

**EXCESS POST-EXERCISE OXYGEN CONSUMPTION
RESPONSE TO A BOUT OF RESISTANCE EXERCISE**

A MANUSCRIPT-STYLE THESIS PRESENTED

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ABSTRACT

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To examine the excess post-exercise oxygen consumption (EPOC) response following a bout of heavy resistance exercise (HRE), seven healthy males (age = 22 ± 3 yr; height = 177 ± 8 cm; mass = 83 ± 10 kg, percent body fat = $10.4 \pm 4.2\%$) who weight trained recreationally, engaged in a 31-minute bout of HRE. The bout consisted of four circuits of bench press, power cleans, and squats, selected to recruit most major muscle groups. Each set was performed using the subject's predetermined ten-repetition maximum and continued until failure. Each set was followed by a two-minute rest interval. Oxygen consumption (VO_2) measurements were obtained at regular intervals throughout the day, before and after HRE (34 h pre, 29 h pre, 24 h pre, 10 h pre, 5 h pre, immediate post, 14 h post, 19 h post, 24 h post, 38 h post, 43 h post, 48 h post). Post-exercise VO_2 measurements were compared to the baseline measurements that corresponded with the same time of day. A repeated measures ANOVA revealed that EPOC was significantly elevated ($p \leq 0.05$) immediately, 14, 19, and 38 hours post-exercise. Mean daily VO_2 values for both post-exercise days were also significantly elevated above the baseline day. These results suggest that EPOC duration and magnitude following HRE may exceed the EPOC produced by following moderate aerobic exercise. Furthermore, the cumulative energy expenditure as a result of EPOC following HRE may exceed the combined total energy expended during and after aerobic exercise.

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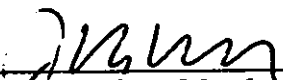
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The candidate has successfully completed the thesis final oral defense.



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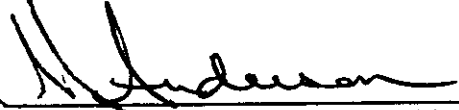


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This thesis is approved by the College of Health, Physical Education, Recreation, and Teacher Education.



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EXCESS POST-EXERCISE OXYGEN CONSUMPTION RESPONSE TO A BOUT OF RESISTANCE EXERCISE

INTRODUCTION

In order to manage weight and alter body composition, individuals commonly turn to exercises that utilize aerobic metabolic pathways. This may be due to the fact that aerobic exercise is continuous in nature, whereas resistance exercise utilizes rest periods. Therefore, more calories may be expended during aerobic exercise than during a bout of resistance exercise of the same duration. However, this does not account for the processes required for the body to recover from exercise. Excess post-exercise oxygen consumption (EPOC) must be taken into consideration when comparing the effectiveness of aerobic and resistance exercise on the energy balance equation.

Several physiological responses appear to contribute to EPOC. During steady state, aerobic exercise, the body responds to increased energy demands by raising heart rate, stroke volume, and pulmonary ventilation. The subsequent rise in body temperature, as well as an ionic disturbance and increased plasma catecholamine levels, are believed to be linked to EPOC (1). In addition to the proposed explanations given for steady state exercise, the short bursts of energy characterized in non-steady state activities require anaerobic metabolic pathways. These pathways include the degradation of adenosine triphosphate (ATP) into adenosine diphosphate (ADP), the transfer of phosphate from phosphocreatine (CP) to ADP in order to recreate ATP, and the breakdown of glucose into pyruvic acid, which in the absence of oxygen becomes lactate. Following anaerobic

exercise, the body requires oxygen for lactate disposal and rephosphorylation of creatine and ADP (1). Additionally, homeostatic imbalances of hormone levels (19) and protein degradation and reparation also take place (6, 13). EPOC is likely due to a combination of the aforementioned occurrences, but the significance of each factor is unknown.

Several studies have examined the EPOC of aerobic exercise with variable results. Many of the studies indicated that oxygen consumption remained elevated for less than 60 minutes (3, 12, 16, 24, 27, 28) following cardiovascular exercise. Conversely, several other studies found that EPOC remained significantly elevated above baseline for 7.5-12 hours (2, 5, 9, 14, 15). Although exercise intensity and duration are commonly implicated as causes for EPOC, they do not fully account for the aforementioned discrepancy, because studies using similar intensities and durations often had contradictory results. Therefore, the entire range of those results must be considered when comparing results of aerobic exercise to those of resistance exercise.

As with aerobic exercise, the duration of EPOC following resistance exercise varies in the literature. Some studies found EPOC to normalize within 60 minutes (7, 10, 21) whereas others found EPOC to remain elevated for 14 hours or more (8, 20, 23). However, in the case of resistance exercise, it appears that exercise intensity heavily influences EPOC duration. The study that found EPOC to continue for several hours utilized loads that could be moved for a maximum of 8-12 repetitions, which is characteristic of a program designed for muscle hypertrophy (29). Other studies indicating a much more attenuated EPOC response used resistance exercise protocols emphasizing local muscular endurance (7, 10, 21) or muscular strength (7). Therefore, it

appears that the same damage and hormonal mechanisms that lead to muscular hypertrophy may cause enough homeostatic disruption to maximize EPOC.

A major factor in the issue of weight control is the balance of caloric intake and expenditure. Although more energy is expended during activity than afterwards, the amount of calories utilized following exercise is not negligible. Even a small caloric deficit may contribute to an eventual weight loss. The magnitude and duration of EPOC are, therefore, important components of a successful weight loss program. None of the resistance exercise studies that found metabolism to be elevated for 14 hours or more were able to determine at what point EPOC returns to baseline. Therefore, the purpose of this study was to extend the examining period to 48 hours post-exercise in an attempt to more clearly quantify excess post-exercise oxygen consumption following a resistance exercise program designed for muscle hypertrophy and to determine its possible impact on weight management.

METHODS

Subject Characteristics

Seven males volunteered to participate in the present study as a result of in-class recruitment at the University of Wisconsin-La Crosse. All subjects had been weight training regularly (3-4 times/week) for a minimum of 6 months and denied use of anabolic supplements prior to or during the study. They were also free from any known injuries or illness that could inhibit lifting performance or metabolism. Selected demographic information is presented in Table 1. To ensure the safety of the subjects, all treatments involved in this study were examined and approved by the University of

Wisconsin-La Crosse Institutional Review Board (IRB). In accordance with IRB guidelines, all subjects read and signed an informed consent form prior to participation (see Appendix A).

