

A Weekly Bout of Eccentric Exercise Is Sufficient to Induce Health-Promoting Effects

VASSILIS PASCHALIS^{1,2}, MICHALIS G. NIKOLAIDIS^{1,2}, ANASTASIOS A. THEODOROU^{1,2},
GEORGE PANAYIOTOU^{1,3}, IOANNIS G. FATOUROS⁴, YIANNIS KOUTEDAKIS^{1,2,5},
and ATHANASIOS Z. JAMURTAS^{1,2}

¹Institute of Human Performance and Rehabilitation, Center for Research and Technology-Thessaly, Trikala, GREECE; ²Department of Physical Education and Sport Science, University of Thessaly, Trikala, GREECE; ³Laboratory of Exercise, Health and Human Performance, Research Center, European University of Cyprus, Nicosia, CYPRUS; ⁴Department of Physical Education and Sport Science, University of Thrace, Komotini, GREECE; and ⁵School of Sport, Performing Arts and Leisure, Wolverhampton University, Walsall, UNITED KINGDOM

ABSTRACT

PASCHALIS, V., M. G. NIKOLAIDIS, A. A. THEODOROU, G. PANAYIOTOU, I. G. FATOUROS, Y. KOUTEDAKIS, and A. Z. JAMURTAS. A Weekly Bout of Eccentric Exercise Is Sufficient to Induce Health-Promoting Effects. *Med. Sci. Sports Exerc.*, Vol. 43, No. 1, pp. 64–73, 2011. **Purpose:** The effects of chronic eccentric-only versus concentric-only exercise on muscle physiology and blood biochemistry were investigated. **Methods:** Twenty women performed on an isokinetic dynamometer a concentric ($n = 10$; mean \pm SEM: age = 21.0 ± 0.4 yr, body fat = $22.0\% \pm 0.9\%$) or an eccentric ($n = 10$, age = 20.0 ± 0.3 yr, body fat = $23.2\% \pm 0.7\%$) exercise session using the knee extensors of both lower limbs once a week for eight subsequent weeks. Muscle function (isometric, concentric, and eccentric peak torque, range of movement, and soreness) was evaluated before, immediately after, and 48 h postexercise in each one of the eight training weeks. Body fat, resting energy expenditure (REE), lipid, and carbohydrate oxidation rate as well as blood chemistry measurements (lipid, lipoprotein and apolipoprotein profile, glucose, insulin, glycosylated hemoglobin, and creatine kinase) were examined before and 48 h postexercise at the first and eighth week of training. **Results:** Acute eccentric exercise increased REE and fat oxidation at week 1 (12.7% and 12.9%, respectively) and at week 8 (0.7% and 2.8%, respectively). Chronic eccentric exercise increased resting REE and fat oxidation at week 8 compared with week 1 (5.0% and 9.9%, respectively). Acute eccentric exercise improved blood lipid profile at week 1 and week 8. Chronic eccentric exercise improved resting blood lipid profile at week 8. Acute eccentric exercise increased insulin resistance at week 1 but not at week 8. Chronic eccentric exercise decreased resting insulin resistance at week 8. **Conclusion:** It is reported for the first time that only 30 min of eccentric exercise per week for 8 wk was sufficient to improve health risk factors. **Key Words:** CONCENTRIC, LENGTHENING CONTRACTIONS, LIPID PROFILE, MUSCLE DAMAGE, TRAINING

Nowadays, systematic exercise is an integral component of current guidelines for health promotion and improvement of quality of life (1). It is estimated that if everyone was highly active, the premature death rate from coronary artery disease and type 2 diabetes could presumably be only two-thirds of the current rate (5). Exercise is traditionally categorized in two main types, endurance exercise and resistance exercise. Despite their differences in performing these two types of physical activity, both affect beneficially human health. Indeed, there is strong evidence that people who participate regularly in either endurance or resistance exercise are less likely to develop

obesity, abnormal lipid profiles, coronary artery disease, type 2 diabetes, and sarcopenia (5).

Most resistance exercise programs include dynamic repetitions with both concentric and eccentric muscle actions. A concentric muscle action primarily occurs when the muscle shortens to lift a load (e.g., the upward movement of a bicep curl), whereas an eccentric muscle action occurs when the muscle lengthens to lower a load (e.g., the downward movement of a bicep curl). Most daily life activities contain both types of muscle actions. As an example, walking up the stairs works the quadriceps mainly concentrically, whereas walking down the stairs does the quadriceps mainly eccentrically. Likewise, picking up a child or a laundry basket are total-body concentric actions, whereas lowering them are total-body eccentric actions.

Several studies (3,13,20–24) have compared the effects of concentric and eccentric resistance training on muscle strength using an isokinetic dynamometer that incorporates several advantages: i) muscle group can be isolated; ii) concentric- or an eccentric-only exercise session can be performed; iii) concentric and eccentric actions can be carried out at similar activation levels (e.g., as a percent of maximal voluntary contraction (MVC)) and identical speed; and iv) changes in muscle strength can be reliably measured mode-specifically. Although

Address for correspondence: Michalis G. Nikolaidis, Ph.D., Institute of Human Performance and Rehabilitation, Center for Research and Technology-Thessaly, Karyes, 42100, Trikala, Greece; E-mail: mnikol@pe.uth.gr; mnikol@cereteth.gr.

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several studies compared the influence of chronic concentric and eccentric resistance exercise on muscle strength and performance, to our knowledge, no study has examined the effect of eccentric-only against concentric-only exercise on health-related parameters. In addition, all relevant studies used two to five eccentric exercise sessions per week. The most relevant study on this topic used a partial eccentric or concentric training by hiking downward or upward and reported beneficial effects on blood lipid profile and insulin resistance after three to five downward hiking sessions per week (10). Undoubtedly, it is possible that at least part of the beneficial effects of downhill hiking was a result of the strong aerobic component involved in this type of activity. It is worth noting that increased resting energy expenditure (REE) (35), lipid oxidation rate (35), and improved lipid profile (34,35) have been reported 1–4 d after the end of an acute bout of eccentric-only exercise using an isokinetic dynamometer. However, it is uncertain whether these favorable changes persist after repeated bouts of eccentric exercise.

