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ABSTRACT. Robergs R.A., T. Gordon, J. Reynolds, and T.B. Walker. Energy expenditure during bench press and squat exercises. *J. Strength Cond. Res. 21(1):123–130. 2007.*—Despite the popularity of resistance training (RT), an accurate method for quantifying its metabolic cost has yet to be developed. We applied indirect calorimetry during bench press (BP) and parallel squat (PS) exercises for 5 consecutive minutes at several steady state intensities for 23 (BP) and 20 (PS) previously trained men. Tests were conducted in random order of intensity and separated by 5 minutes. Resultant steady state $\dot{V}O_2$ data, along with the independent variables load and distance lifted, were used in multiple regression to predict the energy cost of RT at higher loads. The prediction equation for BP was $Y' = 0.132 + (0.031)(X_1) + (0.01)(X_2)$, $R^2 = 0.728$ and $S_{xy} = 0.16$; PS can be predicted by $Y' = -1.424 + (0.022)(X_1) + (0.035)(X_2)$, $R^2 = 0.656$ and $S_{xy} = 0.314$; where Y′ is $\dot{V}O_2$, X_1 is the load measured in kg and X_2 is the distance in cm. Based on a respiratory exchange ratio (RER) of 1.0 and a caloric equivalent of 5.05 $kcal{\cdot}L^{-1}$, $\dot{V}O_2$ was converted to caloric expenditure ($kcal{\cdot}min^{-1}$). Using those equations to predict caloric cost, our resultant values were significantly larger than caloric costs of RT reported in previous investigations. Despite a potential limitation of our equations to maintain accuracy during very high-intensity RT, we propose that they currently represent the most accurate method for predicting the caloric cost of bench press and parallel squat.

KEY WORDS. resistance training, weight lifting, oxygen cost, caloric cost

INTRODUCTION

During the past 2 decades resistance training (RT) has evolved from a training mode utilized almost exclusively by athletes to one utilized by almost all exercising populations. Research from the Sporting Goods Manufacturers Association found that 42.8 million Americans trained with free weights in 1999, 60% more than the 26.7 million in 1990 (31). As such, training with free weights became the most popular form of exercise during the 1990s and was one of only a few training modes that continued to increase in popularity into the 21st century.

The American College of Sports Medicine (1), American Heart Association (12), and the Surgeon General's Report on Physical Activity and Health (32) all have recognized the importance of strength training to improved health and well-being. The ACSM included RT in their recommendations for exercise training for healthy adults in 1998. The health benefits of resistance training include improved strength, anaerobic capacity, body composition, bone density, flexibility, and physical function (1).

Given the increased participation in RT and the continued increase in the number of overweight adults, it would be advantageous to accurately estimate the true energy expenditure of RT. However, as RT induces muscle metabolic demands across all 3 energy systems, it is impossible to accurately measure the energy demands of moderate- to high-intensity RT using indirect calorimetry. Nevertheless, Wilmore et al. (33) were the first to attempt to quantify the metabolic cost of RT. They applied indirect calorimetry during not only the RT itself but also during postexercise recovery until subjects returned to pre-exercise metabolic rates. At the time of that investigation, excess postexercise oxygen consumption (EPOC) was still generally thought to be a repayment of "oxygen debt."

However, numerous investigators since the 1980s have proven the invalidity of EPOC to quantify nonmitochondrial ATP turnover in contracting skeletal muscle. For example, Gaesser and Brooks were highly critical of the concept of an oxygen debt, where postexercise $\dot{V}O_2$ was interpreted to represent the added energy costs of high-intensity exercise (14). Furthermore, Scott (28, 29), Bahr et al. (4, 5), and Gore and Withers (15) have demonstrated that several independent factors contribute to the magnitude of EPOC. Excess postexercise oxygen consumption can vary greatly depending on the intensity (15) and duration of exercise (4, 15), the rest period between sets (17), pre-exercise nutrition (5), and training status (30). Consequently, simply measuring $\dot{V}O_2$ after exercise and adding it to the exercise $\dot{V}O_2$ does not accurately represent the true metabolic cost of high-intensity exercise.

It is apparent that the method of estimating the metabolic cost of RT by including EPOC is flawed. Despite evidence of its inherent inaccuracy, investigators researching metabolic costs of various types of RT have continued to use the Wilmore method (10), or a variation of the Wilmore method such as measuring EPOC for a predetermined amount of time (8, 20, 27). Complicating matters further, investigators using a predetermined duration of postexercise $\dot{V}O_2$ have not been consistent, using time periods as short as 10 minutes (27) or as long as 20 minutes (9) without explanation of how such durations were chosen. Furthermore, some recent studies appear to have simply ignored the contribution of nonmitochondrial energy systems to metabolism (7, 24, 25). At this time there does not seem to exist a reliable and consistent method of quantifying the metabolic cost of RT. We propose that a novel approach of using extrapolated steady state values to estimate the metabolic cost of RT throughout a range of intensities is more valid and accurate than previous methods.

The purpose of this study was to quantify the oxygen cost of bench press and parallel leg squat exercise during multiple steady state conditions, and from these values extrapolate the caloric expenditure of these actions when lifting heavier loads. A secondary purpose was to compare the results predicted in the current study to results reported in previous investigations. Our hypothesis was that our predicted metabolic cost values would be slightly higher than those determined in studies that utilized the

TABLE 1. Subject characteristics (mean ± *SD*).*

Characteristic	Bench press (*n* = 23)	Squat (*n* = 20)
Age (years)	23.6 ± 4.6	23.3 ± 3.5
Height (cm)	177.2 ± 4.2	176.0 ± 6.9
Weight (kg)	92.2 ± 19.0	86.6 ± 12.6
1RM (kg)	122.7 ± 21	233.3 ± 67.4 with BW; 146.7 ± 36.1 without BW

* 1RM = 1 repetition maximum; BW = body weights.

Wilmore method and much higher than those that ignored nonmitochondrial metabolism. Although we recognize the limitations of steady state $\dot{V}O_2$ extrapolation to excessively high-intensity exercise, we argue here that until a more valid method is devised, our approach is currently the most accurate method to estimate the true metabolic cost of RT.

