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Effects of circuit low-intensity resistance exercise with slow movement on oxygen consumption during and after exercise

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Abstract

The purpose of this study was to examine oxygen consumption ($\dot{V}O_2$) during and after a single bout of low-intensity resistance exercise with slow movement. Eleven healthy men performed the following three types of circuit resistance exercise on separate days: (1) low-intensity resistance exercise with slow movement: 50% of one-repetition maximum (1-RM) and 4 s each of lifting and lowering phases; (2) high-intensity resistance exercise with normal movement: 80% of 1-RM and 1 s each of lifting and lowering phases; and (3) low-intensity resistance exercise with normal movement: 50% of 1-RM and 1 s each of lifting and lowering phases. These three resistance exercise trials were performed for three sets in a circuit pattern with four exercises, and the participants performed each set until exhaustion. Oxygen consumption was monitored continuously during exercise and for 180 min after exercise. Average $\dot{V}O_2$ throughout the exercise session was significantly higher with high- and low-intensity resistance exercise with normal movement than with low-intensity resistance exercise with slow movement ($P < 0.05$); however, total $\dot{V}O_2$ was significantly greater in low-intensity resistance exercise with slow movement than in the other trials. In contrast, there were no significant differences in the total excess post-exercise oxygen consumption among the three exercise trials. The results of this study suggest that low-intensity resistance exercise with slow movement induces much greater energy expenditure than resistance exercise with normal movement of high or low intensity, and is followed by the same total excess post-exercise oxygen consumption for 180 min after exercise.

Keywords: Repetitive speeds, energy expenditure, excess post-exercise oxygen consumption, resistance exercise

Introduction

Conventionally, resistance exercise is conducted to increase muscular strength and enhance muscle mass in order to maintain or improve physical fitness. Resistance exercise is also now frequently used in exercise prescriptions or programmes for body weight control and weight reduction (ACSM, 2006b).

The acute metabolic demands of resistance exercise have been investigated in previous studies, and their results show significantly larger increases in oxygen consumption ($\dot{V}O_2$) and energy expenditure depending on such variables as lifting speeds (Ballor, Becque, & Katch, 1987; Haltom et al., 1999; Mazzetti, Douglass, Yocum, & Harber, 2007), number of sets (Haddock & Wilkin, 2006; Phillips & Ziuraitis, 2003), number of repetitions (Ratamess et al., 2007), exercise intensity (Hunter, Blackman, Dunnam, & Flemming, 1988; Thornton & Potteiger, 2002), exercise volume (Kang et al., 2005), rest

intervals (DeGroot, Quinn, Kertzer, Vroman, & Olney, 1998; Ratamess et al., 2007), and exercise order (Farinatti, Simão, Monteiro, & Fleck, 2009).

In contrast, after exercise, $\dot{V}O_2$ and energy expenditure remain above resting values for a period of time, denoting high energy expenditure during this period (Gaesser & Brooks, 1984). The extra oxygen consumption is known as excess post-exercise oxygen consumption. During recovery from relatively high-intensity exercise, it may take approximately 60 min or more for $\dot{V}O_2$ and the anaerobic metabolic rate to return to values recorded before exercise (Gaesser & Brooks, 1984; LaForgia, Withers, & Gore, 2006). Some studies found that excess post-exercise oxygen consumption returned to normal within 60 min (Burleson, O'Bryant, Stone, Collins, & Triplett-McBride, 1998; Haltom et al., 1999), whereas others found that $\dot{V}O_2$ remained elevated for 14 h or more (Gillette, Bullough, & Melby, 1994; Melby, Scholl, Edwards, & Bullough, 1993; Osterberg & Melby, 2000). Moreover, two

studies found that resting metabolic rate remained elevated for 48 h after moderate-to-high intensity resistance exercise. The magnitude of excess post-exercise oxygen consumption and its duration are related to the exercise intensity of the prior exercise (Dolezal, Potteiger, Jacobsen, & Benedict, 2000; Williamson & Kirwan, 1997). Some studies investigating higher-intensity compared with lower-intensity exercise have consistently reported greater excess post-exercise oxygen consumption and excess post-exercise energy expenditure responses for higher-intensity exercise (Haltom et al., 1999; LaForgia et al., 2006; Phelain, Reinke, & Harris, 1997; Scott, 1998; Thornton & Potteiger, 2002). Kang et al. (2005) suggested that an exercise routine performed at low to moderate intensity coupled with a moderate to high exercise volume is most effective in maximizing energy expenditure following exercise. Many studies on excess post-exercise oxygen consumption or excess post-exercise energy expenditure suggest that exercise intensity, particularly workloads more than 70% of one-repetition maximum (1-RM) for resistance exercise (Binzen, Swan, & Manore, 2001; Kang et al., 2005; Melby et al., 1993; Poehlman & Melby, 1998; Schuenke, Mikat, & McBride, 2002), is a major factor that affects the magnitude and duration of excess post-exercise oxygen consumption or excess post-exercise energy expenditure. However, the exercise intensity of 70–80% of 1-RM used in these previous studies is too strong for many individuals with low fitness or for elderly people. In general, resistance exercise training for individuals with low fitness or for elderly people is initially performed at a low intensity of approximately 50% of 1-RM (ACSM, 2006a; Feigenbaum & Pollock, 1999). Thus, low-intensity (light load) resistance exercise with slow movement has recently attracted interest as a method of exercise (Goto, Takahashi, Yamamoto, & Takamatsu, 2008; Tanimoto & Ishii, 2006; Tanimoto et al., 2008; Westcott et al., 2001).

