Comparison of Central Hemodynamics Between Powerlifters and Bodybuilders During Resistance Exercise

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ABSTRACT

Falkel, J.E., Fleck, S.J. and T.F. Murray. Comparison of central hemodynamics between powerlifters and bodybuilders during resistance exercise. J. Appl. Sport Sci. Res. 6(1):24-35. 1992. — The purpose of this investigation was to compare the heart rate, stroke volume and cardiac output between a group of five experienced powerlifters and five experienced bodybuilders. Impedance cardiography was used to assess central hemodynamics during the free-weight back squat and single-leg knee extension exercises. Each group performed sets to voluntary concentric fatigue at 50, 80 and 100 percent of the maximal resistance possible for one repetition (1 RM). Peak values of central cardiac function were determined during the eccentric and concentric phases of each contraction for each exercise. Eccentric and concentric peak heart rate significantly decreased as the percentage of 1 RM increased in both groups for both exercises, and was significantly greater for the bodybuilders than for the powerlifters during the 100 and 50 percent sets of knee extension. Eccentric and concentric peak stroke volume and cardiac output were significantly higher for the bodybuilders as compared to powerlifters at all but two percentages of 1 RM for each exercise. All eccentric values for stroke volume and cardiac output, except for the 100 percent knee extension value, were significantly greater than the concentric values. Concentric cardiac output was significantly higher for the knee extension exercise as compared to the squat at the same percentage of 1 RM for the bodybuilders. All concentric stroke volume values at the same percentage of 1 RM were greater for knee extension than for the squat exercise. Eccentric stroke volume was only greater for knee extension compared to the the squat for the bodybuilders during the 100 and 80 percent sets, and for the powerlifters during the 80 percent set. Cardiac output was not different during knee extension compared to the squat for the powerlifters except for the 100 and 50 percent eccentric sets, in which the squat was greater than knee extension. The bodybuilders showed no consistent pattern concerning cardiac output being different between the two exercises during sets at the same percentage of the 1 RM. These results indicate that the type of resistance training (powerlifting versus bodybuilding), as well as the amount of muscle mass, percentage of 1 RM lifted and phase of contraction, have a profound effect on heart rate, stroke volume and cardiac output during dynamic resistance exercises.

KEY WORDS: resistance training, cardiac output, impedance cardiography, powerlifters, bodybuilders, eccentric and concentric contractions

INTRODUCTION

The training programs usually used by powerlifters and bodybuilders are markedly different. Powerlifters, whose main emphasis is the development of maximal strength, perform relatively few repetitions using maximal or near-maximal resistance (one to eight repetitions at maximum resistances) (13). Bodybuilders, in order to develop muscle hypertrophy, use a training regimen that incorporates multiple sets of a relatively high number of repetitions per set of each exercise (eight to 10 repetitions at maximum resistances) (13). While both of these groups of resistance-trained athletes may include the same exercises in their training programs, there may be differences in the central hemodynamics during exercise between these two groups, due in part to the manner of training. During powerlifting, the athlete may execute a Valsalva maneuver while straining to lift a near one-repetition maximum (1 RM) resistance. It
has been speculated that a Valsalva maneuver may decrease cardiac output and stroke volume by reducing venous return (17, 19). The high volume of exercises performed by the bodybuilder resembles circuit weight training, and therefore may enhance cardiovascular conditioning in a manner similar to circuit weight training (5). Circuit weight training increases maximal oxygen consumption, but the increase is relatively moderate (five to eight percent) (6). Therefore, the specificity of training for these two resistance sports may significantly affect the central hemodynamics that occur during resistance exercise.