Several studies have reported that eccentric and concentric actions activate distinct molecular pathways in humans (28) and in rats (19). For example, it has been shown that in skeletal muscle, the effect of eccentric training was greater than concentric training for liver-type insulin-like growth factor I and mechano-growth factor (positive regulators of muscle growth [19]). These molecular differences may give insight into specific adaptations to different modes of contraction. It is worth noting that an acute bout of eccentric exercise usually disturbs muscle function up to a week (e.g., see Paschalis et al. [35]). Moreover, previous studies from our group have shown that most of the changes in REE, substrate oxidation, and blood lipid profile appear and disappear during a week after an acute eccentric exercise session (34,35). As a result, a single weekly bout of exercise was adopted. We chose to examine women because the relevant studies had been conducted predominately with male subjects. In addition, because two relevant previous studies from our group have been performed in women, the present results can be directly compared with those from our earlier studies (34,35). Finally, we limited our subjects to women because there are many reports indicating sex-dependent effects on exercise-induced muscle injury (12), muscle inflammation (38), and exercise metabolism (39). Considering the above, the aim of the present study was to investigate the influence of chronic weekly bouts of eccentric-only versus concentric-only exercise on muscle physiology and blood chemistry in women focusing on health-related parameters. We hypothesized that exercise would produce distinct mode-of-action-dependent effects on muscle function, REE, substrate metabolism, blood lipid profile, and insulin resistance.

METHODS

Participants. Twenty healthy women, who voluntarily expressed interest in participation after local media advertise-

ment of the study, were randomly assigned into either a concentric ($n = 10$, mean \pm SEM: age = 21.0 ± 0.4 yr, body mass = 62.3 ± 1.3 kg, body height = 166.1 ± 1.4 cm, body fat = $22.0\% \pm 0.9\%$, and $\dot{V}O_{2\max} = 38.2 \pm 1.5$ mL \cdot kg $^{-1}\cdot$ min $^{-1}$) or an eccentric ($n = 10$, age = 20.0 ± 0.3 yr, body mass = 63.0 ± 1.6 kg, body height = 167.9 ± 1.2 cm, body fat = $23.2\% \pm 0.7\%$, and $\dot{V}O_{2\max} = 38.9 \pm 1.6$ mL \cdot kg $^{-1}\cdot$ min $^{-1}$) exercise group. Participants were stable at their anthropometric characteristics for at least the last 2 yr and had not experienced any eccentric exercise training or other activities with a large eccentric component for at least 6 months before the study. The participants, except for the training sessions of the experimental intervention, were instructed to abstain from any strenuous exercise during the training period of 8 wk as well as 5 d before the first exercise bout and 2 d after the last exercise bout. In addition, the participants were instructed to record all their recreational activities through the period of experimental intervention. Exclusion criteria included smoking, supplement intake, or medication known to affect REE and muscle function (such as oral contraceptives and statins) as well as consumption of drinks containing caffeine or alcohol. All volunteers were eumenorrheic (reporting their menstrual cycle as lasting 24–30 d). Because REE depends on the phase of the menstrual cycle, the first and the last training bout fell within the luteal phase for all participants. An informed written consent approved by the local university ethics committee was obtained by all participants after they were informed of all risks, discomforts, and benefits involved in the study.

Training protocol. Participants visited the laboratory once a week for eight subsequent weeks to perform the isokinetic concentric or eccentric exercise protocol. Both training protocols were performed on an isokinetic dynamometer (Cybex Norm, Ronkonkoma, NY). During both protocols, participants were seated at 120° hip angle. Functional range of motion was set electronically between full extension (0°) and 90° of knee flexion. Before each exercise session, subjects performed an 8-min warm-up consisting of cycling on a Monark cycle ergometer (Vansbro, Sweden) at 70 rpm and 50 W. The concentric and the eccentric training were performed on both knee extensors of lower limbs at an angular velocity of $60^\circ\cdot$ s $^{-1}$ (knee range = 0° – 90°). A slow action velocity (i.e., $60^\circ\cdot$ s $^{-1}$) was chosen because quadriceps moments are more reliably measured at slow angular velocities (such as $60^\circ\cdot$ s $^{-1}$) than at fast angular velocities (27). In addition, all our previous relevant studies have used this action velocity (e.g., 34,35), thus rendering direct comparisons with the present results feasible. During both concentric and eccentric exercise sessions, participants had to complete five sets of 15 concentric or eccentric MVC in each of their lower limbs being in the seated position as previously described. A 2-min rest interval was used between sets. The resistance training load was solely determined by the participants as the exercise sessions were performed maximally in an isokinetic dynamometer. Likewise, the progression of the training load was solely determined by the participants because they had to complete 75

maximal voluntary actions. Subjects were verbally encouraged to maximally activate their knee extensors, although the performance declined as the exercise proceeded because of fatigue. Each participant was familiarized at least 5 d before the beginning of the experimental procedures. Familiarization involved 8–10 isokinetic concentric or eccentric actions for all participants at very low intensity not capable of inducing muscle dysfunction.

Measurements. All measurements were performed between 08:00 and 10:00 a.m. after overnight fasting. Resting body mass and body fat were measured at the first and the eighth week of the training protocol for both groups. Body mass was measured to the nearest 0.05 kg (Beam Balance 710; Seca, UK), with participants lightly dressed and barefoot. Standing height was measured to the nearest 1 cm (Stadiometer 208; Seca). Percentage body fat was calculated (the Siri skinfold equation was used) from seven skinfold measures (average of two measurements of each site) using a Harpenden caliper (John Bull, England). Isometric, concentric, and eccentric peak torque, pain-free range of movement (ROM), and delayed onset muscle soreness (DOMS) during palpation and walking were evaluated before, immediately after, and 48 h postexercise in each one of the 8-wk (all functional measurements are presented in the Muscle function and muscle performance section). REE, substrate metabolism, and blood chemistry measurements were examined before and 48 h postexercise at the first and eighth week of training (these measurements are presented in the REE and substrate oxidation section and Blood chemistry section).

Nutritional assessment. Participants were instructed to follow and monitor their usual eating habits 2 d before the experiment and during the days of the first and the last week of data collection. Each participant was provided with a written set of guidelines for monitoring dietary consumption as well as a record sheet for recording food intake (17). Diet records were analyzed using the nutritional analysis system Science Fit Diet 200A (Sciencefit, Greece).

