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## Oxygen Costs Peak after Resistance Exercise Sets: A Rationale for the Importance of Recovery over Exercise

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**ABSTRACT**

**Scott CB.** Oxygen Costs Peak after Resistance Training Sets: A Rationale for the Importance of Recovery over Exercise. **JEPonline** 2012;15(2):1-8. During the first minute after a single set of resistance training, oxygen uptake rates are greater than exercise oxygen uptake ( $\text{VO}_2$ ). The purpose of this study was to determine if this is also true for multiple sets using different lifting cadences while attempting to more precisely determine when peak  $\text{VO}_2$  rates took place. Ten male volunteers performed 3 sets of 5 repetitions of the bench press at 70% of one-repetition maximum (1-RM). The timing of eccentric and concentric contractions provided 3 separate protocols: (1) 1.5 sec down and up; (2) 4 sec down, 1 sec up; and (3) 1 sec down, 4 sec up. Gas exchange was collected in 5-sec periods for all three protocols with 15-sec periods for the 1.5/1.5 protocol. Oxygen uptake after brief bouts of resistance exercise increased with all sets and protocols, then, it declined towards resting levels; median time to peak was significantly less for the 3 sets of 1.5/1.5 (35.5 sec) as compared to 4/1 (45.0 sec) ( $P = 0.02$ ) but not 1/4 (41.5 sec) (4/1 and 1/4 did not differ). The respiratory exchange ratio ranged from  $0.80 \pm 0.06$  to  $1.42 \pm 0.18$ , rising and falling twice within 4 min recovery periods between all sets and among all protocols. These findings indicate that the  $\text{VO}_2$  rates peaked within 35 to 45 sec after brief bouts of low intensity resistance exercise. It is suggested that intermittent type exercise programming (weight lifting and Tabata training) consider recurrent rest or active recovery periods as having the potential to play the predominate role in caloric expenditure related to fat loss.

**Key Words:** Oxygen Debt, Respiratory Exchange Ratio, Excess Post-Exercise Oxygen Consumption, Weight Loss

## INTRODUCTION

After a single set (8 reps) of resistance exercise, “*the largest increase in oxygen consumption occurred during the first minute of recovery...*” (10, pg. 27). This 40-yr old statement appears to have received little attention as most descriptions of excess post-exercise oxygen consumption (EPOC) are typically portrayed as falling exponentially the moment exercise stops, back towards resting levels – a scenario that has been defined from observations after aerobic-type exercise (1,2,7,11).

Oxygen uptake ( $\text{VO}_2$ ) during aerobic exercise has always been considered separate from EPOC. Yet, contrary to the separation of exercise  $\text{VO}_2$  and EPOC, most resistant training investigations combine multiple intermittent lifting periods with rest/recovery periods between sets to portray a single rate-function measurement ( $\text{L}\cdot\text{min}^{-1}$ ) for the entire workout (19). Based on this methodology, rest/recovery periods between resistance training sets may be falsely identified as part of exercise and not as part of EPOC. Indeed, if  $\text{VO}_2$  peaks *after* resistance training sets, then, it appears possible that the greatest aerobic costs take place in recovery and not during the actual lifting periods.

Thus, the intent of this study was to better determine from a temporal perspective, using shorter sampling periods and different lifting cadences, the extent and behavior of  $\text{VO}_2$  in the immediate rest/recovery after multiple weight lifting sets. The “problem” addressed by previous authors concerning how rest/recovery periods after individual weight lifting sets should be categorized - as part of EPOC or as part of exercise energy expenditure (8) – is briefly discussed.

## METHODS

### Subjects

Ten male volunteers were informed of the risks associated with participation in this study. All subjects signed an informed consent document, which was approved by the Human Subject Institutional Review Board at the University of Southern Maine before data were collected. The subjects’ mean  $\pm$  SD for age (yr), height (cm), and body weight (kg) are  $23.2 \pm 3.1$ ,  $177.3 \pm 5.3$ , and  $82.1 \pm 11.5$ , respectively, and 70% of 1-RM (kg) was  $74.9 \pm 11.2$ . All subjects were trained weight lifters who engaged in weight training 3 times per week for at least 3 months).

