% of 7-RM. It may be speculated that in order to observe a subsequent increase in fat utilization, the prior resistance exercise protocol needs to be of sufficiently high intensity.

The purpose of the present study was to examine the impact of prior resistance training of varying intensity on energy expenditure and substrate utilization during subsequent aerobic exercise. We hypothesized that performing a prior resistance exercise would elicit a greater increase in fat utilization during subsequent aerobic exercise. However, this enhanced metabolic effect would only occur when a more vigorous resistance exercise protocol is carried out.

Methods

Subjects

Thirty-two subjects including 11 males and 21 females volunteered to participate in this study. These subjects were healthy and free of any orthopedic injury. Although most of them had experience in using resistance machines and some were fitter than others as indicated by their VO_2peak, none had been trained regularly for an endurance or strength/power event. All female subjects had regular menstrual cycles, and those who had used contraceptives agents or devices at the time of investigation or within the past year were excluded from the study. Subjects were informed of the purpose and testing procedures of the study and each gave their written consent to participate. All experimental procedures were evaluated and approved by The College of New Jersey Institutional Review Boards for Human Subjects Experimentation. The physical and physiological characteristics of subjects are presented in Table 1.

Table 1 Physical and physiological characteristics of subjects

Variables	Males ($N = 11$)	Females ($N = 21$)	Total ($N = 32$)
Physical characteristics			
Age	20.7 ± 0.9	20.5 ± 0.8	20.6 ± 0.8
Weight (kg)	84.6 ± 11.0	60.8 ± 7.6	69.0 ± 14.4
Height (m)	1.8 ± 0.1	1.6 ± 0.1	1.7 ± 0.1
BMI (kg m^{-2})	25.7 ± 2.1	22.8 ± 2.8	23.8 ± 2.9
VO_{2peak} test			
VO_{2peak} (l min^{-1})	3.1 ± 0.7	2.0 ± 0.5	2.4 ± 0.8
VO_{2peak} (ml kg^{-1} min^{-1})	36.4 ± 5.6	32.7 ± 5.5	34.0 ± 5.7
HR_{peak} (beat min^{-1})	179.6 ± 13.4	178.5 ± 9.9	178.9 ± 11.0
PO_{peak} (W)	287.5 ± 35.0	203.2 ± 35	232.2 ± 53.3
RER_{peak}	1.3 ± 0.1	1.2 ± 0.1	1.2 ± 0.1
8-RM test			
Leg press (kg)	149 ± 31	80 ± 20	103 ± 41
Lat pull down (kg)	65 ± 16	35 ± 11	44 ± 19
Leg extension (kg)	67 ± 11	37 ± 9	47 ± 17
Seated row (kg)	84 ± 21	39 ± 9	54 ± 26
Shoulder press (kg)	68 ± 16	25 ± 8	39 ± 23
Chess press (kg)	93 ± 21	36 ± 10	56 ± 31

Values are mean ± SD

Experimental design

Each subject completed three experimental trials consisting of (1) 20 min of aerobic exercise only (C), (2) 20-min aerobic exercise that was preceded by a high-intensity resistance exercise protocol (HI), and (3) 20-min aerobic exercise that was preceded by a low-intensity resistance exercise protocol (LO) (Fig. 1). The resistance exercise protocol in HI and LO was equated for total volume as determined by weight × repetition × set. The three experimental trials were randomly assigned and separated by at least 48 h between trials and completed within a 10-day period. All trials were conducted at the same time of the day for each subject and all subjects were tested in a minimal of 4-h postprandial state. Female subjects performed their experimental trials within the first 10 days after the onset of menses.

Before undertaking the experimental trials, subjects also made two extra visits to the laboratory. During the first visit, the maximal aerobic power (VO_2peak) was determined using an incremental cycle ergometer test. During the second visit, muscular strength was assessed for (1) chest press, (2) leg press, (3) lateral pull-down, (4) leg extension, (5) seated row, and (6) shoulder press. On a separate day prior to these two maximal tests, subjects attended a familiarization session during which instructions with regard to the testing protocol and measurement were provided. In this session, subjects were also given the opportunity to practice those required resistance exercises and to undertake an incremental exercise on a cycle ergometer up to 85% of their age-predicted heart rate.

