Circulatory Responses to Weight Lifting, Walking, and Stair Climbing in Older Males

[B]Clinical Investigation[

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Abstract

OBJECTIVES: To compare the heart rate and intra-arterial blood pressure responses during weight lifting, horizontal and uphill walking, and stair climbing in older male subjects.

DESIGN: We used intra-brachial artery catheterization to compare the arterial blood pressure (ABP) and heart rate (HR) responses during 10 repetitions (~40 s) of single-arm curl (SAC) and single-arm overhead military press (SAMP) (70% of the one repetition maximum - 1RM); 12 repetitions (~50 s) of single- (SLP) and double-leg press (DLP) weight-lifting exercises (80% of 1RM); 10 minutes of horizontal treadmill walking (T10) at 2.5 mph holding a 20-pound weight in minutes 4 to 6 (T104-6) and 30 pounds in minutes 8 to 10 (T108-10); 4 minutes of treadmill walking (T4) at 3.0 mph up an 8% incline; and 12 flights (192 steps) of stair climbing (STR) at 60 to 65 steps/minute on a Stairmaster 6000 ergometer (~3 minutes).

SETTING: McMaster University, Hamilton, Ontario, Canada.

PARTICIPANTS: Seventeen healthy males aged ([_ over X] ± SE) 64.4 ± 0.6 years.

MEASUREMENTS: Continuous intra-arterial measurements of systolic, diastolic, and mean arterial pressure and heart rate and rate-pressure product.

RESULTS: The peak values of HR, ABP and rate-pressure product (HR · BPs/1000; (RPP, 103)) were not systematically ordered among the various activities. The lowest peak values for all variables were recorded during the initial 4 minutes of horizontal treadmill walking. The STR and T4 walking exercises elicited higher HRs (151 ± 3.2 and 121 ± 3.4 bpm) than the weight lifting (range from 100 ± 4.8 (SAC) to 113 ± 3.8 bpm (SAMP)), but the converse was true for diastolic pressure (range from 128 ± 6.3 (SAC) to 151 ± 4.8 mm Hg (SAMP) versus 101 ± 2.5 (T4) to 118 ± 3.4 mm Hg (T108-10) and mean arterial pressure (range from 145 ± 4.5 (SAC) to 158 ± 4.8 mm Hg (SAMP) versus 129 ± 3.4 in T4 to 148 ± 3.8 (T108-10) and 157 ± 4.1 mm Hg (STR)). The peak systolic pressure was greatest in STR (271 ± 9.6 mm Hg) followed by SAMP (261 ± 9.3 mmHg) and T108-10 (244 ± 6.4 mm Hg) and was lowest in SAC (224 ± 10.5 mm Hg) and T104-6 (220 ± 5.7 mm Hg). The peak RPP descended in sequence from STR (41 ± 1.8), SAMP(29.8 ± 1.7), T4 (28.1 ± 1.3), DLP (27.2 ± 1.3), T108-10 (27.1 ± 1.4), SLP (25.4 ± 1.7), T104-6(22.7 ± 1.2) and SAC (22.0 ± 2.2).

CONCLUSION: We concluded that older adults who engage in weight lifting with heavy submaximal loads are exposed to no more peak circulatory stress than that created during a few
minutes of inclined walking. Moreover, climbing only three to four flights of stairs at a moderate pace (~50-70 s) elicits peak circulatory demands similar to, but at a much more rapid rate of adjustment than, 10 minutes of horizontal walking at 2.5 mph intermittently carrying a 30-pound weight or 4 minutes of walking up a moderately steep slope.