Previous investigations have suggested several other factors that may influence the central hemodynamic responses during resistance training. Miles et al. showed cardiac output to be significantly greater during the eccentric portion of a resistance exercise than during the concentric phase, due to a higher stroke volume that occurs during the eccentric portion of the contraction (19). It also has been shown that during dynamic resistance exercise at the same relative resistance, cardiac output is significantly greater when a larger muscle mass is involved in the exercise (15). However, no previous study has examined the influence of varying relative resistances on central hemodynamic function during the eccentric and concentric phases of exercise, nor have the responses between powerlifters and bodybuilders been compared. Therefore, the purpose of this investigation was to examine the peak central hemodynamic responses (heart rate, stroke volume and cardiac output) at several relative resistances during the eccentric and concentric phases of two common dynamic resistance exercises (back squat and single-leg knee extension) in a group of experienced powerlifters and bodybuilders.

**METHODS**

Ten experienced resistance-trained athletes (mean ± standard error = 9.35 ± 1.1 years of training) served as subjects. Five subjects were powerlifters and five were bodybuilders. All were active in competitive powerlifting or bodybuilding. Table 1 compares anthropometric data for the two groups. Body composition was estimated using skinfold measurements (22). Subjects were informed of the nature of the investigation, and informed consent was obtained from each subject before testing, in accordance with institutional review board guidelines. The resistance exercises used in this investigation were the free-weight back squat and a seated single-leg knee extension performed on a variable-resistance apparatus (Nautilus Inc., Deland, Florida). The dominant limb was used in the performance of the single-leg knee extension. Both groups of athletes used these two exercises in their normal training routines. Two to three days before the initial experimental procedure, a 1 RM was determined for each of the two exercises. The procedure for determining each subject's 1 RM for each exercise consisted of the performance of one warm-up set of 10 repetitions at 40 to 45 percent of his previous best 1 RM value. After the warm-up set, single repetition sets, separated by three minutes of rest, were attempted with progressively heavier resistances, starting at approximately 85 percent of the subject's previous best 1 RM. The back squat initially was increased by 10 kilograms and the knee extension by 4.55 kilograms per attempt. When the subject considered himself to be near his 1 RM, the back squat resistance was increased by five kilograms and the knee extension by 2.27 kilograms per attempt until the subject failed to complete a full repetition. A back squat was considered successful when the subject descended to a point where the top of the thigh was parallel to the floor and returned to a full standing position. The knee extension was successful when the subject came to full knee extension and held the position for one second. Each subject wore a weightlifting belt and knee wraps during the back squat exercise.

Experimental procedures were performed in duplicate for each type of exercise. Each testing session was separated by seven days. During the seven days between test sessions, subjects underwent their normal resistance training, but did not perform any squat or knee extension exercises. During testing, subjects performed sets to voluntary fatigue of both exercises at 100, 80 and 50 percent of their previously determined, exercise-specific 1 RM. The 100 percent set was always performed first, followed by the other sets in random order. All sets were performed to the point of voluntary fatigue, with five minutes of rest between successive sets. Subjects maintained a cadence of three seconds for the completion of both concentric and eccentric phases of each repetition, with a two-second pause between concentric and eccentric phases of each repetition. As the subject fatigued, the duration of the concentric but not the eccentric phase of the repetitions was allowed to lengthen. Repetitions were judged successful as described in the 1 RM test.

Four aluminized Mylar tape electrodes were placed in the standard positions as previously described (14), and an impedance cardiograph (Minnesota Impedance Cardiograph Model 304 B, Minneapolis, Minnesota) was used to estimate cardiac output and stroke volume during the exercises.

The impedance cardiogram (ZCG) was recorded simultaneously with a three-lead electrocardiogram (ECG),
Table 1. Anthropometric Data of Subjects (X ± SE)

<table>
<thead>
<tr>
<th></th>
<th>Age (yr)</th>
<th>Lifting (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Fat (%)</th>
<th>Lean Body Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powerlifters</td>
<td>23.2 ± 1.7</td>
<td>10.5 ± 1.2</td>
<td>178.5 ± 2.4</td>
<td>92.8 ± 1.6</td>
<td>12.83 ± 1.40</td>
<td>80.89 ± 2.10</td>
</tr>
<tr>
<td>Bodybuilders</td>
<td>23.8 ± 1.6</td>
<td>8.8 ± 1.0</td>
<td>179.5 ± 1.8</td>
<td>91.3 ± 2.7</td>
<td>8.91 ± 1.03*</td>
<td>83.16 ± 1.91</td>
</tr>
</tbody>
</table>