It has been reported that acute low-intensity resistance exercise with slow movement and tonic force generation (<50% of 1-RM) enhanced growth hormone secretion (Tanimoto, Madarame, & Ishii, 2005), and Goto et al. (2008) reported that low-intensity (40% of 1-RM) resistance exercise with slow movement caused significantly greater responses of norepinephrine and free testosterone after exercise than high-intensity (80% of 1-RM) resistance exercise with normal movement. Accordingly, even with low-intensity exercise involving slow repetitive movement, similar effects as those of high-intensity resistance exercise with normal movement can be induced. Some previous studies (Goto et al., 2008; Tanimoto & Ishii, 2006; Tanimoto et al., 2008) investigated the physiological effects of exercise on single joint muscles (e.g. knee extension

on knee extensor muscles), but without examining $\dot{V}O_2$ or energy expenditure during and after low-intensity resistance exercise with slow movement, using a circuit exercise pattern with whole-body exercises. Moreover, few studies have investigated the effects of a single bout of resistance exercise with different intensities (loads) and repetitive movement speeds on $\dot{V}O_2$ and energy expenditure during and after exercise. In the present study, we examined $\dot{V}O_2$ and energy expenditure during and after acute low-intensity resistance exercise with slow movement using a circuit exercise pattern with whole-body exercises.

The responses were compared with those produced by high-intensity resistance exercise to clarify the physiological responses and usefulness of low-intensity resistance exercise with slow movement. We hypothesized that resistance exercise of longer duration, even if the intensity is low, produces greater $\dot{V}O_2$ and energy expenditure responses during and after exercise than high-intensity resistance exercise with normal movement.

Materials and methods

Participants

Eleven healthy men participated in this study. When recruiting participants, we endeavoured to identify individuals of similar age, physique, and physical activity levels. All participants were physically active and trained recreationally, with enough resistance exercise experience (at least 2 days per week in the 6 months prior to the study), but did not have any experience of competitive sports. None of the participants was a smoker, habitual drinker, or took any medications, ergogenic supplements or nutritional supplements known to affect energy metabolism or resistance exercise performance. Following an explanation of all procedures, risks, and benefits of the study, each participant provided informed consent. The procedures of the study were reviewed and approved by the Ethical Review Board of Nippon Sport Science University and undertaken in accordance with the Declaration of Helsinki. The physical characteristics of the participants are presented in Table I.

Experimental schedule

All participants visited the laboratory five times during the experimental period. During the first visit, body composition, resting $\dot{V}O_2$, and heart rate during 180 min of rest while seated on a chair (control) were determined. Subsequently, each participant performed a 1-RM strength test to calculate relative exercise intensity. During their

second visit, participants performed a $\dot{V}O_{2\text{peak}}$ test on a cycle ergometer. This test was conducted to determine the participant's aerobic fitness. During visits 3–5, the participants performed the following three types of resistance exercise trials: (1) low-intensity resistance exercise with slow movement, (2) high-intensity resistance exercise with normal movement, and (3) low-intensity resistance exercise with normal movement. The order of the three exercise trials was counterbalanced with a crossover design. All participants performed all three trials, with at least 4 days between trials, within a period of 4 weeks.

Each trial was performed between 09:00 and 13:00 h after overnight fasting for 12 h. Participants were requested not to participate in any vigorous activities on the day before each session. They were also instructed to refrain from ingestion of alcohol and caffeine. The experiments were conducted in a laboratory with air-conditioning, and room temperature and relative humidity were maintained at 22–24°C and 55–65%, respectively, throughout the experiments.

Measurements of one-repetition maximum in the four resistance exercises

One-repetition maximum (1-RM) was evaluated in four different resistance exercises in the following order: chest press, leg press, seated row, and leg extension, using isotonic exercise machines (Nautilus, USA). A warm-up that included 10–15 repetitions at 50% of the participant's perceived 1-RM was undertaken. Following 3 min of rest, participants attempted their estimated 1-RM. The load was increased progressively by 5 kg after each successful attempt until 1-RM was identified. One-repetition maximum was defined as the maximum amount of weight lifted during one full range of motion with the proper exercise form and without a bounce, according to the guidelines of the National Strength and Conditioning Association for fitness testing protocols and norms (Carmer & Coburn, 2004). All 1-RM

testing and exercise trials were supervised by a certified strength and conditioning specialist.

Measurements of $\dot{V}O_{2\text{peak}}$

Peak $\dot{V}O_2$ was assessed using a graded exercise test on a cycle ergometer (AEROBIKE800, COMBI, Japan). The participants started cycling at 50 W for the first 5 min, and the power output was increased by 25 W every 2 min until maximum volitional exhaustion. The test was terminated when the participant failed to maintain the prescribed pedalling frequency of 60 rpm or reached a plateau in $\dot{V}O_2$. Expired gases were collected and analysed using a portable cardiopulmonary exercise system (METAMAX3B, CORTEX, Germany). Heart rate was also measured continuously using a wireless heart rate monitor (POLAR, Finland).

Experimental procedure and exercise regimens

The experimental procedure of the exercise trial is shown in Figure 1. The physiological responses of all exercise trials were measured continuously before, during, and for 180 min after a single bout of resistance exercise. The participants rested on a comfortable chair for 5 min, followed by a warm-up consisting of 10 repetitions with a load of 50% 1-RM. Subsequently, each resistance exercise trial was performed. After the exercise, the participants returned to a seated position on the chair, and rested continuously for 180 min. During rest, the seated participants were instructed to rest as much as possible and were prohibited from eating foods, leaving the chair or sleeping.

The exercise regimens of the three types of exercise trials were as follows: (1) low-intensity resistance exercise with slow movement trial (intensity: 50% of 1-RM; repetitive movement: 4 s each of lifting and lowering phases); (2) high-intensity resistance exercise with normal movement trial (intensity: 80% of 1-RM; repetitive movement: 1 s each of lifting and lowering phases); and (3) low-intensity resistance exercise with normal movement trial (intensity: 50% of 1-RM; repetitive movement:

Table I. Physical characteristics of participants (mean \pm s; $n = 11$).

