Acute Cardiovascular Responses to Various Forms of Resistance Exercise

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Reference Data

ABSTRACT

Several forms of resistance are available for exercise. The present study evaluated the acute cardiovascular responses to fatiguing resistance exercises with accommodating (Acc), variable (Var), and fixed (Fix) resistances as well as with a graded exercise test (GXT). Heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and rate-pressure product (RPP) were directly and continuously recorded during all exercises. Peak heart rates and blood pressures were highest and lowest, respectively, during the GXT. For the resistance exercises, peak cardiovascular values were highest with Acc, followed by Fix and then Var resistance. There were significant differences (p < 0.05) between GXT and the resistance exercises for HR, SBP, and DBP, but not for RPP. There were also significant differences (p < 0.05) between Acc versus Fix and Var resistance for SBP and RPP. These data show that cardiovascular stress is increased during resistance exercises and that responses may differ between the various forms of resistance.

Key Words: blood pressure, direct measurement, heart rate, intra-arterial, rate-pressure product

Introduction

The effects of resistance exercise on strength and muscular function have been investigated by numerous researchers (3, 4, 7, 9, 16, 28). However, few have researched the effects of resistance exercise on the cardiovascular system. Most of the studies that did investigate the cardiovascular effects have evaluated only the chronic adaptations that occurred in the cardiovascular system as a result of repeated bouts of resistance exercise (1, 2, 19, 26, 27). Very few studies have looked at the acute cardiovascular effects of resistance exercise, and those that have did not consider the form of resistance as a variable.

The effect of resistance selection on the cardiovascular response to dynamic resistance exercise has not been reported. It is our opinion that how an exercise is performed can be as important a contributor to the cardiovascular response as the exercise itself. There are several forms of resistance on the market and some vary the resistance throughout the range of motion in order to more closely match the subject’s strength curve. This is done in part to lessen the biomechanical “sticking region” which may introduce an isometric component into the maneuver. These isometric components are believed to further contribute to the elevated cardiovascular response associated with resistance exercises.

Therefore the purpose of this study was to evaluate the acute cardiovascular responses to single-leg resistance exercises with different forms of resistance, when performed to failure.

Methods

Subjects
Six healthy male college students served as subjects (a small sample size is typical with such invasive procedures). All were normotensive and had experience with resistance exercise, although none were competitive lifters. Descriptive characteristics were as follows:

- Age 21.2 ± 0.7 yrs
- Height 179.1 ± 3.1 cm
- Body mass 83.7 ± 5.2 kg
- Body fat 15.2 ± 2.3%
- Lean mass 71.1 ± 5.0 kg
- VO₂ peak 41.2 ± 3.9 ml · kg⁻¹ · min⁻¹

Body composition was estimated via skinfolds. Peak oxygen uptake was predicted by cycle ergometry and is used to describe the subjects. The subjects were informed of the nature of the investigation, and each provided informed written consent prior to the investigation.

One week prior to data collection the subjects were screened with a medical history, a contralateral blood pressure evaluation by auscultation, and an Allen’s test. The Allen’s test is performed prior to arterial cannulations to ensure that the extremity can be perfused by an alternate source (ulnar artery) in the unlikely event that the cannulated artery (radial) becomes compromised. During the screening the subjects famil-
iarized themselves with the resistance exercise equipment and testing protocols. Each subject also performed a maximal isokinetic (accommodating resistance) test to assess his peak torque. No tests were conducted with the other forms of resistance, and no invasive procedures were performed on this day. The isokinetic test data were used to calculate the amount of resistance required for the other exercise machines.

**Experimental Protocol**

Seven days later each subject performed a graded exercise test (GXT) on a cycle ergometer with a standard protocol (23). This GXT served several purposes: (a) as a medical screening to ensure subject safety; (b) to predict peak oxygen uptake; and (c) to compare the cardiovascular response of aerobic exercise to similar values from resistance exercises. The data collection procedure during the GXT was similar to that during subsequent resistance exercise trials.