Subjects were requested not to participate in any vigorous activities on the day prior to each trial. They were also instructed to refrain from alcohol and caffeine, and to follow a moderate carbohydrate diet that elicited ~50% of the total caloric intake derived from carbohydrate. Subjects were provided with dietary instructions and sample meal plans to ensure that they adhere to the dietary guidelines.

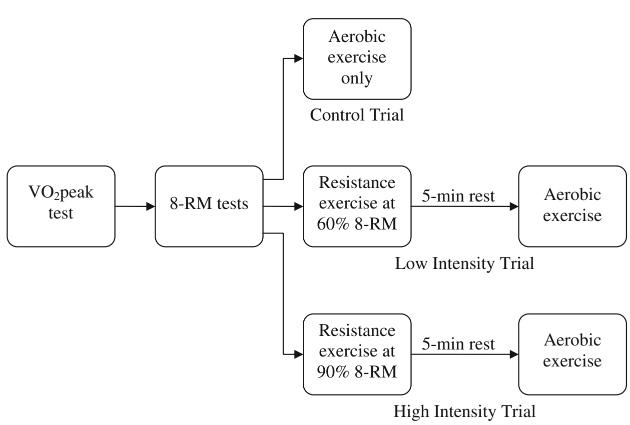

Fig. 1 Schematic illustration of the experimental protocol

We have previously demonstrated that such instructional approaches were effective in helping individuals achieve target diets (Kang et al. 1995).

Testing protocols

VO_2peak tests

During the VO_2peak test, subjects performed a continuous incremental protocol on an electronically braked cycle ergometer (Ergo 800, SensorMedics, Inc., Yorba Linda, CA). The protocol was similar to what was reported previously (Kang et al. 1997). Briefly, the test was preceded by a 5-min warm-up period. The initial power output was set at 25 W for females and 50 W for males. The power output was then increased by 25 W every 2 min. Subjects were instructed to maintain a constant pedal rate at 60 rev min^{-1} throughout the entire test. All subjects were verbally encouraged to continue exercise until volitional exhaustion. During the test, VO_2 was obtained every 20 s and VO_2peak was determined by averaging the two consecutive highest measures. Upon completion of VO_2peak test, a best-fit linear regression in which power output was plotted as a function of VO_2 was calculated for each subject. The power outputs corresponding to 50% VO_2peak were then determined from each of the individual plots.

8-RM tests

The 8-RM was defined as the maximum amount of weight that could be lifted through a full range motion eight times. Each subject performed an 8-RM strength test on six exercises in an order of (1) chest press, (2) leg press, (3) lateral pull-down, (4) leg extension, (5) seated row, and (6) shoulder press using Cybex resistance machines (Cybex International, Inc., Medway, MA). After a warm-up with low weight, the subject performed exercise beginning with 70% of their perceived 8-RM for eight repetitions. The weight was progressively increased by 5–10 pounds after each successful attempt until the 8-RM was reached. A rest interval of 2 min was given between attempts and 3 min between exercises. The 8-RM values were then used to determine corresponding load for both the high- and low-intensity resistance exercise sessions. All tests were administered by the same investigator who was a Certified Strength and Conditioning Specialist.

Experimental trials

Resistance exercise session

Resistance exercise session took place in HI and LO using the same resistance machines as mentioned earlier. During this session, subjects performed six exercises in the following order: (1) chest press, (2) leg press, (3) lateral pull-down, (4) leg extension, (5) seated row, and (6) shoulder press. Each exercise was performed for three sets of eight repetitions at 90% 8-RM in HI and three sets of 12 repetitions at 60% 8-RM in LO. We chose these repetitions in order to attain an equivalent volume between HI and LO so that effects of lifting intensity could be more adequately assessed. During both HI and LO, a rest period of 2 min was prescribed between sets and 3 min between exercises. These rest periods have been found to be associated with a minimal reduction in performance of resistance exercise (Ratamess et al. 2007). All resistance exercise sessions were monitored by investigators who insured that correct form and intensity were achieved for each exercise. The investigators also recorded the level of resistance and number of repetitions completed for each exercise in order to calculate intensity and volume being actually accomplished during each trial.