METHODS

Experimental Approach to the Problem

We applied indirect calorimetry during bench press (BP) and parallel squat (PS) exercises at several steady state intensities for 23 (BP) and 20 (PS) previously resistance-trained men. At such intensities, exercise is fueled completely by oxidative metabolism, eliminating the need to measure or include EPOC. Steady state $\dot{V}O_2$ data, along with the independent variables load and distance lifted, were used in multiple regression to develop equations that predict the cost of RT at loads of any intensity.

One repetition maximum (1RM) testing was conducted at the main campus weight room. All exercise testing that required gas collection was completed at the Exercise Physiology Laboratory. The university medical school Human Research Review Committee approved the protocol for this study. All subjects completed a written informed consent form prior to participating in this study.

Subjects

Thirty male subjects, ages 18 to 45 years, volunteered to participate in this study. Participants were resistance-trained individuals (minimum of 1 year) who were currently including barbell flat bench press and parallel squat exercises in their training. All participants were in good health, as self-reported on a medical history questionnaire. Of the 30 subjects, 23 participated in the bench press protocol, and 20 participated in the squat protocol based on self-reported current resistance training using either action. Subject characteristics are shown in Table 1.

Resistance Equipment

A standard 2.13-m, 20.45-kg Olympic barbell (York Barbell Company, York, PA), York weight plates (20.45, 15.90, 11.36, 4.50, 2.27, and 1.14 kg), and 0.6-kg safety collars were used during 1RM testing. A 5.2-kg bar, 20.45-kg bar, and weights from 1.0 to 4.5 kg were utilized during the gas collection protocols.

Procedures

A National Strength and Conditioning Association (NSCA) certified strength and conditioning specialist ensured that all subjects adhered to proper technique during their testing session. Safety during 1RM testing was achieved by continuous supervision and the 3-person spotting method. After a warm-up, initial 1RM attempt values were 90% of self-estimated 1RM. Each subject attempted progressively heavier weights until 2 consecutive failures at the same weight occurred. A minimum of 2 minutes of rest between attempts was provided for a maximal lifting effort (3). The 1RM was utilized as a means for standardizing the percentage of weight lifted by each subject during the next phase of the testing protocol.

The flat barbell bench press technique required subjects to remain in a 5-point contact zone which consisted of both feet, the buttocks, shoulder blades, and back of the head being in contact with either the bench or ground at all times. A lift was deemed successful if the subject was able to lower the bar eccentrically in a controlled manner, lightly touch the chest, and return the bar concentrically to a fully locked out position without assistance from the spotters (3).

The parallel squat required each subject to eccentrically lower his body through flexion of the knees and hips until the thighs (midline from hip to knee) were parallel to the floor, then return to a full upright and erect standing position using forceful concentric contractions of the hip and knee extensors. Any external assistance provided by a spotter rendered the lift unsuccessful (3).

1 Repetition Maximum Testing

Prior to participating in any of the following exercise trials, subjects were given explicit instructions to refrain from the following activities: eating within 3 hours prior to testing; smoking; consuming caffeine or ergogenic aids containing Ma Huang or ephedrine within 12 hours prior to testing; heavy resistance and/or prolonged (>60 minutes) endurance training within 48 hours prior to testing. Subjects were also asked to come to each trial euhydrated.

For the 2 testing sessions that required the collection of expired gases, participants breathed through a low resistance, low dead-space 2-way nonrebreathing valve (Models #2870A and #2700A; Hans-Rudolph Corporation, Kansas City, MO) connected to a compliant plastic mixing bag. Gas samples were continually pumped from the mixing bag for expired gas sampling, which occurred for a 150-ms interval at the end of each expiration. Electronic gas (oxygen and carbon dioxide) analyzers (AEI, Pittsburgh, PA) were used to measure the gas fractions of air sampled continuously from the mixing chamber. Expired airflow was computed for each breath using a flow turbine (K.L. Engineering, Van Nuys, CA). Analog signals from each analyzer and flow turbine were acquired and integrated to a computer using a peripheral signal processing device and data acquisition card (National Instruments, Austin, TX). Data were acquired and processed for each breath using custom developed software (Lab View, National Instruments, Austin, TX).

Prior to the start of each test, the gas analyzers were calibrated with known concentrations of N_2, O_2, and CO_2 while the flow turbine was calibrated with a 3-L syringe. After each test, data were transferred as a text file to a spreadsheet (Microsoft Excel 2000, Microsoft, Seattle, WA) and graphics and curve-fitting program (Prism 3.0, GraphPad Software, San Diego, CA) for subsequent data processing, curve fitting, and graphical analyses.

Exercise Testing

Pilot testing revealed that loads of 5–23% of 1RM bench press were heavy enough to induce $\dot{V}O_2$ values above resting while light enough to be performed for 5 consecutive minutes. Test protocols consisted of 5 bouts of exercise, 5 minutes each, at 5–23% of 1RM and were conducted on

TABLE 2. Sample raw data for steady state bouts at different intensities for bench press.

