Blood Pressure and Heart Rate Response and Metabolic Cost of Circuit Versus Traditional Weight Training

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Reference Data

ABSTRACT
This study compared metabolic cost and cost-work ratio to blood pressure and heart rate response between circuit and traditional weight training. Subjects (5 M, 3 F) completed one traditional and one circuit weight training workout. VO2 was measured during workout and recovery. Total work was calculated by summing the vertical work on the weights and limbs. Heart rate was continuously monitored. SBP and DBP were measured during the last 10 sec of each leg exercise and once a minute during recovery. Cost:work ratios were significantly higher for traditional weight training (p = 0.003). However, due to the greater total workload, total metabolic cost was higher for circuit weight training (p = 0.032). Exercise and recovery rate-pressure product (RPP) were calculated. Exercise heart rate was significantly higher during circuit weight training. No differences were found in BP response. Exercising RPP was significantly higher during circuit weight training, indicating a higher workload on the heart. This may be an important consideration when recommending weight training programs for persons with cardiovascular complications.

Key Words: economy, oxygen uptake, cardiovascular

Introduction
Traditional weight training can increase strength, lean body mass, and bone density and also improve blood-lipid profiles (3, 13). However, cardiovascular endurance does not improve significantly following traditional weight training programs. Circuit weight training has been shown to improve cardiovascular fitness (7, 20) and may be an attractive option for those who wish to improve both strength and cardiovascular endurance. Traditional weight training programs generally involve lifting a weight equal to 60–80% of the one-repetition maximum (1-RM), the maximum weight that can be lifted one time. Eight to 10 reps comprise a set, and 2–3 sets of each exercise are completed with a 1- to 2-min rest period between sets.

Circuit weight training involves lifting a weight equal to 40–55% of 1-RM as many times as possible in a 30- to 60-sec period. After a 15- to 30-sec rest, the subject moves to the next weight lifting exercise. Traditional weight lifting causes significant elevations in heart rate and arterial blood pressures, which suggests an increased load on the heart (6, 11, 18). For this reason, caution is called for when recommending weight training programs for populations at high cardiovascular risk.

Though blood pressures rise significantly during traditional weight lifting, they usually return to normal before the next set is performed (11). Because of the shorter time allowed between sets during circuit weight lifting, blood pressures do not have as much time to decrease before the next set is performed. In fact they may continue to rise during the following sets if not given time to decrease during recovery. Although heart rate responses to circuit weight training have been determined, to our knowledge no one has compared the cardiovascular response of traditional and circuit weight training. Therefore one objective of this study was to compare heart rate and arterial BP response during traditional and circuit weight training.

Although several investigators have estimated the metabolic cost of either traditional (1, 10, 12) or circuit weight training (5, 21), we know of no one who has compared the metabolic costs of both. It is difficult to predict which would command the largest increase in energy expenditure because two diametrically opposing phenomena may be operating in these two kinds of weight training. Previous research indicates that economy is negatively related to the percentage of 1-RM an individual lifts (10, 12, 14). Because traditional weight training programs involve lifting at a higher percentage of 1-RM than circuit programs do, relatively higher energy-cost-to-work ratios (C:W) would be expected. However, circuit weight training programs involve a larger number of repetitions, resulting in a higher total workload that would elevate the total energy cost of circuit weight training. Therefore a secondary purpose of this study was to compare the metabolic cost as well as the C:W of traditional and circuit weight training programs.
Table 1

<table>
<thead>
<tr>
<th></th>
<th>Mean % of 1-RM</th>
<th>Work intervals</th>
<th>Rest intervals</th>
<th>Sets/reps</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traditional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench press</td>
<td>68.5</td>
<td>30 sec</td>
<td>90 sec</td>
<td>2 × 10</td>
</tr>
<tr>
<td>Knee exten.</td>
<td>68.5</td>
<td>30 sec</td>
<td>90 sec</td>
<td>2 × 10</td>
</tr>
<tr>
<td>Bent row</td>
<td>69.0</td>
<td>30 sec</td>
<td>90 sec</td>
<td>2 × 10</td>
</tr>
<tr>
<td>Knee flex.</td>
<td>68.6</td>
<td>30 sec</td>
<td>90 sec</td>
<td>2 × 10</td>
</tr>
<tr>
<td><strong>Circuit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench press</td>
<td>47.8</td>
<td>60 sec</td>
<td>30 sec</td>
<td>2 × 20</td>
</tr>
<tr>
<td>Knee exten.</td>
<td>46.9</td>
<td>60 sec</td>
<td>30 sec</td>
<td>2 × 20</td>
</tr>
<tr>
<td>Bent row</td>
<td>47.1</td>
<td>60 sec</td>
<td>30 sec</td>
<td>2 × 20</td>
</tr>
<tr>
<td>Knee flex.</td>
<td>45.6</td>
<td>60 sec</td>
<td>30 sec</td>
<td>2 × 20</td>
</tr>
</tbody>
</table>