Muscle function and muscle performance. An isokinetic dynamometer was used for the measurement of isometric (at 90° knee flexion), concentric, and eccentric peak torque at 60°·s⁻¹ of quadriceps femoris. Five MVC were performed, and the best three were recorded. There was a 1-min rest between efforts. Activation level during the training protocol at week 1 and week 8 was determined as a percentage of the MVC evaluated before each training protocol. The subjects were verbally encouraged in every repetition to perform better than their previous effort.

The assessment of pain-free ROM was performed manually on the isokinetic dynamometer. The investigator moved the calf at a very low angular velocity from full extension (0°) of the knee to the position where the beginning of discomfort was noticed by the participant. The angle was recorded to indicate the end of the pain-free ROM. All participants were pain-free at full extension.

Muscle soreness was rated with a visual analog scale, with 0 indicating no pain and 10 representing extremely painful

(42). Participants were asked to mark their perceived soreness on the scale when the investigator palpated their muscle belly and the distal region of the quadriceps femoris in a seated position with the muscles relaxed. The site and pressure applied to the muscles during the palpation was kept as similar as possible between days and participants. The assessment of soreness of the lower limbs was also performed during motion (walking) using the same scale.

REE and substrate oxidation. REE was estimated with participants in a supine position on a comfortable bed. Data were collected using indirect calorimetry for 40 min by the open-circuit dilution method using a metabolic cart (Vmax29; Sensesmedics, Yorba Linda, CA) after participants rested supine for half an hour. All participants were instructed to relax and to avoid hyperventilation or sleep during the data collection. The gas analyzer was calibrated using 26% oxygen (O₂) and 4% carbon dioxide (CO₂), according to the instructions provided by the manufacturer. Energy expenditure was calculated using the Weir (41) equation and was expressed in kilojoules per 24 h. The evaluation of REE was performed between 08:00 and 09:00 a.m. before the blood sampling in a semidarkened, very quiet, and thermoregulated room (12 m²; 22°C ± 1°C) after 10 to 12 h of overnight fasting, as previously described (6).

Contribution of fat and carbohydrate oxidation to total REE were calculated indirectly by monitoring the rate of O₂ consumption (L·min⁻¹) and CO₂ production (L·min⁻¹) using the following stoichiometric equations (26), assuming that protein oxidation was negligible:

$$\text{fat oxidation} = 1.695 \dot{V}\text{O}_2 - 1.701 \dot{V}\text{CO}_2 \quad [1]$$

$$\text{carbohydrate oxidation} = 4.210 \dot{V}\text{CO}_2 - 2.962 \dot{V}\text{O}_2 \quad [2]$$

Blood chemistry. Blood collection was performed between 09:00 and 11:00 a.m., after 10–12 h of overnight fasting. Volunteers provided venous blood samples in the sitting position from a forearm vein without stasis in vacutainer tubes with serum separator and clotting activator (Vacutainer SST, Becton-Dickinson & Co, Le Pont-de-Claix, France). After clotting, serum was prepared by centrifugation at 1500g for 10 min and was stored in multiple aliquots at -80°C, which were thawed only once before analysis. Serum triacylglycerols (TG) and total cholesterol (TC) were assayed by enzymic spectrophotometric methods with reagent kits from Zafiroopoulos (Athens, Greece). Serum HDL cholesterol (HDL-C) was determined as TC after precipitation of very low-density lipoprotein and LDL with a reagent from Zafiroopoulos. LDL cholesterol (LDL-C) was calculated according to the equation LDL-C = TC - HDL-C - (TG/5) (15). TC/HDL-C (considered an atherogenic index) was also calculated. Serum apolipoprotein A1, apolipoprotein B, and lipoprotein (α) were determined using an immunoturbidimetric assay in an ABX Pentra 400 clinical chemistry analyzer (Horiba ABX, Montpellier, France). Serum glucose was assayed by the enzymic spectrophotometric method with a reagent kit

from Zafiropoulos. Serum insulin was determined by enzyme immunoassay using kit from DRG (Marburg, Germany). The homeostasis model assessment (HOMA) was used as a surrogate measure of insulin resistance and was calculated as fasting insulin ($\mu\text{U}\cdot\text{mL}^{-1}$) \times fasting glucose ($\text{mmol}\cdot\text{L}^{-1}$)/22.5. Whole-blood glycosylated hemoglobin was measured using a Latex immunoturbidimetric assay in an ABX Pentra 400. Serum creatine kinase (CK) was assayed using a kit from Spinreact (Sant Esteve, Spain). Serum estradiol was assayed using an AIA-600 II automated immunoassay analyzer (Tosoh, Japan). The biochemical parameters were determined in duplicate. A control sample was run in each assay. Each parameter was assayed in a single day to eliminate interassay variability. The intra-assay coefficients of variation for each assay were as follows: TG, 3.8%; TC, 2.6%; HDLC, 4.1%; apolipoprotein A1, 2.9%; apolipoprotein B, 2.8%; lipoprotein (α), 4.2%; glucose, 3.9%; insulin, 4.8%; glycosylated hemoglobin, 2.1%; creatine kinase, 5.3%; and estradiol, 4.0%.

Statistical analysis. The distribution of all dependent variables was examined by the Shapiro–Wilk test and was found not to differ significantly from normality. Three-way ANOVA [group (eccentric and concentric) \times week (first and eighth) \times time (preexercise, immediately postexercise, and 48 h postexercise or preexercise and 48 h postexercise)] with repeated measurements on time was used to analyze all studied parameters. If a significant interaction was obtained, pairwise comparisons were performed through simple main effect analysis. The *t*-test was used to compare the anthropometric characteristics between the concentric and the eccentric training groups. Two-way ANOVA [group (eccentric and concentric) \times week (first and eighth)] with repeated measurements on week was used to analyze anthropometric characteristics and nutrient intake between the concentric and the eccentric training groups. Data are presented as mean \pm SEM. The level of significance was set at $\alpha = 0.05$, which is a limitation because performing multiple ANOVA on intercorrelated data increases the probability for type I error. The Statistical Package for the Social Sciences for Windows (Version 13.0; SPSS Inc., Chicago, Illinois) was used for all analyses.

