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A Review of Ergogenesis and Effect of Training Variables on Energy Expenditure in Resistance Training Exercises

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ABSTRACT

Magosso RF, Campanholi Neto J, Carli JPC, Figueira TG, Souza GS, Robert-Pires CM, Baldissera, V. A Review of Ergogenesis and Effect of Training Variables on Energy Expenditure in Resistance Training Exercises. **JEPonline** 2017;20(2):99-110. While it is common that studies are designed to determine energy expenditure (EE) of resistance exercise (RE) using oxygen uptake (VO_2) measurements, the most practical method to quantify EE of RE is the sum of three components: aerobic, excess post-exercise oxygen consumption (EPOC), and anaerobic. The studies on ergogenesis (i.e., the contribution of each component to EE) indicate that despite the predominance of anaerobic metabolism during RE exercises, the greater contribution is between the sets and after the training sessions. This review addresses the effect of intensity, density, and muscular failure based on the studies that employed the three components to quantify EE of RE.

Key Words: Energy Expenditure, Ergogenesis, Resistance Training Exercises, Training Variables

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INTRODUCTION

The energy expenditure (EE) of a given exercise is a consequence of mechanical energy output and heat production from ATP turnover, thus influenced by the balance between ATP resynthesis and hydrolysis (19). This quantification can be done by direct calorimetry where an organism is placed in a chamber surrounded by water at a known temperature from which variation of the water temperature indicates how much energy is released. In general, this method has limitations especially regarding the measure of EE of medium and large organisms, which includes humans (19) and also during exercise due to the space needed for analysis.

Given these considerations, EE during exercise has been measured by indirect calorimetry where the quantity of energy released is related to the amount of metabolized oxygen and the production of carbon dioxide. This method requires the individual to perform exercise with a gas analyzer of which each liter of O_2 is converted to an equivalent of 5.05 kcal where it is assumed that active muscles metabolize only carbohydrates (16). This measure has its limitations when used to determine EE during resistance training (RT), especially since the exercise modality does not rely solely on aerobic metabolism for ATP resynthesis. Previous studies from our laboratory have shown that the anaerobic threshold in RT exercises is ~25% to 30% of one repetition maximum (1RM) (3-5). Thus, any RT protocol above this intensity range will lead to an anaerobic component of EE with lactate production that cannot be quantified by indirect calorimetry.

di Prampero and Ferretti (6) and Margaria et al. (14) proposed a conversion of the accumulated blood lactate calculated by the variation in blood lactate concentration (Δlac) and its equivalent in O_2 consumption. For each millimole of lactate per kg of body mass an equivalent of 3 ml of O_2 is attributed, then the ratio of 5.05 kcal per liter of O_2 is applied.

The first study to apply this method in RT was made by Scott (19) where EE was compared in two protocols of 60% and 80% of 1RM. Results showed that for most of the exercises and intensities adding the anaerobic component (i.e., the rapid anaerobic substrate-level ATP turnover) significantly increased the quantified EE and demonstrated that previous studies using only the aerobic component (i.e., VO_2) underestimated EE of RT protocols.

Today, the best method to quantify EE during RT is through the sum of three components: aerobic, excess post-exercise oxygen consumption (EPOC), and anaerobic. The aerobic component consists of 5.05 kcal per liter of oxygen consumed during the sets, given the assumption that the respiratory exchange ratio (RER) is equal to or higher than 1.00 and active muscles use only glucose as substrate. The EPOC is the oxygen consumed during rest periods between sets and in the recovery from the training session where each liter of O_2 corresponds to an EE of 4.7 to 5.05 kcal, given the assumption of an RER of 0.70 to 1.00 or higher, respectively, where active muscles metabolize fatty acids and carbohydrates. The anaerobic component consists of the proposal by di Prampero and Ferreti (6) and Margaria and colleagues (14).

The purpose of this paper will be to present the relationship between aerobic and anaerobic metabolism and the main factors that affect EE during RT exercises.

Ergogenesis of Resistance Training

As previously described, RT is an exercise modality characterized generally by not allowing an individual to attain a metabolic steady-state, therefore requiring an anaerobic component for energy production. The combination of the metabolic pathways for energy production is called ergogenesis.