In daily life, it is common for older people to utilize large muscle groups in dynamic activities such as walking, climbing stairs, lifting, and load carrying. In exercise training programs there is increasing use of weight lifting and stair climbing as training modalities, yet comparatively little is known about the relative circulatory responses to these forms of exercise in older individuals. Most investigations have focused on the metabolic responses to cycle ergometry and treadmill exercise 1-8 and, to a lesser extent, stair climbing.9,10 Measurements of arterial pressure have been made intermittently using sphygmomanometry and auscultation, which may be appropriate for constant workload exercise but are inadequate for activities such as weight lifting that generate large pulsatile swings in arterial pressure.11-13

Our purpose in this study was to provide more detailed information about the circulatory responses to various exercise tasks in older male subjects. The activities included horizontal treadmill walking with and without load carrying, walking uphill, stair climbing, and weight lifting with the legs and the arms. The various intensities were chosen to be representative of what may occur in daily life or in training programs (weight lifting); no attempt was made to equate the metabolic loads among the activities. The major contribution of the study was the continuous, intra-arterial measurement of blood pressure, allowing for direct comparisons of the responses over time.

METHODS

Subjects

Seventeen healthy men from the local community, aged (mean ± SEM) 64 ± 0.6 years and with weight 86.5 ± 2.3 kg and height 175.2± 1.5 cm, volunteered for the study. Subjects had not taken part previously in any training program using weights. The study was approved by the President's Ethics Committee for Research on Human Subjects of McMaster University. The study design and associated risks were described to all subjects, and signed informed consent was freely obtained. Before acceptance into the study, each subject was screened medically to identify any obvious contraindications to the weight-lifting activity; each also performed a clinical symptom limited incremental exercise test on an electrically braked cycle ergometer.14 The main criteria for exclusion from the study were: history of cardiovascular or respiratory disease; resting systolic blood pressure greater than 160 mm Hg or resting diastolic pressure greater than 95 mm Hg; symptoms of angina or more than 1 mm S-T segment depression on the ECG during clinical exercise testing; abnormal blood pressure response to clinical exercise testing (decrease > 20 mm Hg in systolic pressure after the normal exercise increase; rise in diastolic pressure > 15 mm Hg; maximal systolic pressure > 250 mm Hg); more than 120% of predicted maximum power output during clinical exercise testing 14; major orthopedic disability; cigarette smoking; and ideal body weight greater than 130%.15

Experimental Design

Subjects visited the laboratory on four separate occasions. The first visit was for the completion of the progressive incremental cycle ergometry test; visits two and three were used
to measure the subjects' one repetition maximum (maximal lifting capacity in a single repetition - 1 RM), and to afford practice on the treadmill and the Stairmaster ergometer; the final visit was to measure the circulatory responses to the various tasks. On the testing day the sequence of exercises was selected at random, and after a given activity, there was a rest period of 10 to 20 minutes until resting levels of heart rate and arterial pressure were resumed (± 5 beats/min for heart rate and ± 5 mm Hg for systolic and diastolic pressure). The weight-lifting tasks were one set of 10 repetitions of single-arm curl (SAC) and single-arm military press (SAMP) with the dominant arm at 70% and one set of 12 repetitions of single- (SLP) and double-leg press (DLP) at 80% of the subject's 1 RM. There was a 2-minute recovery time between each set to allow heart rate and blood pressure to return to resting levels. The Valsalva maneuver was avoided by instructing each subject to exhale during the lifting phase. All weight-lifting tasks were done on a Global Gym multistation apparatus (Global Gym Inc., Downsview, Ontario), with the exception of the single arm curl, which was performed on a seated arm curl device (Rubicon Industries, Stoney Creek, Ontario).

The horizontal treadmill walking (Quinton 55xt) consisted of 10 minutes walking at 2.5 mph, carrying a 20-pound weight between the fourth and sixth minutes (T104-6) and a 30-pound weight between the eighth and tenth minutes (T108-10). Subjects also walked for 4 minutes at 3.0 mph up an incline of 8% (T4) and did 12 flights of stair climbing (STR) at 60 to 65 steps/minute on a Stairmaster 6000 ergometer (Stairmaster Sports/Medical Products, Newburgh, NY). During the stair climbing, subjects were allowed one hand finger tip contact with the rail but were not permitted to grip.