RESULTS

Training characteristics, anthropometry, and nutritional analysis. The muscle torque output developed during concentric exercise was $78\% \pm 1\%$ of MVC at week 1 and $76\% \pm 2\%$ of MVC at week 8. The respective values for the eccentric group were $83\% \pm 1\%$ of MVC at week 1 and $80\% \pm 1\%$ of MVC at week 8. The total work performed for the concentric group was 12.3 ± 0.4 kJ at week 1 and 14.2 ± 0.4 kJ at week 8. The respective values for the eccentric group were 15.4 ± 0.4 kJ at week 1 and 17.4 ± 0.3 W at week 8. Resting estradiol concentrations were 115 ± 8 $\text{pg}\cdot\text{mL}^{-1}$ (range = 75–157 $\text{pg}\cdot\text{mL}^{-1}$) at week 1 and 127 ± 9 $\text{pg}\cdot\text{mL}^{-1}$ (range = 71–149 $\text{pg}\cdot\text{mL}^{-1}$) at week 8. The reference interval for this assay in the luteal phase was 68 to 169 $\text{pg}\cdot\text{mL}^{-1}$.

Each participant completed all repetitions, sets, and exercise sessions required. There were no significant differences in anthropometric characteristics between the two groups at week 1 and week 8 and between week 1 and week 8 in the same group (Table 1). However, body mass increased and percentage body fat decreased nonsignificantly between week 1 and week 8 at rest (body fat decreased by 0.38% and 0.40% from week 1 to week 8 for the concentric and eccentric group, respectively). No significant differences were found in daily energy and macronutrient intake between the two groups at week 1 and week 8 and between week 1 and week 8 in the same group.

Muscle function and muscle performance. All muscle function indices were modified significantly after exercise in both groups at the first week, but the modifications were greater after eccentric exercise than concentric exercise (Table 2). By the eighth week, acute concentric exercise generally did not induce muscle dysfunction, whereas acute eccentric exercise induced only slight but significant disturbances in muscle function. At week 8, both training sessions increased resting muscle strength as determined by the assessment of isometric, concentric, and eccentric torque. However, resting isometric torque increased more at week 8 in the eccentric group compared with the concentric group. In general, the improvement in resting concentric and eccentric torque was training mode specific. This means that the concentric group exhibited greater increases in resting concentric torque and lower increases in eccentric torque compared with the eccentric group and vice versa.

REE and substrate oxidation. REE increased only after acute eccentric exercise and only at week 1 (Fig. 1). Specifically, for the concentric group, the percent change of REE postexercise ranged from -4.2% to 7.9% at week 1 and from -0.5% to 3.1% at week 8. For the eccentric group, the percent change of REE postexercise ranged from 6.1% to 19.5% at week 1 and from -0.6% to 2.0% at week 8. For the concentric group, the percent change of resting REE from week 1 to week 8 ranged from -6.1% to 5.8% . For the eccentric group, the percent change of resting REE from week 1 to week 8 ranged from 0.9% to 5.3% . Fat oxidation increased and carbohydrate oxidation decreased only after acute eccentric exercise at both week 1 and week 8 (Fig. 1). At week 8, eccentric training increased REE and fat oxidation as well as decreased carbohydrate oxidation. Acute and chronic

TABLE 1. Body composition and analysis of daily energy intake of concentric and eccentric group in the first and eighth week of exercise (mean \pm SEM).

	Concentric		Eccentric	
	Week 1	Week 8	Week 1	Week 8
Body mass (kg)	62.3 \pm 1.3	62.7 \pm 1.2	63.0 \pm 1.6	63.5 \pm 1.8
Body fat (%)	22.0 \pm 0.9	21.9 \pm 0.8	23.2 \pm 0.7	23.0 \pm 0.6
Fat-free mass (kg)	48.7 \pm 1.4	49.0 \pm 1.4	48.4 \pm 1.3	48.9 \pm 1.4
Energy (kcal)	2053 \pm 34	2076 \pm 30	2049 \pm 35	2058 \pm 31
Carbohydrate (% energy)	53.3 \pm 1.2	52.2 \pm 1.2	52.0 \pm 1.2	53.5 \pm 1.0
Fat (% energy)	29.6 \pm 0.7	30.3 \pm 0.6	31.1 \pm 0.8	29.1 \pm 0.7
Protein (% energy)	17.1 \pm 1.2	17.7 \pm 1.0	17.2 \pm 1.5	17.5 \pm 1.1

No significant differences were detected in any variable between week 1 and week 8 in the same training group or between concentric and eccentric group in the same week.

TABLE 2. Muscle function indices at preexercise, immediately postexercise, and 48 h postexercise in the first and eighth week of concentric and eccentric group (mean \pm SEM).