During each of the 3 remaining resistance exercise days the subjects performed 1 set of resistance exercises to failure with Fx, Var, and Acc resistance. Each testing session was separated by 1 week, during which time the subjects were instructed to remain sedentary.

The resistance exercises used were single-leg, concentric leg extension, and eccentric leg flexion at the knee. These exercises were performed with accommodating resistance (Acc) on the Kin-Com™ 125E+ isokinetic testing and exercise device (Chattecx Corp., Hixson, TN), with variable resistance (Var) on the David™ leg-extension machine (David International, Helsinki, Finland), and with fixed resistance (Fx) on the Universal™ leg-extension machine (Kidde Inc., Cedar Rapids, IA). All subjects executed one continuous set of exercises to failure with each form of resistance, although the order of the forms of resistance was balanced and varied between subjects. Statistical analysis demonstrated no order effect. Subjects were instructed to provide maximal effort during each repetition until they could no longer continue. They also received verbal encouragement during each test.

Range of motion was limited to exactly 90° (from 90 to 0° of flexion) for each repetition. The leg that corresponded to hand dominance was used in all cases. Speed of lift was standardized by performing all resistance exercises at 60° per sec. Velocity was limited in the Acc condition by the isokinetic device; a metronome was used to pace the subjects during the Var and Fx exercises. Subjects completed each exercise while seated upright. The subject’s cannulated wrist was secured to an armboard and both arms were crossed across the chest. The subjects were not allowed to make a fist or hold on to anything.

**Data Collection**

Heart rates were determined from a continuous single-lead electrocardiogram (ECG) (Hewlett Packard Med. Products, Andover, MA) during all exercises. An additional 12-lead ECG was used during the GXT. Peak heart rates were determined on a beat to beat basis by the RR interval of 3 consecutive complexes. Intra-arterial blood pressure was simultaneously recorded with the ECG during GXT and all resistance exercises. The radial artery of each subject was cannulated under local anesthesia with a 20-gauge arterial catheter (Arrow, Reading, PA). A standard intra-arterial blood pressure monitoring kit connected the subject to a disposable transducer and the transducer to a monitor and recorder (Hewlett Packard). Risk of thrombosis was minimized by administering heparinized saline through the arterial catheter at a rate of 3 ml per hour.

The pressure transducer was secured to the height of the subject’s right atrium (4th intercostal space) and the entire monitoring system was calibrated. Both ECG and pressure waveforms were continuously recorded on a strip chart during all exercises (see Figure 1). Peak systolic and diastolic blood pressures were determined on a beat-to-beat basis by the peak waveforms of 3 consecutive complexes. Prior to one of the exercise sessions, resting values were collected while the subject lay supine for at least 20 min. A rate-pressure product (RPP = HR · SBP · 10⁻²) was also calculated from the aforementioned values.

Several precautions were taken in order to avoid any occurrence of the Valsalva maneuver. The subjects were instructed and prompted to inhale and exhale continuously during the concentric and eccentric portion, respectively, of each repetition. In addition, respiratory patterns were observed on the system monitor by impedance pneumography (Hewlett Packard). Any occurrence of the Valsalva maneuver should have been evident in the pressure tracings (see Figure 1). We are confident that little or no breath holding occurred; however, any residual effects of a Valsalva maneuver that remained undetected should not be underestimated. The subjects also reported a subjective rating of perceived exertion immediately after each exercise session.

**Figure 1.** Lead II electrocardiogram (top) and arterial BP waveforms (bottom): (a) obtained during GXT and (b) for the same subject during resistance exercise (and during a Valsalva maneuver). Electrical artifact on ECG caused by contraction of chest skeletal muscles.
The original Borg scale was presented to subjects after each exercise (5).