### Procedures

The subjects were asked to fast 4 hrs prior to testing and to not exercise on the day of testing. Most of the tests were completed in the morning. Four visits to the lab were required. On the first visit, a one repetition maximum (1-RM) for the bench press was recorded on a Smith machine consisting of a horizontal bar that slides on vertical tracks where weight can only be lifted in the vertical plane (York Barbell Company, York, PA). The weight was gradually increased until a single repetition could not be completed. All subjects warmed-up with a light weight of their choice before attempting the 1-RM. Good form was stressed and 5-point contact was maintained with the bench and floor. The tester chose the weight increase for each lift and a period of rest/recovery (3-5 min) between attempts was given. Each subject practiced lowering and lifting the bar at a cadence set by a metronome. A small fly wheel attached to a micro-processor on the Smith machine recorded the distance the bar traveled. Work (J) was recorded as the product of weight lifted and the vertical (upward) distance the bar traveled. During the following 3 visits to the lab, the subjects were randomly assigned to bench press 3 sets of lifts at 70% of their 1-RM ( $74.9 \pm 11.2$  kg). Each set consisted of 5 repetitions. This number was selected from a pilot study to ensure that the subjects could perform the work required without fatigue. Otherwise, if fatigue had been allowed to be part of the energy expenditure estimate, it would have influenced energy expenditure (17). The three lifting cadences practiced and measured included: (1) 1.5 sec down and 1.5 sec up (15 sec of lifting per set, 45 sec overall); (2) 4 sec down

and 1 sec up (25 sec of lifting per set, 75 sec overall); and (3) 1 sec down 4 sec up (25 sec of lifting per set, 75 sec overall).

Oxygen uptake was measured using a metabolic cart (MMS-2400, PavoMedics, Sandy, Utah), which was calibrated a minimum of two times immediately prior to testing, using room air and calibration gas (16% O<sub>2</sub>, 4% CO<sub>2</sub>). Ventilation was calibrated using a 3-L syringe. Oxygen uptake was measured in 5-sec periods for the three separate protocols and 15-sec sampling periods for the 1.5/1.5 protocol (when lifting was completed in 15-sec periods). Before each lift, resting VO<sub>2</sub> was averaged over a 5-min period with each subject lying supine with the back on the bench and the feet on the floor (Figure 1).

The rest period after the 1st and 2nd set was selected as 4-min. After the 3rd set was completed and the weight was racked, the subjects had their feet elevated on a chair parallel to the height of the bench. Excess post-exercise oxygen consumption (EPOC) was recorded until 2 consecutive 15-sec measurements fell below 5.0 mL·kg<sup>-1</sup>·min<sup>-1</sup> (which is considered a typical standing, resting VO<sub>2</sub>).

### Statistical Analyses

Descriptive statistics were collected for VO<sub>2</sub> and RER before, during, and after all resistance training sets. Statistical analyses were completed using SigmaPlot 12.0. Comparisons were made using repeated measures ANOVA and the appropriate post-hoc test. Level of significance was set at P = 0.05. As this was a descriptive investigation, sample size was not determined.

## RESULTS

Because of the skewed VO<sub>2</sub> rate profile during recovery, median values may represent the best measure of central tendency. Within 5-sec sampling periods the highest VO<sub>2</sub> occurred at median values ( $\pm$  25% to 75%) of 45.0 sec (35 to 56 sec) for 4 sec down/1 sec up, 41.5 sec (31 to 53 sec) for 1 sec down/4 sec up and 35.5 sec (19 to 45 sec) for 1.5 sec down/1.5 sec up; 1.5 sec down/1.5 sec up was significantly lower as compared to 4 sec down/1 sec up (P = 0.02). Within protocols mean peak VO<sub>2</sub> rates ( $\pm$  SD) did not differ among sets: 1.5 sec down/1.5 sec up set 1, 32.9  $\pm$  21.7 sec; set 2, 35.8  $\pm$  18.8 sec; set 3, 28.9  $\pm$  31 sec (P = 0.53); 4 sec down/1 sec up set 1, 53  $\pm$  27.8 sec; set 2, 38.9  $\pm$  19.5 sec; set 3, 49.6  $\pm$  13.1 sec (P = 0.33); 1 sec down/4 sec up set 1, 44.3  $\pm$  22.9 sec; set 2, 41.1  $\pm$  33.4 sec, set 3, 46.9  $\pm$  18.7 sec (P = 0.88) (refer to Figure 1).