The study of Scott (19) quantified EE of men and women who had experience in RT in two sets of leg press, bench press, and biceps curls at 60% and 80% of 1RM. At 60% of 1RM the subjects performed 2 sets to failure, and at 80% of 1RM the subjects performed 2 sets of 6 repetitions in biceps curls, 8 repetitions in bench press, and 10 repetitions in leg press. The author chose intensities that would lead to a different duration and metabolism in the sets of each exercise. For ergogenesis determination the aerobic and EPOC components were considered together as a whole aerobic component and the anaerobic component was calculated through variation in blood lactate. At 60% of 1RM the average ergogenesis of the 3 exercises was 36.76% anaerobic and 63.74% aerobic in the first set and 28.19% anaerobic and 71.81% aerobic in the second set. At 80% of 1RM the first set was 36.46% anaerobic and 63.54% aerobic and, in the second set, anaerobic participation was 21.93% and aerobic participation was 78.07%.

Scott et al. (20) quantified EE in 3 sets of bench press with 7, 14, or 21 repetitions at 50% of 1RM performed randomly on separate days. In the set of 7 repetitions, anaerobic, aerobic, and EPOC contributions were 31.4%, 18.2%, and 50.4%, respectively. In the set of 14 repetitions, the percentages were 39.3%, 18.7%, and 42.0%, respectively. Finally, in the set of 21 repetitions, anaerobic component was 44.8%, aerobic component was 21.3%, and EPOC corresponded to 33.9% of total energy production.

In another study that involved sets to muscular failure on separate days, Scott et al. (21) quantified EE in 6 protocols of bench press. Three of the protocols were performed with low intensities at 37%, 46%, and 56% of 1RM and the other three with high intensities at 70%, 80%, and 90% of 1RM. In the high intensity protocols the contribution of the anaerobic component was 50.57% of the energy production in 70% of 1RM, 45.47% at 80% of 1RM and 41.57% at 90% of 1RM. EPOC accounted for 40.08% of EE at 70% of 1RM and 44.61%, and 51.81% at 80% and 90% of 1RM, respectively. The lower contribution was of the aerobic component, which corresponded to 9.35%, 9.91%, and 6.63% of EE at 70%, 80%, and 90% of 1RM, respectively. In the low intensity protocols, anaerobic, aerobic, and EPOC contributions were 46.38%, 21.42%, and 32,20%, respectively at 37% of 1RM, 51.31%, 16.06%, and 32.61%, respectively, at 46% of 1RM and 49.58%, 15.91%, and 34.52%, respectively at 56% of 1RM. It is interesting to note that the failure to consider the anaerobic component of these protocols would lead to an underestimation of EE in 40% to 50%.

Also using bench press, Scott et al. (22) quantified ergogenesis of two sets to muscular failure at 70%, 80%, and 90% of 1RM. The results showed that the greater component of EE was the EPOC, which was responsible for 51.29% of EE at 70% of 1RM, 53.80% at 80% of 1RM, and 61.79% at 90% of 1RM. The anaerobic component was responsible for 34.02%, 36.41%, and 29.66% of EE at 70%, 80%, and 90% of 1RM, respectively. The aerobic component had the lowest contribution of 14.68% at 70% of 1RM, 9,79% at 80% of 1RM, and 8.55% at 90% of 1RM.

In a more recent study in our laboratory, Campanholi Neto (2) quantified ergogenesis in RT protocols with endurance (2 sets of 21 repetitions at 50% of 1RM) and hypertrophy (3 sets of 10 repetitions at 70% of 1RM) characteristics with equated volume and a 2-min rest between sets. During the entire protocol, the aerobic component represented by the sum of O_2 uptake during sets and the EPOC corresponded to 94.3% in the endurance protocol and 96.2% in the hypertrophy protocol.

The combined data give rise to two conclusions. First, despite the predominance of the anaerobic metabolism during the sets in RT, the aerobic metabolism has the greater contribution to total EE due to the amount of O_2 that is consumed during and especially between sets were it reaches its peak values (23). The second conclusion is that during multiples sets of the same exercise, total EE is not altered, but there is an increase in aerobic energy production and a decrease in anaerobic energy production. Table 1 summarizes the studies on resistance exercise ergogenesis.

Table 1. Studies on Resistance Training Ergogenesis.