Subject	Load (kg)	Distance (cm)	$\dot{V}O_2$ (L·min^{-1})
1	0.00	39.0	0.73
	6.90	39.0	0.77
	10.10	39.0	0.81
	20.45	39.0	1.26
	34.00	39.0	1.57
2	0.00	41.0	0.75
	14.90	41.0	1.05
	20.45	41.0	1.42
	24.60	41.0	1.50
	29.95	41.0	1.74
3	0.00	41.5	0.58
	12.10	41.5	1.01
	15.00	41.5	1.29
	20.45	41.5	1.38
	25.05	41.5	1.24
4	0.00	45.5	0.66
	7.90	45.5	1.07
	10.70	45.5	1.28
	13.00	45.5	1.34
	20.45	45.5	1.59

TABLE 3. Sample raw data for steady state bouts at different intensities for parallel squat.*

Subject	Load (kg)	Load w/BW (kg)	Distance (cm)	$\dot{V}O_2$ (L·min^{-1})
1	0.00	121.20	40.5	2.58
	6.90	128.10	40.5	2.87
	13.50	134.70	40.5	3.06
	25.00	146.20	40.5	3.07
	34.00	155.20	40.5	3.28
	43.00	164.20	40.5	3.43
2	0.00	86.10	51.5	2.51
	20.00	106.10	51.5	2.63
	25.00	111.10	51.5	2.74
	29.00	115.10	51.5	2.77
	34.00	120.10	51.5	2.98
3	0.00	75.80	38.0	1.99
	7.90	83.70	38.0	2.12
	27.27	103.07	38.0	2.41
	34.00	109.80	38.0	2.32
	41.00	116.80	38.0	2.39
4	0.00	84.60	43.0	1.77
	7.10	91.70	43.0	2.06
	25.00	109.60	43.0	2.27
	30.00	114.60	43.0	2.38
	35.00	119.60	43.0	2.55

* BW = body weights.

each subject in random order of intensity. Each 5-minute test bout was separated by at least 5 minutes of recovery. For each subject, all 5 bouts were completed on the same day. A Timex portable metronome set at 40 beats·min^{-1} was used to standardize the rate of each repetition (1 repetition every 3 seconds = 20 reps·min^{-1}) to ensure that work rates could be accurately assessed for each subject (17, 30). For parallel squat, subjects' body weights were included in the load so that the lightest workload each subject performed was a parallel squat without a bar or any plates. The range of motion of each repetition was monitored by an observer, and continual feedback was given to the subjects to ensure consistency in range of motion. Pilot testing revealed that loads of 31–57% of 1RM parallel squat (equivalent to ~3–25% of 1RM of above body weight load) were heavy enough to induce $\dot{V}O_2$ values above resting while light enough to be performed for 5 consecutive minutes. Again, a metronome was used to standardize the rate of each repetition at 20 reps·min^{-1}. Distance was defined as the span between where the load started and where it completed the eccentric phase of the contraction. Test protocols consisted of five 5-minute bouts of exercise at 31–57% of 1RM and were conducted on each subject in random order, each separated by 5 minutes of recovery.

For each exercise (flat bench press and parallel squat) and each level of exercise intensity, $\dot{V}O_2$ was measured and indirect calorimetry was performed continuously during a 5-minute bout of exercise. $\dot{V}O_2$ data was fitted with a mono-exponential association curve using commercial software (Prism 3.0). The resulting plateau value was used to represent the steady-state $\dot{V}O_2$.

We compared our predicted values to values reported by previous studies (7, 20, 25, 27, 33) by applying those studies' intensities (% of 1RM) to our subjects' mean 1RM. We used the resulting load in our prediction equations to calculate $\dot{V}O_2$. Then, based on an RER of 1.0 and the associated caloric equivalent of 5.05 kcal·L^{-1}, $\dot{V}O_2$ was converted to caloric expenditure (kcal·min^{-1}). Comparisons were made only to previously studied groups of fit men.

Statistical Analyses

Linear regression analyses were performed, using SPSS (version 12.0; SPSS, Inc., Chicago, IL) to describe the relationships between load, distance lifted, and $\dot{V}O_2$ for each action. Multiple regression analyses were used to derive a regression equation for future prediction of caloric expenditure due to resistance training actions using the independent variables (IV) of load and distance lifted, providing subject to IV ratios of 11.5 and 10.0 for BP and PS, respectively. Regression analyses were tested for assumptions of linearity, homoscedasticity, normality, and independence of residuals. One-sample *t*-tests using our predicted value as the expected mean were utilized to compare the differences between previous caloric expenditure values obtained for RT and the values found in this study. Statistical significance was accepted at $p \leq 0.05$. Because the primary purpose of this study was to develop a predictive regression equation for energy expenditure, we did not use desired statistical power to determine sample size.

RESULTS

Sample data showing load, distance, and steady-state $\dot{V}O_2$ for 4 randomly selected subjects are displayed for bench press and parallel squat in Tables 2 and 3, respectively. A sample linear regression plot for $\dot{V}O_2$ vs. load for bench press for 1 subject displayed in Figure 1, while Figure 2 shows a $\dot{V}O_2$ vs. load regression plot for parallel squat for the same subject.

The regression equation for the bench press was $Y' = 0.132 + (0.031)(X_1) + (0.01)(X_2)$ where X_1 is the load measured in kg and X_2 is the distance in cm. Our combined predictors had a significant relationship with $\dot{V}O_2$, $F(2, 118) = 155.36$, $p < 0.001$. Tables 4 and 5 show regression information for bench press. To best represent this relationship visually, we combined distance and load with rate to calculate power. Figure 3 shows the relationship between power and $\dot{V}O_2$. Load and distance were able to predict 72.8% of total variance (using power reduced R^2 slightly to 0.726). The zero-order correlation for load was 0.848 while the zero-order correlation for distance was 0.014. The semipartial, or part, correlations for load and distance were 0.853 and 0.174, respectively.

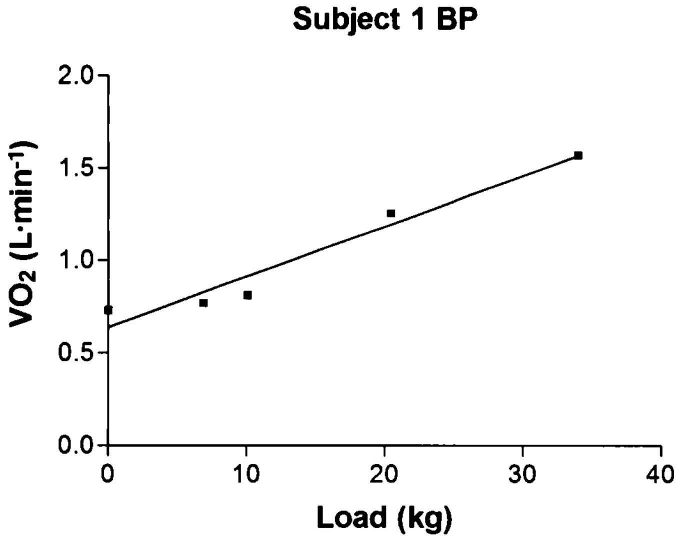

FIGURE 1. Sample data for subject #1 during bench press (BP).

