Effect of Explosive versus Slow Contractions and Exercise Intensity on Energy Expenditure

SCOTT MAZZETTI[1], MATT DOUGLASS[1], AARON YOCUM[1], and MATT HARBER[2]

[1]*Human Performance Center, Anderson University, Anderson, IN; and* [2]*Human Performance Laboratory, Ball State University, Muncie, IN*

ABSTRACT

MAZZETTI, S., M. DOUGLASS, A. YOCUM, and M. HARBER. Effect of Explosive versus Slow Contractions and Exercise Intensity on Energy Expenditure. *Med. Sci. Sports Exerc.*, Vol. 39, No. 8, pp. 1291–1301, 2007. **Objective:** The primary purpose of this study was to compare the effects of explosive versus slow contractions on the rate of energy expenditure during and after resistance exercise. **Methods:** Nine men (20 ± 2.5 yr) performed three exercise protocols using a plate-loaded squat machine, and a no-exercise (CONTROL) session in a randomly assigned, counterbalanced order. Subjects performed squats using either two second (SLOW) or explosive concentric contractions (EXPL), but identical repetitions (8), sets (4), and loads (60% 1RM). A secondary objective was to compare high- versus moderate-intensity exercise. Thus, a third protocol was performed that also used explosive contractions, with heavier loads (80% 1RM) and six sets of four reps (HEAVYEXPL). Eccentric reps (2 s), work (reps × sets × load), range of motion, and rest intervals between sets (90 s) were identical among all three protocols. Expired air was collected continuously for 20 min before, during, and 1 h after exercise and for about 1.5 h during CONTROL. Blood samples (25 μL) were collected before, immediately after, and 15, 30, 45, and 60 min after each protocol, and these samples were analyzed for blood lactate (mM). **Results:** Average rates of energy expenditure ($\text{kcal} \cdot \text{min}^{-1}$) were significantly greater ($P \leq 0.05$) during ($7.27 \pm 2.00 > 6.43 \pm 1.64$ and 6.25 ± 1.55, respectively) and after ($2.54 \pm 1.44 > 2.38 \pm 1.31$ and 2.21 ± 1.08, respectively) EXPL compared with SLOW and HEAVYEXPL, despite significantly ($P \leq 0.05$) greater blood lactate after SLOW. **Conclusion:** Squat exercise using explosive contractions and moderate intensity induced a greater increase in the rate of energy expenditure than squats using slow contractions or high intensity in all subjects tested. Thus, by using explosive contractions and moderate exercise intensity, experienced recreational exercisers can increase their energy expenditure during and after resistance exercise, and this could enhance weight-loss adaptations. **Key Words:** RESISTANCE EXERCISE, WEIGHT LOSS, VOLUME, ACCELERATION, PERSONAL FITNESS TRAINING

Since the 1990s, it has been widely accepted that resistance exercise should be performed with slow muscle contractions to enhance weight loss. Although there are many different variations of slow resistance exercise, the most popular example is super slow, which requires the use of 10-s concentric and 5-s eccentric repetitions (18). A proposed argument for using slow reps is that workout intensity and effectiveness are increased (18,29). But slow muscle contractions do not increase contraction intensity (i.e., rate of acceleration with which training loads are raised) or exercise intensity (i.e., percentage of the one-repetition maximum (% 1RM)). Instead, slow reps increase contraction volume, or the duration of the reps, and this probably causes slow resistance exercise to feel more exhausting because of greater muscle fatigue (i.e., the muscle burn) and temporary feelings of increased muscularity resulting from increased muscle blood flow (i.e., the muscle pump).

Conversely, there is evidence that explosive muscle contractions may enhance energy expenditure because of a preferential activation of fast, energy-inefficient muscle cells. Explosive contractions require intended maximum concentric acceleration (IMCA), which refers to "attempting to lift a resistance as rapidly as possible during the concentric phase of a lift, regardless of the resistance load" (20). Thus, explosive contractions increase the contraction intensity of a workout. Such increased contraction intensity with explosive muscle actions has been shown to increase the activation of higher–recruitment threshold motor nerves (5,13), even when compared with slower contractions using the same external load (6). High–recruitment threshold motor nerves are known to form synapses with a higher proportion of fast muscle cells (5,24), and human fast muscle cells are less energy efficient than slow cells during force production (14). Thus, one might argue that if all resistance exercise variables were equal (e.g., load, reps, sets, etc.), then explosive contractions could induce a greater increase in energy expenditure than would other contractions with less acceleration.

Only two studies have compared the influence of contraction intensity on energy expenditure with resistance exercise (10,17), but these studies did not standardize the

---

Address for correspondence: Scott Mazzetti, Ph.D., Salisbury University, Department of Health, Physical Education, and Human Performance, Salisbury, MD 21801; E-mail: samazzetti@salisbury.edu.

Submitted for publication August 2006.
Accepted for publication April 2007.

0195-9131/07/3908-1291/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/mss.0b013e318058a603

exercise intensity, exercise volume, or speed of eccentric contractions among protocols. Furthermore, one study used continuous knee-extension ergometry (10), and neither study required IMCA (10,17). As a result, there continues to be uncertainty among recreational exercisers and personal fitness trainers as to whether resistance exercise programs should emphasize high or low contraction intensity, as well as high or low exercise intensity for weight loss. In fact, there is conflicting evidence regarding exercise intensity and energy expenditure, with energy expenditure reported to increase as the % 1RM used increases (16), versus findings of high- or moderate-volume resistance exercise inducing greater increases in the rate of energy expenditure compared with very-high-intensity squats (21). When exercise work (i.e., load × reps × sets) is standardized, high-intensity resistance exercise has resulted in greater increases in energy expenditure in men (16) and women (27), but one study has shown no effect of exercise intensity on energy expenditure in men (23). Nonetheless, the longest sustained increase in energy expenditure after resistance exercise is 38 h (i.e., excess postexercise oxygen consumption (EPOC)); and it occurred in response to a resistance exercise session that incorporated explosive contractions (power cleans) and high exercise intensity (25). Therefore, it seems as if high-intensity resistance exercise using explosive contractions would provide the best combination of resistance exercise techniques for optimal energy expenditure (16,17,25,27).

To date, no study has specifically compared the effects of explosive versus slow contractions on energy expenditure during and after resistance exercise, and few studies have compared protocols with different exercise intensities when work was matched. Thus, there is a need to compare explosive versus slow contractions, as well as different exercise intensities, using otherwise identical resistance exercise protocols to accurately examine the effects of contraction and exercise intensity on energy expenditure, while standardizing other factors that could confound the overall workout intensity (i.e., total kilograms lifted, exercise work, rest intervals, etc.). Such data will help improve our understanding of which resistance exercise designs are most advantageous for enhancing energy-expenditure responses for weight loss. Therefore, the purpose of this investigation was to compare energy expenditure during and after nearly identical resistance exercise protocols, using either maximally explosive or deliberately slow contractions. A secondary objective was to examine whether resistance exercise using high exercise intensity could increase energy expenditure to a greater magnitude than would moderate exercise intensity when work was matched.