Aerobic exercise session

The aerobic exercise session involved 20 min of steady-state cycling at 50% VO_2peak using the electromagnetically braked cycle ergometer (Ergo 800, Sensormedics Corporation, Yorba Linda, CA). In C, aerobic exercise was preceded by a 5-min rest period. In HI and LO, aerobic exercise commenced 5 min after the resistance exercise session was completed. The relatively lower intensity was chosen because the potential metabolic acidosis caused by a higher intensity exercise can interfere with the calculation of carbohydrate and fat oxidation using indirect calorimetry. In addition, the chosen intensity has been recommended for maintaining health and reducing body fat (American College of Sports Medicine 1988). The 20-min duration was used mainly for allowing a steady-state to be achieved so that dependent variables such as rates of energy expenditure and substrate oxidation can be obtained. During exercise, subjects wore a heart rate (HR) monitor and were also attached to a pneumotach using a face-fitting mask so that their HR as well as various metabolic and respiratory indices including oxygen uptake (VO_2), carbon dioxide production (CO_2), respiratory exchange ratio (RER), and expired ventilation (V_E) could be determined.

Measurements

VO_2, RER, and V_E were measured using the MedGraphics ULTIMA metabolic system (MedGraphics Corporation, St. Paul, MN). Gas analyzers were calibrated using gases provided by MedGraphics Corporation: (1) calibration gas: 5% CO_2, 12% O_2, balance N_2; and (2) reference gas: 21% O_2, balance N_2. Gas calibration was conducted before each trial. HR was measured using a wireless HR monitor (Pacer, Polar CIC, Inc., Port Washington, NY), which updated HR value every 5 s. VO_2, RER, and V_E measurements were made at a 20-s interval, whereas HR values were recorded every minute.

Calculations

VO_2 and VCO_2 were used to calculate the rate of substrate oxidation using the stochiometric equations (Frayn 1983). The equations for carbohydrate and fat oxidation are as follows:

$$\text{Carbohydrate oxidation } \left(\text{g min}^{-1}\right) = 4.55 \times VCO_2 - 3.21 \times VO_2 - 2.87 \times n$$

$$\text{Fat oxidation } \left(\text{g min}^{-1}\right) = 1.67 \times VO_2 - 1.67 \times VCO_2 - 1.92 \times n.$$

In these equations, n represents nitrogen excretion rate, which was estimated to be 135 μg kg^{-1} min^{-1} according to the study of Romijn et al. (2000). Energy expenditure in kcal min^{-1} was calculated from the VO_2 adjusted for substrate metabolism using the RER values (Péronnet and Massicotte 1991). This procedure assumes that protein breakdown contributes little to energy metabolism during exercise. In this procedure, calories per liter of oxygen were first obtained according to RER. The calories per liter of oxygen were then multiplied by VO_2 to establish the rate of caloric expenditure.

Statistical analysis

The major dependent variables included VO_2, VCO_2, V_E, HR, as well as rates of carbohydrate and fat oxidation and energy expenditure. These variables were first averaged for each exercise session. Between-trial differences for these dependent variables were then analyzed by a one-way analysis of variance (ANOVA) with repeated measures, and such analysis was conducted separately for each gender. Carbohydrate and fat oxidation rates were also averaged for every 5-min interval throughout exercise. These 5-min averages were then used to examine between-trial differences over time using a two-way (trial × time) ANOVA with repeated measures. This analysis used data that combined both males and females. Significant main effects or interaction were followed by post hoc comparisons. In addition, a dependent t test was used to compare actual resistance and volume accomplished between HI and LO. For all statistical tests, a criterion alpha level of $P < 0.05$ was used to denote statistical significance. All analyses were carried out using the Statistical Package for the Social Sciences (Version 15.0, SPSS, Inc. Chicago, IL).

Results

As shown in Table 2, in both gender groups the intensity of exercise was high ($P < 0.05$) in HI than LO for all six exercises as expected. However, there was no difference in exercise volume between HI and LO. It was our intent to attain an equivalent volume between HI and LO because this would allow an adequate assessment of whether the impact of a prior resistance exercise would be influenced by lifting intensity.