Table 1. Demographic statistics of the subject population

Variable	Mean (\pm SD)	Range
Age (yr)	22 \pm 3	19-26
Height (cm)	177 \pm 8	167-193
Body Mass (kg)	83 \pm 10	73-104
Body Composition (% body fat)	10.4 \pm 4.2	7.0-19.3

Study Design

Data collection was conducted over a three-week period. One- and ten-repetition maximum (RM) testing for bench press, power cleans, and squats was conducted first, followed by a familiarization trial of the lifting protocol. To avoid any residual metabolic effects of the 1RM testing and the familiarization period, no further treatments were conducted for the subsequent two weeks. During the last four days of the two-week respite and for the remainder of the study, subjects were required to refrain from any physical activity aside from the activities of daily living. Oxygen consumption (VO_2) measurements were then taken three times daily, each preceded by a four-hour fast to prevent an interaction with the thermic effect of food. All measurements were also

preceded by a 30-minute period of supine rest, except the evening measurement of the second day. In that instance, the weight lifting protocol, consisting of four circuits of bench press, power cleans, and squats, was used in place of the habituation period. VO_2 measurements were taken at 34, 29, 24, 10, and 5 h pre-exercise, as well as immediately after and 14, 19, 24, 38, 43, and 48 h post-exercise.

One-Repetition Maximum Protocol

Maximal strength (1RM) was assessed for the bench press, power cleans, and parallel squats. However, it is difficult to determine absolute strength in power movements, because technique tends to fail before actual muscle strength. Due to this relative inaccuracy, weight selection was conducted using a one-repetition maximum (1RM) protocol similar to that outlined by McBride et al. (18). First, a theoretical 1RM was estimated for each subject as a function of body weight. Subjects then performed several warm-up sets based on 40% (8 repetitions), 60% (4 repetitions), 80% (2 repetitions), and 90% (one repetition) of that theoretical 1RM. Following execution of a singular repetition with that weight, the resistance was adjusted according to performance on the first lift. Increments and decrements of five or ten pounds were used at the discretion of the experimenter. After a three-minute rest period, each subject performed a single repetition trial with the new weight. This pattern continued until the subject was unable to complete a single repetition of the lift with good form. The subject's 1RM was considered to be the weight used on the last successful trial.

Ten-Repetition Maximum Protocol

Following determination of the 1RM, a theoretical 10RM was approximated using 80, 70, and 75% of 1RM for the bench press, power clean, and squat, respectively. Using these 10RM estimations, the subjects familiarized themselves with the lifting protocol by performing four circuits of the aforementioned exercises. Each lift was performed until failure, and two-minute rest intervals were given between sets. Loads were adjusted after each set in order to maintain 10 repetitions on subsequent sets.

VO₂ Measurement

Baseline and post-exercise VO₂ measurements were collected in the University of Wisconsin-La Crosse Human Performance Lab using a Quinton® metabolic cart (Model QMC, Quinton® Instruments Co., Seattle, WA). Prior to each VO₂ measurement, the cart was prepared by inputting values for ambient room temperature, barometric pressure, and relative humidity. Calibration included the injection of one liter of a known gas mixture into the pneumotach. Prior to testing, subjects underwent 30 minutes of supine rest. At the end of this habituation period, subjects were fitted with a facemask, enclosing both the nose and mouth, which collected expired air for analysis in the metabolic cart. Segal (25) compared this facemask technique to the ventilated hood as a means of indirect calorimetry and found no significant differences. One-minute averages were obtained throughout the 30 minutes of resting VO₂ collection. For a given day, VO₂ measurements were conducted at 5-hour intervals (morning, midday, and evening), and 14 hours separated evening measurements from those of the following morning. This

protocol was utilized for all baseline and post-exercise VO_2 measurements, except immediately following the exercise protocol.

Resistance Exercise Protocol

On the second day, in place of their evening habituation period, subjects gathered at the Mitchell Hall Strength Center (University of Wisconsin-La Crosse) to perform the resistance exercise protocol. The session consisted of four sets of three lifts (bench press, power cleans, and parallel squats) in circuit formation. A two-minute rest interval was allowed between exercises. The resistance for each lift was set at the subject's predetermined 10RM, and each set continued until the subject could not perform any more repetitions. Most subjects completed 8-12 repetitions before failure. In the case that a subject was unable to perform 10 repetitions, the resistance was lowered for subsequent sets. Similarly, if subjects performed more than 10 repetitions, the resistance was increased accordingly. Table 2 outlines the average intensity (% 1RM) and number of repetitions for each set during the workout. Throughout the weight lifting session, subjects were supervised for proper technique by the primary researcher. This was done to minimize the risk of injury and to avoid cheating, such as arching the back or bouncing the bar. During this exercise session, subjects were allowed to consume water as desired between sets. Upon completion of the final set, the subjects were quickly returned to the Human Performance Laboratory to begin a post-exercise VO_2 measurement. Due to subject transport and instrument preparation, approximately 5 minutes elapsed between the end of the last lift and the initiation of the 30-minute metabolic measurement.

Table 2. Mean repetitions and intensity during the resistance exercise protocol

Trial	Bench Press				Power Cleans				Squats			
	1	2	3	4	1	2	3	4	1	2	3	4
Repetitions	10.8	9	8	9.2	12.2	8.8	8.4	9.6	10.8	8	8.8	10
% 1RM	73.6	73.8	72.8	70.4	70.4	76	71.6	70	77.6	77.4	76.4	72.8

Statistical Analysis

Prior to statistical analysis, outliers, identified as data with a Z-score greater than or equal to 3, were removed. Baseline and exercise VO_2 data were then compared using a repeated measures ANOVA (Treatment * Time) with specialized contrasts. Mean daily oxygen consumption for pre- and post-exercise days were analyzed using a single factor repeated measures ANOVA, with Scheffé F-test post-hoc comparisons. Significance was set at $p \leq 0.05$.