METHODS

Research Design

To examine the effects of contraction intensity and exercise intensity on energy expenditure, nine men performed two familiarization sessions, a no-exercise (CONTROL) session, and three squat-exercise protocols during 6 wk (Fig. 1). We tested the hypotheses that explosive contractions would increase the rate of energy expenditure to a greater extent than slow contractions, and that high-intensity resistance exercise would increase the rate of energy expenditure more so than moderate-intensity resistance exercise when work was matched. The three experimental protocols included squats using deliberately slow concentric muscle actions (SLOW), explosive squats using intended maximum concentric acceleration (EXPL), and high-intensity explosive squats using heavy loading and intended maximum concentric acceleration (HEAVYEXPL). Expired air was collected continuously before, during, and for 1 h after each protocol, and protocols were performed in a randomly assigned, but counterbalanced, order. Subjects were not permitted to exercise outside of the requirements for this study during the 6-wk experimental period, and all visits to the laboratory were exactly 1 wk apart, to avoid any lingering effects of previous exercise on metabolism.

Subjects

Ten men 18–26 yr of age volunteered to participate as subjects in this investigation. One stopped because of influenza virus, which was unrelated to the study. Thus, the $N = 9$ subjects were 20.2 ± 2.5 yr of age and 178 ± 9.5 cm tall; they had an average body mass of 82.3 ± 16.7 kg with 14.4 ± 3.9% body fat, and they had a 1RM squat of 57.7 ± 17.2 kg. Volunteers had more than 2 yr of resistance training experience and were nonsmoking, healthy, and free from medications, ergogenic supplements, glandular disorders, and any conditions that could affect metabolism. Before any testing, each subject was informed of all procedures and risks associated with participation and gave informed consent by signing a document that was approved by the human research participants committee at Anderson University. This study was in accordance with the Declaration of Helsinki.

Body Composition and Anthropometric Measurements

Body mass and height were measured to the nearest 0.10 kg and 0.10 cm, respectively. Body fat percentage was estimated using the seven-site skinfold procedures according to the guidelines of the American College of Sports Medicine (19).

Squat Machine and Exercise Range of Motion

All testing, familiarization, and squat exercise trials were performed using a plate-loaded squat machine (Paramount Total Leg FW-8800, Paramount Fitness Corp., Los Angeles, CA) (Fig. 2). Before 1RM strength testing, exercise range of motion was determined for each subject by having him lower the squat machine to a position where the angle formed behind the left knee during knee flexion was between 85 and 89°. A goniometer was used to assure an 85–89° joint angle, then an adjustable wooden stool was placed under the subject's buttocks at an accommodating height. The specific height of the stool was recorded for each subject, and the same stool height was used for all protocols. Each subject was required to lower the load during each squat and briefly touch his buttocks to the stool without bouncing, thereby standardizing the ROM for all squats. Foot placement on the platform of the squat machine also was standardized for each subject.

1RM Strength Testing

Before testing, subjects performed three warm-up sets on the squat machine using light to moderate loads. The subject's one-repetition maximum (1RM) was determined by allowing three to five attempts to lift the heaviest load one time. Determining the maximum squat strength required the subject to lower the load until his buttocks touched the ROM stool, and then exert as much force as possible while raising the load to the standing position. Each subject used his own natural concentric and eccentric rep speeds (i.e., not deliberately slow or explosive) to perform all warm-ups and 1RM attempts. Subjects rested for 3 min between each attempt.

Squat Exercise Familiarization

Immediately after 1RM testing, loads for 60 and 80% 1RM were determined, and subjects performed three sets of

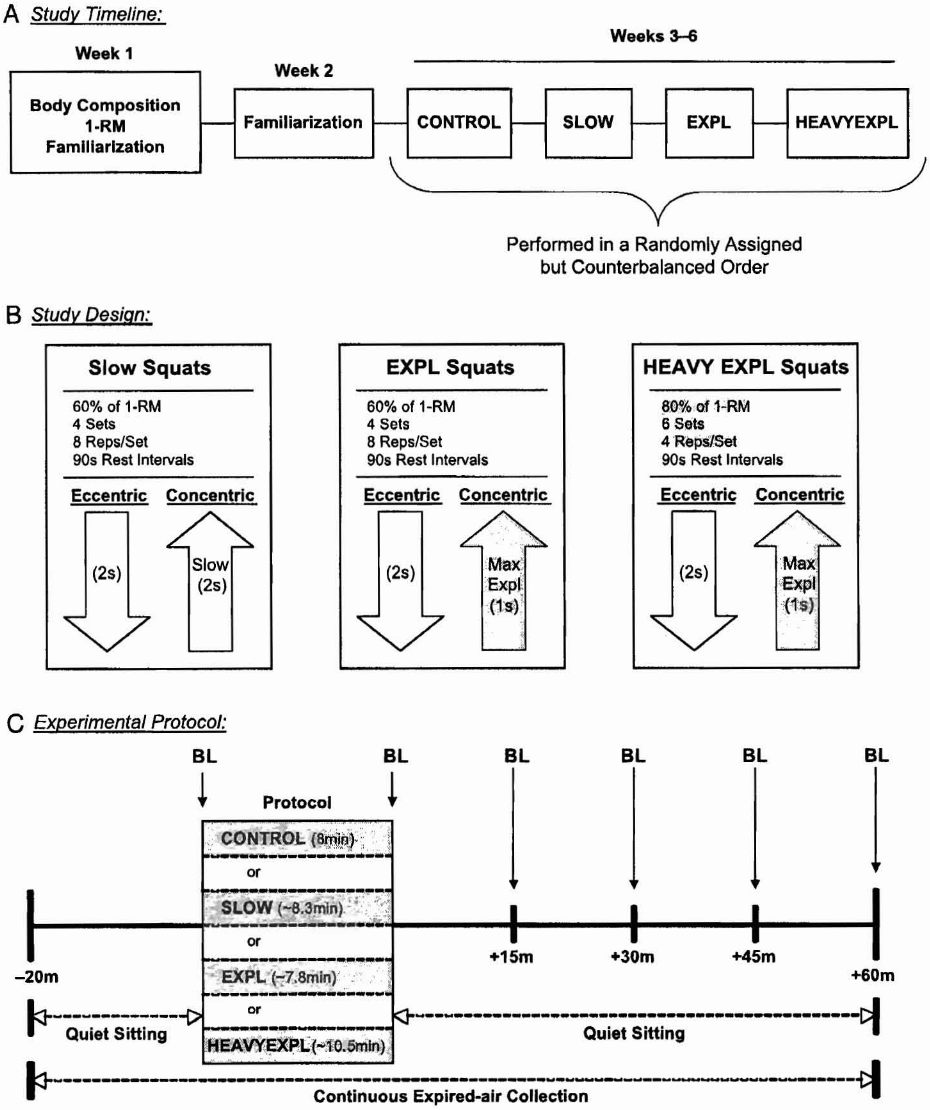

FIGURE 1—Study timeline (*A*), study design (*B*), and experimental protocol (*C*) used to compare the effects of contraction intensity (explosive vs slow) and exercise intensity (high vs moderate) on the rates of energy expenditure during and after nearly identical moderate-intensity squat protocols performed with slow (SLOW) or explosive contractions (EXPL), and high-intensity squats performed with explosive contractions and heavy loading (HEAVYEXPL). 1RM, heaviest load that can be lifted one time; MAX EXPL, raising a load using intended maximum concentric acceleration; BL, finger-prick-sample collection for blood lactate.