Measurements

Intra-brachial artery blood pressure was recorded continuously using a Novatrans transducer and catheter system as described previously. The skin was infiltrated with local anesthetic (xylocaine 2%, Astra, Pharma Inc., Ontario, Canada) before the percutaneous insertion of a 20-gauge Angiocath (Deseret Medical Inc., Park Davis and Co., Sandy, UT) into the brachial artery of the subject's nondominant arm. Blood pressure was recorded on line using a Novatrans transducer (MX800, Medex Inc., Instruments Division Cleveland, OH) and a chart recorder (RS3-5P, General Scanning Inc.). The system was calibrated statically against a mercury manometer using a calibration syringe, and dynamically using square-wave pressure signals. The linearity of the system was verified over the range of 0 to 360 mm Hg. For each subject, the pressure transducer was positioned at midsternum level. Intra-arterial blood pressure and heart rate measurements were recorded continuously before, during, and after the weight-lifting exercises and during the treadmill and stair-climbing ergometry. The chart recorder operated at a speed of 5 mm/s. Values for heart rate (HR), systolic blood pressure (SBP) and diastolic blood pressure (DBP) were derived manually from the recorder paper. The mean arterial pressure (MAP) was derived from electronically calculated pressure integrals each equivalent to 400 Torr·s. The heart rate was calculated from the number of cardiac cycles during each repetition of weight lifting, averaged over each minute during treadmill walking and each flight of stair climbing; mean arterial pressure was averaged in the same manner. Peak values of systolic and diastolic pressure were the highest values recorded in any cardiac cycle. The rate-pressure product was calculated as the product of peak HR and SBP (HR-BPs/1000; RPP, 10^3)

Statistical Analysis
Descriptive statistics included means ± standard deviations. Mean peak values were analyzed using a one factor completely randomized analysis of variance (ANOVA). A least squares linear regression analysis was performed on the five dependent variables for every subject for each of the weight-lifting tasks, the treadmill walking and the stair climbing; a one factor ANOVA with repeated measures was used to statistically compare the mean slopes derived from that analysis. Significant interactions were evaluated using Tukey-A post hoc tests. A probability level of \( P < .05 \) was accepted as statistically significant.

**RESULTS**

Effect of Repetitions, Flights, and Time.

During all four weight-lifting tasks, the heart rate, systolic and diastolic pressures, and rate-pressure product increased with successive repetitions. A similar trend emerged over time during the treadmill tests and during stair climbing. It was only during the first 4 minutes of horizontal treadmill walking that a steady-state response was achieved (Figures 1 and 2).
Figure 1. Systolic (A), diastolic (B) and mean arterial pressures (C) (means ± SE) during 10
repetitions of SAC ([black up pointing small triangle]) and SAMP ([white up pointing small triangle]), 12 repetitions of SLP (^) and DLP (•), 4 minutes of treadmill walking at 3.0 mph, 8% grade ([black small square]), 10 minutes of treadmill walking at 2.5 mph, 0% grade, carrying 20 pounds between minutes 4 to 6 and 30 pounds between minutes 8 to 10 (*) and 12 flights of stair climbing at a rate of 60 steps per minute ([white four pointed star] ;). * P < .05 SAC compared with T4; ** P < .05 SAMP compared with SAC; *** P < .05 SAMP compared with T4; # P < .05 SAMP compared with T108-10 and STR; ## P < .05 SLP compared with T4; ### P < .05 DLP compared with T4; † P < .05 DLP compared with T108-10; ‡ P < .05 T108-10 compared with T4; ### P < .05 STR compared with SAC; * P < .05 STR compared with T4.