	Week 1			Week 8			Main Effects and Interactions						
	Before	After	48 h	Before	After	48 h	G	W	T	G × T	G × W	W × T	G × W × T
Eccentric torque (N·m)													
Concentric	150.3 ± 5.1	127.0 ± 5.2*	147.6 ± 5.0	166.1 ± 2.9‡	132.1 ± 2.9*	166.5 ± 5.1‡	0.002	0.007	<0.001	0.011	<0.001	<0.001	<0.001
Eccentric	155.4 ± 4.5	122.0 ± 3.4*,†	107.6 ± 4.0*,†	209.8 ± 3.2*,†,†	178.6 ± 2.7*,†,†	202.8 ± 3.5†,†							
Concentric torque (N·m)													
Concentric	108.9 ± 5.4	92.1 ± 4.6*	108.4 ± 4.2	135.2 ± 2.7‡	116.5 ± 3.7*,†	137.6 ± 2.7‡	NS	<0.001	0.018	<0.001	0.003	<0.001	<0.001
Eccentric	112.5 ± 4.3	101.7 ± 4.0*,†	87.7 ± 3.4*,†	128.9 ± 2.5‡	116.0 ± 2.2*,†	133.0 ± 2.8*,†							
Isometric torque (N·m)													
Concentric	140.2 ± 7.0	132.4 ± 5.9*	135.5 ± 6.4*	155.7 ± 2.9‡	142.6 ± 4.4*,†	159.0 ± 3.3‡	NS	<0.001	<0.001	<0.001	0.008	<0.001	<0.001
Eccentric	146.7 ± 4.2	121.0 ± 3.5*,†	111.9 ± 4.8*,†	174.4 ± 1.4†,†	154.2 ± 1.9*,†,†	173.7 ± 1.4†,†							
ROM (°)													
Concentric	120.7 ± 1.1	115.0 ± 1.3*	120.9 ± 1.2	120.5 ± 0.6	118.9 ± 0.8‡	119.7 ± 0.6	0.004	<0.001	0.015	<0.001	<0.001	0.005	<0.001
Eccentric	118.7 ± 0.7	105.1 ± 0.8*,†	90.7 ± 1.8*,†	119.8 ± 0.8	116.5 ± 0.8*,†	117.8 ± 1.1‡							
DOMS palpation (1–10)													
Concentric	1.00 ± 0.00	1.90 ± 0.30*	2.70 ± 0.25*	1.00 ± 0.00	1.60 ± 0.23*,†	1.00 ± 0.00	0.003	0.010	<0.001	<0.001	<0.001	<0.001	<0.001
Eccentric	1.00 ± 0.00	3.40 ± 0.25*,†	6.10 ± 0.30*,†	1.00 ± 0.00	1.80 ± 0.26*,†	1.70 ± 0.11*,†,†							
DOMS walking (1–10)													
Concentric	1.00 ± 0.00	2.00 ± 0.31*	3.10 ± 0.92*	1.00 ± 0.00	1.60 ± 0.29*	1.00 ± 0.00‡	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Eccentric	1.00 ± 0.00	3.10 ± 0.32*,†	6.60 ± 0.37*,†	1.00 ± 0.00	1.80 ± 0.26*,†	1.40 ± 0.24*,†,†							
Creatine kinase (U·L ⁻¹)													
Concentric	103.8 ± 14.9	NM	346.8 ± 52.3*	136.5 ± 20.8	NM	143.4 ± 16.8‡	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Eccentric	136.3 ± 29.7	NM	2302 ± 315.6*,†	230.3 ± 34.7‡	NM	339.3 ± 51.2*,†,†							

DOMS, delayed onset muscle soreness; NM, not measured; NS, nonsignificant ($P > 0.05$); G, main effect of training group; W, main effect of week; T, main effect of time; G \times T, two-way interaction for group and time; G \times W, two-way interaction for group and week; W \times T, two-way interaction for week and time; G \times W \times T, three-way interaction for group, week, and time.

* Significantly different from the preexercise value.

† Significantly different from the concentric group at the same time point.

‡ Significant difference between week 1 and week 8 at the same time point.

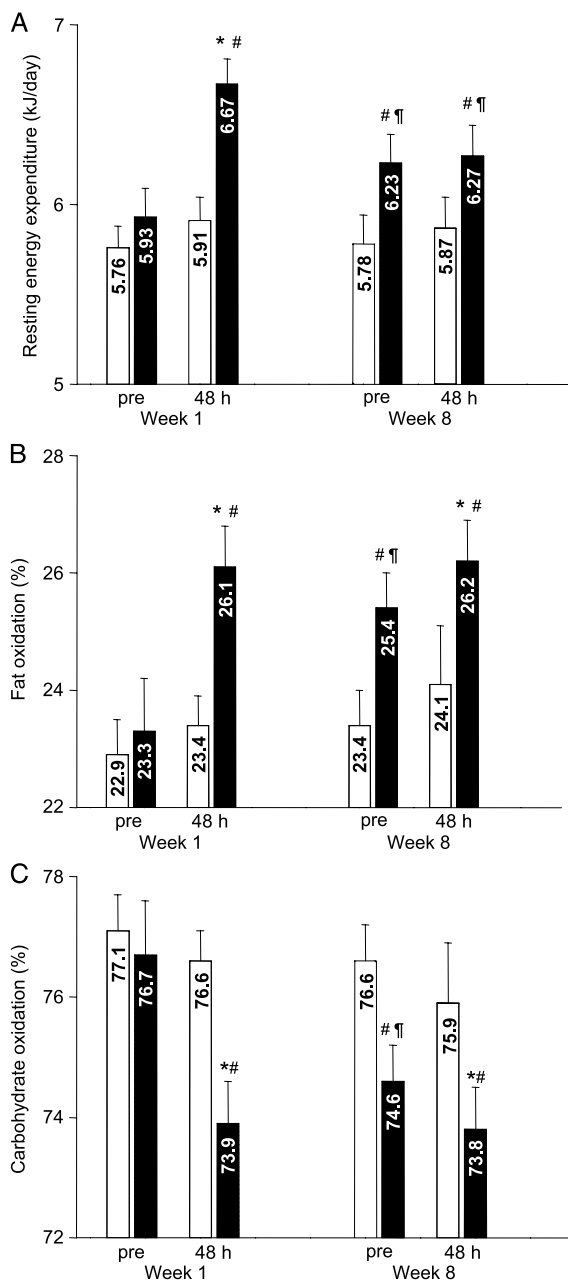


FIGURE 1—REE (A), fat oxidation (B), and carbohydrate oxidation (C) at preexercise and 48 h postexercise in the first and eighth week of concentric (□) and eccentric exercise (■). *Significantly different from the preexercise value. #Significantly different from the concentric group at the same time point. †Significant difference between week 1 and week 8 at the same time point.

concentric exercise did not induce any significant effects on REE or substrate metabolism.

Blood chemistry. Generally, acute exercise modified significantly the levels of TG, TC, HDLC, LDLC, and TC/HDL ratio only after eccentric exercise at week 1 and not at week 8 (Fig. 2). Eccentric training improved the resting levels of blood lipid profile by decreasing the levels of TG by 12.8%, TC by 8.8%, LDLC by 16.4%, and TC/HDL ratio by 17% and by increasing the levels of HDLC by 9.3% at week 8, whereas concentric training favorably modified the

levels of TG only (decreased by 2.8%). In contrast, apolipoproteins and lipoprotein (α) did not change after either training sessions both acutely and chronically (Table 3).

Generally, postexercise levels of glucose, insulin, and HOMA were modified significantly for eccentric exercise group at week 1 but not at week 8 (Fig. 3). Eccentric training improved the baseline levels of the aforementioned parameters at week 8. The levels of glycosylated hemoglobin at baseline and at 48 h postexercise were decreased only after 8 wk of eccentric training (Fig. 3). Acute and chronic concentric exercise did not induce any significant effects on variables relating to insulin resistance.