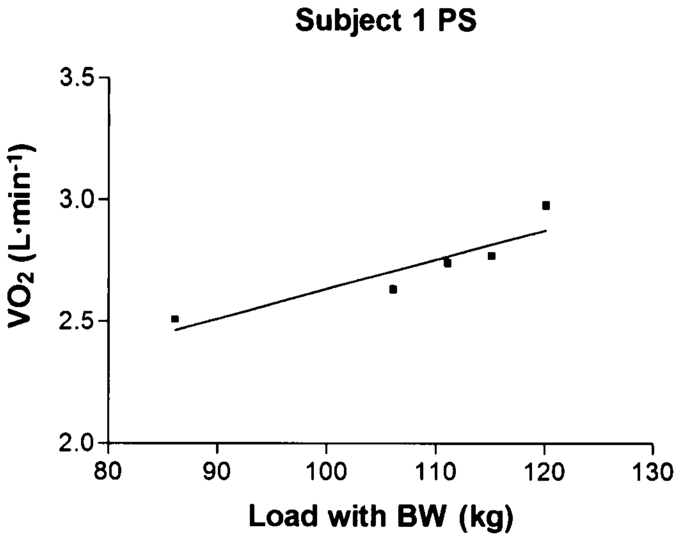

FIGURE 2. Sample data for subject #1 during parallel squat (PS). BW = body weights.

TABLE 4. Multiple regression correlation matrix for bench press.

		Vo_2	Load	Distance
Pearson correlation	Vo_2	1.000	.848	.014
	Load	.848	1.000	−.092
	Distance	.014	−.092	1.000
Significance (1-tailed)	Vo_2		.000	.440
	Load	.000		.160
	Distance	.440	.160	
N	Vo_2	119	119	119
	Load	119	119	119
	Distance	119	119	119

TABLE 5. Multiple regression summary for bench press.*

Model	*R*	R^2	Adjusted R^2	Standard error of the estimate
1	.853†	.728	.723	.162014

* Dependent variable: Vo_2.
† Predictors: (constant), distance, load.

TABLE 6. Multiple regression correlation matrix for parallel squat.

		Vo_2	Load	Distance
Pearson correlation	Vo_2	1.000	.724	.277
	Load	.724	1.000	−.114
	Distance	.277	−.114	1.000
Significance (1-tailed)	Vo_2		.000	.002
	Load	.000		.126
	Distance	.002	.126	
N	Vo_2	102	102	102
	Load	102	102	102
	Distance	102	102	102

TABLE 7. Multiple regression summary for bench press.*

Model	*R*	R^2	Adjusted R^2	Standard error of the estimate
1	.810†	.656	.649	.314080

* Dependent variable: Vo_2.
† Predictors: (constant), distance, load.

The regression equation for the parallel squat was $Y' = -1.424 + (0.022)(X_1) + (0.035)(X_2)$ where X_1 is the load measured in kg and X_2 is the distance in cm. Our combined predictors had a significant relationship with $\dot{V}\mathrm{o}_2$, $F(2, 101) = 94.229$, $p < 0.001$. Tables 6 and 7 show regression information for parallel squat. Again, to best represent this relationship visually, we calculated power and plotted it against $\dot{V}\mathrm{o}_2$ in Figure 4. For the squat, load and distance were able to predict 65.6% of total variance. The zero-order correlation for load was 0.724 while the zero-order correlation for distance was 0.277. The semi-partial, or part, correlations for load and distance were 0.792 and 0.525, respectively.

Figure 5 displays raw and predicted $\dot{V}\mathrm{o}_2$ data with superimposed line of best fit and line of identity for bench press while Figure 6 shows that information for parallel squat. Figures 7 and 8 display plots of residuals for bench press and parallel squat, respectively.

Our predicted values for RT at various intensities were significantly larger than all previously measured values with which they were compared. Table 8 provides a summary of the individual comparisons.

DISCUSSION

Despite the invalidation of historical interpretations of the oxygen debt and the rapidly increasing use of RT as general fitness and a weight loss method, our study is the first to investigate the metabolic cost of RT using steady-state exercise bouts with regression to predict the actual cost of RT at higher intensities. We found that the metabolic cost of the flat bench press could be accurately predicted with an equation of $Y' = 0.132 + (0.031)(X_1) + (0.01)(X_2)$ while the parallel squat can be predicted by $Y' = -1.424 + (0.022)(X_1) + (0.035)(X_2)$ where Y' is $\dot{V}\mathrm{o}_2$, X_1 is the load measured in kg, and X_2 is the distance in cm. These equations should provide the most accurate method to date for exercisers, trainers, and investigators of determining the amount of energy being expended during RT.

Although our predictors were statistically significant for both exercises, our ability to account for variability was less than we had hoped. Our regression equations were able to account for 72.8% and 65.6% of the total variability of the metabolic cost of bench press and par-

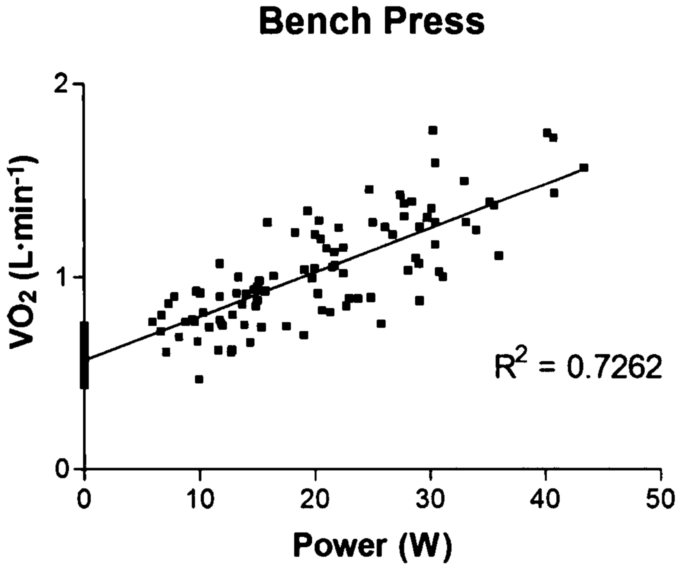

FIGURE 3. Composite O_2 consumption vs. power for bench press.

