The blood pressure response of older men to maximum and sub-maximum strength testing

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Received 13 May 2010; received in revised form 28 September 2010; accepted 10 December 2010

Abstract

Strength testing is commonly used to determine the muscular strength of older individuals participating in a resistance training program. The purpose of this study was to non-invasively examine and compare the blood pressure (BP) and heart rate (HR) response of maximum and sub-maximum strength tests in older men. Twenty-four healthy men aged 70–80 yr were recruited for the study. Participants completed a 1 repetition maximum (RM) strength test and four days later a sub-maximum strength test on an incline squat. Systolic blood pressure (SBP), diastolic blood pressure (DBP) and HR were measured by plethysmography during and immediately after the strength tests. SBP, DBP and HR were (P<0.001) higher during the 1RM and sub-maximum strength tests compared to resting values. Twenty seconds post 1RM, SBP and HR were higher than resting values. Twenty seconds post sub-maximum strength testing SBP and DBP were lower (P<0.02) and HR (P<0.001) was higher than resting values. SBP, DBP and HR were higher (P<0.001) during sub-maximum strength testing compared to 1RM testing. Twenty seconds post testing, SBP and DBP were lower (P<0.001) and HR was higher (P<0.001) for the sub-maximum strength tests compared to the 1RM. The results of our study demonstrate that sub-maximum strength testing resulted in greater changes in BP and HR compared to 1RM testing. The lower cardiovascular stress experienced during the 1RM shows that this may be a safer method of testing compared to sub-maximum strength testing in men aged 70–80 yr.

Keywords: Cardiovascular response; Strength testing; Older men; Plethysmography

1. Introduction

The loss of muscle mass and muscular strength with aging represents a major cause of functional decline and disability.1 However, it is now well established that resistance training can reduce the age-associated decline in muscle mass and strength2 and as a result resistance training is commonly prescribed as a form of exercise for older individuals.3 As part of the prescription for resistance training, strength testing is often required to determine the correct training intensity as well as to evaluate the benefits of resistance training. Both the one-repetition maximum (1RM) method and sub-maximum strength testing are commonly used to assess muscular strength.4,5

Despite the increased participation of older individuals with resistance training, few studies have reported the cardiovascular response during maximum and sub-maximum strength testing, in particular the effect strength testing has on the blood pressure (BP) response of older individuals.6 The change in cardiovascular structure and function with aging7,8 could cause an exaggerated increase in BP during maximum and sub-maximum lifting in older individuals. Therefore the ability to continuously monitor the BP response during strength testing could help prevent an adverse cardiovascular event.

Although previous studies in young9 and older men10 have reported large increases in BP in response to high-intensity strength training and 1RM lifts, these studies used a capacitance transducer connected to a catheter in the brachial artery. While this is the most accurate method for monitoring BP during exercise11 its invasive nature limits its use in most
laboratory and clinical settings. To overcome the invasive nature of intra-arterial BP measurement, previous studies\textsuperscript{12,13} have used a Finapres which is a device that provides a non-invasive method of measuring BP during exercise. Although studies have used the Finapres to measure the BP response of older men during a 1RM\textsuperscript{14} and during isometric strength tests,\textsuperscript{15} to our knowledge no studies have compared the BP and heart rate (HR) response of maximum and sub-maximum dynamic strength tests in men over the age of 70 yr. The hemodynamic response to strength testing may provide valuable information for clinicians and exercise specialists about the safety of strength testing in older populations. Therefore the purpose of the study is to non-invasively examine and compare the BP and HR response of maximum and sub-maximum strength tests in men over the age of 70 yr.