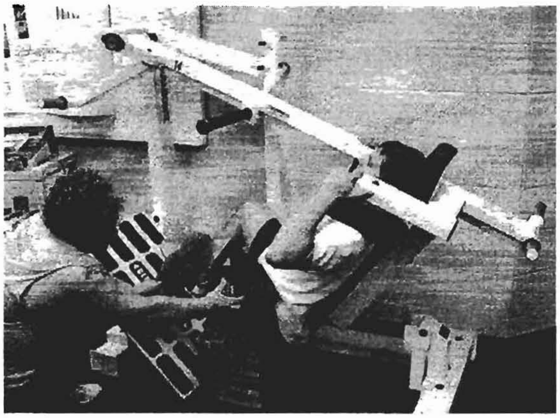

FIGURE 2—Plate-loaded squat machine (Paramount Total Leg FW-8800, Paramount Fitness Corp., Los Angeles, CA) and range-of-motion (ROM) stool used for all squat exercise.

squats separated by 90-s rests to practice the different squat protocols (i.e., first familiarization). Set 1 was SLOW (eight reps, 60% 1RM, 2-s concentric rep speeds); set 2 was EXPL (eight reps, 60% 1RM, explosive concentric reps); and set 3 was HEAVYEXPL (four reps, 80% 1RM, explosive concentric reps). All protocols required 2-s eccentric reps and were paced by a metronome. Specifically, subjects performed the SLOW squats to an audible count of one, two, three, four, one, two, three, four, etc., by a technician counting in unison with a metronome set to beep every second so that the squat load was always lowered during *one* and *two* and always raised during *three* and *four*. Explosive squats (EXPL and HEAVYEXPL) were performed using a similar audible counting approach, but the count was one, two, up, one, two, up, etc., so that the squat load was always lowered during *one* and *two* and raised during *up*. Subjects were not permitted to perform bouncing or jerking movements at any time for any of the squat protocols.

Exactly 1 wk later, subjects performed a second familiarization session consisting of six sets of squats separated by 90-s rests. This familiarization session was as follows: one warm-up set of four reps using 40% 1RM and natural contraction speeds; two sets EXPL; two sets HEAVYEXPL; and two sets SLOW. Subjects also had their expired air collected via indirect calorimetry during this session, but only to allow the subjects to become familiar with wearing the headgear and mask during exercise. Both familiarization sessions were performed at the same time of day in the afternoon (3:00 p.m.).

Indirect Calorimetry

Expired air was collected using a metabolic cart that was calibrated before each experiment (ParvoMedics, Sandy, UT). A two-way nonrebreathing nasal and mouth face mask was used, with the mask sealed to prevent leakage (Hans Rudolph, Inc., Kansas City, MO). Expired air was collected continuously during 20 min of quiet sitting, 7.8–10.5 min of exercise (or control), and 60 min of quiet sitting after exercise for each experiment. O_2 consumption ($L \cdot min^{-1}$) was exported from the metabolic cart in 5-s averages, arranged in a spreadsheet, and used to calculate averages for the rates of energy expenditure ($kcal \cdot min^{-1}$) at baseline (REST), first half of exercise (1st HALF-EXERC), second half of exercise (2nd HALF-EXERC), and +5, +10, +15, +30, +45, and +60 min after exercise. For 1st HALF-EXERC and 2nd HALF-EXERC, protocols were divided in half immediately after completion of the second set (SLOW and EXPL) or immediately after the third set (HEAVYEXPL), according to protocol times that were recorded from the metabolic cart during data collection. Thus, results for 1st HALF-EXERC included the warm-up set, which was identical for all protocols. All data were corrected for dead space associated with the time necessary for expired air to travel from the mouth to the analyzers. All rates of energy expenditure ($kcal \cdot min^{-1}$) were calculated using the equations of Weir (28) and were based on oxidative processes only. Also, total energy expenditure (kcal) was calculated for the entire duration of each protocol (i.e., including resting, exercise, and postexercise data), using the trapezoidal area-under-the-curve method. These total energy-expenditure data were calculated from oxidative processes only, as well as from oxidative plus anaerobic processes using the energy equivalent for each millimole increase in blood lactate after exercise (0.02698 $kcal \cdot kg^{-1}$ body mass) (12).

Experimental Protocols

Exactly 1 wk after the second familiarization session, subjects performed one of the four experimental protocols in a randomly assigned, but counterbalanced, order. Subjects arrived at the laboratory at approximately 6:00 a.m. for all experimental protocols after an overnight fast. A nude body mass was obtained, and the subject sat quietly for 20 min in an upright chair. Subjects remained awake and were instructed to not move, fidget, or talk during all quiet sitting. The face mask was put on, and the subject sat quietly for another 20 min. A preexercise finger prick was collected and analyzed immediately for determination of resting blood lactate concentration ([BL]). The subject then performed one of the four experimental protocols, which ranged from 7.8 min to approximately 10.5 min in duration, and then a postexercise finger prick was collected and analyzed immediately. Lastly, the subject sat quietly in an upright chair for 60 min with a finger prick every 15 min while expired air was collected continuously for the entire protocol.

CONTROL session. The CONTROL protocol required the subject to sit quietly in an upright chair while his expired air was collected and measured for 8 min. This time period was chosen for CONTROL because it was the approximate duration of the SLOW (~8.3 min) and EXPL (~7.8 min) protocols. For this protocol, the subject sat continuously for a total of 1 h 28 min.

SLOW and EXPL protocols. The same warm-up set was performed for SLOW, EXPL, and HEAVYEXPL (four reps, 40% 1RM, natural contraction speeds). For SLOW and EXPL, the reps (eight per set), sets (four), loads (60% 1RM), range of motion, rest intervals (90 s), eccentric rep speeds (2 s), and exercise work were identical (Table 1). The primary difference between SLOW and EXPL was that subjects used 2-s concentric reps for SLOW and maximally explosive concentric reps for EXPL (~1 s). As a result, the total muscle-contraction time (i.e., contraction volume) was greater for SLOW (~128 s) than for EXPL (~96 s). This difference in contraction volume may have influenced the estimates for exercise work for each protocol. Thus, by adding rep time (4 s for SLOW, 3 s for EXPL) to the formula for work (i.e., $\text{work}_{\text{rep time}}$ = load × reps × sets × rep time), the estimated $\text{work}_{\text{rep time}}$ was 76.8 for SLOW and 57.6 for EXPL. The difference in contraction intensity between SLOW and EXPL was evident in the rates of lifting (kg·min^{-1}), with the total amount of resistance lifted per minute 102 ± 36 kg·min^{-1} for SLOW and 109 ± 37 kg·min^{-1} for EXPL. Thus, SLOW and EXPL differed in contraction intensity, contraction volume, and exercise duration.

HEAVYEXPL protocol. The HEAVYEXPL protocol required identical range of motion, rest intervals, eccentric rep speeds, and exercise work as SLOW and EXPL, but it consisted of more sets (six), fewer reps per set (four), and heavier loading (80% 1RM). Because of differences in contraction times between SLOW and HEAVYEXPL (4 vs 3 s per rep), exercise $\text{work}_{\text{rep time}}$ was greater for SLOW (76.8) than for HEAVYEXPL (57.6). Thus, to compare the effects of exercise intensity on energy expenditure when exercise work was matched, HEAVYEXPL was compared with EXPL because they both required the same amount of $\text{work}_{\text{rep time}}$ (57.6). Because HEAVYEXPL required more sets (i.e., six vs four), the HEAVYEXPL protocol was longer than EXPL. Thus, HEAVYEXPL and EXPL differed in exercise intensity, exercise volume, and exercise duration (~10.5 vs ~7.8 min).

