Original Research

Influence of Differences in Exercise-intensity and Kilograms/Set on Energy Expenditure During and After Maximally Explosive Resistance Exercise

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ABSTRACT

Int J Exerc Sci 4(4) : 273-282, 2011. With resistance exercise, greater intensity typically elicits increased energy expenditure, but heavier loads require that the lifter perform more sets of fewer repetitions, which alters the kilograms lifted per set. Thus, the effect of exercise-intensity on energy expenditure has yielded varying results, especially with explosive resistance exercise. This study was designed to examine the effect of exercise-intensity and kilograms/set on energy expenditure during explosive resistance exercise. Ten resistance-trained men (22±3.6 years; 84±6.4 kg, 180±5.1 cm, and 13±3.8 %fat) performed squat and bench press protocols once/week using different exercise-intensities including 48% (LIGHT-48), 60% (MODERATE-60), and 72% of 1-repetition-maximum (1-RM) (HEAVY-72), plus a no-exercise protocol (CONTROL). To examine the effects of kilograms/set, an additional protocol using 72% of 1-RM was performed (HEAVY-72^{MATCHED}) with kilograms/set matched with LIGHT-48 and MODERATE-60. LIGHT-48 was 4 sets of 10 repetitions (4x10); MODERATE-60 4x8; HEAVY-72 5x5; and HEAVY-72^{MATCHED} 4x6.5. Eccentric and concentric repetition speeds, ranges-of-motion, rest-intervals, and total kilograms were identical between protocols. Expired air was collected continuously throughout each protocol using a metabolic cart, [Blood lactate] using a portable analyzer, and bench press peak power were measured. Rates of energy expenditure were significantly greater ($p \leq 0.05$) with LIGHT-48 and HEAVY-72^{MATCHED} than HEAVY-72 during squat (7.3±0.7; 6.9±0.6 > 6.1±0.7 kcal/min), bench press (4.8±0.3; 4.7±0.3 > 4.0±0.4 kcal/min), and +5min after (3.7±0.1; 3.7±0.2 > 3.3±0.3 kcal/min), but there were no significant differences in total kcal among protocols. Therefore, exercise-intensity may not effect energy expenditure with explosive contractions, but light loads (~50% of 1-RM) may be preferred because of higher rates of energy expenditure, and since heavier loading requires more sets with lower kilograms/set.

KEY WORDS: Contraction-intensity; Work; Power; Repetition Speed; Weight Lifting; Program Design.

INTRODUCTION

Resistance exercise-intensity is one of several variables that fitness professionals manipulate to achieve a specific goal, such as increased energy expenditure. Exercise-intensity is typically defined as a percentage of one-repetition maximum (1-RM), where 40-55% of 1-RM would be

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considered light, 55-70% moderate, and 70-85% heavy (15, 17). Despite the fact that some reports vary, it is generally accepted that energy expenditure increases as exercise-intensity increases, especially when total work (total kilograms lifted) is matched (10, 24). Studies where low- or moderate-intensity resulted in greater energy expenditure did not match total kilograms lifted (12). Thus, one might argue that heavy resistance exercise should be used for optimal energy expenditure responses.

Different from traditional where participants use slow or controlled contractions, maximally explosive resistance exercise requires the lifter to raise the load with intended maximum concentric acceleration (IMCA), regardless of the load (2). This type of training has been used by athletes for decades to increase speed and power (16), but it is beginning to become more popular among recreational exercisers (3, 4, 20). In fact, recent evidence suggests that explosive contractions increase energy expenditure more than slow, possibly making this resistance exercise technique favorable for enhancing energy expenditure (19). In that study, however, our laboratory found that moderate-intensity (60% of 1-RM) explosive resistance exercise resulted in greater energy expenditure than high-intensity (80% of 1-RM) (19). A potential explanation for these differential findings may be related to the fact that heavy protocols require more sets with lower kilograms lifted per set (kg/set). As a result, the reported difference in energy expenditure between moderate and heavy squats may have been due to greater kg/set during 60% squats (i.e., more work performed per set), and not because of differences in exercise-intensity.

