Cardiovascular Stress Associated With Concentric and Eccentric Isokinetic Exercise in Young and Older Adults

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Heart rate (HR), mean arterial blood pressure (MAP), and rate-pressure product (RPP) responses to submaximal isokinetic concentric (CON) and eccentric (ECC) knee extension exercise were compared at the same absolute torque output in 20 young (mean ± SD = 23.2 ± 1.7 years) and 20 older (mean ± SD = 75.2 ± 4.6 years) adults. After determination of peak CON and ECC torques, subjects performed separate, randomly ordered, 2-minute bouts of isokinetic CON and ECC exercise (90°/s, exercise intensity: 50% of CON peak torque). CON exercise elicited greater changes in HR, MAP, and RPP than ECC exercise (p < .001) for both age groups. There were no age-related differences in HR, MAP, or RPP responses for either CON or ECC exercise. At the same absolute torque output, isokinetic CON knee extension exercise elicited significantly greater increases in cardiovascular stress than ECC exercise in both young and older adults. This result has implications for determining appropriate fitness and rehabilitation programs.

Little is known about the cardiovascular stress associated with isokinetic resistance exercise despite the fact that this mode of exercise is increasingly used for strength assessment, strength training, and rehabilitation. In older adults, joint stress can be a major and limiting concern for exercise, hence isokinetic exercise may be the preferred method of assessment, training, and rehabilitation (1, 2). However, some investigators have suggested that the cardiovascular stress associated with isokinetic exercise may be substantial (3–5), and have recommended the need for a cardiovascular screening examination before such exercise. Most of the previous studies in this area have examined the cardiovascular response to maximal isokinetic exercise in young adults. Previous research has also generally been confined to the concentric mode of contraction during isokinetic exercise. Hence little attention has been paid to the cardiovascular stress associated with submaximal isokinetic exercise, or to differences in cardiovascular responses elicited by both concentric and eccentric modes of contraction. Even less attention has been focused on whether such responses change across the life span.

Reduction of muscle strength with aging, based on isometric (ISO) and isokinetic concentric (CON) strength measurements, has been reported in many studies of neuromuscular function (6, 7). However, muscles are often required during daily activities to develop tension via a third activation condition, eccentric (ECC) loading, where the muscle is lengthened by an external force while attempting to contract (e.g., walking downstairs, lowering weights with the arms) (8). Torque capacity of the muscle in this type of exercise is much greater than in either ISO or CON exercise (8), perhaps due to the increased role played by the passive elements of the muscle, or an increased force production per crossbridge, or an increased number of crossbridges (9). Although from a clinical perspective, older people appear to have more difficulty performing such exercise, recent observations have indicated that a muscle’s ECC performance may be preferentially preserved by age-related changes in the neuromuscular system (6, 10–12).

Activities of daily living frequently require the production of an absolute force output to accomplish a given task (e.g., sitting down). For a given absolute force level, the ECC type of muscle contraction may require less neural activation and energy consumption than when muscles use ISO or CON contractions (8, 13, 14). Significant functional and physiological implications including greater exercise capacity and less cardiovascular stress associated with ECC resistance exercise may result from these differences (15, 16). Consequently, ECC strengthening and rehabilitation protocols have been advocated for optimal results (17–19).

The purpose of this study was, therefore, to compare the cardiovascular stress (defined as change in heart rate, mean arterial blood pressure, and rate-pressure product) of submaximal isokinetic CON and ECC knee extension exercise at the same absolute torque output in young and older adults. Our hypothesis was that ECC exercise would be associated with reduced increases in cardiovascular stress compared to CON exercise, regardless of age. We chose to compare these cardiovascular responses at the same absolute torque output because physical tasks frequently have fixed or absolute, rather than relative, metabolic demands, and we wanted to compare the cardiovascular stress associated with both ECC and CON methods of generating that torque output.

Methods

General Outline

Peak torques for ECC and CON knee extension movements were determined on an isokinetic dynamometer. Changes in
heart rate (HR), mean arterial blood pressure (MAP), and rate-pressure product (RPP) after 2-minute bouts of both ECC and CON knee extension exercise at 50% of CON peak torque were compared between young and older adults.