Reference	Protocols	Aerobic Contribution (Intra-Set Plus EPOC)	Anaerobic Contribution
Scott (19)	Two maximal sets at 60% of 1RM on leg press, bench press and biceps curls	63.74% on first set and 71.81% on second set	36.76% on first set and 28.19% on second set
	Two sets of 6 repetitions on biceps curls, 8 repetitions on bench press and 10 repetitions on leg press at 80% of 1RM	63.54% on first set and 78.07% on second set	36.46% on first set and 21.93% on second set
Scott et al. (20)	7 repetitions at 50% of 1RM on bench press	18.2% intra-set and 50.4% EPOC	31.4%
	14 repetitions at 50% of 1RM on bench press	18.7% intra-set and 42.0% EPOC	39.3%
	21 repetitions at 50% of 1RM on	21.3% intra-set and 33.9% EPOC	44.8%

	bench press		
Scott et al. (22)	Two maximal sets of bench press at:		
	70% of 1RM	14.7% intra-set and 51.3% EPOC	34.0%
	80% of 1RM	9.8% intra-set and 53.8% EPOC	36.4%
	90% of 1RM	8.6% intra-set and 61.8% EPOC	29.6%
Campanholi Neto (2)	2 x 21 rep at 50% of 1RM on 8 exercises with 2-min rest between sets	94.3%	5.7%
	3 x 10 at 70% of 1RM on 8 exercises with 2-min rest between sets	96.2%	3.8%

Another important finding by Scott (19) is that there is still no method to accurately predict EE during resistance training exercises and protocols. However, the literature has established some of the factors that influence EE during RT.

Effect of RT Variables

Resistance training has many training variables that allow for a great number of combinations to get the greatest benefit from the training sessions and test protocols. It is important that each combination of variables is made with caution and in accordance with the goals of the training program, the desired acute responses, and the phase and training status of the subject.

Currently, RT is a recognized healthcare strategy in decreasing body fat percentage and the treatment of metabolic disorders such as obesity and diabetes. In regards to the scope of the present review, the RT variables will be discussed as to the effect of each on EE.

Effect of Training Density on EE

Training density is the relation between effort and pauses during a session. Thus, the density components consist of the duration of the sets and the rest periods between the sets. Either by increasing the subject's set duration or reducing the rest periods between the sets, or a combination of the two strategies represents the primary means to increasing density of a session. The studies on training density are presented in Table 2.

Ratamess et al. (17) reported the effect of different rest periods on the EE of RT exercises. The subjects performed 5 protocols of 5 sets of 10 repetitions at 70% of 1RM and 5 sets of 5 repetitions at 85% of 1RM with rest periods of 30 sec and 1, 2, 3, and 5 min. Energy expenditure (EE) quantified as kcal per minute (kcal·min^{-1}) at 70% of 1RM was 7.3, 6.2, 5.6, 5.7, and 5.3 kcal·min^{-1} in the 30-sec, 1-, 2-, 3-, and 5-min protocols, respectively. At 85% of 1RM, EE was 6.8, 6.5, 5.3, 5.0, and 4.9 kcal·min^{-1} for the same rest periods, respectively. These data show that when EE is quantified by unit of time (i.e., kcal·min^{-1}), smaller rest periods lead to greater total EE. However, it is noteworthy that the authors did not exclude the resting EE of the subjects, which could have accounted for some and maybe all of the difference.

Farinatti and Castanheiras Neto (8) verified the EE of men during the dumbbell fly and leg press with 5 sets of 10 repetitions at 15RM intensity and 1 or 3 min of rest between sets. To isolate the effect of the protocols, the authors subtracted the resting EE of the protocols. Differences were found only for the dumbbell fly where the 3-min rest protocol led to greater EE compared to 1-min. For the leg press no differences were found between the protocols.

Similarly, Kelleher et al. (12) affected training density but by modifications in the training method. They compared the EE of multiple set protocols, where all the sets of an exercise were performed before going to the next one with a super-set protocol where two of different exercises were combined and the rest was taken only after the two sets were made. In the multiple set protocol EE was 6.29 kcal·min^{-1} and, in the super-set protocol, EE was 8.30 kcal·min^{-1}. This difference was statistically significant. However, the super-set protocol had rest periods only after every 2 sets and thus a lower duration. The total EE of the super-set protocol was 241.6 kcal, which was not significantly different of the 228.2 kcal of the multiple set protocol.

Mazzetti et al. (15) also quantified EE according to training density. They verified EE in three protocols of the squat exercise in a hack machine: (a) a slow protocol with 2 sec of eccentric and 2 sec of concentric phase at 60% of 1RM where 4 sets of 8 repetitions were made with 90-sec rest periods; (b) a fast protocol that differed from the last only for having fast concentric contractions; and (c) a fast protocol at 80% of 1RM with 2 sec of eccentric phase and a total of 6 sets of 4 repetitions and 90-sec rest-periods. Total work and EE were not different between protocols.