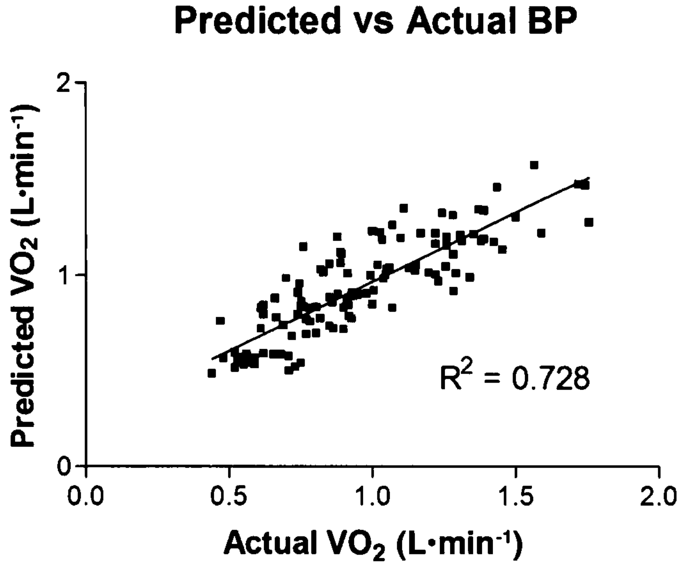

FIGURE 5. Regression plot (predicted VO_2 vs. actual VO_2) for bench press.

allel squat, respectively. The remaining variability could be a result of undetected differences in rate, individual differences in body geometry (e.g., the ratio of femur length to tibia/fibula length), and/or differences in technique (e.g., foot/hand/head positions). Though we watched carefully for variations in rate or technique, subtle differences may have gone unnoticed. Rate is a potentially confounding variable in the field as repetition rate may change with intensity or fatigue despite the best intentions of the lifter. Additionally, if the RT consists of "super-slow" training or plyometric/explosive training, our prediction equations would lose accuracy.

Another possible limitation of our method is the potential that the relationship between work and $\dot{V}O_2$ is not linear through all intensities. Medbo et al. (22) have asserted that it is linear, as have other investigators (16). Green and Dawson (16) demonstrated a linear relationship between intensity and $\dot{V}O_2$ during cycle ergometry from rest through maximal intensity. However, in a similar study, Zoldadz et al. (35) found that during cycle ergometry at intensities below the lactate threshold, $\dot{V}O_2$ showed a linear relationship with power output, but at high power outputs there was an additional increase in $\dot{V}O_2$ above that expected from the extrapolation of the linear relationship, leading to a positive curvilinear $\dot{V}O_2$-power output relationship (e.g., actual $\dot{V}O_2$ at maximal power output was higher than expected $\dot{V}O_2$ at maximal power output from linear extrapolation.) They hypothesized that the change in the $\dot{V}O_2$-power output relationship could be related to the progressive recruitment of different muscle fiber types with a lower mechanical efficiency. Results supporting the notion of a curvilinear relationship have also been found for treadmill running. Lacour et al. (21) found that in running, $\dot{V}O_2$ is only linear at those intensities that do not tax nonoxidative systems. Above those intensities, the relationship again became curvilinear.

Zoldadz and Korzeniewski (34) recently published a

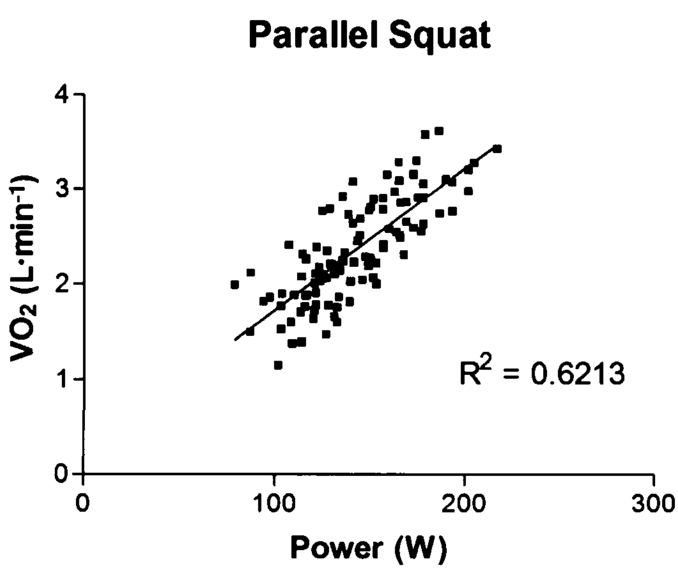

FIGURE 4. Composite O_2 consumption vs. power for parallel squat.

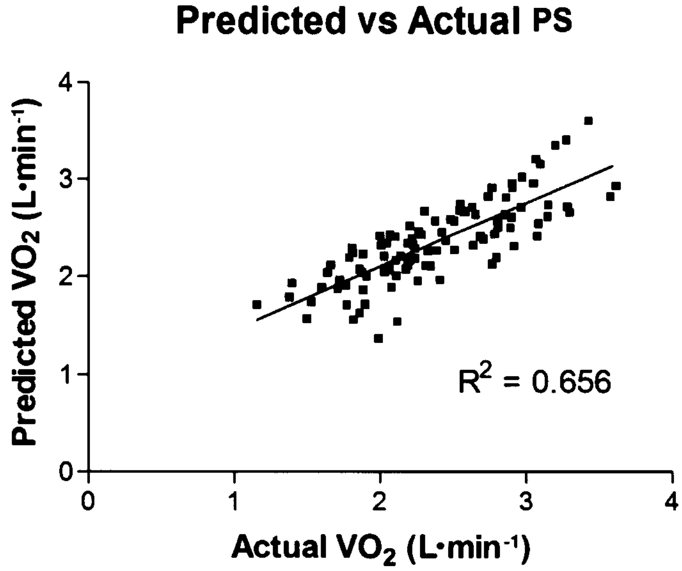

FIGURE 6. Regression plot (predicted VO_2 vs. actual VO_2) for parallel squat.