Comparisons Among Different Activities

**Systolic Arterial Pressure**

The highest SBP response occurred during stair climbing (271 ± 9.6 mm Hg). During weight lifting, the greatest SBP was elicited during the final lift of SAMP (261 ± 9.3 mm Hg) and was lowest for SAC (224 ± 10.6 mm Hg) (P < .05), but the slopes of the increase in SBP were not different (1.36 ± 0.2 vs 1.60 ± 0.2, respectively). No significant differences in the slopes or peak SBP values were found between the SLP and DLP (239 ± 8.8 vs 244 ± 7.7 mm Hg). The SBP during the final flight of stair climbing was comparable to that at the end of minutes 8 to 10 of horizontal treadmill walking carrying a 30-pound weight and during seven repetitions of SAMP at 70% 1 RM or 12 repetitions of DLP at 80% 1 RM. SBP increased by 20 mm Hg during T104-6.
and rose by 40 mm Hg when an additional 10 pounds was added (T108-10) (Figure 1A).

**Diastolic Arterial Pressure**

The peak DBP responses were higher during the weight-lifting tasks (151 ± 4.8, 138 ± 4.6, 134 ± 5.8, 128 ± 6.3 mm Hg in SAMP, DLP, SLP, and SAC, respectively) compared with the walking exercises (101 ± 2.5, 105 ± 2.6, 118 ± 3.4, 121 ± 3.2 mm Hg in T4, T104-6, T108-10, and STR, respectively). The DBP patterns that emerged when comparing SAMP versus SAC and SLP versus DLP were similar to those of the SBP. The peak DBP for T108-10 was 15 mm Hg greater than T104-6, but the difference was not significant. At the end of STR and T108-10 the DBP responses were comparable (121 ± 3.2 vs 118 ± 3.4 mm Hg). Similar DBP values were elicited during minutes 1 to 4 of T4 and T10 (Figure 1B).

**Mean Arterial Pressure**

The average MAP during weight lifting was greatest in the DLP (159 ± 3.9 mm Hg) followed by the SAMP (158 ± 4.6 mm Hg). The MAP after T4 (130 ± 3.4 mm Hg) was lower than T108-10 and STR (P < .05) (Figure 1C). The increase in MAP during the walking exercises was most dramatic between flights two and eight of STR and during T108-10 (122 ± 4.0 to 150 ± 4.9 and 121 ± 3.4 to 148 ± 3.8 mm Hg, respectively). In addition, the slopes of T108-10 and STR were similar (0.23 ± 0.02 and 0.26 ± 0.02, respectively). The difference in the MAP at the sixth minute of T104-6 and the tenth minute of T108-10 was 15 mm Hg; however, the slope of the increase in MAP was greater for T108-10 (0.23 ± 0.02 vs 0.08 ± 0.01, respectively) (P < .05).

**Heart Rate**

The peak HR during stair climbing (151 ± 3.2 bpm) was significantly greater than for all of the other activities (range, 99-121 bpm) (Figure 2A). The peak HR that was elicited carrying a 30-pound weight during minutes 8 to 10 (111 ± 3.8 bpm) was equalled after only 40 seconds (2 to 3 flights) of stair climbing. The peak HR was greater for T4 (121 ± 3.5 bpm) than during the weight-lifting exercises (range, 100-113 bpm). The HR slope for STR was greater (0.33 ± 0.02) than the walking exercises (range, 0.01-0.13) (P < .05), but not compared with SAC, SLP, and DLP (0.42 ± 0.1, 0.38 ± 0.1, 0.46 ± 0.1, respectively). The HR slope for the SAMP (0.62 ± 0.05) was greater than all other exercises (P < .05).

**Rate-Pressure Product**

A twofold increase in RPP occurred after the 12 flights of stair climbing (19.5 ± 1.0 to 41 ± 1.8). In addition, the peak RPP value after STR was higher than in the weight lifting (range from 22 to 29.8) and treadmill walking exercises (range from 22.7 to 28.1). The mean peak values for T4 and T108-10 were similar (28.1 ± 1.3 and 27.1 ± 1.4). Among the weight-lifting exercises, the RPP was highest after 10 repetitions of SAMP (29.8 ± 1.8) and was lowest in the SAC (22 ± 2.2) (P < .05). The greatest slope for RPP was also elicited during SAMP (0.31 ± 0.03) (P < .05) (Figure 2B).