RESULTS

The comparison of pre- and post-exercise measurements at corresponding times of day revealed that significant ($p \leq 0.05$) differences exist between the morning baseline (34 h pre) and both mornings following the exercise (14 and 38 h post-exercise). The 19-hour post-exercise measurement also differed significantly from the corresponding baseline time (29 h pre). The only evening measurement that revealed a significant difference occurred immediately after the weight lifting session (Figure 1).

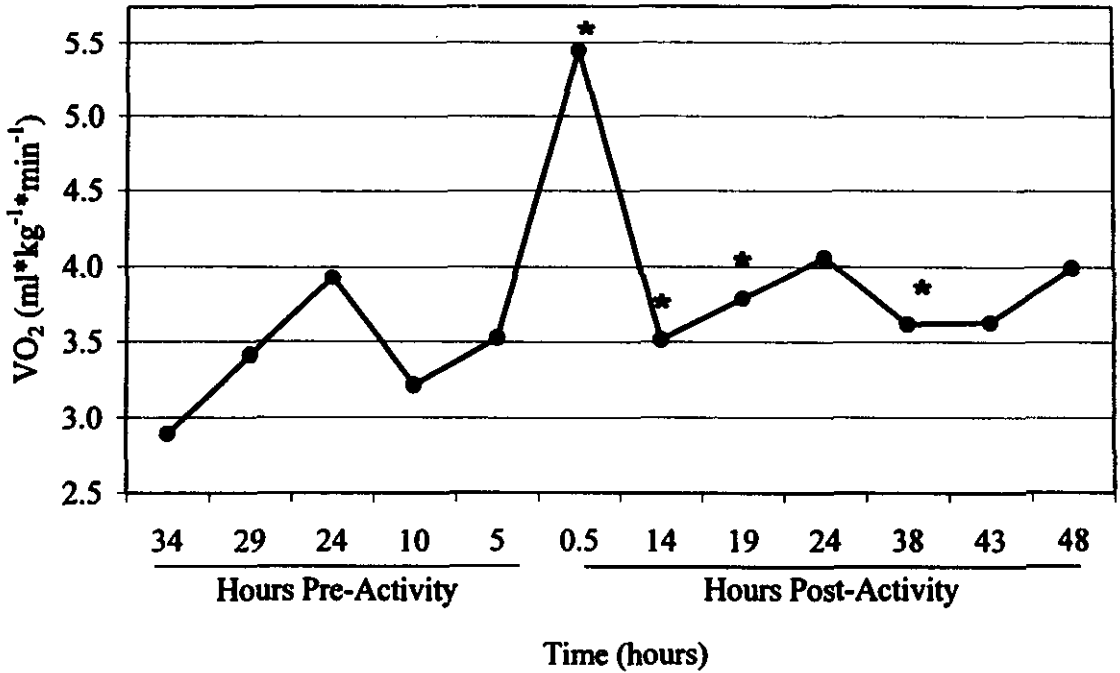


Figure 1. Mean oxygen consumption throughout the research protocol (Note: Data points marked with * indicate significance ($p \leq 0.05$) over the baseline value for the corresponding time of day.)

The baseline measurements reveal a constant increase throughout the day. This is likely due to an accumulation of the effects of activities of daily living, emotions, and circadian rhythms. During the morning baseline, the subjects have been awake for only a short period, so that they are all at a relatively low level of stimulation. However, as the day progresses, the subjects all experienced varying levels of physical and emotional stimulation. They were asked to keep it to a minimum, but a certain amount of stimulation is unavoidable. As a result, there is likely to be more between-subject variation as the day progressed, which made it more difficult to show significant

differences. Therefore, the mean VO_2 of each day was calculated by averaging the three measurements. Daily mean oxygen consumption data are presented in Figure 2. A comparison of these values revealed significant differences between the baseline and both post-exercise days ($p \leq 0.05$).

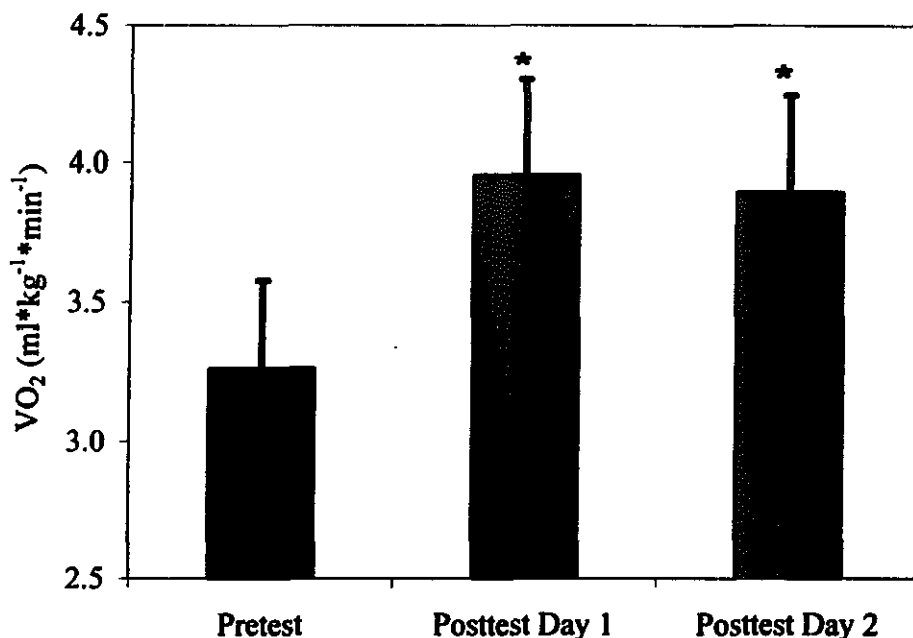


Figure 2. Mean daily oxygen consumption (Note: Both posttest days were significantly different ($p \leq 0.05$) than the baseline day. Error bars indicate standard deviation.)

DISCUSSION

The most noteworthy finding in this investigation was that EPOC following a strenuous bout of heavy resistance exercise remains significantly elevated even at 39 hours post-exercise. The mean oxygen consumption for the first and second days following the weight lifting session were also both significantly elevated above the mean

of the baseline day. These findings parallel the results of Melby, et al. (20), Gillette, et al. (8), and Osterberg and Melby (23) in which metabolism was found to be significantly elevated at 15, 14.5, and 16 hours post-exercise, respectively. It is important to note that these times do not represent when EPOC returned to baseline, but rather are pre-determined times set by the investigators. Similarly, several other studies (4, 10, 22) are not contradicted by the present findings. However, none of these studies continued data collection for more than 90 minutes following the resistance exercise, so they did not indicate the duration of EPOC. Results from the present study are in disagreement with the Haltom, et al. (10), Olds and Abernethy (22), and Elliot, et al. (7) studies, which found that EPOC had returned to baseline within one hour. This finding may be due to variations in the intensity and duration of the different resistance exercise protocols.

