A Description of the Acute Cardiovascular Responses to Isokinetic Resistance at Three Different Speeds

DOUGLAS M. KLEINER,1 DANIEL L. BLESSING,2 JOHN W. MITCHELL,3 AND WILLIAM R. DAVIS3

1Department of Health Science, University of North Florida, Jacksonville, Florida 32224-2645; 2Department of Health and Human Performance, Auburn University, Auburn, Alabama 36849; 3Department of Cardiology, East Alabama Medical Center, Opelika, Alabama 36802-3201.

ABSTRACT
Isokinetics remains a popular form of resistance in the clinical setting for orthopedic rehabilitation; however, little is known about its effect on the cardiovascular system. The present study was designed to describe the acute cardiovascular responses to isokinetic exercises at 3 different speeds. Heart rate, intra-arterial systolic and diastolic blood pressures, and the rate-pressure product were directly and continuously recorded during all exercises. Peak heart rates and the rate-pressure product increased with increases in isokinetic velocity. Systolic and diastolic blood pressures decreased as the isokinetic velocity increased. The differences in cardiovascular values among the isokinetic speeds were not of great magnitude but did increase substantially from the values obtained during rest. Both ratings of perceived exertion and torque values increased as the isokinetic velocity decreased. These data show that cardiovascular stress is increased during isokinetic exercises and that responses may differ among the various speeds.

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


Introduction
Research in strength and conditioning generally addresses the acute responses or chronic adaptations to resistance training of skeletal muscle. The mode of resistance chosen for these studies has traditionally been isometric or dynamic exercises using fixed or variable resistance. However, isokinetic resistance remains a popular tool for orthopedic testing and rehabilitation and is being used more frequently by strength and conditioning professionals. Despite its widespread clinical use, isokinetics remains infrequently studied as a form of resistance. Research that has been conducted with isokinetic resistance has addressed the musculoskeletal adaptations as a result of training, such as the effects on strength, peak torque, or power (13, 19).

Very little information is available regarding the acute cardiovascular effects of resistance training. It is important for strength and conditioning professionals to remember that exercise affects not only skeletal muscle, but also more central parameters such as heart rate (HR) and blood pressure. Although some information is available regarding the cardiovascular effects of manipulating the form of resistance (12), very little is known about manipulating the speed of isokinetic resistance. An earlier investigation by Kleiner (11) reported a nonsignificant trend in the acute HR response to isokinetic resistance exercise at various speeds. Douris (3) found results similar to those of Kleiner (11) with regard to HR and also evaluated blood pressure. However, the use of indirect methods to obtain blood pressure measures in the latter study generated questions relative to methodological constraints. Specifically, blood pressure is known to become dramatically elevated during resistance exercise because of a potent pressor response. These sudden elevations are not detectable by measurements obtained after exercise or by noncontinuous, indirect methods of measurement such as auscultation (2, 7, 9, 26). Several investigators have reported that indirect measures of blood pressure underestimate actual arterial pressures. This inaccuracy is even greater during exercise, and with resistance exercise in particular (10, 12, 21, 22, 26).

Knowing the cardiovascular response to a specific exercise is important because of the stress that is placed on the heart and vasculature as a result of re-
Cardiovascular Responses to Isokinetic Resistance

Methods

Subjects
Six healthy, male college students served as subjects (a small sample size is typical with such invasive procedures). Descriptive characteristics of the subjects (mean ± SD) were as follows: age 22.7 ± 2.8 years, height 179.9 ± 2.5 cm, body mass 83.9 ± 9.6 kg, body fat 14.2 ± 3.6%, and lean mass 71.9 ± 7.8 kg. Body composition was estimated using skinfolds. The subjects were informed of the nature of the investigation, and each provided written consent before participating.