Concentric Rep Speeds and Rest Intervals

Two second concentric reps were chosen for SLOW, instead of longer contraction times (e.g., 10 s), because to do so, very light loading would have been needed for the SLOW protocol (e.g., ~25% 1RM) (17). Differences between protocols in exercise intensity have been shown to affect energy expenditure during and after exercise (16). Thus, 2-s concentric reps were used for SLOW because they permitted the subjects to perform deliberately slow contractions while still using the same load as in the EXPL protocol. Between sets for all exercise protocols, subjects sat immediately after the completion of the previous set in an upright chair for 90 s, including after the warm-up set. Subjects did not move, fidget, or talk between sets. For all protocols, the final 10 s of each rest interval was standardized so that each set began 90 s after the end of the previous set. Rest intervals were timed by the same investigator for all protocols.

Blood Lactate

Finger-prick blood samples (25 μL) were collected into capillary tubes before each protocol, within 30 s after each protocol, and after 15, 30, 45, and 60 min of recovery. All samples were obtained in duplicate and were analyzed immediately for [BL] (mM) using a lactate analyzer (YSI 1500 Sport Lactate Analyzer, Yellow Springs, OH).

Dietary Requirements

Subjects were instructed to consume balanced meals (i.e., 55% CHO, 30% fat, and 15% protein) during the day before the first experiment. Each subject provided a completed food record of all food and drink consumed (items and amounts) during the final meal from the day before the first experiment. Subsequently, this food record was given back to the subject each week as a menu to follow for the final meal during the day before each trial. All subjects reported successfully eating the same foods and amounts during the last meal, and similar foods throughout the day before each trial. Subjects did not eat, but they consumed 16 ounces of water before each 6:00 a.m. experiment. Subjects refrained from caffeine for 24 h before each visit.

Statistical Analyses

Data are presented as means ± standard deviations (SD). A two-way analysis of variance with repeated measures was used to test for significant group × time interactions, and Fisher's least significant difference *post hoc* analyses were used where appropriate to determine specific pairwise differences (Statistica V4.1, StatSoft, Inc.). Separate one-way ANOVA were used to test for group differences

TABLE 1. Concentric contraction intensity, volume, and work, and exercise intensity, volume, and work for squats performed with slow (SLOW) and explosive (EXPL) contractions and for high-intensity squats performed with explosive contractions and heavy loading (HEAVYEXPL).

	Contraction^{++}			Exercise				
Protocol	Intensity (kg·s^{-1})	Volume (s)	Work (kg)	Intensity (% 1RM)	Volume (reps)	Work (intensity × volume)	Rep Time (s)	$\text{Work}_{\text{rep time}}$ (work × rep time)
SLOW	16.6	~64	1063	0.60	32	19.2	4	76.8
EXPL	33.2	~32	1063	0.60	32	19.2	3	57.6
HEAVYEXPL	44.2	~24	1061	0.80	24	19.2	3	57.6

$^{++}$ Identical warm-up sets not included in concentric contraction data. Concentric contraction intensity, rate of lifting over the total concentric contraction time; concentric contraction volume, total concentric contraction time; concentric contraction work, total kilograms lifted; 1RM, heaviest load that can be lifted one time; exercise volume, total number of reps performed (reps × sets); rep time, total duration of each rep.

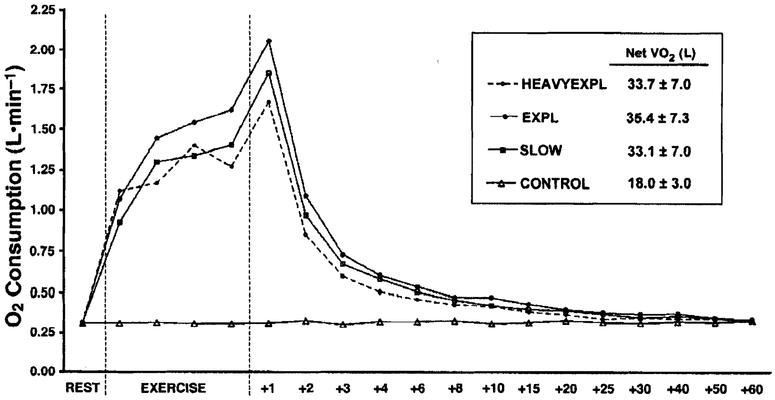

FIGURE 3—Rates of oxygen consumption ($\dot{V}O_2$ in liters per minute) before (REST), during (EXERCISE), and for 60 min after a no-exercise (CONTROL) trial, moderate-intensity squats performed with slow (SLOW) or explosive contractions (EXPL), and high-intensity squats performed with explosive contractions and heavy loading (HEAVYEXPL). Net $\dot{V}O_2$ = the total volume of oxygen consumed for each protocol (exercise $\dot{V}O_2$ plus recovery $\dot{V}O_2$) minus the REST $\dot{V}O_2$. Standard deviation bars have been omitted to provide clarity.

at REST for each variable and for group differences in area under the curve. Statistical power for sample size $N = 9$ at $\alpha = 0.05$ was 0.99. Significance in this study was defined as $P \leq 0.05$.

RESULTS

Oxygen consumption and energy expenditure. The rates of O_2 consumption (L·min^{-1}) before, during, and after each protocol are shown in Figure 3 with the standard deviation bars omitted to provide clarity. Net O_2 consumption (net $\dot{V}O_2$ in liters), calculated as the sum of the exercise and recovery $\dot{V}O_2$ minus the REST $\dot{V}O_2$, did not differ among exercise protocols (Fig. 3). The rates of energy expenditure increased significantly ($P \leq 0.05$) with EXPL, SLOW, and HEAVYEXPL (1st HALF-EXERC, 2nd HALF-EXERC, and +5, +10, +15, +30, and +45 min) (Table 2). Significant ($P \leq 0.05$) group differences for the rates of energy expenditure included EXPL> SLOW (1st HALF-EXERC, 2nd HALF-EXERC, and +5, +10, and +15 min) and EXPL> HEAVYEXPL (1st HALF-EXERC, 2nd HALF-EXERC, and +5, +10, +15, and +20 min). There were no group differences in the rates of energy expenditure at REST. Total oxidative energy expenditure from trapezoidal area-under-the-curve calculations, and total oxidative energy expenditure plus anaerobic energy expenditure (kcal) from the energy equivalent for each millimole increase in [BL] after exercise (0.02698 kcal·kg^{-1} body mass), were greater with EXPL than with SLOW and HEAVYEXPL (Table 3). The differences in total oxidative energy expenditure (kcal) for EXPL > SLOW (11 ± 4.5 kcal) and EXPL > HEAVYEXPL (9 ± 5.0 kcal) were significantly ($P \leq 0.05$) different. The differences in total oxidative energy expenditure plus anaerobic energy expenditure for EXPL > SLOW (9 ± 4.2 kcal) and EXPL > HEAVYEXPL (13 ± 5.3 kcal) were also significantly ($P \leq 0.05$) different. The average rate of energy expenditure for the entire EXPL protocol (20 min rest + exercise + 60 min postexercise sitting) was significantly ($P \leq 0.05$) greater than for SLOW and HEAVYEXPL, but the average rate of energy expenditure for the entire SLOW protocol was not different from HEAVYEXPL (Table 3).