Application of these results suggests that the energy required to recover from resistance exercise may be even more significant to a weight management program than cardiovascular training. For the first 24-hour period following exercise, the mean difference between baseline oxygen consumption and that of post-exercise was $0.69 \text{ ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Similarly, the second 24-hour period following exercise had a $0.63 \text{ ml O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ mean difference over baseline. This equates to a 21.2% and 19.3% increase in metabolism for those two days, respectively. Assuming that an individual will burn 5 kilocalories per every liter of oxygen they consume, these mean differences would produce a 339 kcal and 309 kcal increase per day, respectively, for a 68 kg (150 lb.) individual. To illustrate the impact of this finding, using data from Chad and Wenger (5), when their subjects cycled for an hour at 70% of $\text{VO}_2 \text{ max}$, they had a mean exercise

VO₂ of 95.26 liters. In the 204 minutes that it took for their EPOCs to return to baseline, they consumed an additional 16 liters. Again, approximating that one burns 5 kilocalories for each liter of oxygen consumed, their subjects expended about 556.3 kcal for the exercise and recovery (Figure 3). This means that the entire caloric expenditure required for aerobic exercise and its subsequent EPOC (556.3 kcal) was less than the energy required solely for the post-exercise metabolic costs of resistance exercise (648 kcal). However, with the relatively few data collections throughout each day, we cannot be sure that the subjects' oxygen consumption is consistently elevated. Therefore, these calculations are only estimations.

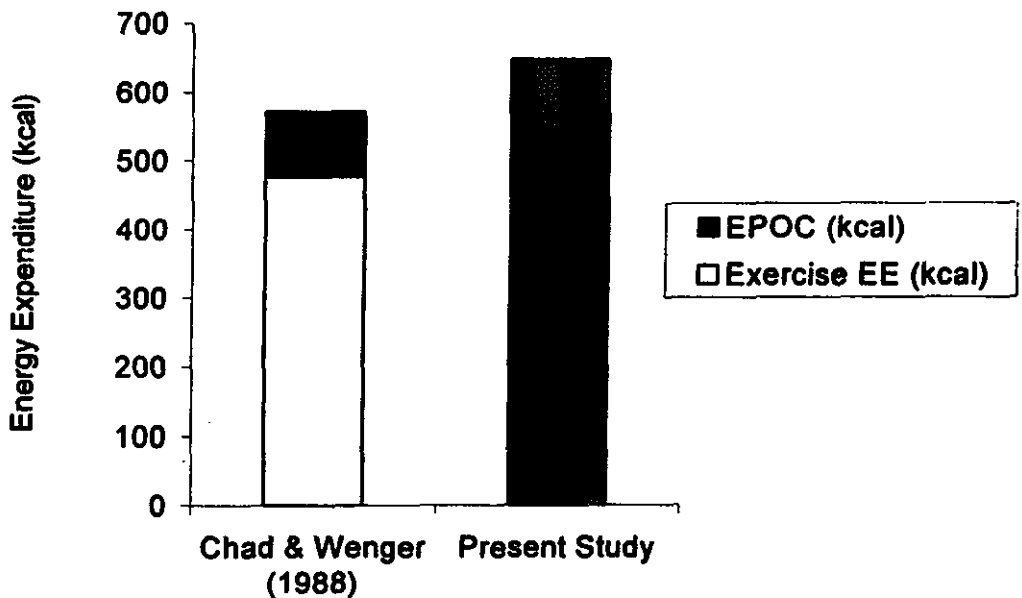


Figure 3. Comparison of EPOC following resistance and aerobic exercise

It is important to note that most resistance training studies that found EPOC to remain elevated for 14 or more hours used a similar lifting protocol of 8-10 exercises for 4 or more sets, each set to failure with a load that could be lifted for 8-12 repetitions. Conversely, the studies that did not show a lasting EPOC duration were either using very low resistances such as 50% of 1RM (7, 10) or very heavy loads that could only be moved for 3-6 repetitions (7). Therefore, it appears that data from the current study supports our initial hypothesis that maximized post-exercise metabolic costs occur as a result of resistance programs designed to enhance muscle hypertrophy.

Possible explanations for this result may include the additional exercise duration required to perform 8-12 repetitions characteristic of muscle hypertrophy program designs relative to the 1-6 repetitions that characterize a strength training program (29). However, exercise duration alone cannot explain the entire increase in EPOC magnitude and duration, because studies conducted on circuit weight training with up to 15 repetitions have not shown EPOC for longer than 60 minutes (10). It appears that there is an optimal combination of intensity and duration for the maximization of EPOC with resistance exercise. From the current research, it appears that a 10RM protocol, utilizing two-minute rest periods, may optimize post-exercise metabolism. Furthermore, this study has shown that an extended EPOC duration may be brought about by as few as four sets of three structural exercises. This indicates that individuals may select to use several isolation exercises or fewer multi-joint structural exercises, as long as the major muscles groups are exhausted.

Of the studies examining EPOC and resistance exercise, none examined blood levels of catecholamines, lactate or anabolic hormones. However, elevated levels of these variables after a 10RM, two minute rest protocol has been reported in the literature (11, 17, 18, 19, 26). The excess oxygen consumption may mark the initiation of the muscle repair process or the body's attempts to eliminate homeostatic disruptions. Plasma hormone levels (e.g. growth hormone and norepinephrine) increase immediately post-exercise and may increase metabolism by stimulating protein synthesis and preventing programmed cell death (26). Norepinephrine, specifically, promotes oxygen uptake by stimulating the dilation of bronchioles and blood vessels; it is also functional in increasing heart rate (26). Both growth hormone and norepinephrine had returned to baseline within 90 minutes (18). Blood lactate levels are also elevated during weight lifting (4). Removal of lactate is carried out, in part, via aerobic metabolism in the skeletal muscle, kidneys and heart (11). Following this immediate reaction to exercise, a biphasic inflammatory response is elicited, in which the damaged muscle is first degraded by phagocytes and then repaired (6, 13, 17). All of these factors could contribute to EPOC after intense resistance exercise, as performed in this investigation.