Age (years)	21.7 \pm 2.8
Height (cm)	172.4 \pm 2.1
Body weight (kg)	66.3 \pm 5.4
Body mass index ($\text{kg} \cdot \text{m}^{-2}$)	22.7 \pm 2.0
Percent body fat (%)	12.7 \pm 4.4
$\dot{V}O_{2\text{peak}}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	48.4 \pm 4.2
Peak heart rate ($\text{beats} \cdot \text{min}^{-1}$)	185.7 \pm 4.5
Chest press 1-RM (kg)	69.1 \pm 14.1
Leg press 1-RM (kg)	235.6 \pm 23.1
Seated row 1-RM (kg)	74.6 \pm 7.2
Leg extension 1-RM (kg)	72.6 \pm 10.2

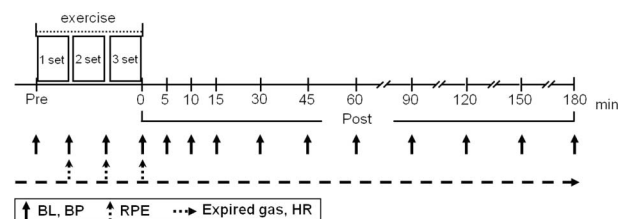


Figure 1. Experimental procedure of exercise trial. BL = blood lactate, BP = blood pressure, RPE = ratings of perceived exertion, HR = heart rate.

1 s each of lifting and lowering phases). The relative intensity (percentage of 1-RM) of the exercise was calculated by reference to a repetitive movement conversion table (Carmer & Coburn, 2004) utilizing previously determined values of 1-RM. Repetitive movement speed for the low-intensity resistance exercise with slow movement trial was determined on the basis of previous studies using low-intensity resistance exercise with slow movement (Goto et al., 2008; Tanimoto & Ishii, 2006). The resistance exercise trials were performed with three sets using a circuit pattern of four exercises on isotonic exercise machines (Nautilus, USA): chest press, leg press, seated row, and leg extension, with 2 min rest between sets. Each set was continued until maximum exhaustion. The participants were asked to repeat movement without breath holding to refrain from performing a Valsalva manoeuvre, and repeated the movement at an approximately constant speed and frequency with the aid of a metronome. In addition, they indicated the ratings of perceived exertion on Borg's 15-point rating scale (Noble, Borg, Jacobs, Ceci, & Kaiser, 1983) immediately after each set.

Measurements of expired gas and heart rate

Expired gases were collected continuously to determine $\dot{V}O_2$ and carbon dioxide production ($\dot{V}CO_2$) by a breath-by-breath method using a portable cardiopulmonary exercise system (METAMAX3B, CORTEX, Germany). Similarly, heart rate was measured continuously using a wireless heart rate monitor (POLAR, Finland) throughout the experimental period. The measured values were converted into average values for each minute using expired gas analytical software (MetaSoft, CORTEX, Germany). The values obtained during the exercise were averaged for each set, and those for the values after the exercise were averaged over 5 min periods, which were compared by statistical analysis. Appropriate calibrations of the O_2 and CO_2 sensors and the volume transducer were conducted before each exercise trial. The respiratory exchange ratio (RER) was determined from $\dot{V}O_2$ and $\dot{V}CO_2$ measurements. Energy expenditure was calculated using the following stoichiometric equation (Elia & Livesey, 1988):

$$\text{energy expenditure (kcal)} = \dot{V}O_2 \cdot (15.480 + 5.550 \cdot \text{RER})/4.184/1000.$$

The end of excess post-exercise oxygen consumption was defined as the instant when $\dot{V}O_2$ post-exercise returned to control values (i.e. there was no significant difference between these values). After the end of each resistance exercise trial, excess post-

exercise oxygen consumption was determined from total amounts of $\dot{V}O_2$ that were subtracted from control values (Bahr & Sejersted, 1991; Haddock & Wilkin, 2006). Excess post-exercise energy expenditure was calculated from excess post-exercise oxygen consumption using the above stoichiometric equation (Elia & Livesey, 1988).

Measurement of blood lactate concentration

Blood lactate samples were collected before each exercise trial, immediately after the end of each set, and at 5, 10, 15, 30, 45, 60, 90, 120, 150, and 180 min after the exercise. Approximately 5 μL of blood was taken from a fingertip with a needle and immediately analysed for blood lactate concentration using a lactate analyser (Lactate Pro LT-1710, ARKRAY, Japan).

Measurement of rate-pressure product

The rate-pressure product from the left radial artery was measured at the same time as measurement of blood lactate concentration with an aneroid-type sphygmomanometer (FM-800, FUKUDADENSHI, Japan). The rate-pressure product was calculated from systolic blood pressure and heart rate. In this study, the rate-pressure product was determined for an index of myocardial oxygen consumption (Huggett, Elliott, Overend, & Vandervoort, 2004). During measurements, the arm was supported by an adjustable table. To minimize the mechanical effects of the concentrations of upper body muscles and change of posture, the upper body was kept relaxed and was immobilized on the machine during exercise.

Statistical analysis

The data are presented as means \pm standard errors (s_x), except for the physical characteristics of the participants, which are presented as means \pm standard deviations (s). A one-way analysis of variance (ANOVA) with repeated measures was used to examine differences in physiological responses during and after exercise among the three types of exercise trials. A two-way (trial \times time) ANOVA with repeated measures was used to examine differences in blood lactate concentration and rate-pressure product after exercise among the three types of exercise trials. For comparison of changes in heart rate and $\dot{V}O_2$ after exercise among the three types of exercise trials and the control, a two-way (trial \times time) ANOVA with repeated measures was applied. When a significant difference was revealed, *post hoc* analysis was performed using Scheffé's multiple comparison test. The effect size on total $\dot{V}O_2$ and

energy expenditure for 180 min after the three types of exercises was calculated to determine the practical significance of exercise-related effect as follows: Cohen's $d = [(\text{exercise trial mean} - \text{control mean}) / \text{standard deviation of the control}]$ (Rhea, 2004). For all statistical tests, $P < 0.05$ was considered significant.