2. Methods

Participants were recruited through advertisements placed in local newspapers and consisted of healthy men aged between 70 and 80 yr. Those respondents with a history of cardiovascular or respiratory disease, diabetes, orthopedic injuries or other medical conditions which contraindicated vigorous exercise, were excluded from further participation. Participants then underwent a detailed medical examination including measurement of resting BP and an incremental exercise test to volitional fatigue on a cycle ergometer. As a result of the screening process, 24 older men (mean age $73.9 \pm 2.9$ yr; height $177.3 \pm 4.9$ cm; weight $79.1 \pm 12.2$ kg) who were moderately active but not participating in regular physical activity were selected to participate in the study. The sample size for this study was based on pilot data from our laboratory and similar studies\textsuperscript{10,14} examining the BP response to strength testing. The study was approved by the Griffith University Ethics Committee.

All participants’ hemodynamic responses were assessed during lower extremity strength testing (1RM) and four days later sub-maximum strength testing on an incline squat machine between 0900 and 1100 h. Participants were requested to avoid caffeine and alcohol for 24 h, and to eat only a light meal until 3 h prior to testing. All participants attended three familiarization sessions before the start of the study to reduce the risk of injury and muscle soreness during testing and to become familiar with the equipment and proper exercise technique. Strength testing with a minimum of two familiarization sessions has been shown to be sufficient to assess the muscular strength of older individuals.\textsuperscript{16}

One repetition maximum strength testing was assessed on the incline squat machine (Body/Solid Inc., Broadview, IL, USA) using procedures as described previously.\textsuperscript{16} The sub-maximum strength test consisted of 15 repetitions at 50% of 1RM on the incline squat machine. The repetitions and load for the sub-maximum strength test were selected as this is a common exercise prescription used by older adults commencing resistance training.\textsuperscript{17} Preceding all familiarization and testing sessions on the incline squat participants were required to perform an adequate warm-up and cool-down. Variations in strength values from test–retest measurements on the incline squat machine are less than 5%.

Systolic (SBP) and diastolic (DBP) blood pressures were obtained non-invasively with the Finapres 2350 (Ohmeda Louisville, CO, USA) and recorded before, during and after the strength tests. The Finapres measures finger arterial pressure through an infrared finger plethysmography finger cuff based on the arterial volume clamp.\textsuperscript{18} This method has been validated against intra-arterial measurement at rest and against manual auscultation during heavy resistance training.\textsuperscript{19} Three ECG electrodes were applied in the CM5 position to monitor and measure HR throughout the testing.

The beat-to-beat amplified signals from the Finapres and electrocardiograph were collected at 100 Hz using a Biopac system (MP 100, SDR Clinical Technology, Middle Cove, Australia) and Acqknowledge 2.0 software package. The start of the repetition time was defined as the commencement of descending phase of the lift with the finish of the repetition when the participant had returned to their original start position. This was approximately 5 s for the 1RM and approximately 75 s for the sub-maximum test. Subsequent values used for analysis were recorded during, 20 and 60 s post for the 1RM and 20 and 210 s post for the sub-maximum strength tests. Within each test period, the maximum (highest reading), minimum (lowest reading) and average values of SBP, DBP and HR were analyzed.

The Statistical Package for the Social Sciences (SPSS Version 10.0) was used for all analyses. All values are reported as means and standard deviation ($\pm$SD). Analysis of variance was used to compare the hemodynamic responses during the 1RM and sub-maximum strength tests to resting values and each test period (20 and 60 s post 1RM and 20 and 210 s post sub-maximum strength test). Where significant results were noted, a Bonferroni post hoc test was used to determine differences. Paired t tests were used for comparisons between the 1RM and sub-maximum strength tests. The level of significance was set at $P$ value less than 0.05.

3. Results

Of the 24 participants who began the study one withdrew due to personal reasons and subsequently 23 participants completed all testing and were used for analysis.

The average time taken to complete the 1RM strength test on the incline squat was approximately 4 s. During the 1RM strength test, the maximum, minimum and average (max, min and avg) SBP, DBP and HR were all higher ($P<0.001$) compared to resting values. Twenty seconds post-testing max, min and avg SBP ($P$ range, 0.021–0.015) and HR ($P$ range, 0.015–0.006) were higher than resting values. By 60 s post-testing avg SBP was significantly lower ($P<0.011$)
than resting values with SBP (max and min) and DBP and HR (max, min and avg) values returning to resting levels (Table 1).