Thus, it remains unclear whether light, moderate, or heavy loading elicits greater energy expenditure, especially with maximally explosive resistance exercise. Also, no study has examined the influence of differences in kg/set on energy expenditure between otherwise identical protocols. Because maintaining or losing body weight is an important fitness goal, and since explosive resistance exercise has become popular among recreational exercisers, it seems necessary to investigate which load optimizes energy expenditure with explosive contractions. Therefore, the objectives of this study were to 1) compare the effect of different exercise-intensities on energy expenditure during and after maximally explosive resistance exercise, and to 2) compare energy expenditure between protocols using the same load, but different kg/set.

METHODS

Participants

Ten resistance-trained men 22±3.6 years of age volunteered to participate as subjects in this investigation. All participants were non-smoking, healthy, and free from medications, ergogenic supplements, glandular disorders, and any conditions that could affect metabolism. Participants had average body mass 84±6.4 kg, height 180±5.1 cm, and body-fat 13±3.8 %; and refrained from exercise outside of the requirements for this study. This study was approved by the Committee on Human Research at Salisbury University, and each participant provided informed consent prior to any testing. This study was in accordance with the Declaration of Helsinki.

Study Design

To examine the effects of exercise-intensity on energy expenditure with explosive resistance exercise, ten college-aged men performed nearly identical experimental protocols using different exercise-intensities including 48% (LIGHT-48), 60% (MODERATE-60), and 72% of 1-RM (HEAVY-72) (Figure 1). Because the total kilograms lifted per set (kg/set) for HEAVY-72 were lower in comparison, and to examine the effects of kg/set on energy expenditure, an additional protocol using 72% of 1-RM was also performed (HEAVY-72^{MATCHED}). For HEAVY-72^{MATCHED}, kg/set were matched with LIGHT-48 and MODERATE-60. Only eight participants completed HEAVY-72^{MATCHED}. We tested the hypothesis that different loads would significantly affect energy expenditure so that HEAVY-72^{MATCHED} > MODERATE-60 > LIGHT-48. Because kg/set were lower, we hypothesized that energy expenditure would be lowest during and after HEAVY-72.

Baseline Testing and Familiarization

To avoid lingering effects of previous exercise on metabolism, participants visited the laboratory once weekly over seven weeks on the same day and at the same time. During the first visit, body mass and height were measured to the nearest 0.10 kg and 0.10 cm, respectively. Skinfold measurements were obtained from 7 sites (triceps, sub-scapular, mid-axillary, chest, supra-iliac, abdomen, and thigh), and the equation described by Jackson and Pollock (1978) was used to estimate body density (11). Percent body fat was subsequently estimated using the value obtained for body density and the Siri equation (23). Participants performed two warm-up sets of squats using light to moderate loads, and 1-RM was then determined for the squat by allowing three-five attempts to lift the heaviest load one time with three-minute rest intervals. Bench press 1-RM performance was assessed using the same procedures. Following 1-RM testing, participants were familiarized with one set of squats and bench press using 60% of 1-RM for eight repetitions (reps). During this