In both gender groups, we observed a significant ($P < 0.05$) main effect of experimental trial for V_E [males: $F(2, 20) = 4.63$; females: $F(2, 40) = 3.87$], HR [males: $F(2, 20) = 9.20$; females: $F(2, 40) = 8.10$], RER [males: $F(2, 20) = 3.45$; females: $F(2, 40) = 3.59$], and fat oxidation rate [males: $F(2, 20) = 5.99$; females: $F(2, 40) = 4.14$]. Further analysis revealed that these variables were higher ($P < 0.05$) in HI than C (Table 3). V_E and HR were also higher ($P < 0.05$) in LO as compared to C. In addition, fat oxidation rate was higher ($P < 0.05$) in HI than LO.

Table 2 Actual resistance and volume accomplished during low (LO) and high (HI) intensity resistance exercise session

	LO (60% 8-RM)		HI (90% 8-RM)	
	Resistance	Volume	Resistance	Volume
Males				
Leg press (kg)	90 ± 19	3228 ± 686	134 ± 28*	3221 ± 673
Lat pull down (kg)	39 ± 10	1407 ± 372	60 ± 15*	1429 ± 369
Leg extension (kg)	40 ± 7	1432 ± 255	61 ± 11*	1463 ± 265
Seated row (kg)	51 ± 12	1845 ± 449	76 ± 20*	1835 ± 487
Shoulder press (kg)	41 ± 9	1482 ± 333	62 ± 15*	1485 ± 366
Chess press (kg)	57 ± 13	2068 ± 486	85 ± 20*	2043 ± 479
Females				
Leg press (kg)	47 ± 12	1695 ± 443	71 ± 18*	1705 ± 428
Lat pull down (kg)	20 ± 3	709 ± 120	29 ± 5*	685 ± 121
Leg extension (kg)	23 ± 5	816 ± 186	33 ± 8*	790 ± 194
Seated row (kg)	23 ± 6	838 ± 204	34 ± 8*	810 ± 200
Shoulder press (kg)	15 ± 5	548 ± 178	23 ± 8*	540 ± 182
Chess press (kg)	22 ± 6	785 ± 234	31 ± 9*	745 ± 222

Values are mean ± SD

The volume is calculated as weight × repetition × set. Each exercise was performed for three sets of 12 repetitions in LO and three sets of eight repetitions in HI

* Significantly different from LO, $P < 0.05$

A significant ($P < 0.05$) main effect of experimental trial was also found for VO_2 [$F(2, 40) = 3.95$], and energy expenditure [$F(2, 40) = 3.37$] in the female group. Further analysis revealed that both VO_2 and energy expenditure were higher ($P < 0.05$) in HI as compared to either C or LO (Table 3). In the male group, although the F-ratio did not reach statistical significance, the differences between trials were consistent with the trend seen in females in that both VO_2 and energy expenditure were the highest in HI that was followed by LO and then C.

Results of two-way ANOVA that combined data of both males and females revealed a significant trial-by-time interaction for carbohydrate [$F(6, 90) = 7.48$, $P < 0.01$] and fat oxidation rate [$F(6, 90) = 9.27$, $P < 0.01$]. These results suggest that the main effect of experimental trial on substrate utilization was divergent over time during aerobic exercise. As shown in Figs. 2 and 3, carbohydrate oxidation rate was lower ($P < 0.05$) in LO or HI compared to C during the first 5 min, but no between-trial differences were observed for the remaining exercise periods. On the other hand, fat oxidation rate was higher ($P < 0.05$) in HI than either LO or C for the first three 5-min periods and in LO than C for the first and third 5-min periods, while no between-trial differences were observed for the last 5-min period.

Discussion

The major finding of the present study was that in both the male and females fat oxidation rate and fractional contribution of fat to the total energy provision as reflected by RER were significantly higher in HI compared to C (Table 3). In addition, in the female group both VO_2 and energy expenditure were higher in HI than either LO or C. Given this evidence, the present study supports the use of combined aerobic and resistance exercise in a single training session. It also recommends that in this combined approach one should perform resistance exercise at a comparatively higher intensity first because this would then help augment energy expenditure and fat utilization during subsequent aerobic exercise.