An alternate explanation for the prolonged EPOC may be a shift in substrate utilization. Blood concentrations of free fatty acids (FFA) are significantly elevated 20 hours post-exercise (19), fueling speculation that resistance training elicits a shift towards FFA metabolism. The excess oxygen required for fat oxidation in the Krebs cycle may explain the present findings. That study also showed that FFA levels varied greatly based on training level, with FFA levels much higher in untrained subjects. While subjects in

the present study were recreational lifters and not untrained, they were not accustomed to the intensity of this protocol and therefore may have responded in a similar manner.

In conclusion, the results of the present study support the use of resistance exercise to stimulate an increase in metabolism and promote loss of adipose mass. Resistance exercise has been linked to a daily mean oxygen consumption that remains elevated for at least 48 hours following a lifting protocol, and the cumulative caloric expenditure can exceed the total energy expenditure involved with aerobic exercise. Therefore, when this post-exercise variable is taken into account, it appears that resistance exercise may be every bit as effective for weight management as aerobic exercise.

Resistance exercise may not address all issues concerning cardiovascular health. The sustained elevated EPOC effect appears to be maximized with a lifting protocol designed to promote muscle hypertrophy, although the exact mechanisms remain unidentified and should be investigated. Future research may utilize a metabolic chamber to obtain continuous data collection. The chamber would also facilitate the control of external variables. Other research may wish to directly compare various resistance exercise protocols, as well as the effects combining aerobic and resistance exercise in the same workout. Furthermore, it remains to be determined whether the EPOC seen in the research will be consistent after the body has acclimated to that routine, so training studies should be conducted. Lastly, the current research did not observe a conclusive return to baseline metabolism; an even longer post-exercise period may be necessary to observe a true return to baseline.

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APPENDIX A

INFORMED CONSENT

Informed Consent
University of Wisconsin – La Crosse

Increased Metabolism Following Resistance Exercise

I, _____, volunteer to be a subject in a research study to investigate the metabolic costs following a single bout of resistance training. I consent to presentation and publication or other dissemination of study results so long as the information is confidential and disguised so that no personal identification can be made. I also have been informed that a number will be used in place of my name to identify all data collected from my participation.

- (1) I have been informed that my participation in this study will involve one- and ten-repetition maximum testing on three weight lifting movements. Two weeks later, I will then return for three 30 minute sessions of quiet sitting followed by 30 minute sessions of oxygen consumption measurement; these three sessions will occur at five hour intervals. This measurement is taken, as I breathe normally, into a facemask that connects to a gas analyzer. This gas analyzer is then used to calculate my metabolism. For the four days immediately prior to these sessions, I will refrain from any resistance training or aerobic exercise. I will also fast for four hours prior to each measurement session. The following day, I will participate in one weight lifting bout that consists of bench press, squats, and power cleans. This bout will be followed by a 30 minute oxygen consumption reading, and then three 30 minute sessions of quiet sitting followed by 30 minutes of oxygen consumption measurement per day until I fully recover (estimated to be within 48 hours). Again, each measurement session will follow a four hour fast.
- (2) I have been informed that the general purpose of this study is to examine how long energy expenditure remains elevated after a single session of resistance exercise.
- (3) I have been informed that the facemask for the metabolic cart may cause slight discomfort. The bout of weight lifting is strenuous, and during this lifting session, there is a minimal risk of injuries, such as muscle pulls, strains, and sprains. These risks are no greater during this study than during my regular resistance training. To reduce the risk of injury, all lifting activities will be monitored for proper form by individuals trained in First Aid and CPR.
- (4) I have been informed that there are no “disguised” procedures involved in this study. All procedures can be taken at face value.
- (5) I have been informed that I may ask questions at any time regarding the procedures.

- (6) I have been informed that I may withdraw from the study at any time without any repercussions.

Questions regarding the protection of human subjects may be addressed to Dr. Garth Tymeson Chair, University of Wisconsin-La Crosse Institutional Review Board (IRB) for the Protection Of Human Subjects at (608) 785-8155.

Any concerns may be referred to Mark Schuenke at 785-8689 or Dr. Richard Mikat at 785-8182.

Researcher	Date	Participant	Date
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APPENDIX B
REVIEW OF RELATED LITERATURE

It is widely believed that the primary mechanism for weight control is the energy-balancing equation (25, 29). The theory proposes that energy consumed in excess of energy that is expended will result in storage as adipose tissue. Therefore, it is important to understand all variables on both sides of the equation. Energy consumed is simply those calories that enter your body in the form of food and drink. Expended energy is chiefly comprised of those calories utilized for basal metabolism (BMR), thermic effect of food (TEF), and physical activity. Of these variables, we have the most control over physical activity. Thus, it is often examined for its caloric demands. In addition to the energy expenditure that takes place during physical activity, calories are needed following the exercise as the body recovers from the bout and returns to a resting metabolic rate. This phenomenon, known as excess post-exercise oxygen consumption (EPOC), may have a substantial impact on the energy-balancing equation.

Mechanisms of Excess Post-exercise Oxygen Consumption

The exact cause of EPOC is unknown, but several physiological responses to exercise may play a role. During steady state, aerobic exercise, the body responds to increased energy demands by raising heart rate, stroke volume, and pulmonary ventilation. The subsequent raise in body temperature, as well as an ionic disturbance and increased plasma catecholamine levels, are believed to be linked to EPOC (1). Additionally, substrate utilization may influence oxygen consumption during exercise and the subsequent EPOC (5). Regardless of the underlying causes, the constant nature of steady state activity does not allow the body to eliminate the oxygen deficit until after

the exercise bout is terminated. Thus, the EPOC is required to return the body to homeostatic functioning.