One week before 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 should be performed before arterial cannulation to ensure that the extremity can be perfused by an alternate source (the ulnar artery) in the unlikely event that the cannulated artery (radial) becomes compromised. A medical screening was performed before data collection to ensure the subjects' safety by having each subject perform a submaximal graded exercise test on a cycle ergometer with a standard protocol (20). During this session, arterial blood pressure was measured and a 12-lead exercise electrocardiogram (ECG) (Hewlett Packard Medical Products, Andover, MA) was obtained for diagnostic purposes. Following the screening session, the subjects' data were reviewed by a physician for safety and cardiovascular capacity to perform stressful exercises. Subjects who were accepted into the study were asked to return 1 week later to begin their isokinetic testing sessions. Each isokinetic testing session was separated by 1 week. Subjects were instructed to remain sedentary during the 7 days between testing sessions.

Experimental Protocol
The resistance exercises used in this experiment were single-leg, dual-concentric flexion and extension isokinetic exercises at the knee. These exercises were performed on the Kin-Com 125E+ isokinetic testing and exercise device (Chattecx Corp., Hixson, TN). All subjects executed 1 continuous set of isokinetic exercise to failure at each isokinetic speed, although the order of the isokinetic speeds was balanced and varied among subjects. Subsequent statistical analysis revealed no order effect. Subjects were instructed to provide maximal effort during each repetition until they could no longer continue. Verbal encouragement was also provided during each test. The leg that corresponded to hand dominance was used in all cases while the contralateral leg remained stationary (Figure 1).

The use of an isokinetic device allowed us to preset a minimum force requirement (70% of peak torque) to ensure that subjects continued to provide maximal effort (Figure 2). The isokinetic device also did the following: (a) allowed us to limit the subjects' range of motion to exactly 90° (from 90° to 0° of flexion) for each repetition, (b) standardized the speed of the exercise, (c) isolated the joint being used, (d) counted each repetition completed, and (e) measured the torque produced.

Data Collection
Heart rates were determined from a continuous single-lead ECG (Hewlett Packard Medical Products) during all exercises. Peak HRs were determined on a beat-to-beat basis by the R-R interval of 3 consecutive complexes. Intra-arterial blood pressure was recorded simultaneously with the ECG by cannulating the radial artery 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 was connected to a monitor and recorder (Hewlett Packard Medical Products). The risk of thrombosis was minimized by administering heparinized saline through the arterial catheter at a rate of 3 ml·h⁻¹. The subject's cannulated wrist was secured to an arm board, and

Figure 1. A subject seated on the isokinetic device with the contralateral leg being stabilized, showing the equipment used.

Figure 2. Kin-Com tracing of a test at (a) 200°·s⁻¹. Notice that despite an initial decline, force (kg) is essentially maintained until failure.
both arms were crossed across the chest. The subjects were not allowed to make a fist or grasp anything.

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

Several precautions were taken to avoid any occurrence of the Valsalva maneuver, which is known to elevate blood pressure. The subjects were instructed and prompted to breathe normally while respiratory patterns were observed on the system monitor by impedance pneumography (Hewlett Packard Medical Products). Any occurrence of the Valsalva maneuver was also evident in the blood pressure tracings (Figure 3). We are confident that little or no breath holding occurred in this study. The subjects also reported a subjective rating of perceived exertion (RPE) immediately after each exercise session. The original Borg scale was presented to the subjects after each exercise (1). Finally, peak torque values were recorded from the isokinetic dynamometer to demonstrate the maximum effort exerted by the subjects.

### Statistical Analyses

Peak cardiovascular data (Table 1) were converted to a percentage of resting values and are referred to as response data (Table 2). All data are presented as means ± SD. Descriptive statistics were used because of the small number of subjects, which may not represent a normal distribution of the greater population. Statistical power analyses were conducted, and even with a greater number of subjects, the likelihood of a reliable difference would be low.

### Results

Impressive changes were observed in all cardiovascular data from resting to peak values (Figure 5). These descriptive data show trends in a particular direction. However, there was no statistically reliable change, perhaps because of the small number of subjects.