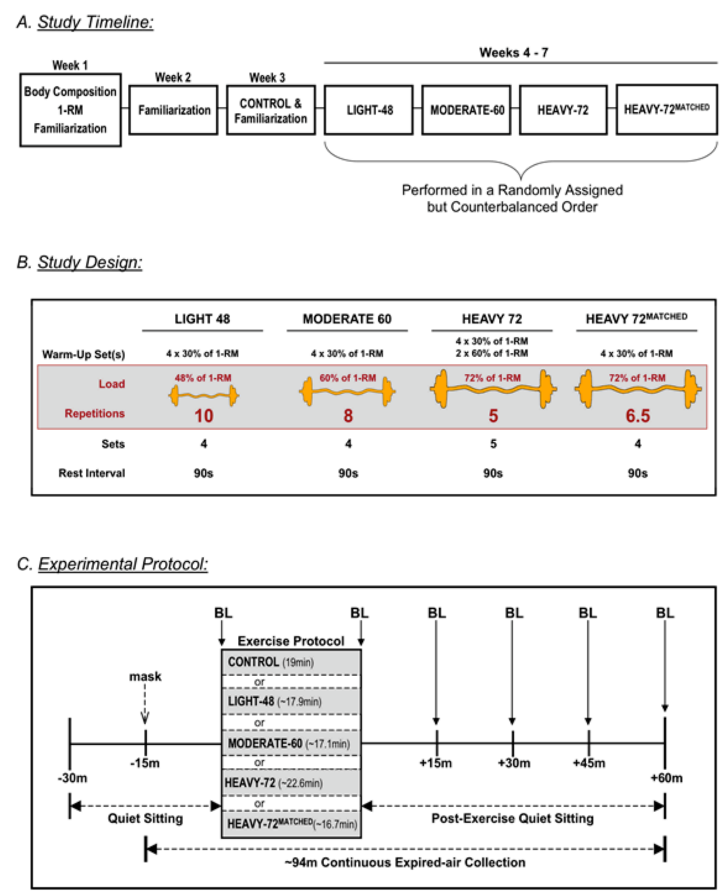

Figure 1. Study timeline (A), study design (B), and experimental protocol (C) used to compare the effects of 48% (LIGHT-48), 60% (MODERATE-60), 72% (HEAVY-72), and 72% of 1-RM with matched kg/set (HEAVY-72^{MATCHED}) on energy expenditure during and after maximally explosive resistance exercise.

1-RM = heaviest load that can be lifted one time; CONTROL = control (no-exercise) protocol consisting of quiet sitting; 4 x 30% of 1-RM = one set of four repetitions using 30% of max strength; 2 x 60% of 1-RM = one set of two repetitions using 60% of max strength; BL = finger prick sample for blood lactate familiarization, participants practiced lowering the load in two seconds and raising the load as maximally as possible without bouncing using a metronome (Seiko Corporation of America, Mahwah, New Jersey).

Exactly one week later, participants performed another familiarization session which included five sets of squats and bench press using 72% of 1-RM for five reps with two second eccentric and maximally explosive concentric muscle actions paced by a metronome. Participants performed one warm-up set for each protocol with 30% of 1-RM for four reps and one warm-up set for each with 60% of 1-RM for two reps. On the third week, each subject was fed a standardized breakfast and lunch, and then completed a no-exercise control trial (CONTROL). These meals were administered in the laboratory under supervision, and were prepared by the same laboratory assistant each week. The meals consisted of approximately 55% carbohydrates, 30% fat, and 15% protein. For this trial, subjects sat in a semi-reclined position for 94 min while expired air and finger prick blood samples were collected. Immediately following CONTROL, subjects performed the last familiarization session which included four sets of squats and bench press using 48% of 1-RM for 10 reps and two second eccentric and maximal concentric muscle actions.

Experimental Protocols

Exactly one week later, participants performed one of four experimental protocols in a randomized, counterbalanced order. All exercise protocols consisted of the same exercises (squat, bench press), total kilograms, rest-intervals, and ranges-of-motion; and subjects were fed the same standardized meals (as explained above) at the same time of day, for each different trial. Range-of-motion for the squat was standardized by having each participant lower all squats until the angle at the back of the right knee was approximately 85°. This angle was determined during familiarization, and a specified number of step-aerobic platform spacers were placed under the participant's buttocks in the lowered position. The number of spacers was standardized for each participant during all trials, and the participants were required to touch their buttocks to the spacers for consistency on each rep. Range-of-motion for the bench press was standardized by ensuring that all participants lowered the barbell until it touched the xyphoid process and raised the barbell to full arm extension for all reps and sets. Peak power measurements were recorded for every bench press repetition using a weight room accelerometer that was connected to the barbell (Tendo Weightlifting Analyzer, Slovak Republic). Participants also utilized two-second eccentric and maximal concentric muscle actions for all trials. Expired air was collected continuously 15min before, during, and for one hour after each protocol using a two-way non-rebreathing nose and mouth face mask (Hans Rudolph, Inc., Kansas City, MO) and a metabolic cart (ParvoMedics, Sandy, UT). Immediately before, after, and in 15min intervals for an hour after exercise, finger-prick blood samples (25µl) were collected into capillary tubes for the measurement of [blood lactate] ($mmol \cdot L^{-1}$). Samples were collected and analyzed immediately using a portable lactate analyzer (YSI 1500 Sport Lactate Analyzer, Yellow Springs, OH).

