Bench Press Metabolic Rate as a Function of Exercise Intensity

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ABSTRACT

The purpose of this study was to determine the effect variations in the percent of one repetition maximum bench press have on weight training economy (total net kcal consumed divided by J work) and blood lactate. Seventeen subjects participated in a number of bench press experiments at various intensities, 20 percent to 80 percent of one repetition maximum (1 RM). Oxygen uptake \( (V O_2) \) was measured continuously both during and following the experiments. Arterialized capillary blood was sampled and analyzed for lactate both prior to and at 4.5 minutes following exercise. Exercise and recovery \( V O_2 \) were summed to determine the total exercise \( V O_2 \) requirement. Metabolism was estimated by assuming 5 kcal of energy released for each liter of oxygen used. Work was calculated by summing the work performed on the barbell and body segments.

The amount of work performed in an exercise and the percent of 1 RM at which work was performed in an exercise have a marked effect on energy used to perform weight training tasks. Both of these factors must be considered in prescription of weight training exercise.

KEY WORDS: Oxygen uptake, work, economy, lactate

Introduction

Several investigators have reported metabolic rate during strength training exercise (8, 9, 14, 20, 22). Estimated caloric expenditure has varied from five to 10 kcal per minute, depending on whether large or small muscle groups were involved in the exercise. No attempts have been made to determine what effect intensity (percent of one repetition maximum) has on metabolic rate during weight training. Several investigators have reported varying effects of work rate on steady state exercise. For example, walking and bicycling have been reported to result in a decrease in efficiency as work rate is increased (3, 4, 5, 6). The work rate of weight training exercise is not steady state and contains a large anaerobic component (20, 22). Although the use of recovery \( O_2 \) uptake to determine total metabolic cost of anaerobic exercise has been criticized (19), Wilmore's (22) approach of adding net exercise and net recovery oxygen uptake \( (VO_2) \) does give a practical estimate of the elevated metabolic rate that occurs as a consequence of an anaerobic activity. Although a true measure of muscular efficiency cannot be calculated, practical comparisons of metabolic rate at different exercise intensities can be made. If energy used is divided by work performed, a practical weight training economy value results that is useful for comparing economy across different intensities for the same exercise. If efficiency of muscular contraction varies during different intensities of weight training exercise, estimates of energy expenditure will be dependent on weight training intensity.

Although increases in blood lactate are associated with an anaerobic energy production (1), no definitive method for utilizing blood lactate levels as a quantitative index of anaerobic energy cost is available. However, blood lactate values can be useful in determining the relative effects exercise has on the balance between fast (anaerobic) glycolysis and lactate removal. Blood lactate levels following weight training workouts have been observed in excess of 13 mmol/L (17). It should be of interest to determine what effects exercise intensity has on blood lactate to determine what effects exercise intensity has on blood lactate levels following different bench press intensities. Therefore, it was the objective of this study to determine what effects variations in bench press intensity have on: 1) practical weight training economy 2) metabolic rate and 3) blood lactate.

Methods

Subjects

Seventeen healthy subjects (10 males and seven females) volunteered for the study. An informed consent was obtained from all subjects prior to participation in the study. Subject ages varied from 25 to 42 years. Thirteen of the subjects had been weight training at least one year, while four had no prior weight training experience when the study began. All subjects participated at a minimum of three and a maximum of five intensities. They were instructed to not vary their current physical activity patterns.

Bench Press Metabolism

Four sets of bench presses were performed with varying repe-
tions per set at five exercise intensities: 1) 30 repetitions at 20 percent one repetition maximum (1 RM); 2) 20 repetitions at 30 percent 1 RM; 3) 20 repetitions at 40 percent 1 RM; 4) 10 repetitions at 60 percent 1 RM; and 5) five repetitions at 80 percent 1 RM.

In an effort to determine whether fatigue might play a role in weight training economy, five subjects were also tested while performing two sets of 40 repetitions at 30 percent of 1 RM. Identical work (80 repetitions) was performed in the two 30 percent of 1 RM protocols, but the two sets of 40 repetitions were accomplished in a shorter time span.