Blood lactate. [BL] increased significantly ($P \leq 0.05$) with EXPL, SLOW, and HEAVYEXPL (immediately after exercise and at +15, +30, +45, and +60 min) (Fig. 4). Significant ($P \leq 0.05$) group differences for [BL] included SLOW >EXPL (immediately after exercise and at +15 and

TABLE 2. Rates of energy expenditure (kcal·min^{-1}) before (REST), during (1st HALFEXERC and 2nd HALFEXERC), and 5, 10, 15, 30, 45, and 60 min after squats performed with slow (SLOW) and explosive (EXPL) contractions and high-intensity squats performed with explosive contractions and heavy loading (HEAVYEXPL).

	CONTROL	SLOW	EXPL	HEAVYEXPL
REST	1.53 ± 0.23	1.53 ± 0.23	1.52 ± 0.19	1.52 ± 0.24
1stHALFEXERC	1.53 ± 0.25	5.66 ± 1.41*	6.34 ± 1.64*, SH	5.73 ± 1.43*
2ndHALFEXERC	1.52 ± 0.24	7.19 ± 1.55*, H	8.21 ± 1.97*, SH	6.78 ± 1.57*
+5 min	1.56 ± 0.25	4.96 ± 1.18*, H	5.41 ± 1.18*, SH	4.25 ± 1.10*
+10 min	1.56 ± 0.24	2.33 ± 0.49*, H	2.47 ± 0.52*, SH	2.14 ± 0.48*
+15 min	1.55 ± 0.28	1.97 ± 0.41*	2.12 ± 0.45*, SH	1.89 ± 0.46*
+30 min	1.57 ± 0.26	1.78 ± 0.33*	1.84 ± 0.33*, H	1.70 ± 0.28*
+45 min	1.57 ± 0.26	1.68 ± 0.31*	1.74 ± 0.32*	1.66 ± 0.26*
+60 min	1.59 ± 0.28	1.58 ± 0.24	1.63 ± 0.21	1.61 ± 0.25

1st HALFEXERC, warm-up plus sets 1 and 2 (SLOW, EXPLOSIVE) or warm-up plus sets 1–3 (HEAVYEXPL); 2ndHALFEXERC, sets 3 and 4 (SLOW, EXPLOSIVE) or sets 4–6 (HEAVYEXPL).

Data are means ± SD. * Significant increase ($P \leq 0.05$) from REST; S significantly greater ($P \leq 0.05$) than corresponding SLOW value; H significantly greater ($P \leq 0.05$) than corresponding HEAVYEXPL value.

TABLE 3. Total energy expenditure (kcal), duration (min), and average rates of energy expenditure (kcal·min^{-1}) across the entire duration of each protocol (i.e., 20 min of sitting + squat exercise or a no-exercise (CONTROL) protocol + 60 min of sitting).

	CONTROL	SLOW	EXPL	HEAVYEXPL
Total energy expenditure (kcal)				
Oxidative	134 ± 19.7	197 ± 39.4	208 ± 39.9	199 ± 39.4
Oxidative + anaerobic	135 ± 20.1	214 ± 44.9	223 ± 44.1	210 ± 42.4
Total duration of each protocol (min)	88 ± 0.02	88.8 ± 0.10	88.2 ± 0.11	91.0 ± 0.11*, SE
Average rates of energy expenditure (kcal·min^{-1})				
Oxidative	1.53 ± 0.22	2.22 ± 0.44	2.35 ± 0.45*, SH	2.19 ± 0.43
Oxidative + anaerobic	1.54 ± 0.23	2.40 ± 0.50 H	2.52 ± 0.50*, SH	2.30 ± 0.47

Different squat protocols included four sets of slow (SLOW) and explosive (EXPL) and six sets of high-intensity squats performed with explosive contractions and heavy loading (HEAVYEXPL). Data were calculated using trapezoidal area under the curve from oxidative processes and from oxidative plus anaerobic energy expenditure using the energy equivalent (0.02698 kcal·kg^{-1} body mass) for each millimole increase in blood lactate after exercise (oxid + anaerob).

Data are means ± SD. S Significantly greater ($P \leq 0.05$) than corresponding SLOW value; E significantly greater ($P \leq 0.05$) than corresponding EXPL value; H significantly greater ($P \leq 0.05$) than corresponding HEAVYEXPL value.

+30 min) and EXPL > HEAVYEXPL (immediately after exercise and at +15, +30, and +45 min). There were no group differences in [BL] at REST.

DISCUSSION

To compare the effects of contraction intensity on energy expenditure, we tested whether explosive (EXPL) squats would induce greater rates of energy expenditure than slow squats (SLOW). As expected, explosive contractions induced greater increases in the rate of energy expenditure and total kilocalories expended compared with SLOW, despite a longer exercise duration and greater [BL] with SLOW. A secondary objective of the study was to compare the effects of exercise intensity on energy expenditure; thus, we tested whether high exercise intensity via heavier loading (HEAVYEXPL) would induce a greater rate of energy expenditure compared with moderate-intensity squats (EXPL) when exercise work and total kilograms lifted were standardized. But energy expenditure was not greater with high exercise intensity, because EXPL squats induced faster rates of energy expenditure and a greater increase in total kilocalories expended compared with HEAVYEXPL, despite a longer exercise duration with HEAVYEXPL and matched exercise work.

Influence of contraction intensity on energy expenditure. This was the first study to examine the influence of contraction intensity on the rate of energy expenditure between resistance exercise protocols using slow versus explosive concentric muscle contractions. We found that greater contraction intensity with explosive squats elicited significantly faster rates of oxygen consumption and energy expenditure during and after exercise than did deliberately slow contractions. This trend was evident for all nine subjects (Fig. 5). These findings are in agreement with those from previous studies that have reported greater increases in energy expenditure (or O_2 consumption) with faster muscle contractions (1,10,17). Our findings are unique, however, in that we compared squat protocols with identical reps, sets, loads, eccentric rep speeds, ROM, and rest intervals between sets. By standardizing all of these variables, we have demonstrated that the rate of energy expenditure was increased by 11.2 ± 2.8% during and 5.2 ± 4.3% after EXPL compared with SLOW. Therefore, explosive concentric muscle contractions may be more effective than slow contractions for enhancing energy-expenditure responses for weight loss when using resistance exercise.