Results

Exercise responses

The average values of workload, number of repetitions, and exercise duration throughout three sets of exercise in the three exercise trials are shown in Table II. The number of repetitions was greater during low-intensity resistance exercise with normal movement than in the other two trials ($P < 0.01$), and the exercise duration of low-intensity resistance exercise with slow movement was longer than in the other two trials ($P < 0.01$).

Table III shows the average values of physiological responses throughout three sets of each exercise trial. Ratings of perceived exertion, blood lactate concentration, and rate-pressure product are shown as the average values determined after the end of each set.

Table II. Average values of workload, number of repetitions, and exercise duration throughout three sets of exercise in the three exercise trials (mean \pm s.e.).

	LS	HN	LN
Workload (%1-RM)	50%	80%	50%
chest press (kg)	32.7 \pm 1.3	53.2 \pm 3.2	32.7 \pm 1.3
leg press (kg)	116.0 \pm 4.6	176.4 \pm 7.3	116.0 \pm 4.6
seated row (kg)	35.6 \pm 1.6	55.0 \pm 2.9	35.6 \pm 1.6
leg extension (kg)	35.0 \pm 1.4	54.8 \pm 2.1	35.0 \pm 1.4
Number of repetitions	9.5 \pm 0.3 ^a	9.4 \pm 0.8	18.5 \pm 0.6 ^{a,c}
Exercise duration (min)	24.3 \pm 0.6 ^{a,b}	11.2 \pm 0.4	14.4 \pm 0.3 ^a

Note: LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement.

^aSignificant difference ($P < 0.05$) from HN. ^bSignificant difference ($P < 0.05$) from LN. ^cSignificant difference ($P < 0.05$) from LS.

The ratings of perceived exertion for low-intensity resistance exercise with slow movement and with normal movement were significantly lower than that for high-intensity resistance exercise ($P < 0.01$). In contrast, blood lactate concentration and rate-pressure product during high- and low-intensity resistance exercise with normal movement were significantly higher than those during low-intensity resistance exercise with slow movement ($P < 0.01$), whereas no significant differences were observed between high- and low-intensity resistance exercise with normal movement. Average heart rates during high- and low-intensity resistance exercise with normal movement were significantly higher than during low-intensity resistance exercise with slow movement ($P < 0.01$), and a significant difference was observed between high- and low-intensity resistance exercise with repetitive movement ($P < 0.05$). In addition, the average values of $\dot{V}O_2$ during high- and low-intensity resistance exercise with normal movement were significantly higher than during low-intensity resistance exercise with slow movement ($P < 0.01$). However, the total $\dot{V}O_2$ (Figure 2a) during low-intensity resistance exercise with slow movement was significantly higher than in the other two trials ($P < 0.01$). Similarly, energy expenditure (Figure 2b) during low-intensity resistance exercise with slow movement was significantly higher than in the other two trials ($P < 0.01$). In contrast, when comparing high- and low-intensity resistance exercise with normal movement, both total $\dot{V}O_2$ and energy expenditure during the exercises were significantly greater with low-intensity resistance exercise than high-intensity resistance exercise (total $\dot{V}O_2 = P < 0.01$, energy expenditure = $P < 0.05$).

Recovery responses

Changes in blood lactate concentration for 180 min after the three types of exercises are shown in Figure 3. Blood lactate concentration was found to be significantly higher from immediately after exercise to 60 min after exercise in the high-intensity

Table III. Average values of physiological responses throughout three sets of exercise in the three exercise trials (mean \pm s.e.).

	LS	HN	LN
Ratings of perceived exertion (Borg's scale)	13.7 \pm 0.4	15.8 \pm 0.4 ^{a,b}	14.1 \pm 0.5
Blood lactate (mmol \cdot L ⁻¹)	6.0 \pm 0.6	8.9 \pm 0.6 ^a	9.1 \pm 0.4 ^a
Rate-pressure product (mmHg \cdot min ⁻¹ \cdot 100 ⁻¹)	174.0 \pm 10.9	204.6 \pm 6.7 ^a	204.3 \pm 6.9 ^a
Heart rate (beats \cdot min ⁻¹)	126.5 \pm 4.8	145.4 \pm 3.7 ^{a,b}	139.3 \pm 3.6 ^a
$\dot{V}O_2$ (ml \cdot kg ⁻¹ \cdot min ⁻¹)	16.1 \pm 0.3	22.2 \pm 0.6 ^a	21.6 \pm 0.7 ^a

Note: LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement.

^aSignificant difference ($P < 0.05$) from LS. ^bSignificant difference ($P < 0.05$) from LN.

resistance exercise ($P < 0.05$), and from immediately after exercise to 30 min after exercise in the low-intensity resistance exercise with normal movement ($P < 0.05$), than in the low-intensity resistance exercise with slow movement.

Figure 4 shows changes in rate-pressure product for 180 min after the three types of exercises. Both immediately after exercise and 5 min after exercise, rate-pressure product values after high- and low-intensity resistance exercise with normal movement were significantly higher than for low-intensity resistance exercise with slow movement ($P < 0.05$).

Changes in heart rate for 180 min after the three types of exercises are shown in Figure 5. Heart rate after the exercise patterns was found to be significantly higher for 35 min after exercise in the high-

intensity resistance exercise ($P < 0.05$), and for 15 min after exercise in the low-intensity resistance exercise with normal movement ($P < 0.05$), than in the low-intensity resistance exercise with slow movement.