Another substudy was designed to determine whether weight training experience may have an effect on weight training economy during bench pressing. Four subjects participated in a 70 percent 1 RM experiment prior to any weight training experience. After training three times each week for eight weeks with three sets of as many repetitions as possible with approximately 70 percent of 1 RM, the subjects' 1 RM was retested. The subjects then participated in two additional bench press metabolism experiments, one with the new 70 percent 1 RM and the other with the old 70 percent 1 RM. Three sets of the maximum number of possible repetitions were used in this experiment so that the training protocol could be duplicated. Since the old 70 percent 1 RM was now between 59 and 60 percent of the new 1 RM, these values are included with the 60 percent 1 RM data. Table 2 outlines the overall testing scheme.

Each bench press intensity experiment was conducted on a separate day for each subject, with at least two days separating each test. One minute of rest was allowed between all sets. All bench presses were done in time to a metronome at a rate of 20 repetitions per minute. A repetition was completed when the subject had lowered the bar to the chest and returned it to a straight arm position. Subjects were instructed to take their normal hand spacing on the bar, but were required to keep the same hand spacing for all experiments.

Oxygen uptake and heart rate were measured throughout the bench press activity and during a supine recovery until VO2 was below 4 ml-kg⁻¹-min⁻¹ for two consecutive 30 second gas samples. The gross (total oxygen uptake during work and recovery) and the net (gross VO2 - resting VO2 accumulated for the total period of work and recovery) oxygen uptakes were calculated. Resting VO2 was assumed to be 3.5 ml O2-kg⁻¹-min⁻¹. Metabolic rate was estimated by assuming five kcal of energy released for each liter of oxygen used (20).

Determination of Vertical External Work

Measurable vertical external work (VEW) was performed on the barbell arms and hands. The arms and hands were assumed to be a two link system with the lower arm and hand forming one link and the upper arm making up the second link. Centers of gravity and weights of the two links were estimated from the data of Dempster (2). A metal tape was used to measure the vertical distance the centers of gravity of the two links and barbell traveled with each repetition (Figure 1). Vertical external work for each link was determined from the product of vertical distance and weight. Total VEW was determined by summing the VEW for the hands, arms, and barbell.

Weight Training Economy

Weight training economy was calculated by dividing net kcal expended by total Joules work accomplished.

Bench Press Strength Measure

Bench press strength was measured with free weights. Subjects warmed up with a weight each normally used as a warm-up in their training. Subjects then attempted successive bench presses, gradually increasing the weight (4.5 or 9.0 kg at first, but decreasing to 2.5 and 1.1 kg as difficulty became evident) until two consecutive failures occurred. The highest success was used as the 1 RM. One minute of rest was allowed between trials. The 1 RM was reached after three to four trials in all cases.

Maximum Oxygen Uptake Test

Maximum oxygen uptake was determined by a modified Bruce protocol graded treadmill test (21). Heart rate, blood pressure, and VO2 were measured throughout the exhaustive test.

Oxygen Uptake and Heart Rate Measurement

Oxygen consumption was determined on an open circuit system. After passing through a mixing chamber, oxygen and carbon dioxide were determined using Beckman OM-11 and Beckman LB-2 gas analyzers, respectively. The analyzers were calibrated prior to each test with Micro Scholander analyzed gases. Expired volumes of gas were measured on a Parkinson - Cowan Dry Gas meter. On-line calculations of VO2 were accomplished on an Aim 25 computer (Rockwell International). Heart rate was recorded using a Burdick EKG unit with a single bi-polar EKG configuration.

Blood Sampling and Lactate Analysis

For nine of the 60 percent and all of the 30 and 70 percent 1 RM experiments, samples of arterialized capillary blood were drawn from the fingertip (18). Blood was drawn immediately prior to exercise and four and one half minutes after exercise (18). Lactate was analyzed by the enzymatic method (15). A Beckman model 26 spectrophotometer was used to measure light absorbance at 340 NM.

Statistical Analysis

Because of differences in sample size at the various exercise intensities, analysis of variance was not performed across all exercise intensities. However, analyses were performed across intensities in which the same subjects completed workouts. Weight training economy and lactates between bench press intensities were evaluated using a one-way repeated measures factorial design for seven subjects across the 20, 40, and 60 percent intensities, for five subjects across the 30, 60, and 80 percent intensities, and for

| Table 2. Outline of Experimental Protocols (Repetitions x Sets at Percent of 1 RM) |
|---------------------|-----------------|-----------------|-----------------|
| Subjects            | 30 x 4          | 20 x 4          | 10 x 4          |
|                     | at 20%           | at 30%           | at 60%           |
| 5 males             | X                | X                | X                |
| 2 males & 5 females | X                | X                | X                |
| 2 males & 2 females | X                | X                | X                |
| 1 male              | X                | X                | X                |

Pre-Trained RM x 3

Post-Trained RM x 3

5 x 4
four subjects at 60 and 70 percent intensities. Tukey post hoc t-tests were run to determine differences between contrasts for those variables that (α = .05) significance was found on the ANOVA. Pearson product-moment correlations were determined for net kcal consumptions and measurable vertical work within each exercise intensity.