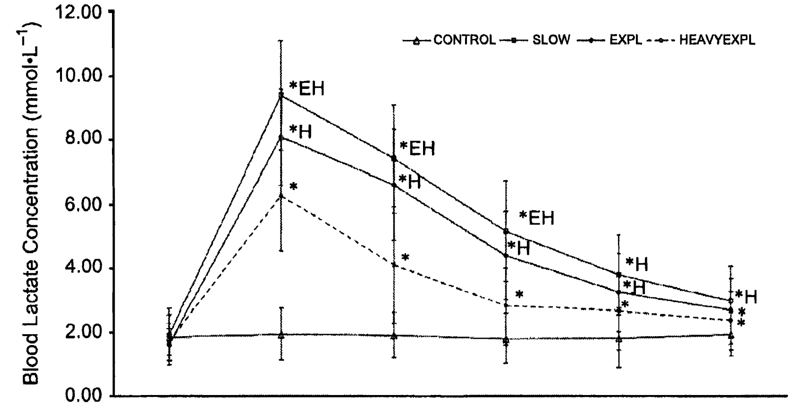

FIGURE 4—Blood lactate concentrations (mM) before (REST), immediately after (postexercise), and at +15, +30, +45, and +60 min after a no-exercise (CONTROL) trial, moderate-intensity squats performed with slow (SLOW) or explosive contractions (EXPL), and high-intensity squats performed with explosive contractions and heavy loading (HEAVYEXPL). * Significant increase ($P \leq 0.05$) from REST; *E*, significantly greater ($P \leq 0.05$) than corresponding EXPL value; *H*, significantly greater ($P \leq 0.05$) than corresponding HEAVYEXPL value. Data are means ± SD.

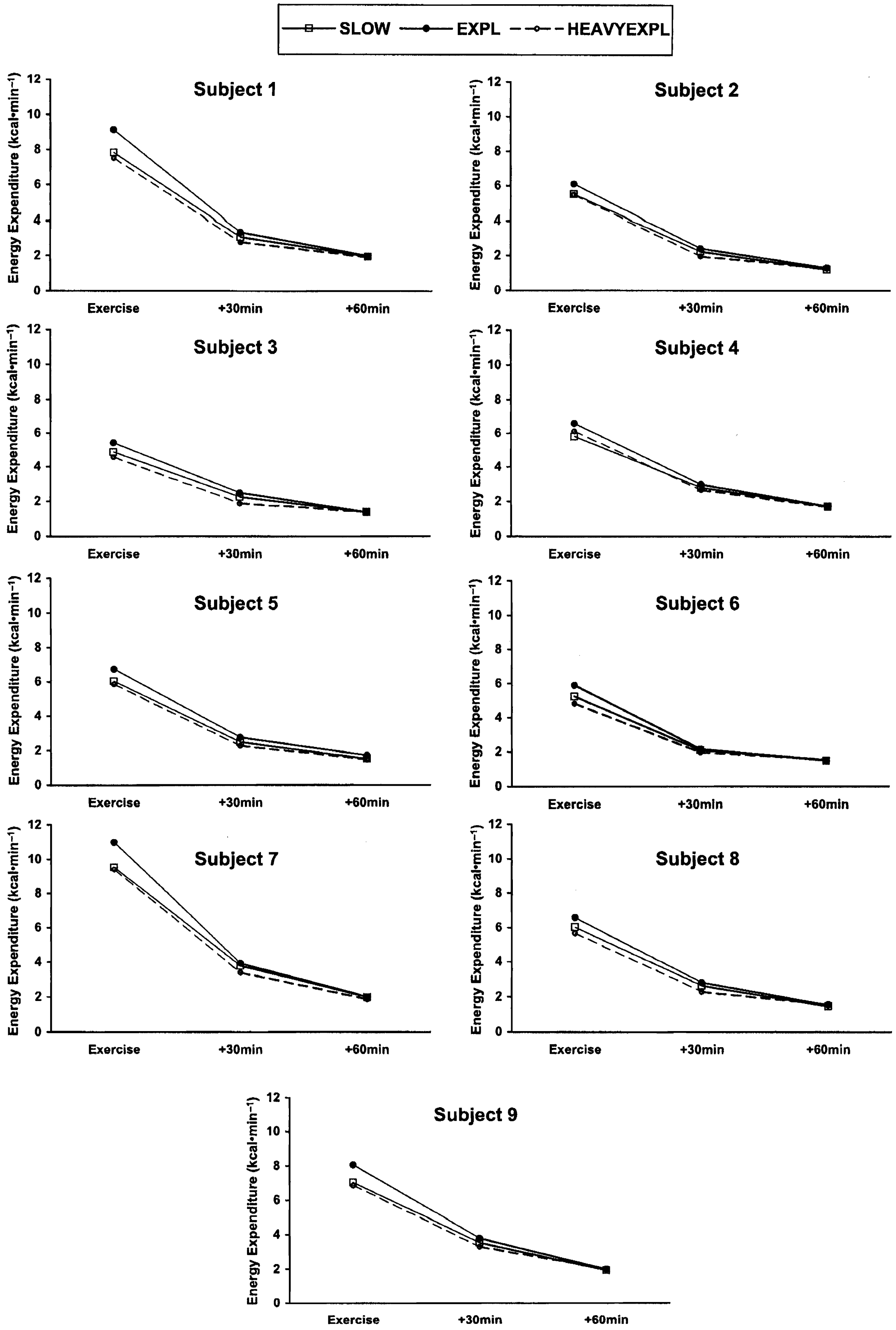

FIGURE 5—The rates of energy expenditure (kcal·min^{-1}) for each individual subject during (exercise) and at +30 and +60 min after moderate-intensity squats performed with slow (SLOW) or explosive contractions (EXPL), and high-intensity squats performed with explosive contractions and heavy loading (HEAVYEXPL).

The most logical explanation for faster rates of energy expenditure with explosive contractions is a greater reliance on fast muscle-fiber activation. Specifically, fast muscle cells have been shown to be energetically expensive during force production compared with slow cells (9,14,22). He et al. (14) report three- to fourfold higher contraction costs in fast as opposed to slow single-muscle fibers from humans. This response may be attributable, at least in part, to a greater proportion of attached myosin heads in fast cells, even as the shortening velocity increases (i.e., cross-bridge cycling) (4). We believe that EXPL probably involved a greater proportion of fast muscle activation compared with SLOW. The reason for this theory is that explosive or ballistic contractions have been shown to involve a preferential activation of larger, higher-threshold motor nerves (5,13), even when explosive contractions are compared with slower contractions using the same external load (6). Higher-threshold motor nerves are known to innervate a greater number of fast muscle cells (15,24). Furthermore, fast muscle activation increases as force production increases (11); therefore, the use of intended maximum concentric acceleration during EXPL would seemingly have caused greater force production (i.e., force = mass × acceleration). Taken together, we speculate that a greater reliance on force production by inefficient fast muscle cells may at least partially explain the faster rate of energy expenditure observed during and after explosive contractions.

Another important finding is that [BL] measurements were greater after SLOW compared with EXPL, which was the reverse of the energy-expenditure results. This is interesting because a higher circulating [BL] implies that SLOW was, at least in some way, physiologically more difficult (2), despite faster rates of energy expenditure with EXPL. Thus, these lactate data support the argument that slow reps increase some component of workout intensity (e.g., total contraction volume relative to rest intervals) (18,29). However, it may be that the workout feels more intense because of greater fatigue. Specifically, it is well known that the accumulation of H^+ in muscle cells during rapid lactate production interferes with the mechanics of muscle contraction, causing fatigue (8). Not surprisingly, all subjects in our study reported being the most fatigued with the SLOW protocol. Thus, although the slow resistance exercise used in this study was very demanding and fatiguing, it did not entail greater contraction intensity or exercise intensity, and thus it did not result in the fastest rate of energy expenditure.