*Bodybuilders significantly different than powerlifters (p < 0.05)

using a CM-5 lead configuration to monitor lead II. Calculations of cardiac output and stroke volume were made with a computer-aided system similar to that previously described (3). Stroke volume was calculated using the equation of Kubicek et al. (14):

\[ SV = \frac{p \times L^2 \times T \times dZ/dT}{Zo^2} \]

Where:
- \( SV \) = stroke volume (milliliters)
- \( p \) = blood resistance (ohm*cm) determined from hematocrit (4)
- \( L \) = mean anterior distance (centimeters)
- \( Zo \) = mean body impedance (ohms) between inner electrodes
- \( T \) = left ventricular ejection time (seconds)
- \( dZ/dT \) = maximum rate of change (ohm*sec\(^{-1}\)) from baseline impedance during the cardiac cycle.

Heart rate was determined on a beat-by-beat basis from the R-R interval on the ECG. Cardiac output (liters per minute) was calculated as heart rate x stroke volume. The event marker on the four-channel recorder (Astro-Med, West Warwick, Rhode Island) was used to designate the beginning and end of the eccentric and concentric phases of each contraction. All ZCG wave forms that occurred during each eccentric and concentric contraction for all exercise sets during both exercise sessions were analyzed, and the mean value of the eccentric and concentric phases of each repetition was determined. The highest mean value for each exercise condition and contraction phase was used in statistical analysis, regardless of the repetition in which it occurred.

Mouth pressures were assessed using a mouthpiece attached with stretch resistance tubing (Tygon 5/32 OD) to a sphygmomanometer as described by MacDougall et al. (17). Peak mouth pressures were recorded during the eccentric and concentric phases of each repetition for all sets. The highest pressure for each contraction phase, regardless of repetition, of each set was used in the statistical analysis. The subjects were encouraged to breathe normally with the mouthpiece in place.

Test-retest reproducibility between the two exercise sessions was assessed using a paired student's t-test and Pearson product moment correlations. Peak mean values for each intensity were analyzed using a three-way repeated measures analysis of variance to determine whether differences existed between values for the powerlifters and bodybuilders, squat and knee extension exercises and eccentric and concentric phases of the exercises. A Scheffe post-hoc analysis was performed to determine differences between significant main effects, where appropriate. Statistical significance was accepted at an alpha level of p < 0.05.

**RESULTS**

The two groups did not significantly differ (p > 0.05) in age, years of lifting experience, height, body weight or lean body weight (Table 1). The bodybuilders had significantly lower (p < 0.05) percent fat compared to the powerlifters. The mean (± standard error) number of repetitions to determine the 1 RM of the back squat and knee extension exercises for all subjects were 4.2 ± 0.5 and 5.1 ± 0.5 trials, respectively. The resistances used and repetitions for the three exercise sets in the back squat and the single-leg knee extension are presented in Table 2. Peak cardiac output, stroke volume and heart rate during all sets demonstrated good reliability in that there were no significant differences (p > 0.05) between the two exercise sessions for each set and phase of contraction. Correlations between the two exercise sessions for peak cardiac output, stroke volume and heart rate ranged from r = 0.88 to r = 0.96 (p < 0.05).