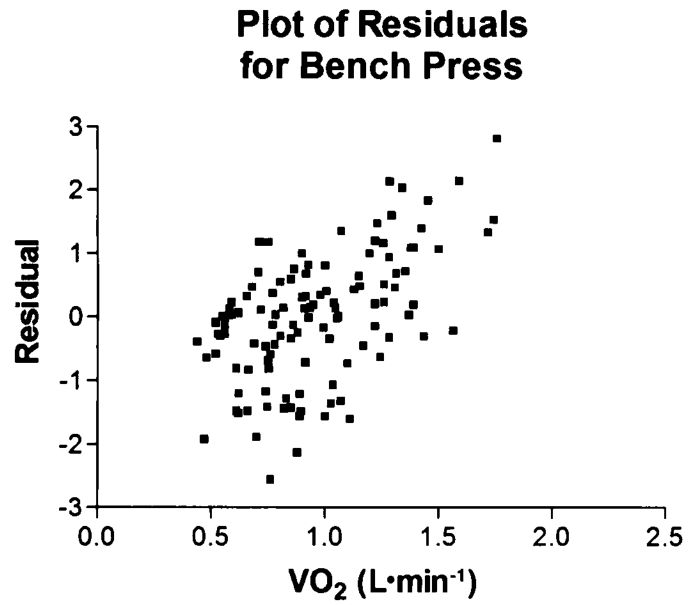

Figure 7. Plot of residuals for bench press.

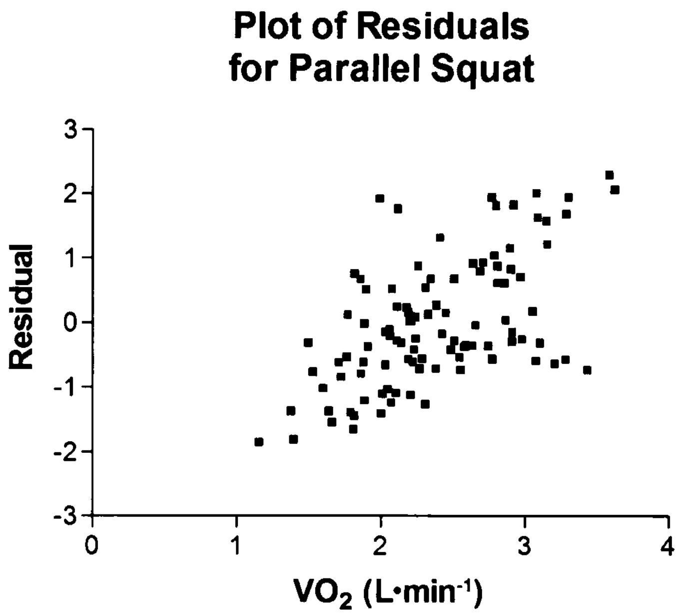

Figure 8. Plot of residuals for parallel squat.

thorough review of investigations into the relationship between power output and $\dot{V}O_2$. Their review of the relevant literature supported the belief that the relationship is curvilinear. They reviewed the potential mechanisms that are involved in setting what they refer to as the "change point" in oxygen uptake. These mechanisms include: increased activation of additional muscle groups, intensification of respiratory muscle activity, recruitment of type II muscle fibers, increased muscle temperature, increased basal metabolic rate, lactate and proton accumulation, proton leak through the inner mitochondrial membrane, and a decrease in the cytosolic phosphorylation potential. Although such research has yet to be performed using RT as the exercise mode and despite the lack of consensus as to the exact mechanism, there appears to be a strong argument that the relationship between $\dot{V}O_2$ and power output may not remain linear at very high power outputs. Therefore, the accuracy of our predicted values could suffer for RT performed at extremely high intensities.

It is not surprising that our predicted values were significantly larger than all previously reported values with which they were compared. Resistance training makes demands on the phosphagen, glycolytic, and mitochondrial energy systems. It is impossible to completely measure RT's metabolic cost by applying indirect calorimetry during moderate- to high-intensity RT as that method ignores the contributions of the phosphagen and glycolytic systems. We expected our values to be moderately higher than those found in studies that used some variation of the Wilmore method (9, 20, 27, 33). Wilmore's method (33) was an inventive idea that attempted to include all energy systems, but was based on the faulty premise of oxygen debt. Because EPOC is so complex and its length and magnitude are affected by so many variables, it is inaccurate to simply continue indirect calorimetry until $\dot{V}O_2$ returns to pre-exercise levels or for a predetermined amount of time as some studies (9, 20, 27) have done. Further, 3 recent studies (7, 24, 25) apparently used $\dot{V}O_2$ from the exercise bout only, and ignored nonmitochondrial metabolism. We expected our values to be much higher than those found in those studies and they were. Admittedly, these comparisons are difficult because previous studies have used widely varying intensities, differ-

Table 8. Comparison of predicted kcal·min^{-1} to values found in previous studies.*

% of 1RM	Predicted	Previous (ref)	Difference	*t*	df	*p*
40.0						
BP	10.49	9.00 (32)	1.49	−4.130	19	<0.001
PS	10.85	9.00 (32)	1.85	−5.140	19	<0.001
50.0						
BP	12.41	6.21 (7)	6.20	−22.095	11	<0.001
PS	13.56	6.21 (7)	7.35	−26.515	11	<0.001
62.5						
BP	14.81	11.50 (27)	3.31	−5.733	9	<0.001
PS	16.95	11.50 (27)	5.45	−9.654	9	<0.001
65.0						
BP	15.29	5.93 (20)	9.36	−25.021	6	<0.001
PS	17.63	5.93 (20)	11.70	−31.227	6	<0.001
70.0						
BP	16.25	5.63 (25)	10.62	−37.125	5	<0.001
PS	18.98	5.63 (25)	13.35	−46.627	5	<0.001