Subjects
Twenty young (11 male) and 20 older (13 male) healthy, recreationally active subjects (Table 1) were recruited from respondents to advertisements placed in the community. Exclusion criteria included any orthopedic or neurological conditions that would limit exercise, a history of cardiovascular or other systemic diseases, the intake of medications for heart rate or blood pressure, or participation in formal exercise activities for more than 10 hours per week. The University’s ethical review board approved the study and all subjects provided informed written consent prior to participation.

Test Procedures
All tests were completed in one visit to a climate-controlled laboratory (range 21–23°C). Subjects were advised not to do any formal exercise before the test protocol, and were tested a minimum of 2 hours after ingestion of any food or caffeinated beverages. After a brief orientation and collection of baseline data (sitting position) for HR (Polar Vantage XL, Polar Electro Inc, Port Washington, NY) and blood pressure (BP) (Finapres, Ohmeda 2300, Englewood, CO), subjects performed a series of stretches and a short walk or cycle ergometer warmup.

The ECC and CON isokinetic strength assessments were carried out on a Kinetic Communicator (Kin-Com, Model 500-H, Chattecx Corp, TN). Subjects were placed in a seated position (back 80° from horizontal) and were secured to the Kin-Com with belts around their chest, pelvis, and the thigh of the test leg. All tests were performed on the dominant leg, defined as the leg with which the subject would kick a ball. The nontest leg, defined as the leg with which the subject would carry the dynamometer resistance arm for the test contraction and RPP, calculated by subtracting the baseline values from the peak values reached at the end of the 2-minute exercise bouts while the differences between ECC and CON muscle actions were emphasized. The specific isokinetic practice (90°/s) consisted of 12 repetitions at a perceived effort of 50%, 8 repetitions at 75%, and 3 repetitions at 100% perceived maximal effort, with rests between each set and again before the actual peak torque trials. Knee flexion and extension movements were performed over a 50-degree range of motion, from 65 to 15 degrees of flexion. Ten Newtons was set as the minimum force required to activate the dynamometer resistance arm for the test contraction while no trigger force was required to return the limb to the starting position. Subjects were taught to breathe out during contractions to prevent performing a Valsalva maneuver, and were not allowed to grasp the table or the restraining belts during testing. The Valsalva maneuver is a forced expiratory effort against a closed airway which helps stabilize the chest and abdomen during heavy lifting. Intrathoracic and intra-abdominal pressure are greatly increased by a Valsalva maneuver, resulting in an acute increase in arterial pressure, followed by a decrease in arterial pressure due to the diminished venous return.

The best three of five maximal trials (15-second rest between trials) were averaged to determine the isokinetic ECC and CON peak torques (25). CON maximal trials were always performed before ECC trials. HR and BP were allowed to return to baseline levels after each set of maximal trials. Following the peak torque determinations, subjects performed two separate, randomly ordered, 2-minute bouts of ECC or CON exercise at a target torque output of 50% of their isokinetic CON peak torque (target torque output for Young group = 78.3 N · m; Older group = 55.5 N · m). Five minutes of recovery were allowed between the two exercise bouts while HR and BP returned to baseline values. Verbal encouragement was provided by the tester and visual feedback on the target torque was provided by a graphic display on the Kin-Com computer screen. HR and BP were recorded during the 2-minute exercise bouts, and a rating of perceived exertion (RPE) on the 6–20-point Borg scale (anchors of “very, very light = 7” and “very, very hard = 19”) (26) was obtained at the end of each work bout. The final HR and BP values for each work bout were recorded during the last 5 seconds of exercise.

Data Analysis
Systolic (SBP) and diastolic (DBP) blood pressures were measured by the Finapres, and MAP was calculated (MAP = DBP + (SBP–DBP)/3). We also calculated rate-pressure product (RPP), a good predictor of myocardial oxygen demand (RPP = HR × SBP × 10⁻², arbitrary units) (27,28).

Data analyses were based on change scores for HR, MAP, and RPP, calculated by subtracting the baseline values from the peak values reached at the end of the 2-minute exercise bouts. All statistical procedures were carried out using the Statistica (Release 5.1, Stat Soft Inc., Tulsa, OK) statistical package.