Although the precise mechanism for why fat utilization increased during subsequent aerobic exercise cannot be determined, we believed that this effect was mediated by an increased lipolysis that was brought about by the preceding resistance exercise. Bahr et al. (1991) reported that the cessation of vigorous exercise would cause a sustained and rapid elevation of glycerol and free fatty acid concentrations during recovery, a finding that was ascribed to an imbalance between the supply and demand of these energy substrates. Such an increase in lipolysis has also been shown by studies that used repeated exercise bouts

Table 3 Average cardiorespiratory and metabolic responses during aerobic exercise with and without a prior resistance exercise session

Variables	C	LO	HI
Males			
VO_2 (l min^{-1})	1.74 ± 0.29	1.92 ± 0.28	1.96 ± 0.30
VCO_2 (l min^{-1})	1.78 ± 0.36	1.91 ± 0.30	1.93 ± 0.22
V_E (l min^{-1})	42.9 ± 9.0	52.2 ± 7.4[a]	52.4 ± 9.6[a]
HR (beats min^{-1})	142.7 ± 18.1	155.9 ± 17.2[a]	154.4 ± 11.6[a]
RER	0.91 ± 0.06	0.89 ± 0.05	0.87 ± 0.04[a]
Carbohydrate oxidation (g min^{-1})	1.63 ± 0.66	1.66 ± 0.51	1.43 ± 0.28
Fat oxidation (g min^{-1})	0.24 ± 0.13	0.31 ± 0.14	0.41 ± 0.15[a,b]
Caloric expenditure (kcal min^{-1})	8.65 ± 1.49	9.44 ± 1.09	9.57 ± 1.60
Females			
VO_2 (l min^{-1})	1.24 ± 0.27	1.26 ± 0.34	1.35 ± 0.29[a,b]
VCO_2 (l min^{-1})	1.23 ± 0.30	1.25 ± 0.36	1.30 ± 0.32
V_E (l min^{-1})	34.1 ± 8.0	37.7 ± 9.3[a]	38.2 ± 10.3[a]
HR (beats min^{-1})	155.2 ± 21.4	162.9 ± 22.1[a]	162.7 ± 21.9[a]
RER	0.89 ± 0.05	0.87 ± 0.06	0.85 ± 0.05[a]
Carbohydrate oxidation (g min^{-1})	1.05 ± 0.47	0.95 ± 0.41	0.93 ± 0.51
Fat oxidation (g min^{-1})	0.21 ± 0.11	0.25 ± 0.13	0.30 ± 0.14[a,b]
Caloric expenditure (kcal min^{-1})	6.11 ± 1.35	6.13 ± 1.65	6.59 ± 1.47[a,b]

Values are mean ± SD

C without a prior resistance exercise, *LO* with a prior resistance exercise at 60% 8-RM, *HI* with a prior resistance exercise at 90% 8-RM

[a] Significantly different from C, $P < 0.05$

[b] Significantly different from LO, $P < 0.05$

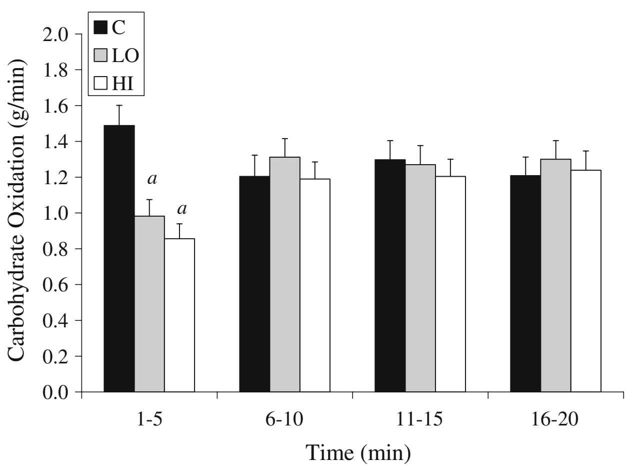

Fig. 2 Carbohydrate oxidation rates over time during aerobic exercise with and without a prior resistance exercise session. Values are mean ± SE. *C* without a prior resistance exercise, *LO* with a prior resistance exercise at 60% 8-RM, *HI* with a prior resistance exercise at 90% 8-RM. [a]Significant from C, $P < 0.05$; [b]Significantly different from LO, $P < 0.05$