The average time taken to complete 15 repetitions of the incline squat during the sub-maximum strength test (50% of 1RM) was approximately 60 s. During the sub-maximum strength test all (max, min and avg) SBP, DBP and HR were all higher ($P < 0.001$) than resting values. Twenty seconds post-testing except for maximum SBP ($P < 0.15$), SBP (min and avg) and DBP (max, min and avg) were lower ($P < 0.001$) and HR (max, min and avg) higher ($P < 0.001$) compared to resting values. Two-hundred and ten seconds post-testing maximum SBP ($P < 0.021$) and HR (max, min and avg) ($P < 0.001$) were higher than resting values (Table 1).

SBP (max and avg), DBP and HR (max, min and avg) were significantly lower ($P < 0.001$) during 1RM strength test compared to the sub-maximum strength test. Twenty seconds post-testing SBP and DBP (max, min and avg) for the 1RM strength test were significantly higher ($P < 0.001$) and HR significantly lower ($P < 0.001$) than the sub-maximum strength test. At the end of testing (60 s for 1RM and 210 s for sub-maximum) SBP (max, min and avg) and HR (max, min and avg) were significantly lower ($P$ range, 0.017 to <0.001) for the 1RM strength test compared to the sub-maximum strength test.

### 4. Discussion

The results of the present study demonstrate that large hemodynamic changes can occur during 1RM strength testing and sub-maximum strength testing in older men. The sub-maximum strength testing resulted in greater changes in BP and HR compared to 1RM strength testing.

The sub-maximum strength test of the present study required participants to complete 15 repetitions at 50% of 1RM. The average, maximum and minimum SBP, DBP and HR were all significantly greater during the sub-maximum strength test than during the 1RM strength test (Table 1). The greater hemodynamic response to the sub-maximum strength test may have been due to the nature of the exercise used for testing and the number of repetitions involved. Previous studies have reported that low-intensity strength training (12–17 repetitions at 40–50% of 1RM) provokes a greater increase in BP and HR compared to high-intensity strength training (8–10 repetitions at 70–80% of 1RM). We found the highest average SBP (234 ± 35 mm Hg) and DBP (135 ± 22 mm Hg) and maximum SBP (268 ± 37 mm Hg) and DBP (151 ± 23 mm Hg) were greater than previously reported during sub-maximum strength testing and was equivalent to maximum HR reached during a graded exercise test with the same participants (data not shown). These trends together with the present study indicate that the hemodynamic responses to strength testing and training are related to the duration (or number of repetitions) and not the load lifted and that sub-maximum strength testing places a greater physiological load on the cardiovascular system than 1RM strength testing. Therefore both sub-maximum strength testing and regular resistance training may potentially be more hazardous than 1RM strength testing for those at risk of a cardiovascular event. Abrupt increases in HR and SBP during strenuous exercise have been shown to trigger ischemic cardiac events including acute myocardial infarctions and increase the potential for a cerebrovascular incident. We also observed significant falls in SBP and DBP 20 s after the completion of the sub-maximum strength test (Fig. 1). This sudden drop in BP may explain the syncope and dizziness experienced by some individuals after strength testing. Although both SBP and DBP were significantly lower than resting values no symptoms of syncope were reported by any participants in the present study. The transient hypotensive response is thought to be due to the sudden reduction in intramuscular pressure and vascular occlusion of the muscles and to a possible baroreceptor-induced overcompensation to the high BP achieved during the strength test. After approximately 120 s SBP had recovered above resting values and remained higher for the remainder of the observation (210 s) although the increase was not significantly greater than resting values. These results are in contrast to

### Table 1

Blood pressure and heart rate response before, during and after 1RM and sub-maximum strength tests.