All protocols consisted of a four-rep warm-up with 30% of 1-RM for both the squat and bench press. The HEAVY-72 protocol had an additional warm-up consisting of two reps with 60% of 1-RM to match the total kilograms lifted with other protocols. For LIGHT-48, participants completed four sets of ten reps with 48% of 1-RM, MODERATE-60 four sets of eight reps at 60% of 1-RM, and HEAVY-72 five sets of five repetitions with 72% of 1-RM. In order to match kg/set to the other protocols, HEAVY-72^{MATCHED} consisted of four sets of six and 1/2 repetitions with 72% of 1-RM. The 1/2 repetition range-of-motion was standardized during the squat by adding two additional step-aerobic platform spacers. For the bench press, a foam cylinder was placed on the sternum for the half rep. However, due to the shorter warm-up and high-intensity, it was extremely difficult to complete, with two participants failing on the final rep of the final set of bench press, and two other participants not completing the protocol. After each protocol, participants sat in a semi-reclined position for 60 min post-exercise while watching a randomly assigned, counterbalanced Disney movie (Walt Disney Company, Burbank, CA). Participants were instructed to remain still, silent and awake during the post exercise period.

Indirect Calorimetry

Oxygen consumption ($L \cdot min^{-1}$) data were used to calculate average rates of energy expenditure ($kcal \cdot min^{-1}$) at baseline (REST); individually for squat and bench press, and for +5, +10, +15, +30, +45, and +60 min post-exercise. All data were corrected for dead-space associated with the time necessary for expired air to travel from the mouth to the analyzers. Energy expenditure ($kcal \cdot min^{-1}$) was calculated using O_2 consumption data and the equation $L\ O_2 \cdot min^{-1}$ multiplied by 4.9. Total energy expenditure values (kcals) were calculated for the duration of each protocol (i.e., REST, exercise, and post-exercise) using the trapezoidal area under the curve method (AUC) for each participant and for each trial separately. To obtain an accurate representation of total energy expenditure, we corrected the total energy expenditure for differences in the durations of each trial. To do this, we calculated a single average rate of energy expenditure for each protocol, and then multiplied it by 94 min. We selected 94 min because this was the duration of the CONTROL trial, and it enabled us to estimate what the total energy expenditure might have been for each protocol if they had been the same duration. Also, energy expenditure associated with the production of lactate was added by using the energy equivalent for each mmol increase in blood lactate after exercise (0.02698 kcal/kg body mass) (6, 22).

Statistical Analysis

Results were considered significant at $p \leq 0.05$. Data are presented as means ± standard deviations (MEANS±SD). A four-factors repeated measures analysis of variance was used to test for significant group x time interactions, and Fisher's Least Significant Difference (LSD) post hoc analyses were used where appropriate to determine specific pair-wise differences (Statistica V4.1, StatSoft, Inc.). Separate one-way ANOVA's were used to test for group differences at REST for each variable, and for group differences in total energy expenditure, exercise-intensity, kilograms/set, and peak power.

RESULTS

Exercise-Intensity, Kilograms/Set, and Peak Power

There were no differences among protocols in the total weight lifted (kg) (Figure 2, Panel-A). Significant ($p \leq 0.05$) differences among protocols for kg/set included LIGHT-48, MODERATE-60, AND HEAVY-72^{MATCHED} > HEAVY-72 (Figure 2, Panel-B). Significant ($p \leq 0.05$) differences among protocols for peak power included LIGHT-48 > HEAVY-72 and HEAVY-72^{MATCHED}, and MODERATE-60 > HEAVY-72^{MATCHED} (Figure 2, Panel-C).

Energy Expenditure

Rates of energy expenditure ($kcal \cdot min^{-1}$) increased significantly ($p \leq 0.05$) with LIGHT-48, MODERATE-60, HEAVY-72 and HEAVY-72^{MATCHED} during exercise and after +5, +10, +15, and +30 min of recovery (Figure 3, Panel-A). Rates of energy expenditure remained significantly ($p \leq 0.05$) elevated at +45 min following LIGHT-48 and MODERATE-60. There was a significant group x time interaction ($p=0.00$) for the rates of energy expenditure, and the significant ($p \leq 0.05$) differences among protocols were LIGHT-48, MODERATE-60 and HEAVY-72^{MATCHED} > HEAVY-72 and LIGHT-48 > MODERATE-60 (squat, bench press). Also significant ($p \leq 0.05$) were LIGHT-48 and HEAVY-72^{MATCHED} > HEAVY-72 (+5 min). There were no differences among protocols in rates of energy expenditure at REST, and the differences in total energy expenditure among protocols were not significant.