Results

The VO₂ max and bench press 1 RM data indicate the subjects are moderately fit (Table 1). Table 3 contains the results of tests of statistical significance.

With the exception of an anomaly at the 30 percent intensities, kilocalories per minute needed to accomplish the various tasks increased as the intensity of exercise increased (Table 4). Mean values include subjects of different strength levels. Since the subjects that participated at the 30 percent intensities were relatively strong, they lifted much heavier weights. This obscures the relationship somewhat for the mean values at the 30 percent intensities. Figure 2 demonstrates the linear relationship for one subject. This relationship was consistent for each individual subject.

As the intensity of exercise increased, weight training economy decreased (Table 4). All differences observed between intensities were significant, while the differences between the two 30 percent and two 70 percent experiments were not significant (Table 3). Economy varied from a low of only 1.47 x 10⁻⁹ kcal·J⁻¹ at 20 percent to 4.3 x 10⁻⁹ kcal·J⁻¹ at 80 percent 1 RM.

Table 5 shows the correlations and standard errors of estimate for predicting net kcal used from external work at each of the intensities. The correlations varied from .83 to .99 while the standard error of estimate varied from eight to 23 percent of the estimated values.

The amount of time following exercise required for metabolism to return to 4.0 ml O₂·kg⁻¹·min⁻¹ increased as the intensity of exercise increased up to 60 percent of 1 RM. This recovery time dropped from a high of 10.0 minutes at 60 percent 1 RM to six and a half minutes at 80 percent 1 RM (Table 4).

Lactate was only measured at the two 30 percent intensities, the 60 percent intensity and two 70 percent intensities. The values varied from 3 mmol-liter⁻¹ at the 30 percent to almost 5 mmol-liter⁻¹ at 60 percent intensity (Table 4). Significant differences were seen between the 30 and 60 percent intensities but not between the 60 and 70 percent intensities.

Discussion

The primary objective of this study was to determine what effect bench press exercise intensity has on weight training economy. Weight training economy decreased as greater percentages of 1 RM were performed (Table 4). This decrease in weight training economy is consistent with previous work on steady state walking and bicycling (3, 4, 5, 6). Several possibilities might explain this finding: 1) muscle efficiency decreases; 2) metabolism not directly related to the external work increases in a non-linear manner (greater activity of stabilizer muscles); 3) metabolism related to external work not measured increases asymmetrically (horizontal deflections of the bar, tremor in the limbs, etc.); and 4) some combination of 1, 2, or 3.

Gaesser and Brooks (5) have shown that with increasing force a shift from relatively efficient slow twitch skeletal muscle fibers to less efficient fast twitch fibers may occur. Although an increase in metabolism due to an increase in external work that is not measured and in metabolism not associated with external

<table>
<thead>
<tr>
<th>Table 1. Subject Characteristics (X ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
</tr>
<tr>
<td>Yrs</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>±6.0</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>±4.3</td>
</tr>
</tbody>
</table>
work probably does occur, it is difficult to see how these two factors could increase in significantly greater proportions than external work during a work task of such short duration. This study is unable to shed light on the causes for the decrease in weight training economy in weight training exercise and/or in efficiency during steady state walking and bicycling.

Running efficiency does not seem to change significantly as running speed increases (13). This is felt to be related to a greater use of stored elastic energy derived from more rapid and stronger eccentric stretch of the elastic component of muscle (10). Since the bench presses were executed in time to the beat of a metronome in this study, little opportunity for increasing the speed of the eccentric phase of the weight training cycle occurred. Therefore, little change in use of stored elastic energy would have been expected under the bench pressing conditions found in this study.

High correlations were found between energy used and external work at each of the intensities (Table 5). These correlations, combined with relatively low standard errors of estimate (Table 4), indicate that energy used can be predicted during a bench press workout, if external work and the percent 1 RM at which the work was done are known.