Heart rates appeared to increase with increases in isokinetic velocity. The mean peak HR was 183.5 ± 16.8 b-min\(^{-1}\) and occurred during the 200°·s\(^{-1}\) trial, as did the individual peak HR (205 b-min\(^{-1}\)). Both SBP and DBP decreased with increases in isokinetic velocity. The mean peak SBP was 181.1 mm Hg and occurred during the 50°·s\(^{-1}\) trial, as did the individual peak SBP (380 mm Hg). The mean peak DBP (181.1 mm Hg) also occurred during the 50°·s\(^{-1}\) trial, as did 1 individual's peak DBP (185 mm Hg). The RPP increased with increases in isokinetic velocity, much like the HR data. The mean peak RPP was 616.7 ± 84.1 and occurred during the 200°·s\(^{-1}\) trial, with 1 individual obtaining a very high peak RPP value of 738.0. Although extremely high values were frequently observed in the cardiovascular parameters, abnormal ECG or blood pressure responses were not observed.

Peak torque and the number of repetitions completed were also recorded by the isokinetic dynamom-
Cardiovascular Responses to Isokinetic Resistance 363

Table 1. Mean cardiovascular values (±SD) for isokinetic exercises at 50°s⁻¹, 100°s⁻¹, and 200°s⁻¹.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rest</th>
<th>50°s⁻¹</th>
<th>100°s⁻¹</th>
<th>200°s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>70.3 ± 10.9</td>
<td>163.3 ± 28.4</td>
<td>174.7 ± 20.3</td>
<td>183.5 ± 16.8</td>
</tr>
<tr>
<td>Peak systolic blood pressure</td>
<td>154.3 ± 10.1</td>
<td>348.2 ± 18.1</td>
<td>337.2 ± 23.7</td>
<td>335.5 ± 27.4</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td>77.0 ± 11.9</td>
<td>157.3 ± 34.0</td>
<td>147.2 ± 25.3</td>
<td>135.0 ± 31.1</td>
</tr>
<tr>
<td>Rate–pressure product</td>
<td>108.8 ± 19.6</td>
<td>569.2 ± 104.8</td>
<td>589.1 ± 79.9</td>
<td>616.7 ± 84.1</td>
</tr>
</tbody>
</table>

Table 2. Mean response (peak/rest) data (± SD) for isokinetic exercises at 50°s⁻¹, 100°s⁻¹, and 200°s⁻¹.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Resting value (%)</th>
<th>50°s⁻¹</th>
<th>100°s⁻¹</th>
<th>200°s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>235.0 ± 46.0</td>
<td>251.5 (37.5)</td>
<td>264.4 ± 35.9</td>
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<tr>
<td>Peak systolic blood pressure</td>
<td>226.5 ± 20.6</td>
<td>219.5 (24.3)</td>
<td>218.7 ± 28.5</td>
<td></td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td>209.7 ± 64.3</td>
<td>192.6 (28.9)</td>
<td>182.9 ± 65.7</td>
<td></td>
</tr>
<tr>
<td>Rate–pressure product</td>
<td>533.0 ± 119.1</td>
<td>554.0 (115.8)</td>
<td>579.5 ± 118.9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Mean resting and peak heart rates (b·min⁻¹) (± SD) for isokinetic exercises.

Discussion

Much of the research involving the cardiovascular response to resistance exercise has been conducted with isometric resistance. These studies have shown that cardiovascular responses increase with changes in the duration, intensity (percentage of maximum voluntary contraction), and muscle mass involved in the contraction (14, 18, 23–25). As a result, many researchers believe that a slower isokinetic velocity, which allows the subject to produce greater torque, may also produce a greater cardiovascular response. In the present study, increases in blood pressure were related to decreases in isokinetic velocity, or those exercises that enabled the subject to produce more force. However, this was not true for HR, and extrapolation from static exercise to dynamic exercise is generally not prudent.
In the present study, HR increased with increases in isokinetic velocity. We believe this trend occurred because the higher isokinetic speeds produce less resistance and more closely resemble an “aerobic” activity than the lower-velocity resistance exercises.

Although previous investigations have reported increases in HR while using different speeds of isokinetic exercise (3, 11), changes in SBP, DBP, and RPP with these exercises were usually assessed with indirect methods (3). Freedson et al. (8) did, however, report intra-arterial blood pressures with hydraulic (accommodating) resistance at unidentified slow and fast speeds. They reported significant differences in peak SBP and DBP for slow vs. fast hydraulic speeds, with the slower speed producing the greater values (8).

