Cardiovascular Response to Restricted Range of Motion Resistance Exercise

James J. Sullivan¹, Ronald G. Knowlton¹, Paul DeVita¹, and Dale D. Brown²

¹Department of Physical Education, Southern Illinois University, Carbondale, Illinois 62901; ²Department of HPERD, Illinois State University, Normal, Illinois 61790.

Reference Data

ABSTRACT
The purpose of this study was to determine if restricted range of motion (RERom) resistance exercise would accentuate the cardiovascular response compared to full range of motion (FReom) resistance exercise. Subjects (N = 14, age 24 ± 2.5 yrs) were experienced male weight trainers. Using a counterbalanced design, each subject underwent a control and treatment condition performing 4 sets of biceps curls at 40% 1-RM. FReom involved 4 sets of 8 full range-of-motion repetitions, while RERom consisted of 4 sets of varying restricted range-of-motion exercise. Total angular displacement, rate of movement, and time per set were equal for both conditions and all sets. Heart rate (HR), blood pressure (BP), and rating of perceived exertion (RPE) data were obtained immediately after each exercise set. Blood pH and lactate (HLA) data were obtained at rest and postexercise. High speed cinematography data were obtained on 3 subjects to assist in data interpretation. Results from repeated measures two-way ANOVA showed that RERom significantly increased HR, HLA, and RPE compared to FReom (p < 0.05), with no effect on BP and pH. Analysis of the joint torques indicated that Sets 2, 3, and 4 of RERom produced more angular impulse than at FReom. It was concluded that restricted range-of-motion forearm flexion exercise increases the cardiovascular response and torque production compared to full range-of-motion exercise.

Key Words: free weights, pressor response, lactate

Introduction
Both isometric contractions and dynamic full range-of-motion (FReom) muscular contractions produce an immediate pressor response (6, 11), the mechanism for which appears to be both centrally and peripherally mediated (9, 13). The magnitude of the pressor response is primarily related to the extent of muscle mass involved and the intensity of the exercise (9, 12, 13). Recently, Stebbins and Longhurst (17) demonstrated an increased pressor response to both light and intense static contractions under ischemic conditions, with the decreased blood flow causing an increase in hydrogen ions, lactate, and PCO₂ following light intensity contractions.

Restricted range-of-motion (RERom) exercise is performed by athletes and prescribed for injury rehabilitation (15). However, it is unclear as to how RERom exercise affects the cardiovascular response to resistance exercise. At a constant rate of contraction, limiting the range of motion during resistance training would restrict blood flow and allow an increased number of contractions to be performed in a given amount of time. Together these factors could increase the pressor response typically associated with dynamic exercise. The present study was designed to compare the cardiovascular responses of RERom to FReom exercise in which the rate of contraction, resistance mass, and total degrees of motion were equated for the two forms of exercise.

Methods

Subjects and Data Collection
Fourteen healthy, normotensive men (age 24 ± 2.5 yrs) volunteered for the present study and gave their informed consent. All had been regularly training with free weights for at least 2 years prior to the study. The two-arm standing biceps curl was chosen for the study for several reasons: (a) it is a common exercise; (b) it requires little skill; and (c) it involves fewer muscle groups than complex exercises such as the power clean, bench press, or squat.

During the initial laboratory session each subject’s one-repetition maximum (1-RM) was determined with a curl bar and free weights using the procedures described by Berger (1). The subjects were instructed on the weight-lifting procedures and were allowed to practice the lifting techniques of both conditions until they attained proficiency.

The two conditions of the study involved two weight-lifting procedures administered on separate days using a counterbalanced design. In order to provide consistency in the overall response to the exercise...
bout and reduce the complexity of the study, the order of sets was not randomized during REom. Two to 5 days were allowed between REom and FLrom, and the subjects were told not to exercise 24 hrs prior to data collection. Pilot work showed that approximately 40% of the 1-RM was the maximum resistance with which the REom condition could be completed without compromising proper technique. A workload of 40% 1-RM is a practical one for circuit training, untrained individuals, or rehabilitation settings. Therefore all subjects used a resistance of approximately 40% 1-RM during testing conditions.