Blood Lactate

Blood lactate concentrations [BL] increased significantly ($p \leq 0.05$) with LIGHT-48,

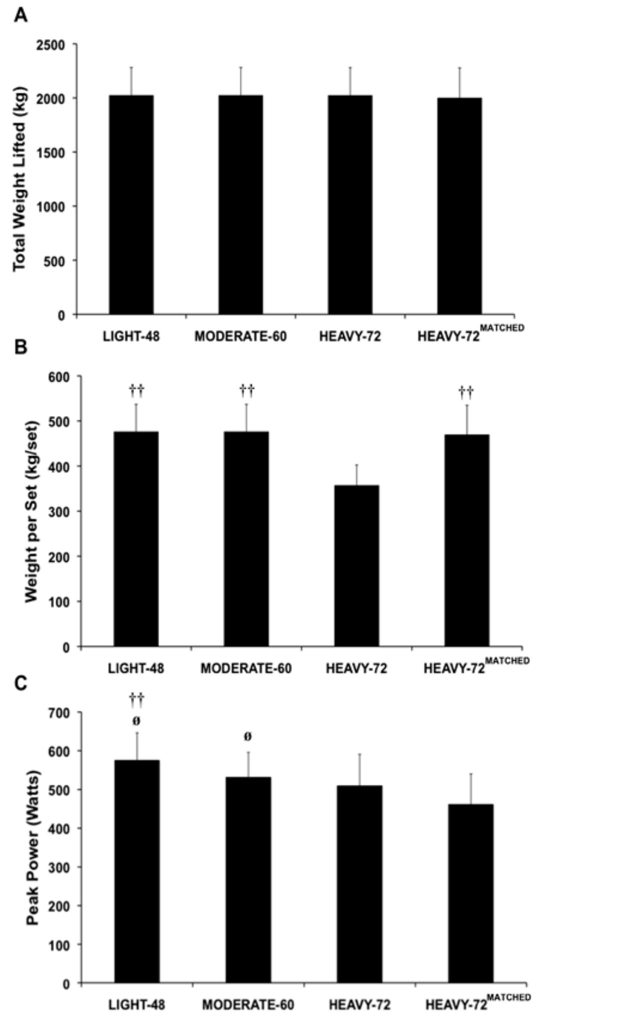

Figure 2. Total weight lifted (kg) (A), weight lifted/set (kg/set) (B), and peak power (Watts) (C) for maximally explosive bench press exercise using 48% (LIGHT-48), 60% (MODERATE-60), 72% (HEAVY-72), and 72% of 1-RM with matched kg/set (HEAVY-72^{MATCHED}). †† denotes $p \leq 0.05$ versus corresponding HEAVY-72 value; ø denotes $p \leq 0.05$ versus corresponding HEAVY-72^{MATCHED} value; Data are Means ± SD

MODERATE-60, HEAVY-72, and HEAVY-72^{MATCHED} immediately following exercise (Figure 3, Panel-B). Blood lactate remained significantly ($p \leq 0.05$) increased at +15, +30 and +45 min after LIGHT-48, MODERATE-60, and HEAVY-72^{MATCHED}, and at +15 and +30 min after HEAVY-72. There was a significant group x time interaction ($p=0.00$) for [BL], and the significant ($p \leq 0.05$) differences among protocols were LIGHT-

48 and HEAVY-72^{MATCHED} > HEAVY-72 (post-exercise, +15 min), and MODERATE-60 > HEAVY-72 (post-exercise).