The combination of these data allows for the conclusion that EE of a RT session is more dependent on the volume and not the density. Modifications in training density seem to only affect EE in kcal·min^{-1} but not the total amount of energy.

Table 2. Studies on Resistance Training Density.

Reference	Protocols	Energy Expenditure
Ratamess et al. (17)	5 sets of 10 repetitions at 75% and 85% of 1RM with rest periods of:	EE (kcal·min^{-1}) at 75% and 85% of 1RM:
	30 sec	7.3 and 6.8 kcal·min^{-1}
	1 min	6.2 and 6.5 kcal·min^{-1}
	2 min	5.6 and 5.3 kcal·min^{-1}
	3 min	5.7 and 5.0 kcal·min^{-1}
	5 min	5.3 and 4.9 kcal·min^{-1}

Farinatti and Castanheiras Neto (8)	5 sets of 10 repetitions with intensity correspondent to 15RMs on dumbbell fly and leg press with rest periods of:	
	1 min	50.28 kcal on dumbbell fly and 88.73 kcal on leg press kcal·min^{-1}: NA
	3 min	54.14 kcal on dumbbell fly and 91.05 kcal on leg press kcal·min^{-1}: NA
Kelleher et al. (12)	Multiple set method	6.29 kcal·min^{-1} and Total EE of 228.6 kcal
	Super-set method	8.30 kcal·min^{-1}and total EE of 241.6 kcal
Mazetti et al. (15)	Slow: 2 sec ECC and 2 sec CONC, 4 sets of 8 repetitions at 60% 1RM and 90-sec rest on a hack machine + 60-min EPOC	2.22 kcal·min^{-1}
	Fast: 2 sec ECC and fast CONC, 4 sets of 8 repetitions at 60% 1RM and 90-sec rest on a hack machine + 60-min EPOC	2.35 kcal·min^{-1}
	Fast: 2 sec ECC and fast CONC, 6 sets of 4 repetitions at 80% 1RM and 90-sec rest on a hack machine + 60-min EPOC	2.19 kcal·min^{-1}

Effect of Training Intensity on EE

Intensity is the qualitative component of the training session. It determines the amount of effort during the execution of an exercise. Higher exercise intensity, expressed as percentage of 1RM leads to greater recruitment of type II motor units, which, despite their higher force production, are less metabolic efficient and consume higher amount of ATP per unit of work (11).

In the study by Scott (19), 2 sets of bench press to muscular failure at 60% of 1RM and 2 submaximal sets at 80% of 1RM were performed. When EE was divided by the number of repetitions (kcal·rep^{-1}; data calculated from the results presented), EE was 0.65 kcal·rep^{-1} in the first set and 0.72 kcal·rep^{-1} at 60% of 1RM and at 80% of 1RM EE was 0.95 kcal·rep^{-1} at the first set and 1.05 kcal·rep^{-1} at the second set. Although the sets at 80% of 1RM were submaximal, EE per repetition was still significantly higher when compared to maximal sets at 60% of 1RM.

Similarly, two more studies allowed quantifying EE per repetition. In the study of Scott et al. (20), EE in the low intensity sets at 37%, 46%, and 56% of 1RM was 0.42 $\text{kcal}\cdot\text{rep}^{-1}$, 0.54 $\text{kcal}\cdot\text{rep}^{-1}$ and 0.70 $\text{kcal}\cdot\text{rep}^{-1}$, respectively. In the high intensity sets of 70%, 80%, and 90% of 1RM, EE was 0.98 $\text{kcal}\cdot\text{rep}^{-1}$, 1.42 $\text{kcal}\cdot\text{rep}^{-1}$ and 1.82 $\text{kcal}\cdot\text{rep}^{-1}$, respectively. In another study of the same group (21), two sets were performed in the bench press at 70%, 80%, and 90% of 1RM. EE was 0.99 and 1.10 $\text{kcal}\cdot\text{rep}^{-1}$ in the two sets at 70% of 1RM, 1.37 and 1.43 $\text{kcal}\cdot\text{rep}^{-1}$ in the two sets at 80% of 1RM and 2.00 and 1.98 $\text{kcal}\cdot\text{rep}^{-1}$ in the two sets at 90% of 1RM.