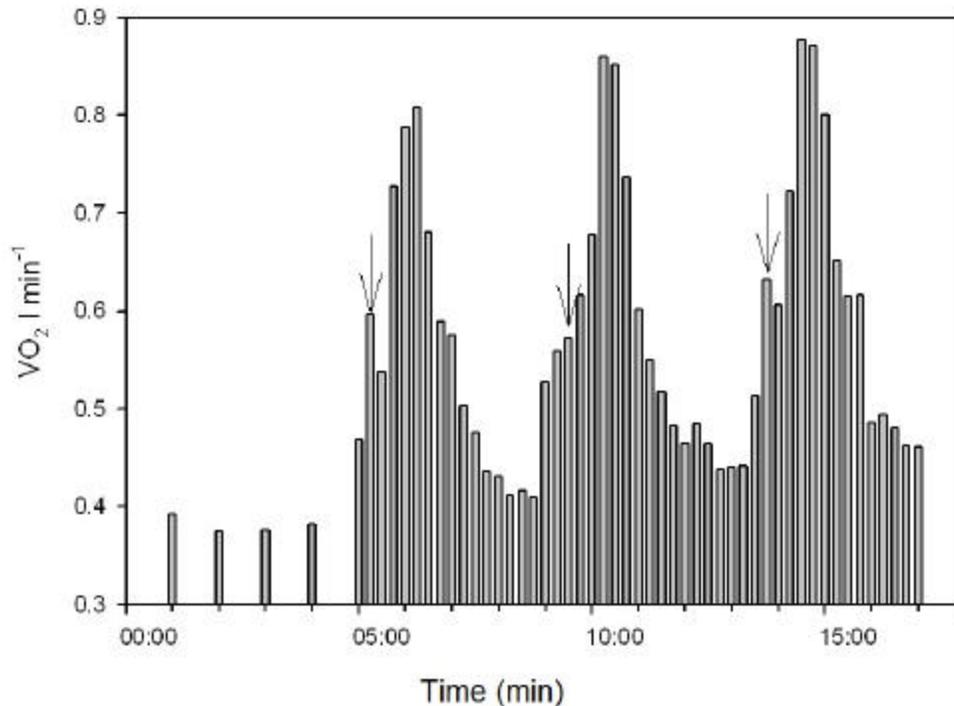
The bimodal characteristic of the RER in recovery is reported descriptively as a range. As part of 4 min of rest/recovery periods a continually changing pattern within protocols with the following ranges was seen: 1.5 sec down/1.5 sec up, 0.81 – 1.36; 4 sec down/1 sec up, 0.80 – 1.42; 1 sec down/4 sec up, 0.84 – 1.46 (see Figure 2). Because of the sporadic sampling times for the 5 sec sampling periods, 12 sampling periods per min often were not available, with actual measurement periods ranging from 3 to 18 sec (for the 1.5/1.5 protocol 15 sec sampling periods provided 4 measures per min). Even so a distinct pattern emerged within the data for all lifts regardless of the sampling period time; an immediate rise in RER that followed each lift followed by a subsequent drop, followed by another gradual rise and, then, a final gradual drop. This pattern also occurred within 3 min.

## DISCUSSION

### Recovery Oxygen Uptake Characteristics

After all sequential lifts (3 sets in total) of the bench press exercise, VO<sub>2</sub> always peaked within the 1st min of recovery – between 35 sec and 45 sec - regardless of lifting the time-under-tension and the eccentric/concentric cadence (Figure 1). Moreover, slower lifting times could prolong time to peak

$\text{VO}_2$ . McArdle and Foglia (10) first found after a single set of resistance exercise (8 reps), that  $\text{VO}_2$  measured in minute long sampling intervals peaked within the 1st min of recovery. Collectively, the data reveal that  $\text{VO}_2$  following resistance-type training does not follow a pattern that is typically portrayed for aerobic exercise, where  $\text{VO}_2$  always falls exponentially toward resting values the moment exercise is stopped. Given brief lifting and elongated recovery/rest periods with some resistance training programs, the greatest  $\text{VO}_2$  rates take place within rest/recovery periods, not during the exercise. From this perspective, a single rate function measure of  $\text{VO}_2$  ( $\text{L}\cdot\text{min}^{-1}$ ) used to represent a complete resistance training workout may consist predominantly of recovery not exercise  $\text{VO}_2$ .