<table>
<thead>
<tr>
<th></th>
<th>1 repetition maximum (1RM)</th>
<th>Sub-maximum (50% of 1RM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resting</td>
<td>During</td>
</tr>
<tr>
<td>Average SBP (mm Hg)</td>
<td>141±21</td>
<td>215±34*</td>
</tr>
<tr>
<td>Maximum SBP</td>
<td>144±17</td>
<td>231±31*</td>
</tr>
<tr>
<td>Minimum SBP</td>
<td>129±21</td>
<td>190±33*</td>
</tr>
<tr>
<td>Average DBP (mm Hg)</td>
<td>70±12</td>
<td>118±17*</td>
</tr>
<tr>
<td>Maximum DBP</td>
<td>83±14</td>
<td>128±21*</td>
</tr>
<tr>
<td>Minimum DBP</td>
<td>61±10</td>
<td>109±22*</td>
</tr>
<tr>
<td>Average HR (beats min⁻¹)</td>
<td>68±10</td>
<td>112±12*</td>
</tr>
<tr>
<td>Maximum HR</td>
<td>76±11</td>
<td>121±15*</td>
</tr>
<tr>
<td>Minimum HR</td>
<td>59±10</td>
<td>94±14*</td>
</tr>
</tbody>
</table>

Values are mean ± SD. SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate.
* Significantly ($P < 0.05$) different from resting values.
* Significantly ($P < 0.05$) different from sub-maximum test.
the BP response we observed after the 1RM strength test. After 60 s SBP was significantly lower than resting values while DBP had returned to resting values following the 1RM strength test. Previous studies have also found contrasting results with some finding decreases, \(^24\) increases \(^25\) and no change \(^26\) in post exercise BP. Recent research \(^24,27\) has indicated that exercise intensity is a key factor in determining the hemodynamic response after resistance exercise. Low-intensity resistance exercise promotes a greater post exercise hypotensive response than high-intensity. Although the BP in the present study reached resting levels after 210 s further observation may have seen the BP return below resting values. The mechanisms responsible for the post-exercise BP response are unclear. A reduced vascular resistance and cardiac output as a result of reduced sympathetic nerve activity has been suggested as one possible reason. \(^24\)

During the 1RM strength testing we observed a sharp, transient rise and fall in SBP and DBP. The rise in BP occurred during the concentric phase of the lift with the eccentric phase coinciding with the fall in BP. Previous studies have also observed similar changes in BP during 1RM strength testing using intra-arterial \(^18,19\) and plethysmography \(^14\) in young and older individuals. However the average and maximum BP values observed in the present study (Table 1) are higher than most \(^14,28\) but not all studies. \(^10\) This may be due to several reasons including the method of BP measurement and the type of exercises performed during the 1RM testing. Several studies \(^28,29\) have measured BP with manual auscultation during or immediately after 1RM testing which has shown to underestimate peak SBP compared to intra-arterial measurement \(^11\) and continuous Finapres measurement. \(^19\) Furthermore the incline squat used in the present study for strength testing involves a greater amount of muscle mass than other testing exercises commonly used such as the leg extension or leg press. Previous studies \(^30\) have shown that the amplitude of the hemodynamic response is related to the amount of muscle mass involved during strength testing and the number of arteries occluded by the intramuscular mechanical compression.

5. Conclusion

The results of our study demonstrate that sub-maximum strength testing resulted in greater changes in blood pressure and heart rate compared to 1RM strength testing. The lower cardiovascular stress experienced during the 1RM shows that this may be a safer method of testing compared to sub-maximum strength testing in men aged 70–80 yr. Our results indicate that older individuals should be closely monitored during and following strength testing, in particular sub-maximum strength testing, due to the large transient changes in blood pressure and heart rate.

Practical implications

- One repetition maximum and sub-maximum strength tests result in large changes in blood pressure and heart rate during and immediately after strength testing in men aged 70–80 yr.
- Sub-maximum strength testing results in greater changes in blood pressure and heart rate compared to one repetition maximum strength testing.
- Older individuals should be closely monitored during and following strength testing due to the large transient changes in blood pressure and heart rate.

Acknowledgment

This study was undertaken with no external financial support.

References