Figure 6 shows changes in $\dot{V}O_2$ for 180 min after the three types of exercises. Oxygen consumption after exercise was found to be significantly higher during the periods 0–5 min, 10–15 min, 15–20 min, and 25–30 min after exercise in the high-intensity resistance exercise ($P < 0.05$), and during the periods 0–5 min and 10–15 min in the low-intensity resistance exercise with normal movement ($P < 0.05$), than in low-intensity resistance exercise with slow movement. Compared with the control, $\dot{V}O_2$ after all exercises was significantly higher throughout

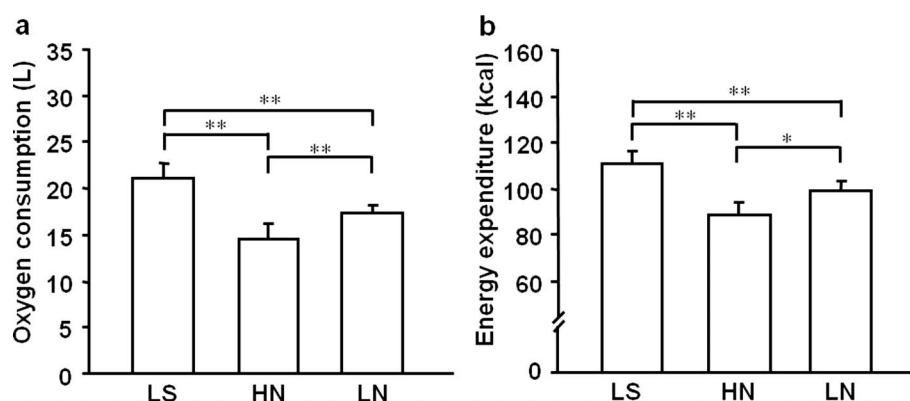


Figure 2. Total oxygen consumption (a) and energy expenditure (b) throughout three sets of exercise in the three exercise trials (mean \pm s_x). LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement. Significant differences (* $P < 0.05$, ** $P < 0.01$) between exercise trials.

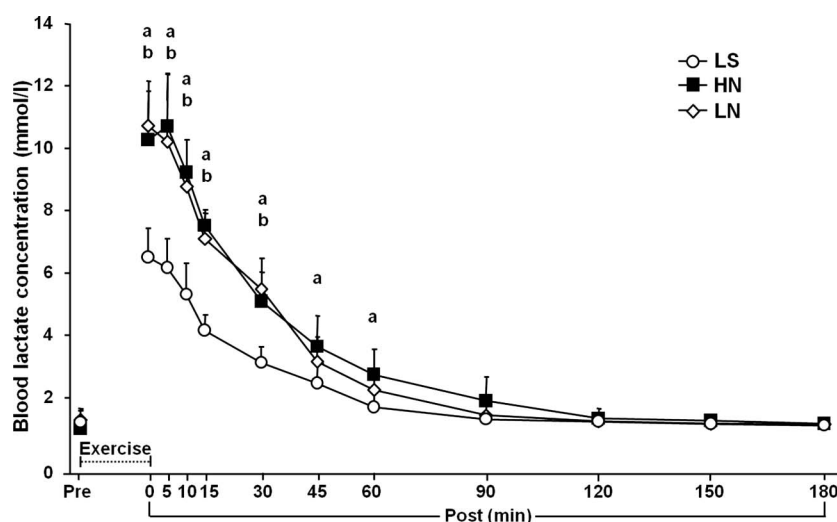


Figure 3. Changes in blood lactate concentration after the three exercise trials (mean \pm s_x). LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement. ^aSignificant difference ($P < 0.05$) between HN and LS. ^bSignificant difference ($P < 0.05$) between LN and LS. Compared with resting values (pre-exercise), significant difference ($P < 0.05$) continued to 60 min post-exercise in all three trials.

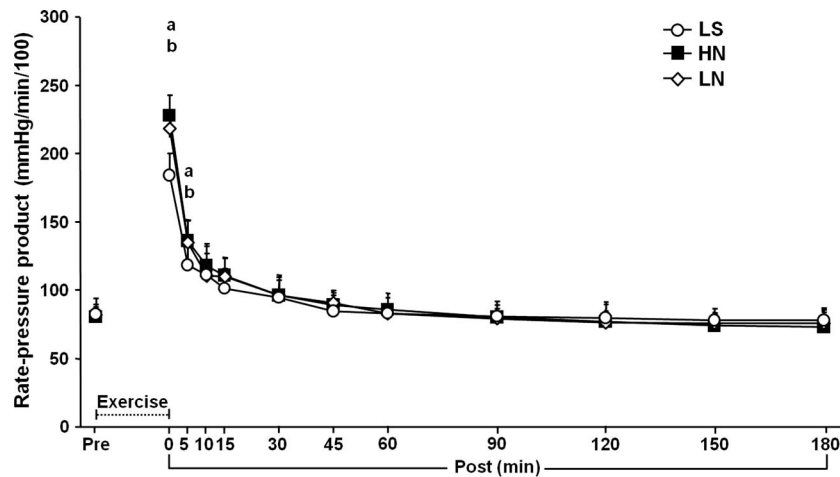


Figure 4. Changes in rate-pressure product after the three exercise trials (mean \pm s.e.). LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement. ^aSignificant difference ($P < 0.05$) between HN and LS. ^bSignificant difference ($P < 0.05$) between LN and LS. Compared with resting values (pre-exercise), significant difference ($P < 0.05$) continued to 30 min post-exercise in all three trials.