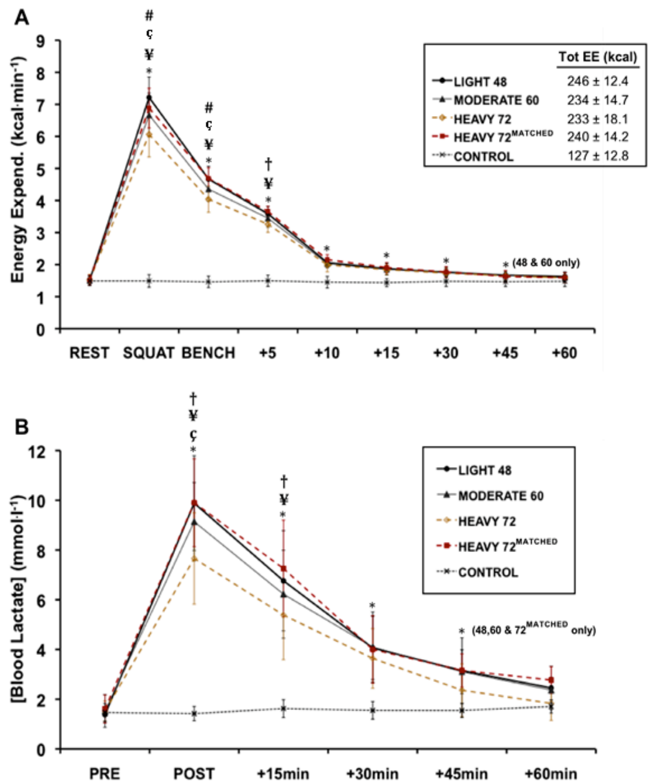

Figure 3. Rates of energy expenditure (kcal·min^{-1}) (A) and blood lactate concentrations (mmol·L^{-1}) (B) before (REST); during maximally explosive squats (SQUAT) and bench press (BENCH); and for 60 min after resistance exercise using 48% (LIGHT-48), 60% (MODERATE-60), 72% (HEAVY-72), or 72% of 1-RM with matched kg/set (HEAVY-72^{MATCHED}), and a no-exercise (CONTROL) trial.

* denotes $p \le 0.05$ versus corresponding REST value; # denotes LIGHT-48 value significantly greater ($p \le 0.05$) versus corresponding HEAVY-72 and MODERATE-60 values; † denotes LIGHT-48 value significantly greater ($p \le 0.05$) versus corresponding HEAVY-72 values; ¥ denotes HEAVY-72^{MATCHED} value significantly greater ($p \le 0.05$) versus corresponding HEAVY-72 value; ç denotes MODERATE-60 value significantly greater ($p \le 0.05$) versus corresponding HEAVY-72 value; Data are Means ± SD; Tot EE = total energy expenditure (kcal).

DISCUSSION

To determine which load optimizes energy expenditure during maximally explosive resistance exercise, we tested whether loading would influence energy expenditure so that heavy > moderate > light when squat and bench press exercises were performed with the same total kilograms. Contrary to our hypotheses, rates of energy expenditure were greater during and after light resistance exercise than moderate and heavy, and there were no differences in total energy expenditure among protocols. Because heavy loading requires more sets due to lower kg/set, a secondary objective of the study was to examine the effect of differences in kg/set on energy expenditure. Therefore, we tested whether heavy loading with greater kg/set while using the same intensity (HEAVY-72^{MATCHED}), would induce a greater rate of energy expenditure compared with lower kg/set (HEAVY-72). As expected, rates of energy expenditure during HEAVY-72^{MATCHED} were greater than HEAVY-72. Because there were no differences among protocols in total kcal expended, we conclude that exercise-intensity may not have an effect on energy expenditure when explosive contractions are used. However, rates of energy expenditure were higher with light resistance exercise, and heavy loading (i.e., lower kg/set) resulted in lower energy expenditure. Therefore, light loading may be the best exercise-intensity for enhancing energy expenditure responses with maximally explosive resistance exercise.

Influence of Exercise-Intensity on Energy Expenditure

This was the first study to compare energy expenditure between light, moderate and heavy resistance exercise using maximally explosive contractions with matched total kilograms lifted. We found that LIGHT-48 elicited greater rates of energy expenditure compared to MODERATE-60 and HEAVY-72. These findings do not agree with data reported for traditional resistance exercise, where energy expenditure was reported to increase concomitantly with exercise-intensity (10, 24). Instead, the current findings are in agreement with our previous study where we found greater energy expenditure with maximally explosive squats using 60% of 1-RM compared to 80% (19). However, HEAVY-72 and the very heavy (80% of 1-RM) protocol reported previously are confounded in that each used lower kg/set than their counterpart protocols. To determine for sure whether light, moderate, or heavy loading was optimal for increased energy expenditure with maximally explosive contractions, we matched kg/set among the HEAVY-72^{MATCHED}, LIGHT-48, and MODERATE-60 protocols. This allowed us for the first time to demonstrate that light loading provided the most practical combination of exercise-intensity and explosive resistance exercise to enhance energy expenditure responses. This is because even though HEAVY-72^{MATCHED} resulted in similar rates of energy expenditure compared to LIGHT-48, it also consisted of an unrealistic exercise design that was extremely difficult and unsafe to perform without supervision. Two participants did not complete the trial, two were unable to complete the last repetition of the last set of bench press, and all participants found it far more difficult. Thus, even though total energy expenditure did not differ among protocols, our data suggest that light loading (~50% of 1-RM) could be more effective for enhancing energy expenditure responses with maximally explosive resistance exercise.