DISCUSSION

Regular physical activity is known to exert a beneficial effect on several factors affecting the risk of developing many chronic diseases (5). Implementing and maintaining changes of lifestyle are, however, known to be difficult. In this study, the effects of a brief exercise intervention performed only once per week were investigated. On the basis of the evidence derived from the current study, eccentric training markedly increased muscle strength and performance, REE, and lipid oxidation as well as decreased insulin resistance and blood lipid profile. It is reported that only 30 min of eccentric exercise per week for 8 wk was sufficient to improve human performance and health, rendering eccentric exercise a promising novel type of physical activity.

REE and substrate oxidation. In the present investigation, acute eccentric exercise produced larger increases in REE compared with concentric exercise, which could be attributed to the greater muscle malfunction that usually follows eccentric exercise than concentric (30). This could be partly explained by the increased rate of muscle protein synthesis, which lasts for about 48 h after an acute bout of eccentric exercise (8). The 8 wk of eccentric training was sufficient to elevate baseline REE by 5.0%, a value similar to that reported after endurance training and “traditional” resistance training (i.e., involving both concentric and eccentric actions) (18). Increased fat-free mass in the eccentric exercised group may be partially responsible for the raised basal REE reported in this group. This corroborates the trend for higher increases in fat-free mass and the greater increases in isometric torque that appeared in the eccentric group compared with the concentric. In addition, it was found that acute eccentric exercise increased fat oxidation only in the untrained (i.e., at week 1) and not in the trained individuals (i.e., at week 8). Taking into consideration that the current trend in overweight and obesity statistics has become epidemic, such enhanced energy expenditure and lipid oxidation levels during recovery from eccentric exercise could assist in body weight management regimens.

Insulin resistance. Many studies have reported that acute eccentric exercise increases insulin resistance, reduces glucose disposal rates, and increases plasma insulin levels (40). Indeed, in the present study, we found increased glucose and insulin levels and as a result increased levels of

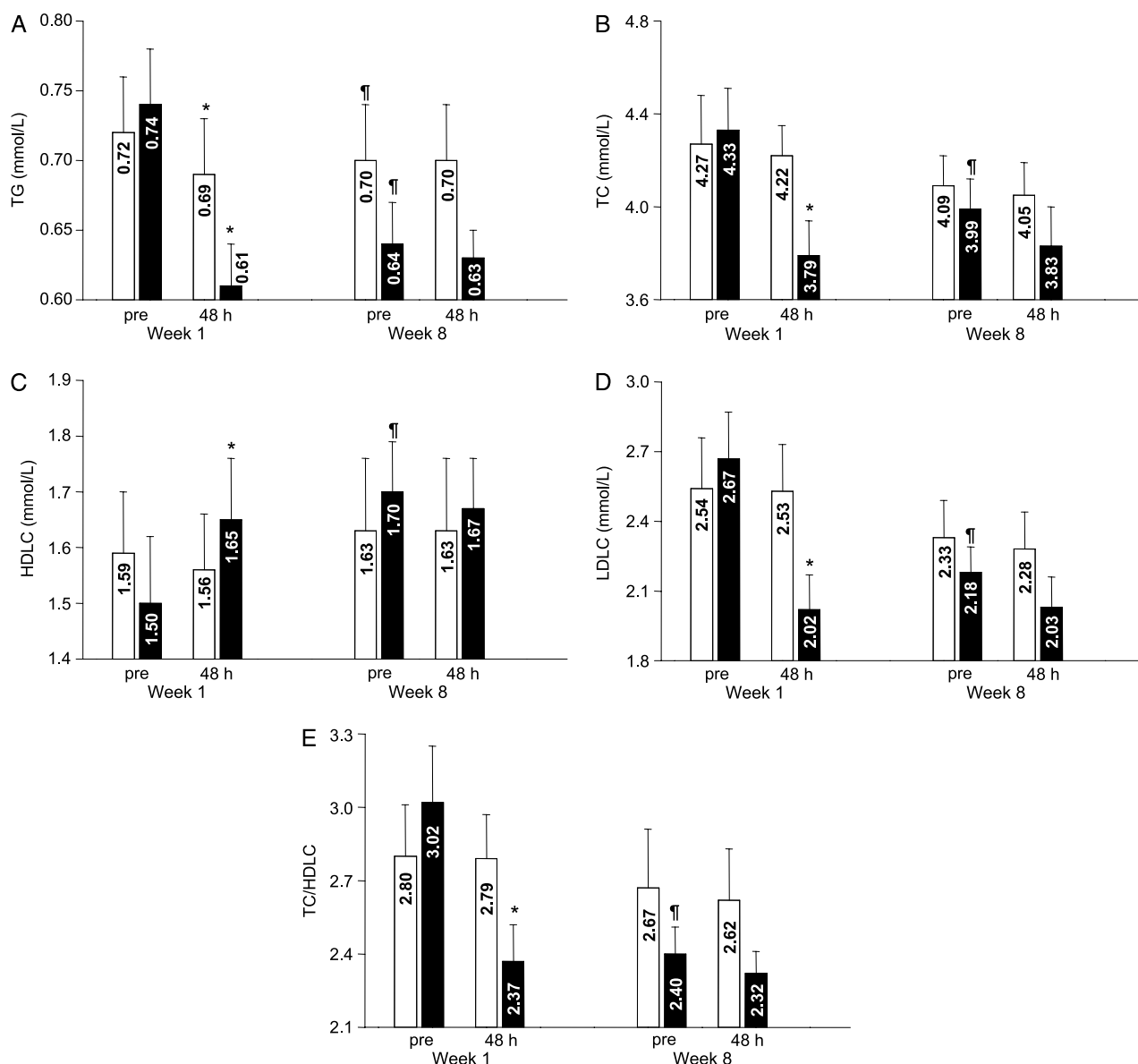


FIGURE 2—Blood lipid profile (TG, A; TC, B; HDLC, C; LDLC, D; TC/HDL, E) at preexercise and 48 h postexercise in the first and eighth week of concentric (□) and eccentric exercise (■). TG, triacylglycerols; TC, total cholesterol; HDLC, HDL cholesterol; LDLC, LDL cholesterol. *Significantly different from the preexercise value. #Significant difference between week 1 and week 8 at the same time point.