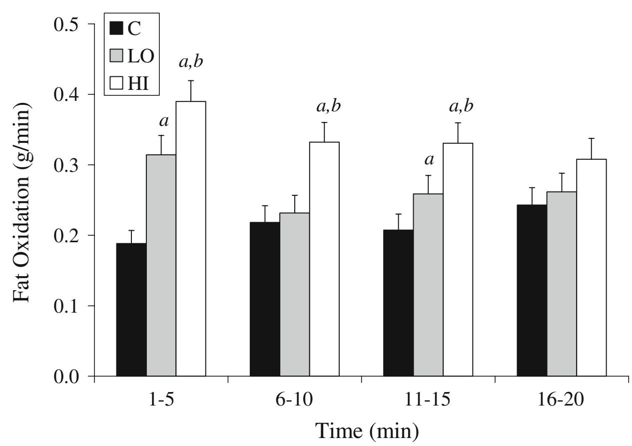

Fig. 3 Fat oxidation rates over time during aerobic exercise with and without a prior resistance exercise session. Values are mean ± SE. *C* without a prior resistance exercise, *LO* with a prior resistance exercise at 60% 8-RM, *HI* with a prior resistance exercise at 90% 8-RM. [a]Significant from C, $P < 0.05$, [b]Significantly different from LO, $P < 0.05$

(Stitch et al. 2000; Goto et al. 2007a, b). For example, by comparing a single prolonged exercise of 60 min with two repeated 30-min exercise session separated by a 20-min rest, Goto et al. (2007a) found that increases in plasma glycerol and fatty acid concentrations were higher during the second 30 min of the repeated trial as compared to the single trial. These authors also observed at the onset of the second exercise bout a greater increase in plasma epinephrine and growth hormone concentrations and a greater decrease in plasma insulin concentrations, which together may have explained a greater lipolysis observed in their repeated trial. The speculation that an increased lipolysis would augment fat utilization can be supported by the early concept of glucose-fatty acid cycle in which Randle et al. (1963) have demonstrated that the availability of fatty acids suppresses glucose oxidation. In a study in which this concept was examined under exercise condition, Ravussin et al. (1986) observed an enhanced fat oxidation following lipid/heparin infusion during early phases of prolonged cycling at 45% VO_2peak.

Fat oxidation rate during subsequent aerobic exercise was significantly higher in HI than LO despite the same volume that was accomplished between the two intensity trials (Tables 2 and 3). This finding suggests that the intensity of the preceding resistance exercise is a more important determinant than the total volume of exercise completed. It is possible that the resistance exercise protocol in HI may have facilitated lipolysis to a greater extent. Indeed, the secretion of the aforementioned lipolytic hormones including catecholamine and growth hormones has been found to be intensity dependent, that is, the greater the intensity of exercise, the greater the secretion of hormones (Pritzlaff et al. 2000; Mora-Rodriguez and Coyle 2000). The finding seems to be also consistent with our previous study in which we found that the total fat oxidized during aerobic exercise of mixed intensity was higher when the higher intensity exercise bout was performed first (Kang et al. 2003).