**Statistical Treatment**

Peak cardiovascular data were converted to a percent of resting value and are referred to as response data. An ANOVA with repeated measures was used for all cardiovascular response data. Each subject was treated as a randomized block. Tukey’s post hoc analysis was employed to determine differences between significant main effects. Statistical significance was set at $p < 0.05$.

**Results**

Changes were observed in the cardiovascular data from resting to peak values (Table 1). The response data presented in Table 2 and Figure 2 were used for ANOVA. Significant differences ($p < 0.05$) were discovered for HR, SBP, DBP, and RPP among the 4 conditions. However, most of the differences were between the aerobic exercise and the 3 resistance exercises. Mean peak values for HR, SBP/DBP, and RPP were 189 bpm, 330/184 mmHg, and 545, respectively. These values are consistent with what might be expected considering body position, catheter location, and the amount of muscle mass involved.

Heart rates were higher during the aerobic exercise than during any of the resistance exercises. Post hoc analysis for HR response revealed significant differences between the GXT and all resistance exercises (Figure 3). There were no significant differences between the resistance exercises. Conversely, both SBP and DBP were higher during the resistance exercises than during aerobic exercise. Post hoc analysis revealed significant pairwise comparisons for SBP between GXT and all other exercises, and between ACC and all other exercises (Figure 4). Post hoc analysis for DBP revealed significant differences only between GXT and the resistance exercises (Figure 5). The RPP was highest during ACC, followed by FIX, GXT, and finally VAR (Figure 6). The RPP was significantly different only between the ACC-VAR and ACC-FIX conditions.

An additional ANOVA revealed significant differences ($p < 0.05$) between conditions for work, repetitions, and time. However, pairwise comparisons revealed that only the ACC-VAR comparison was significant for repetitions. For the time variable, the ACC-VAR and ACC-FIX comparisons were both significant, and all pairwise comparisons were significant for work (Table 3). Subjects reported significantly ($p < 0.05$) higher mean RPE for all resistance exercises versus GXT. Mean values ($\pm SE$) were 17.5 (0.9), 19.0 (0.4), 19.3 (0.7), and 19.3 (0.5) for GXT, ACC, VAR, and FIX, respectively. There were no significant differences in RPE between the resistance exercises. No abnormal ECG or blood pressure responses were observed during any exercises.

### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rest</th>
<th>GXT</th>
<th>ACC</th>
<th>VAR</th>
<th>FIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>57.8</td>
<td>189.0</td>
<td>165.7</td>
<td>156.8</td>
<td>156.8</td>
</tr>
<tr>
<td></td>
<td>(4.2)</td>
<td>(2.7)</td>
<td>(5.1)</td>
<td>(9.6)</td>
<td>(4.7)</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>142.0</td>
<td>244.7</td>
<td>329.5</td>
<td>282.5</td>
<td>296.0</td>
</tr>
<tr>
<td></td>
<td>(2.4)</td>
<td>(12.7)</td>
<td>(11.5)</td>
<td>(12.7)</td>
<td>(12.1)</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>61.8</td>
<td>74.0</td>
<td>184.3</td>
<td>162.5</td>
<td>164.3</td>
</tr>
<tr>
<td></td>
<td>(3.3)</td>
<td>(7.2)</td>
<td>(10.4)</td>
<td>(16.0)</td>
<td>(5.8)</td>
</tr>
<tr>
<td>RPP (HR · SBP · $10^{-2}$)</td>
<td>82.2</td>
<td>461.6</td>
<td>545.3</td>
<td>445.7</td>
<td>463.5</td>
</tr>
<tr>
<td></td>
<td>(6.5)</td>
<td>(21.9)</td>
<td>(22.9)</td>
<td>(38.2)</td>
<td>(20.3)</td>
</tr>
</tbody>
</table>

*Note:* Values during exercise obtained at peak HR.

### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>GXT</th>
<th>ACC</th>
<th>VAR</th>
<th>FIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>335.1</td>
<td>291.6</td>
<td>274.7</td>
<td>276.5</td>
</tr>
<tr>
<td></td>
<td>(23.8)</td>
<td>(15.8)</td>
<td>(15.3)</td>
<td>(16.0)</td>
</tr>
<tr>
<td>SBP</td>
<td>172.0</td>
<td>232.3</td>
<td>199.1</td>
<td>172.0</td>
</tr>
<tr>
<td></td>
<td>(7.1)</td>
<td>(8.7)</td>
<td>(9.2)</td>
<td>(7.1)</td>
</tr>
<tr>
<td>DBP</td>
<td>120.8</td>
<td>302.9</td>
<td>261.3</td>
<td>120.8</td>
</tr>
<tr>
<td></td>
<td>(11.6)</td>
<td>(25.6)</td>
<td>(19.7)</td>
<td>(11.6)</td>
</tr>
<tr>
<td>RPP</td>
<td>580.8</td>
<td>678.4</td>
<td>547.2</td>
<td>580.8</td>
</tr>
<tr>
<td></td>
<td>(58.0)</td>
<td>(48.0)</td>
<td>(45.5)</td>
<td>(58.0)</td>
</tr>
</tbody>
</table>

*Significant ($p < 0.05$) ANOVA for dependent variable across conditions.

![Figure 2](image-url)  
**Figure 2:** Mean cardiovascular responses for all exercises, reported as \% of resting value (peak/resting).
Figure 3. Mean resting and peak heart rates (bpm) (±SE) for GXT and resistance exercises, showing that GXT produced the greatest peak HR.

Figure 4. Mean resting and peak systolic BP (mmHg) (±SE) for GXT and resistance exercise, showing that GXT produced the least SBP response while Acc produced the most, followed by Fix, then Var.

Discussion

Although the effects of using different forms of resistance on strength have been investigated (8, 22), there is little information on cardiovascular response. Studies evaluating acute cardiovascular response to resistance exercise are few, partly because intra-arterial methods of measurement are required for accuracy. Blood pressures are known to become dramatically elevated during resistance exercise, due to a potent pressor response. These sudden elevations may remain undetected by measurements obtained postexercise or by discontinuous, indirect methods of measurement such as by auscultation (6, 13, 17, 29). Furthermore, it has been shown that indirect BP measures underestimate actual arterial pressures. This inaccuracy is even greater during exercise, particularly resistance exercise (18, 24, 25, 29).

One study that did evaluate the acute cardiovascular response to resistance exercise examined the difference between static and dynamic resistance exercises (20). Investigations that used only dynamic resistance exercise have evaluated the acute cardiovascular responses to different resistance exercises and at different intensities (15, 21). Other such studies have examined variables such as the acute cardiovascular response of the Valsalva maneuver during resistance exercise (20), or the effect of weight training experience on the pressor response (10, 11).
Table 3
Mean Values (±SE) for No. of Repetitions Completed (RM), Concentric Work, and Time for Resistance Exercises

<table>
<thead>
<tr>
<th>Variable</th>
<th>ACC</th>
<th>VAR</th>
<th>FIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM'</td>
<td>27.8</td>
<td>15.8</td>
<td>21.5</td>
</tr>
<tr>
<td>(1.2)</td>
<td>(1.4)</td>
<td>(1.5)</td>
<td></td>
</tr>
<tr>
<td>Work' (kJ)</td>
<td>4.5</td>
<td>1.5</td>
<td>3.1</td>
</tr>
<tr>
<td>(0.6)</td>
<td>(0.2)</td>
<td>(0.4)</td>
<td></td>
</tr>
<tr>
<td>Time' (sec)</td>
<td>118.3</td>
<td>48.3</td>
<td>67.0</td>
</tr>
<tr>
<td>(7.4)</td>
<td>(4.0)</td>
<td>(10.3)</td>
<td></td>
</tr>
</tbody>
</table>

*Significant (p < 0.05) ANOVA for dependent variable across conditions.