Prior to the exercise, each subject did a light warm-up with upper body stretches and one full range-of-motion set of 8 curls with only the curl bar. The FLrom condition consisted of 4 sets of 8 full range-of-motion repetitions, while REom involved sets of restricted range-of-motion exercise at various repetitions. The first set of REom was identical to the first set of FLrom to determine whether there was between-day variability for the cardiovascular responses to the exercise. The remainder of REom consisted of 3 sets of varying repetitions. Set 2 of REom contained upper 1/3 (120 to 180°), upper 2/3 (60 to 180°), and full range-of-motion (0 to 180°) repetitions repeated in sequence 4 times. Set 3 of REom utilized 24 reps in the middle 1/3 (60 to 120°) range of motion. Finally, Set 4 involved 16 reps in the upper 1/2 (90 to 180°) range of motion.

The REom and FLrom conditions were not equated for in terms of actual work because the amount of work performed changes in response to the length of the lever arm, and the muscles may have been in a constant state of contraction during REom. Instead, rate of contraction, total degrees of motion, and mass of resistance were equated. The number of repetitions for the sets of REom was varied so that the equivalent degrees of motion of 8 full range-of-motion repetitions would be performed. During both conditions a constant rate of contraction was maintained such that each set would be completed in 30 sec.

The speed of contraction during exercise was controlled by an observer with a stopwatch who verbally paced the subject during exercise. Range of motion was controlled by a second observer who used his hands to guide the subject during exercise. The observer’s hands were placed at predetermined stopping points for the various ranges of motion, with no contact made between the hands and the weight bar. Three minutes of rest were allowed between sets. All subjects were told to breathe freely during the exercise to reduce the possibility of the Valsalva maneuver interfering with blood pressure during and after exercise (7, 13). Since the subjects were neither lifting maximal weights nor lifting to failure, it was considered unlikely that the Valsalva maneuver would interfere with blood pressure responses (13).

Immediately after each set of exercise, heart rate was determined from an ECG using CM-5 electrode placement, and blood pressure was measured from auscultation over the right brachial artery. The same technician obtained all blood pressures within 45 sec of completing the exercise set. In order to determine blood lactate and pH, arterialized capillary blood was obtained by finger puncture prior to exercise and within 45 sec following Set 4. The capillary blood was arterialized by placing the hand in a container of very warm (35 to 40°) tap water for 30 sec. This method has been shown to accurately represent arterial blood (14). One minute after each set of exercise, the rating of perceived exertion was obtained using the original 15-point Borg scale (3). Blood lactate concentration was measured using a Yellow Springs 23L lactate analyzer (Yellow Springs, OH), and blood pH was determined using a Radiometer pH-47 meter (Westlake, OH).

**Biomechanical Data Collection**

Limited biomechanical data were collected to ascertain the physiological responses to REom. The data were collected on a separate day to avoid interfering with physiological data collection. Three subjects were randomly chosen from the 14 subjects and were filmed to assess joint torques at the elbow and shoulder. Since the elbow joint was not fixed during the exercise, it is likely that the shoulder flexors contributed to total torque production. Therefore shoulder torque was included in the estimation of total torque production. Identifying marks were placed on each subject’s right elbow and shoulder and on the end of the curl bar.

The subjects were filmed in the sagittal plane with a high-speed 16-mm cine camera using a film speed of 50 Hz for 5 reps of each test condition. Data from the first and last repetition were discarded and the torque production was calculated from the average of 3 reps. For each subject, the 3 markers on the film records were digitized in the middle 3 trials for each condition and the resultant position data were smoothed with an interactive cubic spline routine. A two-segment biomechanical model was used to represent the hand/forearm and arm. An inverse dynamic analysis was used to calculate the joint reaction forces and torques at the elbow and shoulder (5).