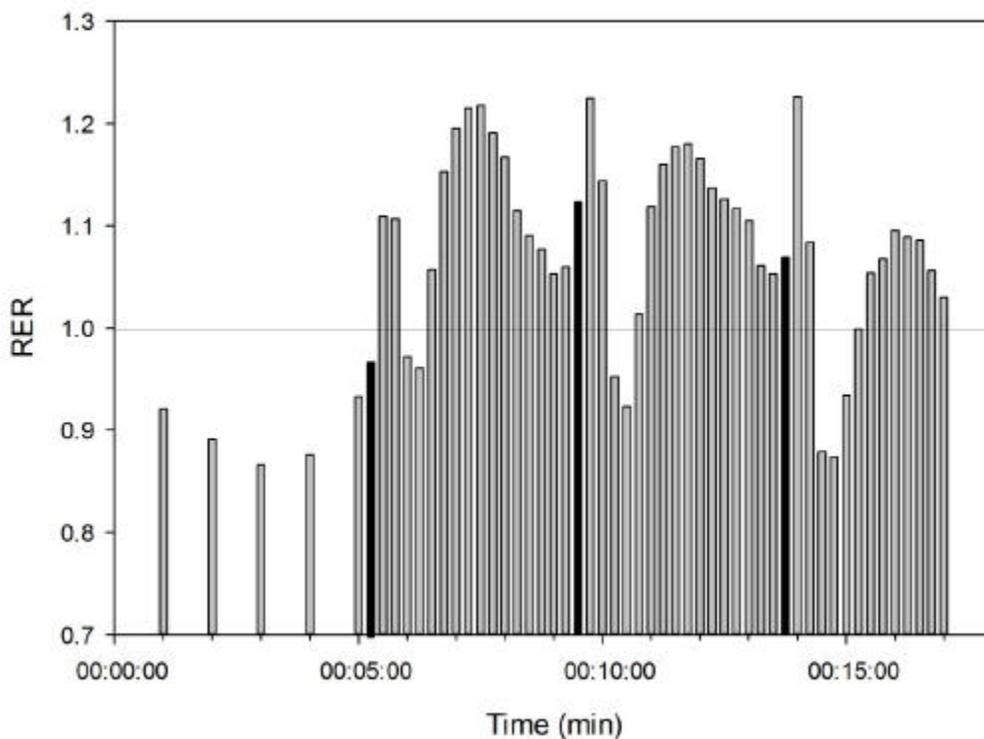


**Figure 1.** Oxygen uptake rates are shown within 15 sec measurement periods for 1.5 sec down and 1.5 sec up weight lifting (bench press). Note that after the lifting periods (marked by arrows)  $\text{VO}_2$  always peaked within rest/recovery – total exercise time was 45 sec, total rest/recovery time was ~12 min. If the design of the exercise program emphasized recovery, for this lifting format, rest periods of 75 sec would likely maintain  $\text{VO}_2$  rates above that of exercise (averaged data for 10 subjects).

Why does excess post-exercise oxygen consumption (EPOC) fall exponentially after aerobic-type exercise, while increasing momentarily before falling after resistance exercise? Ischemic cycling studies use pneumatic cuffs placed proximally around both thighs, then inflate them to impede blood flow and  $\text{O}_2$  delivery during steady-state exercise (9,14). When the cuffs are inflated,  $\text{VO}_2$  drops slightly, as expected. When the cuffs are deflated however, an *overshoot* of  $\text{VO}_2$  beyond the exercise steady-state is observed. During resistance training, it appears likely that muscle contracts intensely enough to likewise impede blood flow and  $\text{O}_2$  delivery (18). After completion of the weight lifting set a similar overshoot of  $\text{VO}_2$  may take place within the rest/recovery periods between sets. Holding the breath during lifting may further contribute to a  $\text{VO}_2$  overshoot during recovery. Such increases in recovery  $\text{VO}_2$  rates and the extent (time) to which these elevations take place should be exploited within the design of exercise programs that focus on energy costs (Figure 1).

## Respiratory Exchange Ratio Characteristics

The RER never maintained consistency throughout exercise and rest/recovery periods, ranging from 0.80 to 1.42 among and within lifting protocols. Given this information, the type of substrate oxidized cannot be properly identified. Regardless of the actual (and quite varied) sampling period times the pattern of the RER was similar among all lifting and rest/recovery periods revealing at first an increase followed by a steep drop, followed by a subsequent rise, followed by a slower decline; all within a 3-min period (Figure 2). This roller coaster pattern is certainly not associated with a steady-state, and provides a rationale for focusing on EPOC - a measure of  $\text{VO}_2$  - as opposed to attempting to estimate recovery/rest energy expenditure (kJ) based on substrate utilization. However, substrate utilization may play a key role in differentiating between exercise and recovery. While focus can certainly be placed on the exercise itself (3,6), it might be that multiple recovery periods have a more prominent effect on fat oxidation and weight loss.



**Figure 2.** The respiratory exchange ratio (RER) is shown within 15 sec measurement periods for 1.5 sec down and 1.5 sec up of resistance exercise. The black bars indicate the lifting period for each of the 3 sets. After each set the RER increased substantially above 1.00, then dropped consistently to a nadir after ~30 to 45 sec, followed by another rise and subsequent drop. This roller coaster pattern of non-steady state RER, often elevated well above 1.00, does not properly indicate substrate utilization during both exercise and rest/recovery periods (averaged data for 10 subjects).