On the other hand, there is evidence that quantifying the anaerobic energy expenditure related to increased lactate may be important for accurate estimation of total energy expenditure with resistance exercise (3,26). Therefore, we used area-under-the-curve calculations to estimate total energy expenditure from oxidative processes, calculated the energy equivalent for each millimole increase in [BL] after exercise (0.02698 $\text{kcal}\cdot\text{kg}^{-1}$ body mass) to estimate anaerobic energy expenditure (12), and then added these two values together to yield total energy expenditure from oxidative and anaerobic processes for the entire EXPL and SLOW exercise protocols (i.e., before, during, and for 1 h after exercise) (Table 3). Total oxidative energy expenditure for EXPL was 11 ± 4.5 kcal greater compared with SLOW, and total oxidative plus anaerobic energy expenditure for EXPL was 9 ± 4.2 kcal greater than SLOW (Table 3). Thus, total energy expenditure was significantly greater with EXPL than with SLOW, despite greater contraction volume (EXPL $\approx$ 96 s vs SLOW $\approx$ 128 s) and blood lactate production with SLOW. Although it does seem that greater energy expenditure from anaerobic processes with SLOW may have accounted for a small portion of the difference in total energy expenditure between protocols, this difference can probably be attributed to the higher total contraction volume with SLOW compared with EXPL. In other words, another study is needed to compare squat protocols using explosive and slow contractions, but with matched contraction volume and total exercise duration to more accurately determine exactly how much greater the energy expenditure would be with EXPL than with SLOW resistance exercise.

Influence of exercise intensity on energy expenditure. To our knowledge, this was the first study to examine the influence of exercise intensity on energy expenditure when the eccentric rep speeds, ROM, rest intervals, and exercise work were identical between protocols (i.e., EXPL vs HEAVYEXPL). In designing this study, the majority of the existing literature suggested that high-intensity resistance exercise using explosive contractions would provide the best combination of resistance exercise techniques for optimal energy expenditure (16,17,25,27). Contrary to our hypothesis, high-intensity resistance exercise did not induce faster rates of energy expenditure than did moderate-intensity resistance exercise, even though exercise work was matched. Our findings, therefore, are not in agreement with those of Thornton and Potteiger (27) and Hunter et al. (16), who have reported faster rates of energy expenditure with high-intensity resistance exercise in women and men, or with those of Olds and Abernethy (23), who have reported no difference in energy expenditure between 75 and 60% 1RM resistance exercise in men when work was matched. Potential reasons for the different findings in this study with high-intensity resistance exercise may be related to the fact that the other investigations did not match exercise ROM or eccentric contraction speeds. Furthermore, those studies did not use IMCA with their protocols, nor did they standardize contraction intensity. From data reported here (i.e., the EXPL vs SLOW data), contraction intensity does seem to have an effect on energy expenditure with resistance exercise; thus, it could have been an unrealized confounding factor in those previous studies.

Perhaps most importantly, resistance exercise power has been demonstrated to be optimal with exercise loads between

30 and 60% 1RM (30). This is very interesting because EXPL required a load of 60% 1RM, whereas HEAVYEXPL required a load of 80% 1RM. Thus, it seems possible that any potential enhancement of energy expenditure from explosive contractions may be limited to resistance exercise using moderate loads where acceleration and power can be optimal. This difference in power with moderate versus heavy loads also may help explain why energy expenditure was greater with SLOW compared with HEAVYEXPL, but not with SLOW compared with EXPL. Specifically, the estimated $\text{work}_{\text{rep time}}$ for SLOW (76.8) was greater compared with EXPL and HEAVYEXPL (57.6), which would suggest that energy expenditure should have been greater with SLOW than with EXPL and HEAVYEXPL, because of greater work. But, the rate of energy expenditure was as follows: EXPL > SLOW > HEAVYEXPL. Thus, our data suggest that explosive contractions with moderate squat loads, where power was more optimal (i.e., 60% 1RM), were sufficient to increase energy expenditure to an extent that was larger than the effect from greater $\text{work}_{\text{rep time}}$ (i.e., EXPL > SLOW). But, when heavy exercise loads are used, where power is not optimal (i.e., 80% 1RM), greater $\text{work}_{\text{rep time}}$ may enhance the rate of energy expenditure to a greater extent than would the use of explosive contractions (i.e., SLOW > HEAVYEXPL). Evidently, further research is needed.

Another potential explanation for the greater rate of energy expenditure with EXPL (and SLOW) compared with HEAVYEXPL is related to differences in the work:rest ratio. Even though the total contraction work (1061 vs 1063 kg, respectively) and exercise work (load × reps × sets = 19.2) were the same between the protocols, the HEAVYEXPL protocol was performed during a longer duration (~10.5 min vs ~7.8 and 8.3 min). This means that the subjects performed the same amount of work during HEAVYEXPL, but during a longer duration compared with EXPL and SLOW. This is evident in the fact that exercise work for one set of HEAVYEXPL was smaller at 3.2 (1 set × 4 reps × 0.80 load intensity) compared with the exercise work for one set of EXPL, which was 4.8 (1 set × 8 reps × 0.60 load intensity). This difference in work:rest ratio may help explain a portion of the difference in the rates of energy expenditure between the HEAVYEXPL and EXPL protocols. However, it is important to recognize that high-intensity resistance exercise workouts are deliberately designed to have a smaller work:rest ratio, to be consistent with the overall training objective of the workout. In other words, during training with heavier loads and fewer reps, it is important to permit adequate rest between sets (~2–3 min) to allow time for complete recovery of the ATP–phosphocreatine energy system before the next set (7). Otherwise, peak performance with heavy loads will decline rapidly with each subsequent set performed, thereby causing the lifter to reduce the workout load, which is not consistent with the original training goal of heavy loading. Furthermore, the total exercise work, when all sets of each protocol were considered, was the same for HEAVYEXPL (6 sets × 4 reps × 0.80 load = 19.2) and EXPL (4 sets × 8 reps × 0.60 load = 19.2). Also, we calculated average rates of energy expenditure for the entire duration of each protocol (i.e., 20 min rest + exercise + 60 min postexercise sitting) to account for the differences in exercise duration and work:rest ratio between protocols (Table 3). The average rate of energy expenditure across the entire EXPL protocol was significantly greater than HEAVYEXPL and SLOW, regardless of whether anaerobic energy expenditure was included. Thus, our findings demonstrate that high exercise intensity with a smaller work:rest ratio, but longer exercise duration and more sets (HEAVYEXPL), results in less total energy expenditure and a slower average rate of energy expenditure than EXPL squats using moderate exercise intensity.

Further research is evidently needed to fully elucidate the relationships between variations in exercise intensity and volume, and their effect on energy expenditure in both women and men. In fact, we recognize that there could have been other unrealized factors that may have caused exercise work to be greater during EXPL compared with HEAVYEXPL squats (e.g., higher work exerted on the body during lower-intensity exercise). However, we believe that these data are unique and important because they suggest that moderate-intensity (60% 1RM) and moderate-volume (four sets of eight reps) resistance exercise elicits greater increases in the rate of energy expenditure than does high-intensity resistance exercise (i.e., six sets of four reps with 80% 1RM), even when eccentric rep speeds, ROM, and rest intervals between sets are matched. Furthermore, attempts were made to match the contraction intensity and exercise work between protocols. Thus, considering that increases in exercise intensity (16) and exercise volume (21) each have been shown to have separate profound effects to increase energy expenditure, it certainly is possible that a program that emphasizes both exercise intensity and exercise volume by using moderate levels of each may be optimal for enhancing energy expenditure with resistance exercise. Also, because power output is greatest with moderate (30–60% 1RM)—not heavy—loads, explosive contractions and moderate exercise intensity seem to provide an effective combination of resistance exercise techniques to optimize energy expenditure.