**Heart Rate**

Peak eccentric and concentric heart rates were significantly greater (p < 0.05) than the pre-exercise heart rate values for all sets of each exercise, with the exception of the 100 percent knee extension set for the bodybuilders (p > 0.05). The mean pre-exercise heart rate values before
Table 2. Resistances Used and Number of Repetitions for the Squat and Single Knee Extension Exercises (kg of resistance, X ± SE)

<table>
<thead>
<tr>
<th></th>
<th>Powerlifters</th>
<th>Bodybuilders</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100%</td>
<td>80%</td>
<td>50%</td>
<td>100%</td>
<td>80%</td>
</tr>
<tr>
<td>Squat (kg)</td>
<td>185.0 ± 18.5</td>
<td>148.0 ± 11.2</td>
<td>92.5 ± 8.9</td>
<td>161.8 ± 7.8*</td>
<td>129.4 ± 5.6*</td>
</tr>
<tr>
<td>(reps)</td>
<td>1.0 ± 0.0</td>
<td>6.7 ± 0.3</td>
<td>16.7 ± 0.7</td>
<td>1.0 ± 0.0</td>
<td>7.0 ± 0.5</td>
</tr>
<tr>
<td>KE (kg)</td>
<td>64.5 ± 1.4</td>
<td>51.6 ± 1.0</td>
<td>32.2 ± 0.8</td>
<td>48.1 ± 1.2*</td>
<td>38.5 ± 0.7*</td>
</tr>
<tr>
<td>(reps)</td>
<td>1.0 ± 0.0</td>
<td>7.8 ± 0.2</td>
<td>15.2 ± 0.5</td>
<td>1.0 ± 0.0</td>
<td>8.0 ± 0.4</td>
</tr>
</tbody>
</table>

*Bodybuilders significantly different than powerlifters (p < 0.05)

the squat were 93 ± 2.3 and 99 ± 3.2 beats per minute for the powerlifters and bodybuilders, respectively. The mean pre-exercise heart rates before the knee extension exercise were 87 ± 2.09 and 94 ± 2.8 beats per minute for the powerlifters and bodybuilders, respectively. Peak eccentric and concentric heart rates during all sets were significantly higher (p < 0.05) during the 50 and 80 percent sets compared to the 100 percent set, except during the 80 percent squat set for the bodybuilders (Figure 1). Heart rate during the 50 percent set was greater than that during the 80 percent set in all cases, except during knee extension for the powerlifters. Peak eccentric and concentric heart rates were significantly higher for the bodybuilders at the 100 and 50 percent sets of the squat and during the 80 and 50 percent sets of knee extension as compared to the powerlifters. In addition, the eccentric and concentric heart rates at all three percentages of 1 RM were significantly higher (p < 0.05) during the squat than during the knee extension for both groups, except during the eccentric 80 percent set for the bodybuilders (p > 0.05). However, there were no significant differences (p > 0.05) between the eccentric and concentric peak heart rates at the same relative resistance for any set of either exercise.

Stroke Volume

The mean pre-exercise stroke volumes before the squat were 79.2 ± 2.2 and 78.9 ± 3.1 milliliters per beat for the powerlifters and bodybuilders, respectively, and before the knee extension were 80.3 ± 3.4 and 84.5 ± 2.8 milliliters per beat for the powerlifters and bodybuilders, respectively. Figure 2 presents the peak eccentric and concentric stroke volume results. Peak eccentric stroke volume was significantly less (p < 0.05) than pre-exercise values for the powerlifters during the 80 percent squat set. Peak eccentric stroke volume was significantly greater (p < 0.05) than pre-exercise stroke volume for the bodybuilders during the 50 percent squat set and the 50 and 100 percent knee extension sets, but was significantly less (p < 0.05) than before exercise for the 80 percent squat set. During the concentric phase for the powerlifters, the peak stroke volume for all three squat sets and the 100 and 80 percent knee extension sets were significantly lower (p < 0.05) than pre-exercise values. The peak concentric stroke volumes for all sets of both exercises were significantly lower (p < 0.05) than pre-exercise values for the bodybuilders, except during the 100 percent and 50 percent knee extension sets (p > 0.05).