**Methods**

Subjects were 8 healthy students (5 M, 3 F) 23 to 34 years of age, with a mean age of 27.25 ± 4.3. Mean height for the subjects was 175 ± 11 cm. Mean weight was 74.8 ± 20.8 kg. The project was approved by the appropriate institutional review board and the subjects provided informed consent.

**Design**

Each subject performed one circuit and one traditional workout. Workouts were separated by 3 to 5 days. Both workout protocols are summarized in Table 1 and included 2 sets each of bench press, knee extension, bent row, and knee flexion. The traditional weight training workout consisted of 30-sec sets interspersed with 90-sec rest intervals. Weight loads were established at approximately 69% of 1-RM, and 10 lifts were executed per set. The circuit weight training workout consisted of 1-min sets interspersed with 30-sec rest intervals. Weight loads were established at approximately 47% of 1-RM, and 20 lifts were executed per set. No differences in mean % 1-RM occurred among exercises for either workout. Lifts were performed to tape recorded instructions to ensure proper timing. Exercises were completed consecutively during the traditional workout while 2 circuits of the 4 exercises were completed during the circuit workout. Recovery VO₂ was measured for 5 min immediately after both workout protocols.

**One Repetition Maximum Testing.** Subjects warmed up by lifting light weights, then attempted successive lifts, gradually increasing the weight until 2 consecutive failures occurred. They were allowed 1 min of rest between attempts. The heaviest weight successfully lifted was used as the 1-RM. Free weights were used for the bench press and bent row. A Universal knee extension/extension machine was used for knee extension and knee flexion exercises. A successful lift was defined as 180° of flexion for knee extension and 90° for knee flexion.

**Measurement of Oxygen Uptake.** Expired respiratory gases were analyzed continuously during each of the 8 sets and for 5 min following the last set (the recovery VO₂). Expired gases were collected in meteorological balloons and analyzed for oxygen on a Beckman OM11 and for carbon dioxide on a Beckman LB2, and volume was measured with a Tissot spirometer. One researcher manipulated gas collection equipment to ensure that subjects were not inhibited during the exercise. Balloon sample times were 120 sec for the last 4 min of recovery. In order to determine actual metabolic cost of the exercise, net VO₂ was calculated by subtracting the resting VO₂ (assumed to be 3.5 ml O₂/kg²·min⁻¹) from the sum of the exercise and the recovery VO₂. Oxygen and carbon dioxide analyzers were calibrated using micro-Scholander analyzed calibration gases.

**Determination of Energy Expenditure.** The energy expenditure from both workouts was calculated from net VO₂ consumption. According to previously developed techniques for weight training research (9, 10, 21), the caloric equivalent of 1 liter of oxygen was assumed to be 5 kilocalories. Net kilocalories were calculated by multiplying net VO₂ by 5.

**Heart Rate, Blood Pressure, and Rate Pressure Product.** Heart rate was monitored with a Burdick EKG unit using a single modified V5 bipolar EKG configuration. Exercise heart rate was recorded during the last 5 sec of each set. Recovery heart rate was measured each minute for 5 min following the workout. Heart rates for the entire exercise and recovery time periods were averaged and recorded.

Systolic (SBP) and diastolic (DBP) blood pressures were measured at the brachial artery by auscultation. While some have found this method to be less accurate than direct methods for measuring exercising BP (19), our purpose was to compare BP between the 2 exercise protocols. Although absolute mean values may have been underestimated, the underestimation should be consistent for both protocols. Exercising BPs were recorded during the last 10 sec of each leg exercise. Subjects inhaled during eccentric actions and exhaled during concentric actions to avoid Valsalva maneuver. Blood pressures were not measured during the bench press or bent row because of arm use during the exercise. Recovery BPs were recorded once each minute for the 5 min following the weight lifting session. Mean value for exercise and recovery were calculated. Exercising rate-pressure product (RPP) and recovery RPP were calculated by multiplying SBP and heart rate.