We are aware of only one intra-arterial study that compared the BP response during resistance exercise with different forms of resistance: Freedson et al. (14) compared 10 reps of free weight bench press at 25 and 50% of maximum isometric strength versus hydraulic (accommodating) resistance at fast and slow speeds. The slow hydraulic speed produced the greatest mean SBP and DBP values, followed by the 50% fixed resistance, then the 25% fixed resistance; the fast hydraulic speed produced the least values.

In the present study, the RPP, which is a noninvasive indicator of myocardial oxygen consumption and incorporates both HR and SBP, differed significantly between ACC and the other two forms of resistance (VAR and FIX). We are unsure of why ACC produced the greatest cardiovascular response. One explanation may be that ACC had more "aerobic" qualities than the other resistance exercises. The higher HR and increase in SBP would be similar to what would occur in response to aerobic exercise and would be consistent with the greater duration of exercise (less resistance and more repetitions). For their part, Fleck and Dean found a higher arterial BP response in longer sets (70 to 80% 1-RM) than in shorter sets with near-maximal resistance (90 to 100% 1-RM) (11). It is possible that RPP was highest during ACC because of the increase in SBP, which may be a result of straining, or a pressor response.

A more likely explanation for our results is that the cardiovascular data are related to amount of work performed. This would explain why ACC had the greatest cardiovascular response, as it also allowed for the most work to be done (time, RM, etc.). However, there were no significant differences in cardiovascular response between VAR and FIX, whereas differences in their work data were apparent.

Theoretically, work values should have been similar for each form of resistance. However, it appears there were biomechanical differences in the various machines which we were unable to account for and which prevented us from equating workloads by our method. We had hoped that our method for equating torque for 1-RM would eliminate any differences between the machines. The mean peak isokinetic torque values obtained during preliminary testing were used to calculate the resistance employed with the other exercise machines. But it appears that our method of calculation only gave us a value approximating the amount of resistance for 1-RM for the other machines. Consequently, we discovered that the various machines have inherent differences that permit different amounts of total work to be accomplished.

Although the total work was not equal between resistance exercises and may be a limitation, it was not our objective to equate work. The purpose of this study was to provide descriptive information on the cardiovascular response to one set of resistance exercises when performed to failure, using different forms of resistance. We believe the cardiovascular responses are still comparable because our subjects performed maximally during each protocol.

Much of the cardiovascular data did not differ significantly between the resistance exercises, but nonsignificant trends did become apparent. The differences posed no adverse cardiovascular conditions in these healthy subjects. However, resistance exercise is now commonly prescribed for cardiac patients and other special populations. In a paper detailing resistance exercises for cardiac patients, Franklin et al. (12) suggest that machines that offer resistance may be preferable to free weights. Although we did not compare resistance from machines versus free weights, our data suggest that machines with different forms of resistance may allow for more work to be performed, which might in turn affect the cardiovascular response. Even though the values observed in the current study did not pose any problems in our healthy subjects, they were a stress to the cardiovascular system nonetheless. It is unclear what consequences these elevations might have on less healthy populations.

**Practical Applications**

These data revealed that the cardiovascular response to resistance exercises when performed to fatigue differs significantly from the response during aerobic exercise. Increases in BP occur during resistance exercises, even with fatiguing exercises (high repetitions, low resistance) and even in the apparent absence of the Valsalva maneuver. Despite these elevations, the exercises in this study were safe and should not discourage anyone from participating in resistance exercises. Instead, we suggest that when prescribing resistance exercises to special populations such as hypertensive athletes or cardiac patients, the strength and conditioning professional should consult with medical personnel and should consider the cardiovascular consequences from the form of resistance selected.
References


Acknowledgment

This research was supported in part by equipment grants provided by the Chattecorp and the Hewlett Packard Co. We would like to thank Michael E. Worley for his invaluable assistance with data collection.