* 1RM = 1 repetition maximum; df = degrees of freedom; BP = bench press; PS = parallel squat.

ent equipment, and diverse exercises. For example, Phillips and Ziuraitis (24) had their subjects perform a 15RM set. There is some inherent variability in determining exactly what percent of 1RM that is. We used Hoeger's (19) values for trained men in estimating 15RM to be equivalent to 70% of 1RM. In another case, Scala et al. (27) provided a breakdown of caloric cost specific to large muscle mass exercises (11.5 kcal·min^{-1}) and small muscle mass exercises (6.8 kcal·min^{-1}) but were not specific regarding what exercises constituted their large vs. small muscle mass groupings. Because we judged BP and PS to match more closely to their large muscle mass exercises, we used their large muscle mass exercise caloric cost value of 11.5 kcal·min^{-1} as the value with which we compared our predicted value. Only 2 of the studies we used for comparisons used free weights in their RT protocols (7, 27). Other studies (18, 24, 25, 33) used some form of RT machine while Hunter et al. (20) did not specify whether their subjects used free weights or a machine. It is predictable that the metabolic cost of RT using free weights would be higher than the cost of RT using most machines because of the greater recruitment of accessory muscles with free weights.

The fact that our predictions contend RT demands more energy than formerly thought may explain why the number of recreational athletes and fitness exercisers performing RT has grown so rapidly in recent years. Perhaps these populations are discovering anecdotally what several recent studies have implied: that RT is better at improving body composition than previously believed. Park et al. (23) found that subcutaneous fat and visceral fat levels were decreased in an RT plus aerobics training group more than in the aerobics only group. Banz et al. (6) demonstrated that after 10 weeks of endurance training or endurance training with RT, both groups showed a significant reduction in waist-to-hip ratio but only the RT group showed a reduction in total body fat. Prabhakaran et al. (26) showed that 14 weeks of RT resulted in a significantly lower body fat percentage in young women. Accordingly, studies investigating the body composition of male Olympic weightlifters (13) and powerlifters (14) have consistently reported that their subjects' body fat percentages compared favorably to those of average college-aged men.

We conclude that the metabolic cost of bench press for fit men can be accurately predicted with an equation of $Y' = 0.132 + (0.031)(X_1) + (0.01)(X_2)$ while the parallel squat can be predicted by $Y' = -1.424 + (0.022)(X_1) + (0.035)(X_2)$ where Y' is $\dot{V}O_2$, X_1 is the load measured in kg, and X_2 is the distance in cm. However, our findings cannot be generalized beyond trained men. Investigations similar to this study need to be performed for other populations, particularly trained women, and for other common exercises and types of equipment.

PRACTICAL APPLICATIONS

There are several lessons that athletes and their trainers may take from this research. The first, and most general, is the fact that low- to moderate-intensity RT likely has a higher caloric cost than previously thought. This notion lends more support to the importance of including RT into exercise programs that are designed to promote fat loss or body composition improvement. Several studies (6, 13, 14, 23, 26) have previously shown that RT can be effective in these types of programs, and the current study provides support as to why. Second, our results indicate that a lower quantity of RT than previously thought may be sufficient to meet the common guidelines (2, 11) for expending up to 2000 kcal·week^{-1} to optimize health and body composition. For example, the current study indicates that RT at 65% of 1RM burns approximately 15 kcal·min^{-1}. At that rate, only 1 hour per week of RT results in an expenditure of ~900 kcal. Finally, for trainers and athletes who desire to maintain a very precise tally of caloric expenditure, the regression equations listed above likely provide the most accurate means yet of which to do so. However, trainers should keep in mind that these equations may accurately be used only for resistance-trained men and for the specific exercises of BP and PS.