**Determination of External Work.** Work (W) performed during a repetition was calculated for both training workouts using techniques previously described (10, 12). Centers of mass of each body segment and distance increments traveled by the barbell were clearly marked so that the distance traveled by each body segment and the barbell was recorded without interfering with the subject's normal pattern of exercise. Centers of mass of
body segments were estimated from the data of Dempster and Gaugram (2). Work performed during the bench press and the bent row was then calculated from the following formula:

\[
(\text{weight of body segment} \times \text{distance moved against gravity}) + (\text{weight of the bar and plates} \times \text{distance moved against gravity})
\]

During a repetition of knee flexion and knee extension, vertical external work (VEW) was performed on the weight stack, lower legs and feet, and Universal support bar (the hinged bar against which one pushes or pulls). Because the support bar consisted of 2 metal bars at approximately 90° angles, the VEW of the support bar was estimated from the following equation:

\[
\text{VEW} = W \left[ \frac{L}{2} \cos \left( \frac{\alpha}{2} \right) \right] \sin \left[ \alpha - \left( 90 - \frac{\alpha}{2} \right) \right]
\]

Where \( W \) = weight of the support bars; \( L/2 \) = length from the fulcrum of the bar to the bar's center of gravity (assumed to be half the length of the bar); \( \alpha \) = angle between bars; and \( \alpha \) = angle between downward vertical line and position of lower bar at end of a repetition.

VEW for each link was calculated as the product of vertical distance and weight. Work performed during the knee extension and knee flexion was determined by summing the VEW for the weight stack, the lower legs and feet, and the Universal support bar. Total work performed during each was calculated separately by summing the total work performed during a repetition of each of the 4 exercises and multiplying by 20 or 40, respectively (i.e., 20 or 40 reps per workout).

Cost-to-Work Ratio. The cost-work ratio (C:W) was calculated by dividing total kilocalories expended during exercise and recovery by the vertical work performed.

Statistical Analyses. The SPSS statistical package for social sciences was used for the calculations and analyses. Paired samples \( t \) tests were used to evaluate the differences between traditional and circuit weight training for average recovery heart rate, SBP, DBP, and RPP, as well as total energy expenditure, total work, and C:W ratio. Statistical significance was \( p \leq 0.05 \) for all tests.

Results
The mean ± standard deviation 1-RM values in kilograms were: 63.9 ± 33.8 kg for bench press, 60.4 ± 21.9 kg for knee extension, 43.9 ± 18.7 for bent row, and 26.3 ± 14.3 for knee flexion. Heart rate and blood pressure results are listed in Table 2. Heart rates were significantly higher during the circuit program \( (p = 0.024) \). Differences in BP responses were not significant. Exercising RPP was significantly higher during the circuit weight training workout \( (p = 0.026) \); however, no significant difference was found between recovery RPP.

Total energy expenditure, energy expenditure rate, total work performed, and C:W ratios are listed in Table 3. Total energy expenditure and total work performed were greater during the circuit program. However, C:W ratio was significantly higher for the traditional workout \( (p = 0.003) \).

Discussion
During the circuit workout, heart rates were significantly higher \( (p = 0.024) \) than during the traditional workout. This is probably due to the shorter rest intervals and longer work periods of circuit weight training. Blood pressure response between the two protocols was not significantly different. Factors that influence BP response to resistive exercise include \% of 1-RM lifted, the muscle mass involved, and the central and peripheral reflex components (15, 17). Relative intensity (i.e., \% of 1-RM) was greater in the traditional program while exercise duration was longer in the circuit program. Intensity and duration factors may have canceled each other out, resulting in a relatively small difference in BP between the two programs. The exercising RPP was a significant 16.8% higher during circuit weight training than during traditional weight training, indicating a greater workload on the heart.