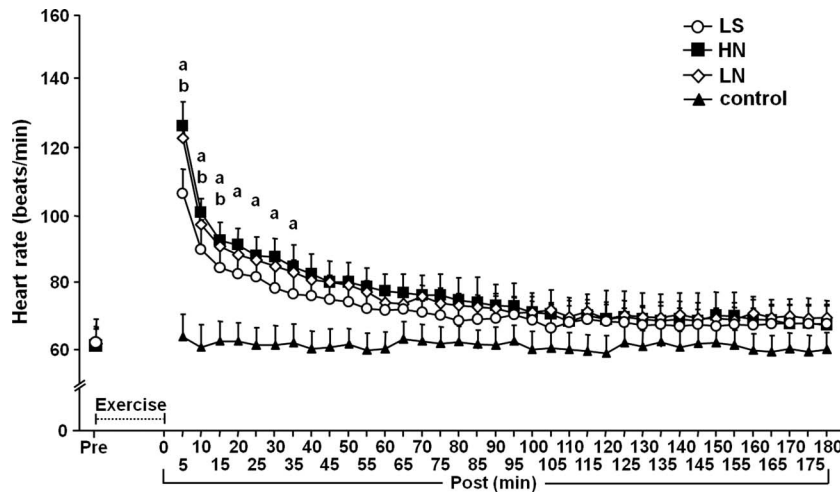


Figure 5. Changes in heart rate after the three exercise trials (mean \pm s.e.). LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement. ^aSignificant difference ($P < 0.05$) between HN and LS. ^bSignificant difference ($P < 0.05$) between LN and LS. Compared with resting values (pre-exercise), significant difference ($P < 0.05$) continued to 75 min post-exercise in the HN and LN trials, and to 60 min in the LS trial.

180 min after exercise ($P < 0.05$), that is, excess post-exercise oxygen consumption over 180 min was observed after completion of the three types of exercises.

Total $\dot{V}O_2$, excess post-exercise oxygen consumption, energy expenditure, and excess post-exercise energy expenditure for 180 min after the three types of exercises are shown in Figure 7. The total $\dot{V}O_2$ (Figure 7a) after each exercise was 73.4 ± 3.2 L (effect size = 2.34) in low-intensity resistance exercise with slow movement, 78.7 ± 2.7 L (effect size = 3.06) in high-intensity resistance exercise with normal movement, and 77.4 ± 2.3 L (effect size = 2.89) in low-intensity resistance exercise with normal movement. The total excess post-exercise

oxygen consumption (Figure 7a) was 17.2 ± 2.7 L in low-intensity resistance exercise with slow movement, 22.5 ± 3.5 L in high-intensity resistance exercise with normal movement, and 21.2 ± 2.2 L in low-intensity resistance exercise with normal movement. The total energy expenditure (Figure 7b) after each exercise was 348.3 ± 16.9 kcal (effect size = 2.22) in low-intensity resistance exercise with slow movement, 373.0 ± 13.5 kcal (effect size = 2.89) in high-intensity resistance exercise with normal movement, and 365.8 ± 10.9 kcal (effect size = 2.70) in low-intensity resistance exercise with normal movement. The total excess post-exercise energy expenditure (Figure 7b) was 81.6 ± 12.7 kcal in low-intensity resistance exercise with slow move-

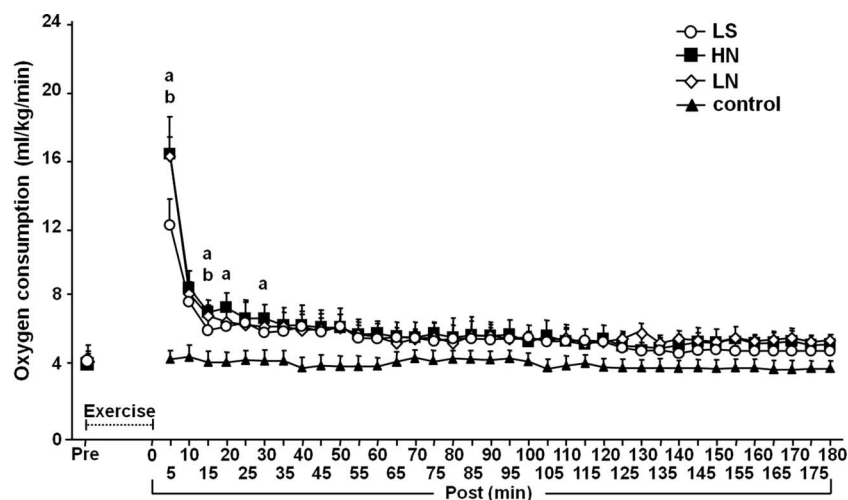


Figure 6. Changes in oxygen consumption after the three exercise trials (mean \pm s.e.). LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement. ^aSignificant difference ($P < 0.05$) between HN and LS. ^bSignificant difference ($P < 0.05$) between LN and LS. Compared with resting values (pre-exercise), the values after exercise (at all time points) for all exercise trials were significantly higher throughout 180 min after exercise ($P < 0.05$).