All comparisons of eccentric stroke volume between percentages of 1 RM during the squat were significantly different for both groups. During the knee extension exercise, the eccentric stroke volume for the 50 percent set was significantly higher (p < 0.05) than the 80 percent set for both groups. Eccentric stroke volume during the 50 percent set was significantly higher (p < 0.05) than the 100 percent set for the powerlifters, and the 100 percent set was greater (p < 0.05) than the 80 percent set for the bodybuilders. During the concentric phase of the squat, stroke volume during the 100 and 50 percent sets was significantly greater (p < 0.05) than the 80 percent set for both powerlifters and bodybuilders, but there was no significant difference (p > 0.05) between the 100 and 50 percent sets. The powerlifters showed no significant differences in concentric stroke volume during knee extension between sets, except for the 50 percent set being greater than the 80 percent set (p < 0.05). All comparisons of the bodybuilders’ concentric stroke volume between sets of the knee extension exercise were significantly different (p < 0.05), with the 100 percent set significantly greater than both the 80 and 50 percent sets, and the 50 percent set significantly greater than the 80 percent set. For all sets in both the eccentric and concentric phases of the squat exercise, the bodybuilders had significantly higher (p < 0.05) peak stroke volumes than the powerlifters. The bodybuilders also demonstrated a significantly greater (p < 0.05) stroke volume than the powerlifters at all three
Figure 1. Comparison of peak heart rate during eccentric and concentric phases of the squat and knee extension exercise (X ± SE) between powerlifters and bodybuilders: (a) represents bodybuilders significantly different (p < 0.05) from powerlifters; (b) represents knee extension significantly different (p < 0.05) from squat.
Figure 2. Comparison of peak stroke volume during eccentric and concentric phases of the squat and knee extension exercise (X ± SE) between powerlifters and bodybuilders: (a) represents bodybuilders significantly different (p < 0.05) from powerlifters; (b) represents knee extension significantly different (p < 0.05) from squat; (c) represents eccentric phase significantly different (p < 0.05) from concentric phase of the exercise.
Figure 3. Comparison of peak cardiac output during eccentric and concentric phases of the squat and knee extension exercise (X ± SE) between powerlifters and bodybuilders: (a) represents bodybuilders significantly different (p < 0.05) from powerlifters; (b) represents knee extension significantly different (p < 0.05) from squat; (c) represents eccentric phase significantly different (p < 0.05) from concentric phase of the exercise.
Figure 4. Comparison of mouth pressures during eccentric and concentric phases of the squat and knee extension exercise (X ± SE) between powerlifters and bodybuilders: (a) represents bodybuilders significantly different (p < 0.05) from powerlifters; (b) represents knee extension significantly different (p < 0.05) from squat; (c) represents eccentric phase significantly different (p < 0.05) from concentric phase of the exercise.
percentages of the 1 RM sets during the eccentric phase of knee extension. During concentric knee extension, the bodybuilders showed a significantly greater (p < 0.05) stroke volume than the powerlifters only for the 100 percent set. In the concentric phase of each exercise, the peak stroke volume for both groups was significantly greater (p < 0.05) during knee extension than during the squat for each set. Eccentric knee extension stroke volume also was greater than eccentric squat stroke volume for the powerlifters during the 80 percent set and for the bodybuilders during the 100 and 80 percent sets.

**Cardiac Output**

The mean values for pre-exercise cardiac output were 7.34 ± 0.22 and 7.81 ± 0.13 liters per minute for the powerlifters and bodybuilders, respectively, before the squat exercise. Pre-exercise cardiac output values before the knee extension exercise were 69.6 ± 0.17 and 7.89 ± 0.24 liters per minute for the powerlifters and bodybuilders, respectively. Peak eccentric cardiac output was significantly greater (p < 0.05) than pre-exercise cardiac output values for all sets of both exercises for both groups. Peak concentric cardiac output was significantly greater (p < 0.05) than pre-exercise cardiac output for all sets of both exercises for both groups, except for the 80 and 100 percent squat sets and the 100 percent knee extension set for the powerlifters (p > 0.05).