The contention that performing resistance exercise at higher intensity is of more benefit is also supported by our VO_2 data. We observed that in the female group VO_2 as well as energy expenditure during subsequent aerobic exercise was significantly higher in HI than either LO or C (Table 3). This finding suggests that one should expect to achieve a greater energy output from the same aerobic exercise that is preceded by a higher resistance exercise protocol. Such a greater metabolic effect associated with a higher intensity resistance exercise is consistent with previous findings concerning the relationship between exercise intensity and post-exercise oxygen consumption (EPOC). The fact that exercising at a higher intensity provokes greater EPOC has been demonstrated under the conditions of both aerobic (Hagberg et al. 1980) and resistance exercise (Thornton and Potteiger 2002). As such, the higher VO_2 seen in HI in this study can be attributed to more profound physiological alterations induced by the prior higher intensity resistance exercise. Given that EPOC represents only resting VO_2 following exercise, the VO_2 we reported presently may be viewed as the sum of EPOC resulting from the prior resistance exercise and metabolic demand imposed by the subsequent aerobic exercise per se. The higher VO_2 seen in HI may also result from fatigue that one would normally encounter, which often leads to a recruitment of additional motor units. Sproule (1998) has demonstrated a reduction in metabolic efficiency coupled with a greater increase in VO_2 during 2nd exercise bout that followed 60-min running at 80% VO_{2max}. Such a lingering effect of fatigue seems quite plausible given that our subjects were average in fitness and relatively less experienced in resistance training.

It appears that in order to have augmented fat oxidation and energy expenditure during subsequent aerobic exercise, it is necessary to perform a prior resistance exercise at a comparatively higher intensity. However, this finding should not be interpreted as an obstacle for those who have a little or no weight training experience. To our knowledge, the six weight lifting exercises we used are among those most commonly chosen, and they are machine-based so that they should post a minimal risk and can be easily learned. In addition, given that 8-RM is normally associated with 80% of 1-RM for a majority of lifting exercises (Kraemer et al. 2006), the intensity of 90% of 8-RM in HI should really be considered moderate and equivalent to approximately 70% of 1-RM. Our subjects were average in fitness as shown in Table 1 and relatively less experienced in resistance training. Nevertheless, all of them were able to complete both resistance and aerobic exercise sessions, and none had demonstrated any unusual sign of fatigue in either HI or LO.

In the present study, we observed a great deal of divergent responses between V_E or HR and VO_2 (Table 3). For example, V_E and HR were higher in LO than C in both genders. However, no difference in VO_2 was found between LO and C. In addition, in the female group, while VO_2 was higher in HI than LO, V_E and HR remained the same between HI and LO. Under the condition of resistance exercise, responses of V_E and HR do not always reflect the level of metabolic demand. An increase in V_E without a concurrent increase in VO_2 seen in LO may reflect pulmonary compensation aimed to re-establish acid–base balance following resistance exercise. In addition, a disproportional increase in HR relative to VO_2 has long been reported during weight lifting exercises (Collins et al. 1991).

In the present study, a 5-min rest interval was given between resistance and aerobic exercise sessions. A greater increase in lipolysis and fat oxidation was also observed during aerobic exercise that commenced 20 min after the completion of resistance exercise (Goto et al. 2007b). However, these authors failed to observe the similar effect on fat utilization when resistance and aerobic exercises were separated by a rest period of 120 min. These findings suggest that the metabolic effect produced by a prior resistance exercise may be somewhat short-lived. It is possible that such prolonged rest period may have allowed those lipolytic hormones to revert to their resting levels well before the next exercise bout was initiated. In this same study, plasma concentrations of epinephrine and norepinephrine at the onset of second exercise bout were found to be higher than baseline following a rest period of 20 min, whereas no such difference was observed when a rest period was extended to 120 min. Interestingly, in our trial-by-time analysis, we found that the favorable changes in fuel utilization were more pronounced during early periods of aerobic exercise, and there were no between trial differences observed during the last 5 min of exercise (Figs. 2, 3). It appears that time in between exercises can be critical, and in order to obtain metabolic benefits from this combined exercise regimen, the aerobic session should be resumed sooner enough, preferably within no more than 20 min of rest following resistance exercise.

In conclusion, the present study demonstrated that fat utilization and energy expenditure could be augmented during low-intensity aerobic exercise that was preceded by a multi-set resistance exercise protocol performed at a comparatively higher intensity. This finding supports a training approach that combines both aerobic and resistance exercise, and also recommends that resistance exercise be performed first and followed by aerobic exercise commencing in no more than 5 min of rest period. Although there appears to be a minimal intensity of resistance exercise necessary, the intensity that we proved effective is considered moderate and can be tolerated by a majority of young individuals.

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