For example, an individual who did four sets of 10 repetitions in the bench press with 74.8 kg would do approximately 7546 joules of external work. The exact external work will depend on the length of the individual's arms, the weight of the arms and hands and his/her hand spacing on the barbell. Assuming 74.8 kg is 60 percent of this individual's 1 RM, the predicted energy expenditure for this external work is 20.3 kcal (7546 J external work x 2.68 x 10^-3 kcal J^-1). Since the standard error of estimate in kcal for this example is 1.7 kcal, we would expect 68 percent of the individuals who did 7546 J bench press external work with 60 percent of their 1 RM to burn between 18.6 and 22.0 kcal.

Weight training economy during bench pressing seems to be stable and to be affected very little by fatigue. Five subjects did bench presses at 30 percent 1 RM under two different protocols.

Table 3. Economy and Lactate Differences at Various Intensities

<table>
<thead>
<tr>
<th>Intensities</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>kcal-J^-1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>kcal-J^-1</td>
<td>30%</td>
<td>30%</td>
<td>60%</td>
<td>80%</td>
</tr>
<tr>
<td>lactate</td>
<td>XX</td>
<td>XX</td>
<td>X</td>
<td>NA</td>
</tr>
<tr>
<td>kcal-J^-1</td>
<td>60%</td>
<td>70%</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>lactate</td>
<td>no significant differences</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X Different from other levels
XX Different from 60 and 80% levels but not other 30% level
XXX Different from 60% level, but not other 70% level

significance level set at .05

Table 4. Mean Metabolic and Work Results (± SD)

<table>
<thead>
<tr>
<th>Percent 1 RM</th>
<th>Number of subjects</th>
<th>Bench Press 1 RM (kg)</th>
<th>Work J</th>
<th>Total Net VO2 (ml O2·Kg^-1·min^-1)</th>
<th>Economy kcal-J^-1</th>
<th>Metabolic Rate kcal-min^-1</th>
<th>Rec. Time (min)</th>
<th>4 1/2 min. Lactate Mmol-1^-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2 5</td>
<td>61.7 ± 32.3</td>
<td>6115.4 ± 3003</td>
<td>1.8 ± 0.8</td>
<td>1.47 x 10^3</td>
<td>1.0 ± 0.4</td>
<td>2.1 ± 1.0</td>
<td>NA</td>
</tr>
<tr>
<td>30</td>
<td>5 0</td>
<td>111.9 ± 15.5</td>
<td>12590.0 ± 1880</td>
<td>5.1 ± 1.6</td>
<td>2.02 x 10^3</td>
<td>2.8 ± 0.9</td>
<td>5 ± 2.8</td>
<td>3.4 ± 0.8</td>
</tr>
<tr>
<td>4 sets of 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>5 0</td>
<td>111.9 ± 15.5</td>
<td>12590.0 ± 1880</td>
<td>4.8 ± 0.9</td>
<td>1.91 x 10^3</td>
<td>4.4 ± 0.8</td>
<td>6.5 ± 1.6</td>
<td>3.1 ± 0.9</td>
</tr>
<tr>
<td>4 sets of 40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>2 5</td>
<td>61.7 ± 32.3</td>
<td>7211.6 ± 3395</td>
<td>3.0 ± 1.8</td>
<td>2.08 x 10^3</td>
<td>2.1 ± 1.3</td>
<td>4.5 ± 1.9</td>
<td>NA</td>
</tr>
<tr>
<td>60</td>
<td>10 7</td>
<td>74.3 ± 35.7</td>
<td>7280.0 ± 3244</td>
<td>3.9 ± 0.9</td>
<td>2.68 x 10^3</td>
<td>3.9 ± 0.9</td>
<td>10.0 ± 2.5</td>
<td>4.9 ± 1.1</td>
</tr>
<tr>
<td>70 Untrained</td>
<td>2 2</td>
<td>43.9 ± 20.8</td>
<td>4280.8 ± 2263</td>
<td>2.7 ± 1.0</td>
<td>3.15 x 10^3</td>
<td>4.0 ± 1.5</td>
<td>6.4 ± 2.1</td>
<td>4.7 ± 2.7</td>
</tr>
<tr>
<td>70 Post train</td>
<td>2 2</td>
<td>51.9 ± 24.9</td>
<td>4634.0 ± 2077</td>
<td>3.0 ± 1.2</td>
<td>3.2 x 10^3</td>
<td>4.3 ± 1.7</td>
<td>5.8 ± 1.9</td>
<td>4.2 ± 0.8</td>
</tr>
<tr>
<td>80</td>
<td>5 0</td>
<td>114.4 ± 17.1</td>
<td>7850.0 ± 1096</td>
<td>6.8 ± 2.0</td>
<td>4.3 x 10^3</td>
<td>8.6 ± 2.5</td>
<td>6.5 ± 1.4</td>
<td>NA</td>
</tr>
</tbody>
</table>
(four sets of 20 and two sets of 40 repetitions). Even though the two sets of 40 repetitions protocol were completed two minutes faster and the subject completing it felt more fatigued than in the four sets of 20 protocols, the weight training economy coefficient varied little between the two protocols (results ranged from 2.02 \times 10^3 to 1.91 \times 10^3). In addition, training does not seem to affect weight training economy. Four subjects did 70 percent 1 RM sets prior to initiating a training program and after eight weeks of training. The weight training economy coefficients were very consistent (3.15 \times 10^3 and 3.20 \times 10^3 kcal/J after training) despite an increase in absolute weight lifted. When these subjects used the previous 70 percent 1 RM (which was now 60 percent of 1 RM) the economy values corresponded closely to the 2.68 \times 10^3 kcal/J found for the other 60 percent 1 RM tests.