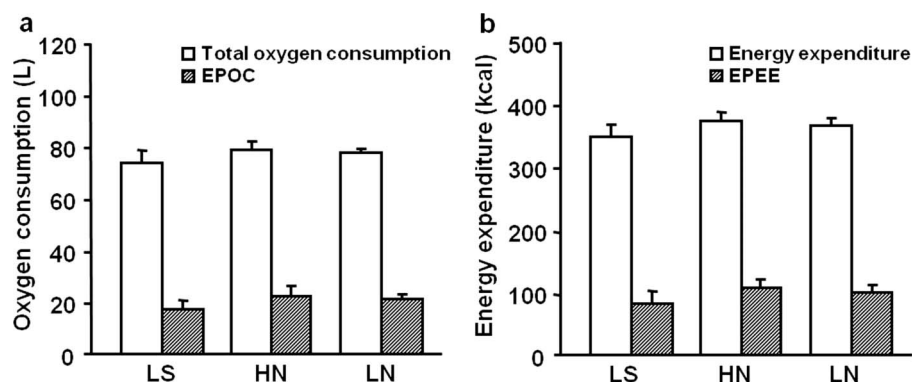


Figure 7. (a) Total oxygen consumption and excess post-exercise oxygen consumption (EPOC), and (b) energy expenditure and excess post-exercise energy expenditure (EPEE) after the three exercise trials (mean \pm s.e.). LS = low-intensity resistance exercise with slow movement, HN = high-intensity resistance exercise with normal movement, LN = low-intensity resistance exercise with normal movement. No significant differences were observed among the three exercise trials.

ment, 106.3 ± 17.0 kcal in high-intensity resistance exercise with normal movement, and 99.0 ± 10.0 kcal in low-intensity resistance exercise with normal movement. For total $\dot{V}O_2$, excess post-exercise oxygen consumption, energy expenditure, and excess post-exercise energy expenditure for 180 min after the three types of exercises, no significant differences were observed among the three exercise trials.

Discussion

The exercise intensity and repetitive movement speed in the present study were designed based on methods used in previous studies (Goto et al., 2008; Tanimoto & Ishii, 2006). The resistance exercise trials in this study were performed until voluntary

exhaustion or maximum repetition without matching the duration and workload of exercise in each exercise trial, for the purpose of maintaining the characteristics of the original resistance exercise. The present study showed that blood lactate concentration, rate-pressure product, average heart rate, and average $\dot{V}O_2$ during low-intensity resistance exercise with slow movement were significantly lower than those during high- and low-intensity resistance exercise with normal movement (Table III). In contrast, total $\dot{V}O_2$ (Figure 2a) and energy expenditure (Figure 2b) during low-intensity resistance exercise with slow movement were significantly higher than those during high- and low-intensity resistance exercise with normal movement. The main reason for the increased total $\dot{V}O_2$ and energy expenditure in low-intensity resistance exercise with

slow movement compared with those in high-intensity resistance exercise may be exercise duration. The higher the exercise intensity, the greater the increase in total $\dot{V}O_2$ or energy expenditure (Haddock & Wilkin, 2006; Kang et al., 2005); however, if the intensity is high, the ratio of anaerobic metabolism rises and intramuscular acidosis is enhanced, which is expected to result in the exercise duration being shortened (Thornton & Potteiger, 2002). Moreover, in high-intensity resistance exercise with normal movement, it is difficult to maintain a constant muscular tension with ballistic actions (Tanimoto et al., 2005) and a Valsalva manoeuvre can be required, which may result in an acute increase in blood pressure (MacDougall et al., 1992). In the exercise trials in this study, exercise duration during low-intensity resistance exercise with slow movement was 13 min longer than high-intensity resistance exercise with normal movement and 10 min longer than low-intensity resistance exercise with normal movement. As a result, it is considered that the exercise duration of high-intensity resistance exercise with normal movement was shorter than that of low-intensity resistance exercise with slow movement because the exercise intensity of high-intensity resistance exercise with normal movement was relatively high. In other words, the present results indicate that low-intensity resistance exercise involving extended exercise duration can result in a greater total $\dot{V}O_2$ or energy expenditure with a low physiological load compared with that in high-intensity resistance exercise with normal movement.

The resistance exercise regimens in this study involved the anaerobic metabolism, with induction of an increase of blood lactate concentration. Tanimoto and Ishii (2006) showed that there was no difference in lactate response between low-intensity exercise with slow movements and high-intensity exercise with faster movements, suggesting that exercise-induced metabolic stresses in low-intensity resistance exercise with slow movement and high-intensity resistance exercise with normal movement were similar. However, in the present study, average blood lactate concentrations during high- and low-intensity resistance exercise with normal movement were significantly higher than during low-intensity resistance exercise with slow movement (Table III), and blood lactate concentrations after exercise were significantly higher for 60 min after exercise in the high-intensity resistance exercise with normal movement, and for 30 min after exercise in the low-intensity resistance exercise with normal movement, than in the low-intensity resistance exercise with slow movement (Figure 3). It is considered that blood lactate concentration during and after each exercise was influenced by a difference in exercise intensity,

since the utilization of muscle-stored glycogen is influenced by exercise intensity (Gaesser & Brooks, 1984).

In a previous study, Gaesser and Brooks (1984) reported that the enhancement of $\dot{V}O_2$ is necessary for the oxidation of blood lactate. In contrast, Scott and colleagues (Scott, Boby, Lohman, & Bunt, 1991) showed that exercise-induced blood lactate responses may not necessarily be associated with the $\dot{V}O_2$ response. In the present study, although $\dot{V}O_2$ values after high- and low-intensity resistance exercise with normal movement were slightly higher than after low-intensity resistance exercise with slow movement, the amounts of excess post-exercise oxygen consumption and excess post-exercise energy expenditure for 180 min after exercise were not significantly different among the three exercise trials. Thus, it seems that the blood lactate responses were not related to the magnitude or duration of excess post-exercise oxygen consumption. Furthermore, in terms of the changes in heart rate after the three types of exercises (Figure 5), heart rates were significantly higher for 35 min after high-intensity resistance exercise with normal movement, and for 15 min after low-intensity resistance exercise with normal movement, than after low-intensity resistance exercise with slow movement. Kang et al. (2005) demonstrated that heart rate following resistance exercise was higher in an exercise trial performed at low-to-moderate intensity coupled with a moderate-to-high exercise volume than in an exercise trial performed at high intensity coupled with a low exercise volume. Indeed, in the present study, exercise volume [load (kg) \times repetitions] per set in low-intensity resistance exercise with slow movement (2193 ± 62 kg/set) was less than that in high-intensity resistance exercise with normal movement (3395 ± 117 kg/set) and low-intensity resistance exercise with normal movement (3948 ± 113 kg/set). Thus, it is speculated that the heart rate response in resistance exercise is affected by exercise intensity and the number of repetitions.