The equations used in this analysis included the reaction force of the curl bar and weights onto the hand/forearm segment, which were derived from the accelerations of the curl bar and weights and their known masses. The magnitude of the segmental masses and the mass center locations of the upper extremity, along with their moments of inertia, were estimated using a mathematical model (8), segmental masses reported by Dempster (4), and the subject’s anthropometric measures. The torque curves were evaluated by calculating the angular impulse in the flexor direction at the elbow and shoulder joints and summing these values to pro-
duce a single biomechanical description of each movement. The angular impulse values were adjusted for discrepancies between the performance times in the physiological and biomechanical data collection sessions.

**Statistical Analysis**

All physiological data were analyzed using a mainframe version of SAS (SAS Institute Inc., Cary, NC); statistical significance was accepted at the level of $p < 0.05$. A repeated measures two-way analysis of variance was used to assess treatment main effects and interaction between exercise treatment and time. Cardiovascular data were further analyzed using a post hoc Tukey HSD test to determine which exercise sets differed significantly between conditions. Biomechanical data were interpreted descriptively because of the small number of subjects used for kinetic analyses.

**Results**

Analysis of data showed that increases in HR and RPE were significantly ($p < 0.05$) greater following $R_E$rom than $F_L$rom (treatment $\times$ time interaction; Figures 1 and 2, respectively). Post hoc data analysis showed that HR following Sets 2 and 3 of $R_E$rom were significantly greater than $F_L$rom. Also, RPE for Sets 2, 3, and 4 of $R_E$rom were significantly greater than the corresponding sets of $F_L$rom. There were no significant differences for Set 1 between $R_E$rom and $F_L$rom, indicating that between-day variability within subjects was minimal.

Blood lactate concentration increased from rest to postexercise for both conditions ($R_E$rom, $0.8 \pm 0.32$ to $3.28 \pm 0.85$ mM; $F_L$rom, $0.67 \pm 0.24$ to $1.95 \pm 0.57$ mM; means $\pm SD$) and was significantly greater following $R_E$rom than $F_L$rom. Blood pH decreased from rest to postexercise for both conditions ($R_E$rom, $7.38 \pm 0.02$ to $7.33 \pm 0.03$; $F_L$rom, $7.39 \pm 0.05$ to $7.35 \pm 0.01$); however, there were no significant differences between conditions. Although mean values for SBP and DBP were higher following $R_E$rom compared to $F_L$rom (SBP, $138.6 \pm 20.58$ vs. $136.0 \pm 13.37$; DBP, $93.0 \pm 10.32$ vs. $89.4 \pm 9.95$), these differences were not statistically significant.

Film analysis showed that the fractional movements in the upper $1/3$, upper $1/2$, upper $2/3$, and middle $1/3$ range of motion were approximately $32$, $50$, $67$, and $33\%$, respectively, of the total range of motion. However, the angular impulse values (Table 1) in the upper $2/3$ and upper $1/2$ range were $77$ and $60\%$, respectively, of the angular impulse value produced in the full range of motion. The largest difference occurred in the middle $1/3$ movement, which produced $45\%$ of the angular impulse performed in the full range of motion. Based on these findings, Sets 2, 3, and 4 of $R_E$rom would produce substantially greater torque than each set of $F_L$rom.

**Figure 1.** Heart rate response to 4 sets of $F_L$rom compared to $R_E$rom exercise (mean values with associated $SEE$); $N = 14$; significant difference: $§$ between conditions, * between sets.

**Figure 2.** Rating of perceived exertion response to 4 sets of $F_L$rom compared to $R_E$rom exercise (mean values with associated $SEE$); $N = 14$; significant difference: $§$ between conditions, * between sets.