REFERENCES

1. AMERICAN COLLEGE OF SPORTS MEDICINE POSITION STAND. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med. Sci. Sports Exerc.* 30:975–991. 1998.
2. AMERICAN COLLEGE OF SPORTS MEDICINE POSITION STAND. Appropriate intervention strategies for weight loss and prevention of weight regain for adults. *Med. Sci. Sports Exerc.* 33:2145–2156. 2001.
3. BAECHLE, T.R., AND R.W. EARLE, eds. *Essentials of Strength Training and Conditioning/National Strength and Conditioning Association (2nd ed.).* Champaign, IL: Human Kinetics, 2000. pp. 292–298.
4. BAHR, R.I., I. INGES, O. VAAGE, O.M. SEJERSTED, AND E.A. NEWSHOLME. Effect of duration of exercise on excess postexercise oxygen consumption. *J. Appl. Physiol.* 62:485–490. 1987.
5. BAHR, R.I., AND O.M. SEJERSTED. Effect of feeding and fasting on excess postexercise oxygen consumption. *J. Appl. Physiol.* 71:2088–2093. 1991.
6. BANZ, W.J., M.A. MAHER, W.G. THOMPSON, D.R. BASSETT, W. MOORE, M. ASHRAF, D.J. KEEFER, AND M.B. ZEMEL. Effects of resistance versus aerobic training on coronary artery disease risk factors. *Exp. Biol. Med. (Maywood)* 228:434–440. 2003.
7. BECKHAM S.G., AND C.P. EARNEST. Metabolic cost of free weight circuit weight training. *J. Sports Med. Phys. Fitness* 40:118–125. 2000.
8. BYRD, R.K., J. HOPKINS-PRICE, D. BOATWRIGHT, AND K.A. KINLEY. Prediction of the caloric cost of bench press. *J. Appl. Sport Sci. Res.* 2(10): 7–8. 1988.
9. BYRD, R.K., K. PIERCE, R. GENTRY, AND M. SWISHER. Predicting the caloric cost of parallel back squat in women. *J. Strength Cond. Res.* 10:184–185. 1996.
10. CARUSO, J.F., D.A. HERNANDEZ, K. SAITO, M. CHO, AND N.M. NELSON. Inclusion of eccentric actions on net caloric cost resulting from isoinertial resistance exercise. *J. Strength Cond. Res.* 17:549–555. 2003.
11. FAHEY, T.D., L. AKKA, AND R. ROLPH. Body composition and VO_2max of exceptional weight trained athletes. *J. Appl. Phys.* 39:559–561. 1975.
12. FLETCHER, G.F., G. BALADY, V.F. FROELICHER, L.H. HARTLEY, W.L. HASKELL, M.L. POLLOCK. Exercise standards: A statement for healthcare professionals from the American Heart Association. *Circulation* 91:580–615. 1995.
13. FRY, A.C., M.H. STONE, J.T. THRUSH, AND S.J. FLECK. Precompetition training sessions enhance competitive performance of high anxiety junior weightlifters. *J. Strength Cond. Res.* 9:37–42. 1995.
14. GAESSER, G.A., AND G.A. BROOKS. Metabolic bases of excess post-exercise oxygen consumption. *Med. Sci. Sports Exerc.* 16:29–43. 1984.
15. GORE C.J., AND R.T. WITHERS. Effect of exercise intensity and duration on postexercise metabolism. *J. Appl. Physiol.* 68:2362–2368. 1990.
16. GREEN S., AND B.T. DAWSON. Methodological effects on the VO_2-power regression and the accumulated O_2 deficit. *Med. Sci. Sports Exerc.* 28: 392–397. 1996.
17. HALTOM, R.W., R.R. KRAEMER, R.A. SLOAN, E.P. HEBERT, K. FRANK, AND J.L. TRYNIECKI. Circuit weight training and its effects on excess postexercise oxygen consumption. *Med. Sci. Sports Exerc.* 31:1613–1618. 1999.
18. HEMPEL, L.S., AND C.L. WELLS. Cardiorespiratory cost of the Nautilus Express Circuit. *Phys. Sportsmed* 113:82–97. 1985.
19. HOEGER, W.K., D.R. HOPKINS, S.L. BARATTE, AND D.F. HALE. Relationship between repetitions and selected percentages of one repetition maximum: A comparison between untrained and trained males and females. *J. Strength Cond. Res.* 4:47–54. 1990.
20. HUNTER, G.R., D. SEELHORST, AND S. SNYDER. Comparison of metabolic and heart rate responses to super slow vs. traditional resistance training. *J. Strength Cond. Res.* 17:76–81. 2003.
21. LACOUR, J.R., E. BOUVAT, AND J.C. BARCELEMY. Post-competition blood lactate concentrations as indicators of anaerobic energy expenditure during 400-m and 800-m races. *Eur. J. Appl. Physiol. Occup. Physiol.* 61:172–176. 1990.

22. MEDBO, J.I., A.C. MOHN, I. TABATA, R. BAHR, O VAAGE, AND O.M. SEJERSTED. Anaerobic capacity determined by maximal accumulated O2 deficit. *J. Appl. Physiol.* 64:50–60. 1988.
23. PARK, S.K., J.H. PARK, Y.C. KWON, H.S. KIM, M.S. YOON, AND H.T. PARK. The effect of combined aerobic and resistance exercise training on abdominal fat in obese middle-aged women. *J. Physiol. Anthropol. Appl. Human Sci.* 22:129–135. 2003.
24. PHILLIPS, W.T., AND J.R. ZIURAITIS. Energy cost of the ACSM single-set resistance training protocol. *J. Strength Cond. Res.* 17:350–355. 2003.
25. PHILLIPS W.T., AND J.R. ZIURAITIS. Energy cost of single-set resistance training in older adults. *J. Strength Cond. Res.* 18:606–609. 2004.
26. PRABHAKARAN, B., E.A. DOWLING, J.D. BRANCH, D.P. SWAIN, AND B.C. LEUTHOLTZ. Effect of 14 weeks of resistance training on lipid profile and body fat percentage in premenopausal women. *Br. J. Sports Med.* 33:190–195. 1999.
27. SCALA, D., J. MCMILLAN, D. BLESSING, R. ROZENEK, AND M.H. STONE. Metabolic cost of a preparatory phase of training in weightlifting: A practical observation. *J. Appl. Sports Sci. Res.* 1:48–52. 1987.
28. SCOTT, C.B. Interpreting energy expenditure for anaerobic exercise and recovery: An anaerobic hypothesis. *J. Sports Med. Phys. Fitness* 37:18–23. 1997.
29. SCOTT, C.B. Energy expenditure of heavy to severe exercise and recovery. *J. Theor. Biol.* 207:293–297. 2000.
30. SHORT, K.R., AND D.A. SEDLOCK. Excess postexercise oxygen consumption and recovery rate in trained and untrained subjects. *J. Appl. Physiol.* 83:153–159. 1997.
31. SPORTING GOODS MANUFACTURERS ASSOCIATION. Sports participation in America 2006. Available at: http://www.sgma.storelistitem.cfm?itemnumber=189. Accessed December 2006.
32. U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES. *Physical Activity and Health: A Report of the Surgeon General.* Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion. 1996.
33. WILMORE, J.H., R.B. PARR, P. WARD, P.A. VODAK, T.J. BARSTOW, T.V. PIPES, G. GRIMDITCH, P. LESLIE. Energy cost of circuit weight training. *Med Sci Sports.* 10:75–78. 1978.
34. ZOLDADZ, J.A., AND B. KORZENIEWSKI. Physiological background of the change point in VO2 and the slow component of oxygen uptake kinetics. *J. Physiol. Pharmacol.* 52:167–184. 2001.
35. ZOLDADZ, J.A., A.C. RADEMAKER, AND A.J. SARGEANT. Non-linear relationship between O2 uptake and power output at high intensities of exercise in humans. *J. Physiol.* 488(Pt 1):211–217. 1995.

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