**DISCUSSION**

The purpose of this study was to measure continuously the heart rate and intra-brachial artery blood pressure responses during weight-lifting training, stair climbing, horizontal treadmill walking with and without load carrying, and walking uphill in older healthy males. The results provided new insights into the comparative cardiovascular responses during these tasks.
Heart Rate and Blood Pressure Responses

Dynamic Weight Lifting

The arterial blood pressure pattern that emerged during weight lifting is in agreement with the work of others.11-13,16 A large increase in pressure occurred during the lifting phase; there was a decrease during lowering, and peak pressures rose with successive repetitions. Immediately after the final lift, pressures dropped to near resting levels. The heart rate and blood pressure values for the SAC, SLP, and DLP in this study are comparable to those reported previously in older males of similar ages.16

Stair Climbing

Stair climbing produced the greatest peak systolic blood pressure, heart rate, and rate-pressure product. Stair climbing is a form of often unsteady state dynamic exercise that involves a large muscle mass.17 The near maximal heart rate response after only 3 minutes of stair climbing at a moderate stepping rate demonstrates the high cardiovascular demands imposed by this activity. The heart rate response following 4 minutes of walking at 3.0 mph up a moderately steep slope (8% grade) was equalled after only 1 minute of stair climbing.

Treadmill Walking

Combinations of dynamic and static exercise are common during normal daily life, especially when holding and carrying suitcases, shopping bags, and other objects. The static component of these activities adds a rapid onset pressure load to the demands of dynamic exercise.16

An increase in both systolic and diastolic blood pressure was observed with the addition of 20- and 30-pound loads to light dynamic exercise(walking 2.5 mph @ 0% grade). This increased pressor response during a combined static-dynamic activity is in agreement with previous reports in healthy young subjects 18,19 and in patients with coronary artery disease.20

Average systolic and diastolic blood pressure increased progressively during each 2-minute weight-loading phase. The systolic blood pressure increased 20 mm Hg during T104-6 when subjects carried 20 pounds, and it elevated 40 mm Hg in total during T108-10 when subjects carried an additional 10 pounds. This suggests that in older healthy males, the relationship between weight carrying while walking and the systolic pressure response is not linear.

Comparisons Among Stair climbing, Treadmill Walking, and Dynamic Weight Lifting

In recent years, interest in the use of resistance training to increase dynamic strength and promote muscle hypertrophy in older adults has increased.21-24 On the other hand, there are reports of extremely high arterial pressures during weight lifting in young subjects 11 that would be potentially deleterious in older individuals. In this study, however, although there were substantial increases in systolic pressure during weight lifting, compared with horizontal walking, the values were similar to those recorded in 4 minutes of uphill walking and walking with a 30-pound load and were less than the responses during stair climbing. The comparable heart rates during weight lifting and treadmill walking yielded similar values of rate-pressure product, suggesting that the myocardial oxygen demands of these activities were fairly equal.25 In contrast, the markedly higher diastolic pressures associated with weight lifting would theoretically ensure a greater coronary artery perfusion pressure in this exercise. This may be related to the reduced incidence of ischemic signs and symptoms during weight lifting compared with traditional forms of aerobic activities in patients with coronary artery disease.26
observations would support the safety of resistance training in healthy older individuals.

The circulatory responses to stair climbing were much more pronounced than responses to the other forms of exercise. Increases in heart rate, mean arterial pressure, and rate-pressure product were extremely rapid and reached very high levels. The rate-pressure product was more than twice the value recorded in horizontal walking and 50% greater than during 4 minutes of uphill walking or weight lifting, suggesting a markedly elevated myocardial oxygen demand. This, coupled with the high heart rate and only modest increase in diastolic pressure, indicates that myocardial oxygen balance may be least favorable in this mode of exercise. In light of this, we suggest that when stair climbing is incorporated as part of an exercise training program for older adults, the circulatory responses should be monitored closely.

REFERENCES


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