Peak eccentric cardiac output during the squat exercise was significantly greater (p < 0.05) for the 50 percent set as compared to the 80 and 100 percent sets for the powerlifters. The bodybuilders’ eccentric squat cardiac output was significantly greater (p < 0.05) for the 50 and 100 percent sets compared to the 80 percent set, and for the 50 percent set versus the 100 percent set. Powerlifters’ peak eccentric knee extension cardiac output during the 50 percent set was significantly greater (p < 0.05) than the 100 and 80 percent sets. The bodybuilders’ 80 and 50 percent eccentric knee extension cardiac outputs were significantly greater than during the 100 percent set, and the 50 percent set was significantly greater (p < 0.05) than the 80 percent set. During the concentric phase of the squat and knee extension, the powerlifters’ peak cardiac output for the 50 percent set was significantly greater (p < 0.05) than during the 100 or 80 percent sets. Peak concentric cardiac output for the bodybuilders was significantly greater (p < 0.05) for the 100 and 50 percent squat sets as compared to the 80 percent set, and the 50 percent squat set was significantly greater (p < 0.05) than the 100 percent set. The bodybuilders’ peak concentric cardiac output for the knee extension exercise was significantly greater (p < 0.05) for the 50 percent set compared to the 100 and 80 percent sets, and the 80 percent set was greater than the 100 percent set. During the eccentric and concentric phases of all sets of both exercises, peak cardiac output was significantly greater (p < 0.05) for the bodybuilders than for the powerlifters, with the exception of the eccentric 80 percent squats set (p > 0.05). Eccentric cardiac outputs for both bodybuilders and powerlifters during all sets were significantly greater (p < 0.05) for the squats exercise as compared to the knee extension exercise, except for the 80 percent set for both groups (p > 0.05). The powerlifters showed no significant difference (p > 0.05) in concentric cardiac output between the squat and knee extension for any sets at the same percentage of the 1 RM. The bodybuilders’ concentric cardiac output during the squat was significantly greater (p < 0.05) during the 100 and 50 percent sets compared to knee extension. However, the bodybuilders’ concentric 80 percent set cardiac output was significantly greater (p < 0.05) during knee extension compared to the squat. Peak eccentric cardiac output was significantly greater (p < 0.05) than peak concentric cardiac output for both groups in all sets of both exercises, except for the 100 percent knee extension set for the powerlifters (p > 0.05).

**Mouth Pressure**

Figure 4 presents the mouth pressure data. The powerlifters recorded no mouth pressure in either the eccentric or concentric phases during any of the sets, with the exception of small pressures during the 50 percent sets for the squats and knee extension exercises. Bodybuilders exerted significantly higher (p < 0.05) mouth pressures during each set of both exercises than did the powerlifters. The peak concentric mouth pressures from the bodybuilders were significantly greater (p < 0.05) for all sets of the squat exercise and the 50 percent set of knee extension when compared to the eccentric mouth pressures. The eccentric squat mouth pressure of the bodybuilders was significantly greater (p < 0.05) for the 100 percent set as compared to the other eccentric squat sets. The bodybuilders’ mouth pressure during the 100 and 80 percent sets of knee extension were significantly greater (p < 0.05) than the 50 percent set, and the 80 percent set was significantly greater (p < 0.05) than the 50 percent set. The 100 and 80 percent sets of the concentric squats for the bodybuilders were significantly greater (p < 0.05) than the knee extension values at the same relative intensity. The bodybuilders’ mouth pressure during the 100 percent set concentric squat was significantly greater (p < 0.05) than during the 50 percent set, and during the 100 percent set of
concentric knee extension was significantly greater \((p < 0.05)\) than during the 50 percent set.