HOMA after the first bout of eccentric exercise. On the contrary, these adverse effects of acute eccentric exercise on insulin resistance subsided after chronic exercise. This was probably due to the almost complete absence of muscle malfunction after the bout of eccentric exercise at week 8 because muscle injury has been shown to induce insulin resistance (40). On the other hand, chronic eccentric exercise decreased resting levels of insulin, glucose, and HOMA. Moreover, chronic eccentric exercise decreased by 10.6% the resting serum levels of glycosylated hemoglobin, a reliable index of the average serum glucose concentration over prolonged periods of time. In support to our findings, a recent study has indicated that chronic eccentric-biased exercise (downhill hiking) decreased insulin resistance (10). The improved insulin sensitivity appeared after chronic eccentric

exercise may be related to the increased fat oxidation that also appeared after chronic eccentric exercise in the present study. In fact, increased fat oxidation prevents the accumulation of fatty-acid derived metabolites in skeletal muscle, which in turn impairs insulin signal transduction and/or the activity of enzymes involved in glucose disposal leading to insulin resistance (25). In addition, elevated plasma TG concentration (as observed in this study) impairs insulin action through overactivity of the glucose fatty-acid cycle (36).

Lipid and lipoprotein profile. The results of this study revealed that both acute and chronic eccentric exercise—but not concentric exercise—favorably modified the levels of lipids and lipoproteins. This is an important clinical finding because a “healthy” blood lipid profile is one of the main targets for people participating in physical activity programs.

TABLE 3. Blood apolipoprotein and lipoprotein (α) profile at preexercise and 48 h postexercise in the first and eighth week of concentric and eccentric group (mean \pm SEM).

	Week 1		Week 8	
	Before	48 h	Before	48 h
Apolipoprotein A1 (mg·dL ⁻¹)				
Concentric	154 \pm 7	157 \pm 7	156 \pm 7	155 \pm 7
Eccentric	147 \pm 11	145 \pm 9	167 \pm 9	168 \pm 9
Apolipoprotein B (mg·dL ⁻¹)				
Concentric	91 \pm 4	92 \pm 4	89 \pm 5	89 \pm 5
Eccentric	89 \pm 6	87 \pm 6	85 \pm 7	85 \pm 6
Lipoprotein (α) (mg·dL ⁻¹)				
Concentric	22.5 \pm 3.3	20.3 \pm 2.6	22.0 \pm 2.8	20.6 \pm 2.8
Eccentric	22.7 \pm 3.3	19.8 \pm 2.5	20.3 \pm 2.6	20.1 \pm 1.9

No significant differences were detected in any variable between week 1 and week 8 in the same training group or between concentric and eccentric group in the same week.

The changes in lipid and lipoprotein profile that observed after the first bout of eccentric exercise were larger compared with the changes induced after the last bout. This may be related to the less muscle malfunction the participants experienced after the last bout of eccentric exercise (34).

After acute and chronic eccentric exercise, serum TG concentration may have been reduced because of the increased demand of the working muscles for fatty acids as energy-yielding substrate as well as the replenishment of fatty acid-containing stores (i.e., cholesterol esters, phospholipids, and TG) for the regeneration of injured muscle fibers. This mechanism is also supported by the increased fatty acid oxidation rates observed after acute and chronic eccentric exercise. Given that cholesterol constitutes \approx 13% of muscle membranes, it can be suggested that the reduction in serum TC and LDLC during the days after eccentric exercise could be potentially due to the outflow of cholesterol from plasma into muscle, providing substrate for the synthesis of new cell membranes. Molecular findings in skeletal muscle biopsies also support our hypothesis that blood lipids used to support increased levels of lipid biosynthesis. Mahoney et al. (31) reported that an acute bout of eccentric exercise induced an immediate increase in expression of the transcription factor sterol regulatory element binding protein 2, which was followed by a delayed increase (at 48 h post-exercise) in several sterol regulatory element binding protein 2 gene targets, including LDL receptor, stearoyl-CoA desaturase, acetyl-CoA acetyl transferase 2, and insulin-induced gene 1. These expression changes suggest a transcriptional program for increasing cholesterol and phospholipid biosynthesis in the eccentrically trained skeletal muscles (31). The attenuated decrease in TC and LDLC values found after the last bout of eccentric exercise at week 8 compared with the first bout at week 1 may be partly due to the lower degree of muscle malfunction experienced because less cholesterol and phospholipid molecules would be needed for the repair process that takes place in the injured muscle cells.

The increases in HDLC after both acute and chronic eccentric exercise may be caused by the increased activity of lipoprotein lipase (that is supported by the lower levels of TG), which augments the degradation of TG from very low-density lipoproteins and causes the lipoprotein particles to shrink. This, in turn, creates a surplus of shell lipids that

are mainly transferred to HDLC (14). Finally, it is important to underline the absence of effects of either concentric or eccentric exercise (both acutely and chronically) on the levels of apolipoprotein A1, apolipoprotein B, and lipoprotein (α).

Muscle function and muscle performance. During the first week of training, the effects of exercise on muscle function followed the typical pattern, namely, altered more after eccentric exercise than after concentric exercise (7). However, muscle dysfunction was minimized after the 8 wk of training (as indicated by mild changes in torque, ROM, DOMS, and CK), demonstrating that adaptations took place in skeletal muscle after both eccentric and concentric training. In the present study, we directly compared the effects of eccentric and concentric resistance isokinetic training on muscle torque measured during the three types of muscle action (i.e., eccentric, concentric, and isometric). Eccentric training increased eccentric torque 35%, concentric torque 17%, and isometric torque 19%, whereas the respective values after concentric training were 11%, 23%, and 11%. Three main observations arise from these results. First, eccentric and concentric training led to greater increases in muscle torque, when the latter was assessed using the action type used during the training period. Second, eccentric training increased baseline eccentric torque (35%) more than concentric training increased concentric torque (23%). Third, eccentric training increased baseline isometric torque (19%) more than concentric training (11%). The greater increases noted in baseline eccentric and isometric torque after eccentric training compared with concentric training at week 8 are in accordance with previous observations (3,13,20–24). It is clear that the present results corroborate the principle of specificity; that is, the specific physiological adaptations to resistance exercise are determined by the muscle actions involved (11). The greater gain in muscle torque that appeared after eccentric than concentric training could be partially attributed to the greater muscle hypertrophy that follows eccentric training compared with concentric training (13,21).