All these results clearly show that despite the dependence of EE on the volume rather than the density of RT, this relationship seems to be true only when training intensity is the same. According to Henneman's size principle, as intensity is increased, less efficient higher threshold motor units are progressively recruited (18). Results of studies on training intensity are displayed on Table 3.

Table 3. Studies on Resistance Training Intensity.

Reference	Protocols	Energy Expenditure
Scott (19)	Two maximal sets at 60% of 1RM	0.65 $\text{kcal}\cdot\text{rep}^{-1}$ on the first set and 0.72 $\text{kcal}\cdot\text{rep}^{-1}$ on the second set
	Two submaximal sets at 80% of 1RM	1.05 $\text{kcal}\cdot\text{rep}^{-1}$ on the first set and 0.95 $\text{kcal}\cdot\text{rep}^{-1}$ on the second set
Scott et al. (20)	One maximal set on bench press at:	
	37% of 1RM	0.42 $\text{kcal}\cdot\text{rep}^{-1}$
	46% of 1RM	0.54 $\text{kcal}\cdot\text{rep}^{-1}$
	56% of 1RM	0.70 $\text{kcal}\cdot\text{rep}^{-1}$
	70% of 1RM	0.98 $\text{kcal}\cdot\text{rep}^{-1}$
	80% of 1RM	1.42 $\text{kcal}\cdot\text{rep}^{-1}$
	90% of 1RM	1.82 $\text{kcal}\cdot\text{rep}^{-1}$
Scott et al. (21)	Two maximal sets of bench press at:	
	70% of 1RM	0.99 $\text{kcal}\cdot\text{rep}^{-1}$ on the first set and 1.10 $\text{kcal}\cdot\text{rep}^{-1}$ on the second set
	80% of 1RM	1.37 $\text{kcal}\cdot\text{rep}^{-1}$ on the first set and 1.43 $\text{kcal}\cdot\text{rep}^{-1}$ on the second set
	90% of 1RM	2.00 $\text{kcal}\cdot\text{rep}^{-1}$ on the first set and 1.98 $\text{kcal}\cdot\text{rep}^{-1}$ on the second set

Effect of Muscular Failure on EE

To our knowledge only two studies have directly verified the effect of muscular failure on the EE of RT. Gorostiaga et al. (10) evaluated the EE on the leg press in two protocols: (a) maximal set of 10 repetitions (10RMs); and (b) a set of 5 repetitions with the intensity corresponding to 10RMs. The authors reported that EE per repetition was higher in the 10RMs set, which indicates that the second half of the set that is closer to the muscular failure has the greater EE.

Scott et al. (21) compared EE with and without muscular failure in the bench press. Submaximal protocols consisted of 7, 14, and 21 repetitions at 50% of 1RM. Maximal protocols (i.e., with muscular failure) were performed at 37%, 46%, 56%, 70%, 80%, and 90% of 1RM. Comparison showed that the maximal protocols led to greater EE through aerobic and anaerobic components.

Two main factors can explain the greater EE in maximal sets. The first is the motor units recruitment pattern. As previously described, maximal sets lead to progressive recruitment of higher diameter motor units that are less metabolic efficient and spend more energy for unit of muscular work. Despite not using maximal sets, a study in our laboratory (2) is in accordance with these findings, where individuals with experience in RT were submitted to 4 sets of 10 repetitions in leg press and bench press. In both exercises, EE was significantly higher in the 4th set, given the proximity to muscular failure. Velocity of movement was held constant at 3 sec per cycle of movement throughout the protocols.

The second factor is the time under tension of the sets. As demonstrated by Duffey and Challis (7) and Izquierdo et al. (9), during the last repetitions of a set to muscular failure, velocity of movement decreases and becomes closer to the velocity of a 1RM test. The lower velocity increases the time under tension and thus increases EE.

CONCLUSIONS

Despite the predominance of anaerobic metabolism during the sets of RT, the greater component of EE is the oxygen consumption during the sets and especially on EPOC. Affecting training density only affects EE when it is quantified per minute ($\text{kcal}\cdot\text{min}^{-1}$) but not the total EE of a training session, which is more dependent on training volume. EE is also proportional to exercise intensity due to the recruitment of higher threshold motor units and muscular failure also increases EE of a set due to motor units and velocity of movement. Future studies should focus on determining how other variables affect EE and comparing the EE between different populations and exercises.

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