SUMMARY

In summary, we examined the effects of contraction intensity and exercise intensity on energy expenditure by comparing nearly identical resistance exercise protocols. Our results are the first to show that explosive contractions enhance energy expenditure to a greater extent than a more fatiguing exercise protocol with higher contraction volume and greater blood lactate responses. Our results also reinforce previous findings by Hunter et al. (17) by demonstrating that slow resistance exercise is not the most effective resistance exercise technique for optimal energy expenditure, even when we standardized the exercise load, reps, ROM, and eccentric rep speeds between protocols. Whether moderate-intensity resistance exercise is better for increasing energy expenditure than high-intensity resistance exercise may require further investigation. But, our data seem to reinforce recent findings from Kang et al. (21) in demonstrating that moderate-intensity exercise resulted in greater energy expenditure than did high-intensity resistance exercise, even when we standardized the exercise work, ROM, and eccentric rep speeds between protocols. In conclusion, by performing concentric muscle actions as explosively as is safely possible (i.e., without bouncing), and with moderate exercise intensity and moderate exercise volume, experienced recreational exercisers can increase their energy expenditure during and after resistance exercise, which could enhance weight-loss adaptations. These findings have useful implications for recreational exercisers and personal fitness trainers, because they suggest that explosive contractions and moderate exercise intensity may provide the most effective combination of resistance exercise techniques to increase energy expenditure for weight loss.

The authors would like to thank the study volunteers for their time and effort, and Abby Peters, Doug Seelbach, and Ryan Shockey for their assistance throughout the project. This project was supported in part by the Department of Kinesiology, Anderson University.

REFERENCES

1. Abbott, B. C., B. Bigland, and J. M. Ritchie. The physiological cost of negative work. *J. Physiol.* 117:380–390, 1952.
2. Antonutto, G., and P. E. Di Prampero. The concept of lactate threshold. A short review. *J. Sports Med. Phys. Fitness* 35:6–12, 1995.
3. Bangsbo, J. Quantification of anaerobic energy production during intense exercise. *Med. Sci. Sports Exerc.* 30:47–52, 1998.
4. Barclay, C. J., J. K. Constable, and C. L. Gibbs. Energetics of fast- and slow-twitch muscles of the mouse. *J. Physiol.* 472: 61–80, 1993.
5. Behm, D. G., and D. G. Sale. Intended rather than actual movement velocity determines velocity-specific training response. *J. Appl. Physiol.* 74:359–368, 1993.
6. Bigland, B., and O. C. Lippold. The relation between force, velocity and integrated electrical activity in human muscles. *J. Physiol.* 123:214–224, 1954.
7. Bogdanis, G. C., M. E. Nevill, L. H. Boobis, H. K. Lakomy, and A. M. Nevill. Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. *J. Physiol.* 482:467–480, 1995.
8. Brooks, G. A., T. D. Fahey, and K. M. Baldwin. Fatigue during muscular exercise. In: *Exercise Physiology: Human Bioenergetics and Its Applications*. New York, NY: McGraw Hill, pp. 856–857, 2005.
9. Coyle, E. F., L. S. Sidossis, J. F. Horowitz, and J. D. Beltz. Cycling efficiency is related to the percentage of type I muscle fibers. *Med. Sci. Sports Exerc.* 24:782–788, 1992.
10. Ferguson, R. A., D. Ball, P. Krustrup, et al. Muscle oxygen uptake and energy turnover during dynamic exercise at different contraction frequencies in humans. *J. Physiol.* 536:261–271, 2001.
11. Freund, H. J. Motor unit and muscle activity in voluntary motor control. *Physiol. Rev.* 63:387–436, 1983.
12. Gladden, L. B., and H. G. Welch. Efficiency of anaerobic work. *J. Appl. Physiol.* 44:564–570, 1978.
13. Grimby, L., and J. Hannerz. Firing rate and recruitment order of toe extensor motor units in different modes of voluntary contraction. *J. Physiol.* 264:865–879, 1977.
14. He, Z. H., R. Bottinelli, M. A. Pellegrino, M. A. Ferenczi, and C. Reggiani. ATP consumption and efficiency of human single muscle fibers with different myosin isoform composition. *Biophys. J.* 79:945–961, 2000.
15. Henneman, E., and C. B. Olson. Relations between structure and function in the design of skeletal muscles. *J. Neurophysiol.* 28: 581–598, 1965.
16. Hunter, G., L. Blackman, L. Dunnam, and G. Flemming. Bench press metabolic rate as a function of exercise intensity. *J. Appl. Sport Sci. Res.* 2:1–6, 1988.
17. Hunter, G. R., D. Seelhorst, and S. Snyder. Comparison of metabolic and heart rate responses to super slow vs. traditional resistance training. *J. Strength Cond. Res.* 17:76–81, 2003.
18. Hutchins, K. *Super Slow*, 2nd ed. Casselberry, FL: Media Support, 1992.
19. Jackson, A. S., and M. L. Pollock. Practical assessment of body composition. *Phys. Sportsmed.* 13:76–90, 1985.
20. Jones, K., P. Bishop, G. Hunter, and G. Fleisig. The effects of varying resistance-training loads on intermediate- and high-velocity-specific adaptations. *J. Strength Cond. Res.* 15:349–356, 2001.
21. Kang, J., J. R. Hoffman, J. Im, et al. Evaluation of physiological responses during recovery following three resistance exercise programs. *J. Strength Cond. Res.* 19:305–309, 2005.
22. Katz, A., K. Sahlin, and J. Henriksson. Muscle ATP turnover rate during isometric contraction in humans. *J. Appl. Physiol.* 60: 1839–1842, 1986.
23. Olds, T. S., and P. J. Abernethy. Postexercise oxygen consumption following heavy and light resistance exercise. *J. Strength Cond. Res.* 7:147–152, 1993.
24. Schiaffino, S., V. Hanzlikova, and S. Pierobon. Relations between structure and function in rat skeletal muscle fibers. *J. Cell Biol.* 47:107–119, 1970.
25. Schuenke, M. D., R. P. Mikat, and J. M. McBride. Effect of an acute period of resistance exercise on excess post-exercise oxygen consumption: implications for body mass management. *Eur. J. Appl. Physiol.* 86:411–417, 2002.
26. Scott, C. B. Contribution of blood lactate to the energy expenditure of weight training. *J. Strength Cond. Res.* 20:404–411, 2006.
27. Thornton, M. K., and J. A. Potteiger. Effects of resistance exercise bouts of different intensities but equal work on EPOC. *Med. Sci. Sports Exerc.* 34:715–722, 2002.
28. Weir, J. B. New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol.* 109:1–9, 1949.
29. Westcott, W. L., R. A. Winett, E. S. Anderson, et al. Effects of regular and slow speed resistance training on muscle strength. *J. Sports Med. Phys. Fitness* 41:154–158, 2001.
30. Wilson, G. J., R. U. Newton, A. J. Murphy, and B. J. Humphries. The optimal training load for the development of dynamic athletic performance. *Med. Sci. Sports Exerc.* 25:1279–1286, 1993.