In general, previous studies (Haddock & Wilkin, 2006; Kang et al., 2005; Thornton & Potteiger, 2002) have shown that the factors that affect $\dot{V}O_2$ or energy expenditure after resistance exercise are exercise intensity and exercise volume. Thornton and Potteiger (2002) showed that total excess post-exercise oxygen consumption over 120 min was significantly greater for high-intensity exercise than for low-intensity exercise, even though workloads or energy expenditures during the exercises were similar. In other words, the factors that affect the magnitude and duration of excess post-exercise oxygen consumption or excess post-exercise energy expenditure may be associated with exercise intensity rather than exercise volume. However, Kang et al.

(2005) reported that $\dot{V}O_2$ after exercise was higher in an exercise trial involving 10 repetitions per set at 75% of 1-RM than in an exercise trial involving 4 repetitions per set at 90% of 1-RM. Moreover, several studies (Gillette et al., 1994; Melby et al., 1993; Osterberg & Melby, 2000; Schuenke et al., 2002) found that $\dot{V}O_2$ remained elevated for several hours with an exercise trial of eight to ten repetitions of three or more sets, with each set being performed to maximum repetition with a moderate intensity within the range of a maximum of 8–12 repetitions at 70–80% of 1-RM. Conversely, excess post-exercise oxygen consumption was not observed in studies that involved very low-intensity exercise, such as below 50% of 1-RM (Haltom et al., 1999), or very high-intensity exercise, such as 90% of 1-RM (Kang et al., 2005). From these results, it is considered that the exercise intensity or volume alone cannot explain the increases in the duration and magnitude of excess post-exercise oxygen consumption. It is speculated that there is an optimal combination of exercise intensity and exercise volume (e.g. three or more sets of 8–10 exercises at 70–80% of 1-RM for 8–12 repetitions) to increase excess post-exercise oxygen consumption with resistance exercise.

On the other hand, in a recent study comparing muscle protein synthesis at two distinctly different exercise intensities (90% 1-RM or 30% 1-RM) together with differing exercise volumes, it was shown that the increase in the rate of protein synthesis at 4 h and 24 h after exercise was not significantly different between exercise performed until voluntary failure at 30% of 1-RM and exercise performed until voluntary failure at 90% of 1-RM, and it was suggested that exercise of low intensity and high volume of longer duration is more effective in inducing acute muscle anabolism than high-load and low-volume exercise (Burd et al., 2010). In the present study, exercise volume in the low-intensity resistance exercise with slow movement was less than that in the high- and low-intensity resistance exercise with normal movement, but exercise duration during low-intensity resistance exercise with slow movement was longer than in high- and low-intensity resistance exercise with normal movement. Exercise intensity has traditionally been defined as a percentage of 1-RM. However, exercise intensity in this study appears to be influenced by the degree of effort that provides a major part of the stimulus. Because resistance exercise in each trial was performed to exhaustion, all exercises could be higher intensity as degree of effort. That is, even in the low-intensity resistance exercise with slow movement, similar effects as those in high-intensity resistance exercise with normal movement could be induced. In addition, the exercise duration could also contribute to the increase of excess post-exercise oxygen

consumption or excess post-exercise energy expenditure. Because exercise with slow repetitive movement can increase the duration of the exercise session and may create a somewhat different fatigue pattern than conventional repetitive movement, those factors might be partly related to the increase of acute metabolism. Furthermore, the use of a moderate intensity and longer repetitive movement while exercising to failure may make resistance safer and more accessible to more people, and be effective for strength increases and for muscular hypertrophy (Burd et al., 2010; Tanimoto & Ishii, 2006).

A previous study (Børsheim, Knardahl, Høstmark, & Bahr, 1998) showed that excess post-exercise oxygen consumption response was correlated with a rise in catecholamine secretion or deep body temperature. Goto et al. (2008) demonstrated that low-intensity resistance exercise with slow movement markedly enhanced hormone secretion. In particular, it resulted in a significantly stronger response of norepinephrine and free testosterone than high-intensity resistance exercise with normal movement. Enhanced sympathetic nervous system activity may also contribute to an elevated metabolic rate after exercise (Børsheim et al., 1998). Epinephrine and norepinephrine are strong stimulators of energy metabolism and, although not measured in the present study, it is speculated that the increase in excess post-exercise oxygen consumption or excess post-exercise energy expenditure might be related to the factors that increased heart rate, such as sympathetic nervous system activity or hormonal responses. Given the limitations of the current study, further studies are required.

Conclusion

The results of the present study indicate that low-intensity resistance exercise with slow movement increased $\dot{V}O_2$ and energy expenditure during exercise, with lower values of blood lactate concentration, rate-pressure product, and heart rate compared with those in high- and low-intensity resistance exercise with normal movement. Moreover, excess post-exercise oxygen consumption and excess post-exercise energy expenditure following the three types of resistance exercises were observed for 180 min, and there were no significant differences in the total amounts of excess post-exercise oxygen consumption or excess post-exercise energy expenditure among the three exercise trials. Therefore, we suggest that low-intensity resistance exercise with slow movement is effective for increasing energy expenditure during and after exercise, even with a low physiological load. This type of low-intensity resistance exercise might contribute to the prevention of obesity or weight reduction. However, further research focusing on different groups, including

inactive, obese, and elderly people, should be conducted with a regimen of controlled exercise intensity, volume, and repetitive movement, along with ratings of perceived exertion.

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