While it remains unclear why light loads would increase the rates of energy expenditure more with explosive contractions, a potential explanation may be related to the ability to contract muscles more powerfully. Power output is suggested to be greatest between 30-45% of 1-RM for upper-body exercises (14), and 40-50% of 1-RM for bench press (18). Our results supported these findings, with average peak power being greatest when 48% of 1-RM bench press was used. This is interesting because it has been documented that maximal contractions result in greater motor unit recruitment, especially of fast motor units (7). Greater fast muscle recruitment is associated with faster shortening and faster cross bridge cycling (9, 21), leading to a higher rate of ATP hydrolysis (1). Taken together, it seems that LIGHT-48 permitted the participants to lift with greater power, which may have been associated with greater fast motor unit recruitment and muscle activation, resulting in greater rates of energy expenditure. Indeed fast muscle cells have been shown to consume three to four times more ATP compared to slow human muscle cells (8), and ATP consumption correlates directly with the rate of energy expenditure. It is also worth noting that we have previously demonstrated significantly greater energy expenditure during and after maximally explosive squats compared to nearly identical slow squats (19). Therefore, it is our contention that explosive resistance exercise is best performed using light loads because this enables the lifter to achieve optimal peak power, which could be associated with more energetically expensive fast muscle activation (7, 8, 13).

Influence of Kilograms/Set on Energy Expenditure

This is also the first study to examine the influence of kg/set on energy expenditure. We found that when kg/set were lower with HEAVY-72, the rates of energy expenditure were lower compared to LIGHT-48 and MODERATE-60. But when kg/set were matched (HEAVY-72^{MATCHED}), rates of energy expenditure were greater than MODERATE-60 and similar to LIGHT-48. These results are interesting because they imply that energy expenditure increases as intensity increases, provided that the number of sets and kg/set are not altered (to accommodate the higher exercise-intensity). In other words, heavy resistance exercise (≥70% of 1-RM), regardless of contraction-intensity, is associated with progressively increasing motor unit recruitment which elicits higher energy expenditure (5). Another interesting finding was that blood lactate measurements were greatest after LIGHT-48 and HEAVY-$72^{MATCHED}$, further supporting that these protocols required more maximal efforts. However, as mentioned above, HEAVY-$72^{MATCHED}$ consisted of an unrealistic exercise design that was extremely difficult and unsafe to perform.

In summary, this study examined the effects of exercise-intensity and kg/set on energy expenditure during maximally explosive resistance exercise by comparing four different protocols. Figure 4 provides a schematic representation, based on the results presented here and previous scientific findings (10, 19, 24), of the influences of traditional and explosive contractions, and the effect of lowering the kilograms per set on energy expenditure with resistance exercise. These results are the first to suggest that exercise-intensity may not affect energy expenditure when explosive contractions are used. However, since peak power and rates of energy expenditure were higher, we recommend that light loading with approximately 50% of 1-RM be used when trying to enhance energy expenditure responses with explosive resistance exercise. Our results also reinforce previous findings (10, 24), since we demonstrated that heavy loading optimized energy expenditure when kg/set were maintained. However, heavy loading may not be preferred for optimizing energy expenditure with explosive resistance exercise because the exercise design requires more sets of fewer repetitions which reduces the amount of kg/set. Lastly, our results are also the first to show that lowering the kg/set dramatically reduced rates of energy expenditure, even when total kilograms lifted during each protocol were matched. Thus, fitness professionals should consider the kilograms-per-set as an acute variable for resistance exercise program designs.

ACKNOWLEDGEMENTS

The authors would like to thank the study volunteers for their participation in this study. This study was supported in part by the Salisbury University Department of Health and Sport Sciences, University Student Academic Research Award (USARA), and Healthy U of Delmarva (www.healthyudelmarva.org).

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