Special characteristics of the exercise protocol used. The favorable effects of eccentric training, as evident in the present investigation, are probably equal to or even superior to classical modes of training, like resistance and aerobic exercise lasting for about an hour and performed three to five times per week (2,4). It is worth considering that in a position stand published by the American College of Sports Medicine, it is recommended that previously untrained individuals (as was the case in the present study) should perform one set of 8 to 12 repetitions two to three times per week for all the major muscle groups to improve muscle strength and hypertrophy (1). Although that the present training protocol was performed in much lower frequency per week compared with that recommended, its effects on REE, blood lipid profile, and insulin resistance were comparable (2,4). It appears that three factors mainly contributed to this effect: i) the type of muscle action (i.e., eccentric); ii) the intensity of muscle action (maximal); and iii) the number of muscle actions (i.e., 75 actions).

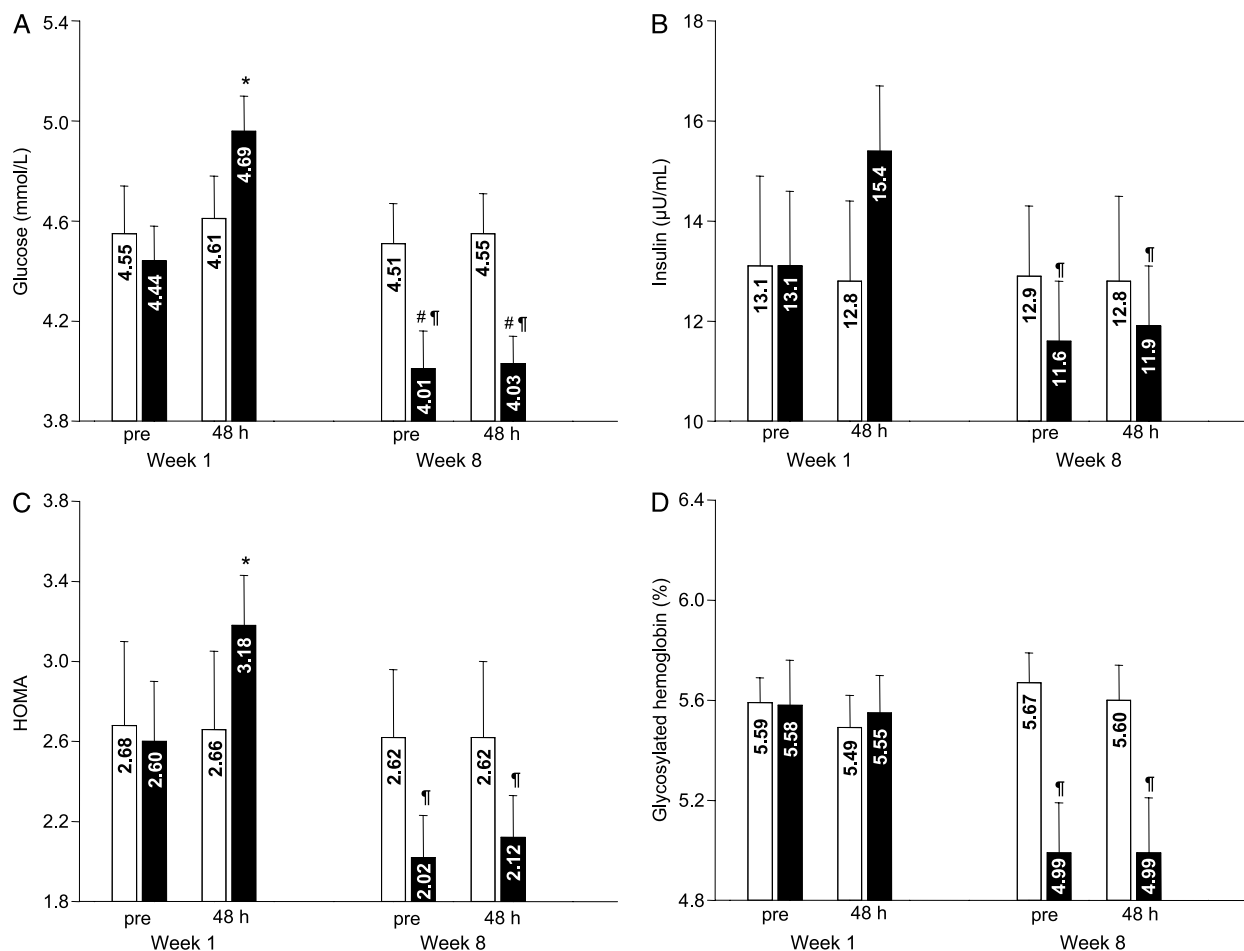


FIGURE 3—Blood insulin resistance indices (glucose, A; insulin, B; HOMA, C; glycosylated hemoglobin, D) at preexercise and 48 h postexercise in the first and eighth week of concentric (□) and eccentric exercise (■). HOMA, homeostasis model assessment. *Significantly different from the preexercise value. #Significantly different from the concentric group at the same time point. ¶Significant difference between week 1 and week 8 at the same time point.

Practical applications and conclusions. The very low frequency of eccentric exercise per week and the short duration of each exercise session, which is required to produce the favorable effects of eccentric exercise, are potentially important practical advantages of eccentric training over other types of physical activities. People who wish to participate in activities containing eccentric actions may perform exercises with strong eccentric component, such as bench stepping, downhill walking, or placing emphasis on the negative phase of conventional resistance exercises.

To our knowledge, this is the first investigation on the effect of chronic eccentric-only exercise on a large array of health-related measures. On the basis of the evidence derived from the present study and other studies (9,10,16,29,32,33,37), it is

clear that eccentric training, except for its muscle-damaging nature, can induce health-promoting effects that may improve quality of life. It is worth noting that these favorable effects induced after performing only 30 min of eccentric exercise per week for 8 wk. Moreover, the effects of eccentric exercise on muscle dysfunction were minimized after 8 wk of training, whereas the positive effects of eccentric training were still evident.

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