In the present study, both SBP and DBP decreased with an increase in isokinetic velocity. Isokinetic exercises at slower speeds are similar to other forms of resistance exercises in which greater amounts of resistance are used. Slower isokinetic speeds allow the subject to produce more force within the muscle, and consequently greater amounts of resistance are provided by the isokinetic machine in an attempt to accommodate the force being produced. Increases in blood pressure appear to be more closely related to the less-aerobic activities that often produce “straining.”

The peak systolic pressures found in the current study were similar to the pressures reported by MacDougall et al. (16) (group mean of 320/250 mm Hg and a peak pressure of 480/350 mm Hg in 1 subject). It had been hypothesized that the extremely high pressures reported by MacDougall et al. were due to the location of the catheter. However, other resistance exercise studies that also used intrabrachial pressures failed to produce similar extreme values. The radial artery was cannulated in the present study, and mean SBP and DBP values were considerably higher than in other reported intraradial studies (4–6, 17), although they were still not as high as those of MacDougall et al. (16). The great SBP and DBP values observed in this study (group mean of 348/157 mm Hg and a peak in 1 subject of 380/185 mm Hg at 50°-s⁻¹) may have occurred because isokinetics was the form of resistance used (12). Kleiner et al. (12) reported a greater response in all cardiovascular parameters (HR, SBP, DBP, and RPP) with accommodating (isokinetic) resistance than with fixed or variable isotonic resistance.

These extremely high intra-arterial pressures appear to be common, even in the absence of a Valsalva maneuver. Much of the increase in blood pressure during resistance exercise had been attributed to the Valsalva maneuver. However, in the present study, like other studies (12), subjects were discouraged from performing the Valsalva maneuver, although it may still have occurred in some instances. MacDougall et al. (15) have stated that the Valsalva maneuver is an unavoidable consequence of high-resistance exercise with repeated contractions to failure. Although intrathoracic
pressure was not measured in this study, any occurrence of the Valsalva maneuver was evident through impedance pneumography and by visible increases in the pressure tracing for both SBP and DBP. However, these sudden increases in blood pressures as a result of the maneuver rapidly decreased and immediately returned to their pre-Valsalva values. This dramatic but short-lived increase and decrease are graphically demonstrated in the pressure waveforms (Figure 3). Any values obtained during this brief period of elevated pressure were not used in the analysis. However, residual effects of the Valsalva maneuver, although not apparent, cannot be entirely dismissed. The occurrence of a Valsalva maneuver should not be considered a limitation of this study, but rather an unavoidable element of resistance exercise. The purpose of this study was to describe the acute cardiovascular responses to isokinetic resistance exercises, and the Valsalva maneuver may occur during such exercises.

The present study revealed no differences among isokinetic velocities for SBP or DBP, although a trend was apparent and may be clinically relevant. Values of SBP and DBP decreased with increasing isokinetic speeds, whereas HR and RPP increased with faster isokinetic speeds. Because RPP is a function of HR and SBP, it follows that HR had a greater effect on RPP than did SBP. The RPP is a noninvasive indicator of myocardial oxygen demand and should be of particular interest to populations whose myocardial workloads should be minimized during exercise. In the present study, RPP was lower during the exercises with the greater resistance. However, it is important to recall that these are the same exercises that also produced the greatest responses in SBP and DBP. It is more likely that a strength and conditioning professional will encounter an athlete who is hypertensive, whether he or she is aware of it or not. This study attempted to provide unique and clinically important information in describing the cardiovascular responses to velocity-specific isokinetic exercises with direct measurements of arterial pressure.

**Practical Applications**

Our data revealed great increases in HR, SBP, DBP, and RPP during isokinetic resistance exercises when compared with rest. Although these extreme values during resistance training did not appear to pose any problems in these healthy subjects, they were a stress to the cardiovascular system nonetheless, and may have clinical significance. In conclusion, we believe that these findings should not discourage anyone from using isokinetics, but particular attention should be paid to protocol selection when prescribing resistance exercises to hypertensive athletes. The strength and conditioning professional should consult with team medical personnel and should consider the cardiovascular consequences of the form and velocity of resistance selected.

**References**


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