**Table 1**

<table>
<thead>
<tr>
<th>Total Angular Impulse Values (N $\cdot$ m $\cdot$ s) Describing Complete Movement Cycle of Forearm Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subject</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>SD</td>
</tr>
</tbody>
</table>

*Note.* Values are mean of $3$ reps during full and restricted range of motion.
Discussion

The present study shows that restricted range of motion exercise increases heart rate compared to full range of motion exercise. The differences in HR between FLrom and RERom were likely a result of either the increased torque production or the increased frequency of contraction. It is also possible that the restricted blood flow was a result of the constant tension during RERom. One or more of these factors could have caused the differences observed between RERom and FLrom. Because torque values were greater during RERom, we would expect blood pressure to be greater in response to RERom compared to FLrom. However, there were no significant differences between the two conditions.

Since research has shown that the blood pressure response to resistance exercise is attenuated in trained lifters (7), it is possible that the subjects' training experience decreased the sensitivity of the blood pressure response to differences in workload. If there was a significant difference in blood pressure between conditions, it went undetected perhaps because blood pressures were measured postexercise rather than during exercise.

Film analysis showed that RERom produced greater torque than FLrom. This was due to an increase in moment arm length during the middle phase of the curl. Blood lactate and perception of effort (Figure 2) were also significantly greater following RERom. This indicates that the restricted range-of-motion exercise was more strenuous than the full range-of-motion exercise. It has been well established that exercise intensity is a primary contributor to the cardiovascular response to exercise (10, 12, 13). Therefore, the increased work performed during the restricted range-of-motion exercise likely contributed to the elevated cardiovascular response associated with RERom.

In addition to the increased torque production, the cardiovascular response to RERom may have resulted from an increase in contractions and reduction in blood flow due to the limited range of motion during RERom. Post hoc analysis showed that HR significantly increased across Sets 1, 2, and 3 RERom as the number of movements increased from 8, 12, and 24, respectively (Figure 1). Bergstrom and Hultman (2) have shown that per unit of work, increasing the number of contractions leads to increased expenditure of energy and generation of lactate and hydrogen ions.

In the present study, lactate was significantly increased following the series of restricted range-of-motion exercise, likely because of increased torque production and reduced clearance due to restriction of blood flow (16, 18). Although an increased lactate concentration from light static ischemic muscle contractions has been shown to be associated with increased blood pressure in cats (17), the trained men in the present study did not demonstrate an increased blood pressure in association with increased lactate production.

MacDougall et al. (13) have shown that as the number of exercise repetitions increase, the magnitude of the heart rate and blood pressure response also increases. They concluded that the pressor response to resistance exercise is primarily a central response to the compression of blood vessels, as their data showed a rapid, direct relationship between the concentric phase of exercise and the cardiovascular response. During Sets 2, 3, and 4 of RERom it is likely that the elbow flexors did not relax between the concentric and eccentric phase. Therefore it is possible that an increased compression of blood vessels occurred and heart rate was increased due to the central response suggested by MacDougall et al. (13).

In summary, this study shows that when resistance mass, rate of contraction, and total degrees of motion are equated between restricted and full range-of-motion exercise, the former results in higher responses for heart rate, blood lactate, and perception of effort. These responses may be due to an increased total amount of work, physiological mechanisms associated with restricted range-of-motion exercise, or both. It cannot be determined from these data whether similar responses would occur using greater workloads or other lifting exercises.

Practical Applications

Restricted range-of-motion resistance exercise may increase the work performed for a given amount of time and rate of movement, resulting in a greater training effect. However, limited range-of-motion exercise increases the cardiovascular responses associated with full range-of-motion resistance exercise in healthy, trained men. Whether the increased cardiovascular response would be accentuated in older or unfit populations is not known, therefore restricted range-of-motion resistance exercise may not be appropriate for certain populations.

References


**Note**

James J. Sullivan is now with the Dept. of Human Performance, MSU 28, Mankato State University, Mankato, MN 56002-8400.