Table 1. Descriptive Information for the Two Experimental Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (y)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young (n = 20)</td>
<td>23.2 (1.7)*</td>
<td>1.72 (0.09)</td>
<td>67.6 (10.4)</td>
</tr>
<tr>
<td>Older (n = 20)</td>
<td>75.2 (4.6)</td>
<td>1.70 (0.10)</td>
<td>74.0 (14.3)</td>
</tr>
</tbody>
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* Mean (SD).
Two-factor ANOVA tests (Age: young vs older, Exercise: CON vs ECC), with repeated measures on Exercise, were also used to analyze peak torque values and RPE scores. The critical value for significance for all comparisons was set at $p < .05$.

**Results**

All subjects completed our test protocols without incident. Baseline measures for HR and MAP for the young (66.7 b/min, 86.2 mm Hg) and older (69.3 b/min, 91.1 mm Hg) adults were within normal ranges and not significantly different from each other. There were significant main effects for exercise ($F = 280.0, p < .001$) and age ($F = 15.20, p < .001$) on peak torque. ECC peak torques were approximately 50% greater than CON peak torques, and both CON and ECC peak torques for the young group were greater than for the older group (Table 2). The ECC:CON ratio for the older group was significantly greater than for the young group (Table 2).

Significant main effects for exercise were indicated by each of the two-way ANOVA tests (Table 3) for HR ($F = 63.38, p < .001$), MAP ($F = 37.05, p < .001$), and RPP ($F = 46.91, p < .001$) (Figure 1), with CON exercise eliciting significantly greater changes in each measure. There was no significant main effect for age (i.e., no differences between the Young and Older groups) for HR, MAP, or RPP responses, and no significant exercise-by-age interactions.

Similarly, there were no age-related differences in RPE for either CON and ECC exercise, and CON exercise (14.9±2.3) also elicited a significantly greater RPE than ECC exercise (12.4±1.7) ($F = 41.55, p < .001$).

Although MAP was the primary variable reflecting changes in blood pressure, we also calculated change scores for SBP and DBP. The same pattern of results was seen for these two variables (Table 3), with no main effect for age, and CON exercise eliciting significantly greater changes in SBP and DBP compared to ECC exercise.

**Discussion**

This is the first study, to our knowledge, in which cardiovascular responses to both submaximal isokinetic CON and ECC exercise have been determined in both young and older adults. Several previous studies have focused on the cardiovascular responses to maximal isokinetic CON exercise (3–5,25–31), and with the exception of one study that included subjects up to the age of 60 (25), have examined these responses exclusively in younger men and women. Only one study has examined cardiovascular responses to submaximal isokinetic exercise (24). Studying responses to submaximal exercise is important because most training and rehabilitation resistance programs utilize submaximal, rather than maximal, contractions. Thus our study has provided new information with respect to cardiovascular responses to submaximal isokinetic ECC exercise and particularly with respect to such responses in older adults.

There were two main findings of this study. The first was that submaximal isokinetic CON exercise elicited greater cardiovascular responses (measured as change scores) than isokinetic ECC exercise at the same absolute torque output. The second was that there were no age-related differences in HR, MAP, or RPP responses for either CON or ECC exercise. These results have potential significance for isokinetic assessment, training, and rehabilitation programs in older adults.

It is difficult to compare our results directly with those of previous studies because of differences in exercise protocols, measurement techniques, and subjects. We used a submaximal isokinetic exercise protocol, and we studied both young and older adults. Although one other study has studied responses to submaximal isokinetic exercise (24), only young adults were involved. A protocol of 60 seconds of isokinetic CON exercise (180°/s) at an intensity of 40% CON peak torque elicited absolute HR, MAP, and RPP values for their subjects (10 young males) which were similar to ours.