Similar to aerobic activity, the mechanisms behind the post-exercise energy expenditure for non-steady state exercises, such as weightlifting, have not been clearly defined. However, in addition to the proposed explanations given for steady state exercise, the short bursts of energy characterized in non-steady state activities require anaerobic metabolic pathways. These pathways include the degradation of adenosine triphosphate (ATP) into adenosine diphosphate (ADP), the transfer of phosphate from phosphocreatine (CP) to ADP in order to recreate ATP, and the breakdown of glucose or glycogen into pyruvic acid, which in the absence of oxygen becomes lactate. Following the anaerobic exercise, the body requires oxygen for lactate disposal and rephosphorylation of creatine and ADP (1). Furthermore, free fatty acid blood levels are significantly elevated 20 hours post-exercise (20), and fat oxidation requires additional oxygen. Additionally, hormones levels (e.g., growth hormone and norepinephrine) are elevated for approximately 90 minutes after exercise (20). In the case of muscle damage, protein degradation and reparation also take place (7, 14). EPOC is likely due to a combination of the aforementioned occurrences, but the significance of each factor is unknown.

Of the studies examining EPOC and resistance exercise, none examined blood levels of catecholamines, lactate, or anabolic hormones. However, elevated levels of these variables after a 10RM, two minute rest protocol have been reported in the literature (12, 18, 19, 20, 30). The excess oxygen consumption may mark the initiation of

the muscle repair process or the body's attempts to eliminate homeostatic disruptions. Plasma hormone levels (e.g., growth hormone and norepinephrine) increase immediately post-exercise and may increase metabolism by stimulating protein synthesis and preventing programmed cell death (30). Norepinephrine specifically promotes oxygen uptake by stimulating the dilation of bronchioles and blood vessels; it is also functional in increasing heart rate (30). Both growth hormone and norepinephrine had returned to baseline within 90 minutes (19). Blood lactate levels are also elevated during weight lifting (4). Removal of lactate is carried out, in part, via aerobic metabolism in the skeletal muscle, kidneys, and heart (13). Following this immediate reaction to exercise, a biphasic inflammatory response is elicited, in which the damaged muscle is first degraded by phagocytes and then repaired (7, 14, 18). All of these factors could contribute to EPOC after intense resistance exercise, as performed in this investigation.

Without a clear understanding of the mechanisms behind EPOC, it is not feasible to compare the post-exercise energy expenditure of steady and non-steady state activity. Furthermore, the intermittent nature of non-steady state exercise allows for partial recovery between sets, which further complicates a direct comparison between steady state and non-steady state activity. Nevertheless, similar mechanisms may be behind the EPOC of both steady and non-steady state exercise. Therefore, literature on both types of exercise were reviewed.

EPOC of Steady State Activity

Several studies have examined the effects of steady state exercise on energy expenditure, and most agree that energy expenditure remains elevated for a period

following activity. However, the duration of this EPOC period has been inconsistent among studies. Several have found that EPOC returned to pre-exercise levels within one hour following an exercise bout (3, 13, 17, 26, 31, 32). Conversely, other studies have reported that EPOC remained elevated for many hours following a bout of steady state activity (2, 6, 10, 15, 16).

In a 1987 study, Kaminsky, et al. (13) compared the EPOC following a 30-minute bout of treadmill running at 70% of VO_2 max to the EPOC after a 60-minute bout of treadmill walking at 35% of VO_2 max. Both exercise trials required the same total work, and the during-exercise energy expenditure was not significantly different. Furthermore, there was no significant difference in magnitude or duration of EPOC between the 30- and 60-minute bouts. Oxygen consumption in both cases returned to baseline within 15 minutes of terminating the exercise.

Sedlock, et al. (26) sought to determine the relationship between exercise intensity and duration on the magnitude and duration of EPOC. Highly trained triathletes were used as subjects to avoid large inter-subject variation in fitness levels. Following a fasting, resting metabolic baseline measurement, subjects randomly performed exercise bouts on a cycle ergometer. In all, three bouts were performed: (1) high intensity (75% of VO_2 max) and low duration (time required to expend 300 calories), (2) low intensity (50% of VO_2 max) and low duration, or (3) low intensity and high duration (time required to expend 600 calories). After each bout, EPOC was measured. Results indicated that the high intensity, low duration bout produced the longest EPOC duration and a significantly larger magnitude than the other two

treatments. The low intensity, high duration treatment produced the second longest duration, but the low intensity, low duration exercise resulted in the second highest magnitude. Nevertheless, no durations for any of the treatments exceeded 33.3 ± 10.4 minutes.

A similar study (3) compared the post-exercise metabolism of experienced runners at varying intensities. The experimenters also compared the EPOC recovery rates at one workload to the EPOC of non-exercisers for that same workload. The runners walked and ran for 2 miles on a treadmill at 2, 4, 5, and 7 miles per hour (mph). The non-exercisers completed only the 4-mph treadmill walk. Resultant EPOC values did not suggest any relationship. The EPOC duration following the 7-mph bout was the longest at 48 minutes. However the next longest EPOC duration of 42 minutes was following the 4-mph exercise, not the 5-mph exercise, which produced an EPOC of 31 minutes.

Maresh, et al. (17) also studied the roles that exercise intensity and duration play in EPOC. On four separate occasions, subjects exercised on a cycle ergometer for 20 and 40 minutes at 60 and 70 % of their $VO_2\text{max}$. The resulting EPOC did not vary significantly between any of the conditions. Furthermore, oxygen consumption returned to resting levels within 40 minutes regardless of the exercise intensity or duration.

Short and Sedlock (31) hypothesized that an individual's fitness level may influence his or her EPOC. Twelve trained ($VO_2\text{max} = 53.3 \pm 6.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and ten untrained ($VO_2\text{max} = 37.4 \pm 3.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) subjects cycled for 30 minutes at 70% $VO_2\text{max}$. The trained individuals returned to baseline more quickly ($40 \pm 15 \text{ min}$) than

the untrained subjects (50 ± 14 min). However, the EPOC magnitude did not vary significantly between trained and untrained subjects (3.2 ± 1.0 l O₂ and 3.5 ± 0.9 l O₂, respectively). These same subjects then cycled at the same absolute workload of 1.5 l O₂*min⁻¹. In this case, EPOC of the trained group was significantly shorter (TR: 21 ± 9 min; UT: 39 ± 14 min) and lower in magnitude (TR: 1.5 ± 0.6 l O₂; UT: 2.4 ± 0.6 l O₂). It should be noted that under all conditions, EPOC duration was no longer than 50 ± 14 min).