Resistive exercises result in an increased blood flow against constant or increasing peripheral resistance. This causes SBP and DBP to rise (11, 16), which corresponds to a similar increase on the workload of the heart. Increased blood pressure and heart rate are associated

### Table 2
Blood Pressure and Heart Rate Results \( (N = 8) \)

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>Circuit</th>
<th>2-tail probabil.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exerc. HR</td>
<td>120.4</td>
<td>150</td>
<td>-2.88 0.024</td>
</tr>
<tr>
<td>Exerc. SBP</td>
<td>142.2</td>
<td>148.6</td>
<td>-0.97 0.366</td>
</tr>
<tr>
<td>Exerc. DBP</td>
<td>98.5</td>
<td>78.7</td>
<td>0.30 0.770</td>
</tr>
<tr>
<td>Recov. SBP</td>
<td>132.6</td>
<td>127.6</td>
<td>0.92 0.386</td>
</tr>
<tr>
<td>Recov. DBP</td>
<td>83.9</td>
<td>77.8</td>
<td>1.34 0.221</td>
</tr>
<tr>
<td>Exerc. RPP*</td>
<td>17.17</td>
<td>2.00</td>
<td>-2.81 0.026</td>
</tr>
<tr>
<td>Recov. RPP*</td>
<td>12.49</td>
<td>3.3</td>
<td>0.97 0.364</td>
</tr>
</tbody>
</table>

Note: 7 degrees of freedom.

* \( \times 10^3 \)

### Table 3
Results of Training Protocols \( (N = 8) \)

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>Circuit</th>
<th>2-tail probabil.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tst. energy expend (kcal)</td>
<td>49.8</td>
<td>22.6</td>
<td>-2.67 0.032</td>
</tr>
<tr>
<td>Energy expended (kcal/min(^{-1}))</td>
<td>4.5</td>
<td>2.0</td>
<td>-2.67 0.032</td>
</tr>
<tr>
<td>Total work (Joules ( \times 10^3 ))</td>
<td>15.4</td>
<td>7.0</td>
<td>6.38 0.000</td>
</tr>
<tr>
<td>C:W ratio (kcal/J ( \times 10^3 ))</td>
<td>3.42</td>
<td>0.61</td>
<td>4.58 0.003</td>
</tr>
</tbody>
</table>
with increased myocardial oxygen uptake and risk of stroke (19). For this reason, resistive training has traditionally been avoided by persons with coronary or cardiovascular heart disease (6). Less intense and more rhythmic forms of exercise are often recommended for such individuals.

Since circuit weight training utilizes lighter weights and more repetitions, it might seem to be a reasonable alternative to traditional weight training, which is more intense in terms of relative weight load. However, researchers who have evaluated responses to circuit weight training (8, 20) and high resistance training (4, 6) have concluded that both forms of exercise are safe for stable cardiac patients in a supervised environment. Although the results of this study are limited to the timing of BP measurements, the higher cardiovascular stress we found during circuit weight training suggests that traditional weight training may be safer for individuals with cardiovascular disease. We suspect that the higher RPP observed during circuit weight training may be a function of its shorter rest intervals and longer exercise periods.

Previous studies have shown that as the percentage of 1-RM is increased, the C.W ratio increases to reflect a corresponding decrease in weight training economy (10, 12, 14). The C.W ratio was significantly higher for our subjects during the traditional workout. Since a higher percentage of 1-RM was used during the traditional workout, the greater increase in C.W ratio may have been due in part to the increased exercise intensity of that workout.

Even though the traditional workout was metabolically less efficient, as indicated by the higher C.W ratio, total energy expenditure, including the recovery period, was significantly higher for circuit weight training (p = 0.032). This can be explained by the greater total work performed during the circuit workout (21.4 ± 9.6 vs. 15.1 ± 6.8 joule x 10^-7). Circuit weight training involves more repetitions and less time between exercise sets. As a result, energy expenditures are significantly higher.

**Practical Applications**

These results suggest that persons participating in a circuit weight training program will expend more energy and place a higher workload on the heart than those participating in a traditional weight training program. However, traditional weight training will utilize more energy per unit of work, as indicated by the higher C.W ratio. Higher stress on the heart, as indicated by the higher exercising RPP during circuit weight training, probably imparts little risk to healthy individuals. Although we are reluctant to conclude from the results of this one study that traditional weight training is safer than circuit weight training for persons with potential cardiovascular complications, we do feel that such individuals should be allowed to recover fully between sets regardless of which weight training protocol is used.

**References**