**DISCUSSION**

Impedance cardiography has been shown to be a reliable, non-invasive method of determining central hemodynamics during rest and exercise (19, 20, 24). Goldstein et al. showed good correlations \((r = 0.85, p < 0.05)\) between cardiac output values obtained by impedance methods and thermodilution in response to cardiac pacing (7). In addition, cardiac output and stroke volume measurement determined by impedance cardiography have been shown to be highly reproducible at rest and during cycle ergometry (26). The test-retest reliability between the two trials in the present investigation support these findings, based on the good correlations \((r = 0.89 \text{ to } 0.96)\) and insignificant differences \((p > 0.05)\) between trials for heart rate, stroke volume and cardiac output values. Miles and Gotshall reported on the reliability and use of impedance cardiography, and concluded that it is an effective, non-invasive tool for estimation of central hemodynamics (20).

The major finding of this investigation is the marked effect that the percentage of the maximal resistance used during resistance exercise had upon the central hemodynamics in two groups of resistance-trained athletes. The heart-rate responses of the powerlifters and bodybuilders during the back squat and knee extension exercises (Figure 1) are similar to values reported by several other investigations for a variety of resistance exercises (2, 9, 12, 15, 17, 19). The observation of lower peak heart rates at the higher relative resistances is consistent with the results of Fleck and Dean (2). While the present investigation did not examine mechanism of heart rate control, Mitchell et al. showed that with static contractions, heart rate increases as the duration of the contraction increases (21). These authors related this increased heart rate to a reflex action secondary to sensory nerve endings in the skeletal muscle. In the present study, at the lower relative resistance, the athletes were able to complete more repetitions before voluntary fatigue, which would allow for a sufficient duration of the exercise for this sensory reflex to be activated.

In general, the bodybuilders demonstrated a higher heart-rate response during the sets of each exercise. There were no significant differences \((p > 0.05)\) in the number of completed repetitions for any of the sets in either exercise between the groups. Therefore, the difference in heart-rate response between the groups was not due to a difference in the number of repetitions completed during the set. The regular training routines of bodybuilders use relatively high numbers of repetitions (12 to 15) per set at some time during most training sessions. The powerlifters, on the other hand, rarely if ever perform more than six to eight repetitions during any set of any exercise. Therefore a training effect, due to the nature of the higher repetition training in the bodybuilders, may have been partly responsible for higher peak heart rates. The higher heart rates of the bodybuilders may be an adaptation to training that is partly responsible for the greater cardiac output exhibited by the bodybuilders.

The higher heart rates during the squat as compared to the knee extension exercise are in part due to the greater muscle mass involved in the squat. In a recent review, Fleck concluded that heart rate during dynamic exercise increases with the active muscle mass, but that the increase is not linear (1). The heart-rate response during dynamic resistance training is the same when the exercise is performed with or without a weight-training belt (10). Therefore, the greater heart rates during the squat cannot be attributed to the use of a weight-training belt in the squat, and not during the knee extension exercise. Previous research suggests that bodybuilders demonstrate a lower heart rate during resistance training than do controls and novice weight-trained subjects (2). Therefore, in the present study, it might be expected that the bodybuilders would demonstrate a lower heart-rate response than the powerlifters during the 50 and 80 percent sets of both exercises. This, however, is not the case. Thus, resistance training’s effect upon heart rate remains controversial.

Lewis et al. reported peak stroke volumes during dynamic two-leg knee extension that were of a similar magnitude to the values presented in the current study (15). Miles et al. reported stroke volumes of 50 to 65 milliliters per beat during two-leg knee extension exercise that resulted in voluntary fatigue in 12 repetitions (19). The data of Hoeger et al. (8) suggest that this number of repetitions would correspond with approximately 80 percent of maximal resistance for one repetition. The stroke volumes reported by Miles et al. are in close agreement with the values reported for the 80 percent sets of knee extension in the present investigation.