The oxygen on-kinetics and off-kinetics seen with any exercise and rest/recovery periods would have separate  $\text{VO}_2$  to energy expenditure conversions if fuel utilization differed for each. One liter of  $\text{VO}_2$  at 21.1 kJ (anaerobic + aerobic glucose oxidation) and 19.6 kJ (fat oxidation) represents an energy expenditure difference of approximately 7%. Based on this information substrate utilization has the potential to affect  $\text{VO}_2$  (12). Borsheim and Bahr (2) have suggested that when a workout is completed and long term  $\text{VO}_2$  is measured (over hours, days), a substrate shift from carbohydrate to fat can account for 10 to 15% of the observed EPOC. Care must be taken however, in recognizing that the use of substrate utilization to ascertain the volume of  $\text{O}_2$  consumed is very different as compared to

using a measurement of  $\text{VO}_2$  without regard to fuel oxidation. As an example, both lactate and fat oxidation undergo aerobic energy exchange solely through mitochondrial respiration, presumably at 19.6 kJ per liter of  $\text{O}_2$  consumed (15). Yet, lactate oxidation does not appear to influence EPOC volume (within a 28-min recovery period) (14), though fat oxidation apparently does. Why is this? The answer may be that the fat oxidation scenario *implies* a RER-based energy expenditure estimate to  $\text{VO}_2$ . This was not the focus of lactate oxidation studies. However, compared to glucose, lactate oxidation would indeed have an influence on EPOC (4,15).

### Limitations

Brief gas exchange sampling periods have limitations in that the measurement becomes more variable with shorter collection times (13), with the absence of a steady-state, and with the actual (not selected) sampling period by the metabolic cart. Previous data revealed the coefficient of variation (CV) for EPOC after lifting was greater than 30% and could approach 50% for exercise aerobic and anaerobic energy expenditure with brief lifting periods (16). These CV values are clearly problematic (5). However, while variability is an inherent aspect of non-steady-state measurements, it does not mean there should be no attempt to make a reasonable estimate of a variable measure. As an example, the selected 5-sec gas exchange measurement periods of 2 subjects could be from 3 to 18 sec in length, making the actual peak and nadir times difficult to pinpoint (see results). In fact, the sampling periods often varied by a few seconds or more for all subjects throughout the protocols. Regardless, the 5-sec *patterns* were similar after all sets and among all protocols and identical to 15-sec sampling periods for the 1.5 sec down/1.5 sec up lifts:  $\text{VO}_2$  rising from exercise into rest/recovery before falling and, a double rise and fall of the RER.

### Exercise Programming

For aerobic exercise, recovery  $\text{VO}_2$  (i.e., EPOC) is kept separate from the exercise period (1,2,7,11). Yet, many exercise physiologists continue to average multiple resistance exercise and recovery/rest periods into a single  $\text{VO}_2$  measure ( $\text{L}\cdot\text{min}^{-1}$ ), as with aerobic-type exercise EPOC is considered only as the last recovery period. However, using an aerobic exercise rationale to model the multiple recovery periods following resistance exercises may be shortsighted (8).

Physiological adaptations to high-intensity intermittent anaerobic-type exercise have suggested a more prominent role for fat loss as compared to low-intensity aerobic-type exercise (3, 6). Clearly, the selected exercise, the amount of active muscle mass involved, and the exercise intensity are what drive or promote recovery  $\text{VO}_2$ . Yet, the presence of multiple carefully timed recovery/rest periods in-between exercise sets may further create the potential to maintain increased energy expenditure and fat oxidation with less overall work and lower perceived exertion. Based on this example, intermittent exercise with 6 to 8, 20-sec intense “sets” followed by 10 sec of rest or active recovery may have an energy cost only slightly lower than 6 to 8 sets with 10 sec of equivalent exercises coupled to 20 sec of rest/active recovery – with the latter, work is halved, perceived exertion is lowered, rest periods are doubled and fat oxidation may be enhanced.

### CONCLUSIONS

Oxygen uptake peaks in the recovery/rest periods between weight lifting sets, not during the exercise itself. Fuel oxidation is unknown, given that the RER rises and falls twice within 3 min of recovery. Considering the previous research findings, multiple, specifically timed, rest/active recovery periods need consideration as a separate and essential part of the design of exercise programs when the emphasis is placed on the lowest amount of overall work and a greater potential for body fat loss.

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