In 1993, Smith and McNaughton (32) investigated the relationship between aerobic exercise duration and EPOC duration. Eight male and eight female subjects exercised for 30 minutes on a cycle ergometer at 40, 50, and 70% of their VO₂max. Recovery VO₂ was then measured for the following three hours. The results indicate a minimal increase in EPOC duration with increased intensity, but all measurements had returned to baseline within 47.6 minutes.

Chad and Wenger (6) examined the effects of exercise duration on EPOC. Subjects exercised on a cycle ergometer at 70% VO₂ max for 30, 45, and 60-minute bouts. Following each bout, oxygen consumption was sampled every 4 minutes for the first hour and every 8 minutes for all subsequent hours until two consecutive samples were within one standard deviation of the predetermined resting $\dot{V}O_2$ level. Results indicated that oxygen consumption after the 30 minute bout remained elevated for 128 ± 4.4 minutes. As the bout was increased to 45 minutes, EPOC took 204 ± 15.9 minutes to return to resting levels. Lastly, following the 60 minute bout, oxygen consumption remained elevated for 455 ± 30.0 minutes. The experimenters concluded that there is a

direct correlation between the exercise duration and EPOC duration for steady state activity.

The results of the 1987 Bahr, et al. (2) study also indicated that EPOC remains elevated for several hours. Subjects in this study exercised on a bicycle ergometer for 20, 40, and 80 minutes at 70% VO_2 max; each bout was separated by 2 weeks. After each bout, oxygen consumption was measured continuously for 12 hours and then again 24 hours after ending the exercise. Following 12 hours of post-exercise data collection, oxygen consumption was still $14.4 \pm 1.2\%$, $6.8 \pm 1.7\%$, and $5.1 \pm 1.2\%$ above baseline for the 80, 40, and 20 minute bouts, respectively. By the 24-hour reading, EPOC had returned to baseline in all three instances. The experimenters concluded that a linear relationship existed between exercise duration and the duration of EPOC.

Maehlum, et al. (16) hypothesized that the common exercise durations were too short to evoke large post-exercise metabolic effects. Therefore, subjects exercised at 70% VO_2 max for 80 minutes. The results indicate that oxygen consumption continued for at least 12 hours and accounted for approximately 26 additional liters of oxygen over that time, when compared to the control treatment.

Gore and Withers (10) sought to investigate two variables at once by conducting a study that examined three different exercise durations at three different intensities. Subjects ran for 20, 50, and 80 minutes at 30, 50, and 70% VO_2 max. They found that at lower intensities, a longer duration is required to significantly increase EPOC above baseline for more than one hour. Conversely, at higher intensities extended EPOC can be seen at a lower exercise duration. Still, only three of the treatments (80 min * 50% VO_2

max, 50 min * 70% VO₂ max, and 80 min * 70% VO₂ max) resulted in an EPOC of over one hour (2, 4, and 8 hours, respectively). They determined that exercise intensity accounts for 46% of the variation, whereas the interaction of duration accounts for less than 10%.

In 1997, Laforgia, et al. (15) further examined the effect that exercise intensity has on EPOC by comparing submaximal and supramaximal running. Eight middle distance runners were used as subjects. The treatments were standardized according to oxygen consumed during exercise by using 30 minutes at 70% VO₂ max and 20 one-minute intervals at 105% VO₂ max. Oxygen consumption was then collected for nine hours and then compared to the VO₂ following a resting control. EPOC was 6.9 ± 3.8 liters and 15.0 ± 3.3 liters for sub- and supramaximal running, respectively. Although the higher intensity exercise resulted in a significantly larger EPOC, the researchers did not believe it would significantly impact weight loss.

EPOC of Non-Steady State Activity

Non-steady state exercise is a form of activity that requires short, repeated bursts that are often at high intensity. Resistance exercise is an example of non-steady state activity that has been used in weight control programs in order to maintain or increase muscle mass during caloric restriction. The caloric expenditure required to perform weight lifting, as with all activity, also aids in weight control. However, the EPOC of resistance training has received relatively little attention. Similar to the studies conducted on steady state activity, the research on non-steady state activity varies widely regarding duration and intensity.

In their 1993 study, Olds and Abernethy (23) compared two resistance training protocols common to recreational lifters to determine the magnitude and duration of the ensuing EPOC. Both protocols entailed two sets of seven lifts to be completed in 60 minutes. The first protocol consisted of 12 repetitions with 75% of the subject's predetermined 1RM. Protocol 2 used 15 repetitions with 60% of 1RM. The results did not indicate a significant difference between the EPOC of the two protocols, and most EPOC readings had returned to baseline levels within one hour of terminating the exercise. These EPOC results may have been affected by the relatively long rest periods (3.5 minutes) between sets of lifting, during which time the body had an opportunity to partially recover from the oxygen deficit.

In a similar study (8), EPOC was measured following singular sessions of circuit and heavy resistance weight lifting. The circuit training protocol involved 4 sets of 15 repetitions at 50% of 1RM for 8 lifting movements. Rest periods were limited to 30 seconds; therefore, the entire session was completed in 40 minutes. The heavy resistance bout was also completed in 40 minutes, but consisted of only 3 sets of the same 8 lifting movements with 80-90% of 1RM. For each set, the subjects lifted until failure, which was always between 3 and 8 repetitions. Subjects were allowed to rest for up to 2 minutes between sets. The experimenters found that metabolic rates were significantly elevated 30 minutes after both exercise bouts, but EPOC was not significantly elevated for either bout at the 60 minute interval. Furthermore, the magnitude of energy expenditure did not differ significantly between the two protocols.