Rate of net energy expenditure varied from 1 kcal to 8.6 kcal per minute. These values are in agreement with other studies (8, 14, 20, 22). Both intensity and external work accomplished influenced these values. It is felt, therefore, that kcal/J of external work is a useful measure for estimating metabolic rate during bench pressing. Since the higher intensities produced higher energy expenditures, it is possible that training at 70 to 80 percent of 1 RM may be more beneficial in body weight maintenance programs than training at lower intensities. Training studies must be conducted to substantiate this possibility.

Post-exercise blood lactate levels varied from 3.1 to 4.9 mmol-l^-1. This is considerably lower than 15 mmol-l^-1 values reported by Rozenek (17) and 9 mmol-l^-1 values reported by Kraemer and colleagues (11). These differences are not too surprising since Rozenek's and Kraemer's lactate values were obtained after a comprehensive weight training session, as opposed to after only four sets of benchpresses in this study.

The highest lactates were observed following 60 percent bench press exercise. No difference was seen between the two 30 percent experiments and the two 70 percent experiments or between the 60 and 70 percent experiments. It appears that 10 repetitions at 60 percent 1 RM bench press is sufficiently more intense than the 30 percent 1 RM bench press to produce greater blood lactate values. No further increase in blood lactates was seen at the 70 percent loads. In fact, slightly lower mean values were found at 70 percent. The subjects averaged 50 repetitions in three sets at 70 percent as compared to 40 repetitions in four sets with 60 percent. In addition, the subjects only averaged five repetitions during the last set at 70 percent. Kraemer et al (11) found higher blood lactate values at 10 RM than 5 RM sets. These data seem to support this finding.

The results of this study indicate the energy needed to perform a bench pressing task is strongly related to both the percent 1 RM used and the amount of external work accomplished. Consideration of both these factors in estimation of metabolic rate while bench pressing will result in values with standard errors varying from 10 to 20 percent. These values compare quite favorably to standard errors of estimate of about 13.7 percent for walking and 22 percent for bicycle ergometry (16).

**Practical Applications**

Even though further research must be done to determine whether the results for the bench press are applicable to other exercises, several practical suggestions can be made to the practitioner. Those individuals who are interested in body composition changes should train at 60 to 80 percent 1 RM. This study shows that metabolic rate is higher at increased intensity, thus a greater deficit in kcal can be produced in any time period. Training in this intensity range has the added benefit of producing muscular size and strength increases that will not occur at lower intensities (20).

The coach and athlete must consider both the intensity and amount of work accomplished when trying to evaluate the metabolic cost of a training program. It is possible that a relatively moderate volume but high intensity program might create greater metabolic demands than a high volume/low intensity program. Diet and rest intervals must be manipulated appropriately. Since lactate production was highest at the 60 percent intensity, it is possible this may be a better weight training intensity for improving the athlete's ability to tolerate high lactate levels.

Those coaches and athletes who wish to estimate their metabolic rate while doing this exercise can use the economy values reported. Research is ongoing to determine economy values for other exercises.

**References**