The differences in stroke volume during the eccentric and concentric phases of the two lifts may be due in part to the performance of a more forceful Valsalva maneuver during the concentric versus the eccentric portion of a repetition. The effect of the Valsalva maneuver on decreasing stroke volume has been well documented. In the current investigation, the measurement of mouth pressure during the resistance exercise was used to estimate the Valsalva maneuver as described by MacDougall et al. (17).
The lack of mouth pressure generated by the powerlifters during the exercises, compared with the relatively high pressures recorded by the bodybuilders, indicates that mouth pressure may not accurately reflect intra-thoracic or intra-abdominal pressures. The powerlifters may have been exercising with a completely closed glottis during the exercise sets at the higher percentages of maximal resistance, which may account for the lack of mouth pressure generated during these sets. A Valsalva maneuver is a fairly common phenomenon in powerlifters and olympic weightlifters in an attempt to generate high intra-abdominal pressure to help stabilize the spine during resistance training (18). If no mouth pressure does indicate a closed glottis and an extreme Valsalva maneuver, this in part would explain the lower stroke volumes and cardiac outputs demonstrated by the powerlifters.

Miles et al. reported differences in stroke volume and cardiac output similar to those reported here between the eccentric and concentric phases of dynamic resistance exercise when a Valsalva maneuver was not performed (19). The significantly greater (p < 0.05) stroke volumes during the eccentric as compared to the concentric phases of the exercises may be due to several factors besides a Valsalva maneuver during the concentric phases. MacDougall et al. reported lower systolic, diastolic and mean arterial pressure during the eccentric as compared to the concentric phase of resistance exercise (17). The authors concluded that these decreased pressures may be due to a decrease in intramuscular pressure, with a concomitant decrease in peripheral resistance. Miles et al. showed a negative relationship between stroke volume and total peripheral resistance during resistance exercise (19). In addition, Jarvholm et al. found negative correlations between intramuscular pressure and blood flow during isometric contractions (11). Electromyographic studies indicate that the entire motor unit pool may not be fully activated during maximal eccentric contractions (25). This may result in a decrease in intramuscular pressure and a concomitant decrease in peripheral resistance, and an increased stroke volume and cardiac output. It could be hypothesized that the greater stroke volume in the eccentric phases of the exercises, the lower stroke volume during the squat versus the knee extension, and the greater stroke volume of the bodybuilders as compared to the powerlifters may be caused by the Valsalva maneuver and changes in intramuscular pressures.

For each group, the highest peak cardiac output for the eccentric and concentric phases of both exercises occurred during the 50 percent set. This was the result of the combination of the highest heart rates and a large stroke volume being recorded in the 50 percent sets. The finding of the highest cardiac output at the lowest relative resistance is the reverse of what has been reported for dynamic ergometer exercise (16). This discrepancy between modes of exercise may be due to several factors, such as activity duration (16), performance of a Valsalva maneuver and increased blood pressure response observed during resistance exercise (2, 17). It also has been demonstrated that for dynamic resistance activity and dynamic ergometry, cardiac output is higher when the amount of muscle mass involved in the activity is greater (15, 16). The results of the present investigation support the finding that, in general, cardiac output was significantly greater during the squat exercise (p < 0.05) than during the knee extension exercise for both eccentric and concentric phases in both groups. The higher cardiac output recorded by the bodybuilders would appear to be a function of the relatively lower Valsalva maneuver, resulting in a concomitant higher stroke volume, and in some sets, in part due to significantly higher heart rates (p < 0.05) than the powerlifters.

In conclusion, the central hemodynamics during resistance exercise are significantly affected by several factors. Relative resistance would appear to have an inverse effect on heart rate in most instances, but stroke volume and cardiac output do not consistently increase or decrease with the change in relative resistance. There is generally a higher stroke volume and cardiac output during the eccentric as opposed to the concentric phase of each exercise. The squat exercise, which involves a greater muscle mass than does the knee extension exercise, resulted in larger eccentric and concentric heart rates and cardiac outputs. Finally, the type of resistance-trained athlete also may have a profound effect on the central hemodynamics, probably related to exercise specificity adaptations in heart rate responses, and the performance of a relatively greater Valsalva maneuver by the powerlifters as compared to the bodybuilders. The bodybuilders generally had higher heart rates, stroke volume and cardiac output at any percentage or contraction phase of the maximal resistance during either the squat or knee extension exercise.

**References**