Melby, et al. (21) studied the effects of a single resistance exercise bout on EPOC and resting metabolic rate. The subjects participated in six sets of 8-12 repetitions at 70% of their one repetition maximum (1RM). Five sets of paired lifts (ten lifting movements in all) were performed in 90 minutes while allowing up to one minute of rest between lifts. Upon comparison to a pre-exercise VO_2 reading, the EPOC was still 9.4% above baseline measurements 15 hours after completion of the exercise bout. The experimenters then conducted a second experiment identical to the first, except that subjects only performed five sets of each lift and they were allowed an extra 30 seconds of rest between lifts. They also used a control day as a baseline rather than the pre-exercise measurement. Data indicated that EPOC was 4.7 % above baseline 15 hours later. Following a similar protocol with seven female subjects, Osterberg and Melby (24) found similar results

In 1994, Gillette, et al. (9) conducted a study comparing the EPOC of a singular bout of resistance exercise to an acute aerobic bout. The weight lifting protocols were the same as experiment 2 of the Melby, et al. (21) study, and cycling at 50% of VO_2 max served as the aerobic exercise. In order to have both exercise bouts approximately equal in caloric expenditure, the duration of the aerobic bout was based upon the approximated caloric expenditure for the resistance bout. Upon measurement of the post-metabolic costs of the two bouts, it was found that five hours after exercise, EPOC remained 6.8% above baseline for the bout of resistance exercise and 5.5% above baseline following the aerobic exercise. Energy expenditure was measured again 14.5 hours following the

resistance training bout and found to be significantly above baseline. Due to subject complications, a EPOC measurement was not taken 14.5 hours after the aerobic bout.

Rest Intervals and EPOC

Although several studies have discussed the influence of rest intervals on EPOC, few have actually been designed to quantify the effects. In 1999, subjects in the Haltom, et al. (11) study participated in two bouts of an 8-station circuit weight training program. For both bouts, subjects performed two circuits of 20 repetitions, using 75% of 20 RM. The bouts were standardized by having all lifts concur with the beat of a metronome, and a 20- or 60-second rest period between stations differentiated the two bouts. VO_2 measurements were taken during and after each lifting session. Due to the longer duration required to complete the session with 60-second rest intervals, that session had a larger during-exercise oxygen consumption. However, the EPOC of the session with 20-second rest intervals was significantly larger in magnitude than the session with 60-second intervals (39.4% and 30.6% above baseline, respectively). Unfortunately, EPOC was only measured for one hour; therefore, Haltom, et al. were unable to reach a conclusion regarding the duration of EPOC. The experimenters speculate that differences in EPOC are due to the additional recovery that occurs during the longer rest periods. Regardless of the mechanism behind the longer EPOC, this study demonstrates a need to standardize the rest period when studying EPOC.

Thermic Effect of Food

An increase in energy expenditure may occur as the result of food ingestion. Segal, et al. (28) examined these effects before, during, and after exercise in lean and obese men of similar body weight. On four occasions, following a 12 hour fast, the resting oxygen consumption of lean and obese subjects was measured. Then, in random order, all subjects experienced: (1) a 3 hour seated control RMR measurement, (2) RMR measurement for 3 hours following consumption of a 750 kcal liquid meal, (3) 30 minute bout of cycling without a meal, and (4) 30 minute bout of cycling 30 minutes after consumption of a 750 kcal meal. For the exercise treatments, EPOC was also measured for 3 hours. The experimenters found that oxygen consumption was increased following food ingestion at rest, during, and after exercise. Furthermore, they found that for all instances lean males had significantly higher oxygen consumption. However, the exercise protocol in this study called for subjects to exercise at an intensity that corresponded to their ventilatory thresholds. Therefore, the lean subjects may have exercised at a higher intensity, which could have influenced their findings regarding TEF.

In contrast to the aforementioned study, Willcutts, Wilcox, and Grunewald (34) found that oxygen consumption did not increase significantly during exercise following consumption of a 940-kcal meal. Subjects participated in four bouts of treadmill running for 30 minutes at an average of 62% of VO_2 max. The bouts varied by the amount of time that expired between meal consumption and exercise. An exercise bout was conducted on non-consecutive days after a 12-hour fast, and 30, 60, and 90 minutes after ingestion of a 940-kcal meal. No significant differences regarding exercise oxygen

consumption were found between treatments. Although EPOC was not examined in this study, the similar exercise oxygen consumption data indicates that EPOC for the different treatments would be similar as well.

In a double blind study conducted by Chad and Quigley (5), untrained subjects were given either a beverage with 5mg of caffeine per kg of body weight or a placebo. Prior to this treatment, subjects abstained from caffeine for one week and fasted for 5 hours. Following the beverage consumption, subjects rested quietly for one hour, and then their resting oxygen consumption was measured for 30 minutes. Next, subjects exercised on a treadmill at 55% of VO_2 max for 90 minutes. Lastly, EPOC was measured for one hour. Within two weeks of this treatment, subjects returned and performed the same protocols with the other beverage. Throughout pre-, during, and post-exercise measurements, the intra-subject oxygen consumption was significantly higher after drinking the caffeine.

Although a disruption to eating patterns may affect metabolism, the thermic effect of food also may influence EPOC. Additionally, a fasting condition could influence lifting performance, which could then impact EPOC. The unpredictable nature of TEF compels researchers to impose fasting conditions on their subjects, but this variable cannot be fully controlled and should be listed as a limitation.

Equipment

For the purposes of exercise VO_2 measurements, a mouthpiece and nosepiece are commonly utilized. However, with resting measurements, subjects typically will not be breathing through their mouths. Therefore, Segal (27) compared the accuracy of rest

energy expenditure measurement using a ventilated hood, face mask, and mouthpiece. Eighteen subjects underwent three VO_2 measurements. In all three cases, all variables (e.g. time, diet, exercise) were held constant; only the equipment for measurement was altered. Results indicated that no significant differences exist among any of the three data collection methods.

Summary

Too few studies on the post-exercise metabolic costs of resistance exercise have been performed to form any conclusions. The studies have been divided regarding duration of EPOC. A few studies (8, 22, 23) concluded that baseline VO_2 was re-attained within an hour of exercise termination, whereas a similar number (9, 21, 24) found that EPOC remained significantly elevated for several hours. It appears that duration and intensity of the resistance exercise may influence the magnitude and duration of EPOC. Those studies with shorter post-exercise metabolic measurements used resistance training protocols that lasted 60 minutes or less. Additionally, the subjects were required to perform fewer (2-4) sets and had rest periods of 2 minutes or more. Conversely, the experiments that found EPOC to last several hours had 90-minute training sessions with shorter resting periods and more sets (5-6). Altering one or more of these variables may significantly impact EPOC. Furthermore, the studies with a longer EPOC typically used loads that are typical of a muscle hypertrophy program, whereas studies finding post-exercise metabolism to normalize quickly used loads that are designed more for muscular strength or endurance (33). In order to maximize the energy expenditure, structural exercises that recruit most of the large muscle groups are ideal (19).

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