Few previous studies have compared responses to both ECC and CON isokinetic exercise. Horstmann and colleagues (25) studied HR and BP responses to 60 seconds of maximal CON (180°/s) and ECC (60°/s) knee flexion/extension exercise in 64 male subjects (22 to 60 years of age). Greater cardiovascular system responses (measured as change scores) were elicited by CON exercise but there was no age-dependence. Increases in HR for both young and older adults in our study were smaller, likely due to our sub-

| Table 2. Peak Torques for Concentric and Eccentric Knee Extension Exercise in Young and Older Adults |
|-----------------|--------------|-------------|-----------------|
|                  | Concentric   | Eccentric   | Eccentric/Concentric |
| Young            | 156.4* (33.6)| 227.5† (50.9)| 145.5*           |
| Older            | 111.0 (36.8)| 178.9 (48.7)| 161.3%           |

*Significantly different from Older value; †significantly different from Concentric value.

| Table 3. Heart Rate (HR), Mean Arterial Blood Pressure (MAP), Rate-Pressure Product (RPP), Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), and Change Scores (△) After 2-Minute Bouts of Isokinetic Concentric and Eccentric Exercise at the Same Absolute Torque Output in Young and Older Adults |
|-----------------|--------------|--------------|---------------|
|                  | Concentric   |△ Concentric | Eccentric     |
| HR (b/min⁻¹)    |              |              |               |
| Young            | 112.2 (15.0)| 45.5 (14.9)* | 95.0 (12.0)    |
| Old              | 104.7 (16.8)| 35.4 (18.2)* | 92.7 (14.0)    |
| MAP (mm Hg)      |              |              |               |
| Young            | 135.9 (17.0)| 49.7 (17.4)* | 111.7 (12.5)  |
| Old              | 145.1 (22.7)| 54.0 (23.7)* | 125.1 (24.5)  |
| RPP (arbitrary units) | | |               |
| Young            | 209 (46)     | 129 (46)*    | 151 (27)      |
| Old              | 219 (65)     | 125 (62)*    | 170 (59)      |
| SBP (mm Hg)      |              |              |               |
| Young            | 184.8 (24.3)| 64.2 (24.2)* | 159.0 (19.1)  |
| Old              | 205.7 (31.5)| 70.6 (29.5)* | 179.6 (37.2)  |
| DBP (mm Hg)      |              |              |               |
| Young            | 108.1 (11.0)| 36.5 (11.7)* | 91.1 (11.4)   |
| Old              | 109.7 (16.9)| 39.1 (19.4)* | 95.4 (18.6)   |

*Significantly greater than Eccentric change score.
maximal exercise protocol, whereas the increases in systolic BP were greater, particularly in the older adults. This could be due to the longer test duration in our study, as well as the greater mean age of our older subjects (75.2 vs 55.0 years). We also measured BP continuously via the Finapres system, whereas Horstmann and colleagues (25) made a manual measurement at the end of their exercise bout. As blood pressure decreases precipitously following exercise (4,32), the peak BP may have been missed in the study of Horstmann and colleagues (25). The issues associated with accurate BP measurement during dynamic exercise have been recently reviewed (33).

Energy expenditure during CON work at a given power output is significantly greater compared to ECC work (13,16,34,35). This is an important factor to consider in designing training and rehabilitation programs for older adults with diminished physical capabilities, thus ECC programs may well be more appropriate for this population. There are several possible reasons for the difference in energy demands and cardiovascular stress between CON and ECC exercise. More motor units are recruited in CON exercise compared to ECC (14,36,37). Because ECC movements require less muscle activation, the intramuscular forces are reduced, resulting in a decrease in BP. It has been previously reported that BP decreases during the lowering (ECC) portion of leg press exercise compared to the level reached during the lifting (CON) phase (32). Stroke volume and cardiac output also increase during lowering (ECC) phases of leg extension exercise, suggesting a decrease in peripheral resistance (38). The increase in stroke volume and decrease in peripheral resistance and BP during ECC exercise compared to CON reduce the workload imposed on the heart. In our study, ECC exercise was associated with a reduced RPP, a clinically useful estimate of myocardial oxygen cost. Nelson and colleagues (27) have shown that RPP correlates better with myocardial oxygen demand than HR, tension time index, or the triple product (SBP × HR × Ejection Time). Our RPP values for the younger adults are similar to those reported previously, accounting for differences in protocols (3,24,30). RPP has not been calculated previously for older adults during isokinetic exercise.

The pressor response to exercise includes all of the reflex-induced cardiovascular changes that serve to increase arterial blood pressure during a muscle contraction (39). Exercise mode, intensity, and duration, and size of the active muscle mass are all factors related to the magnitude of increase in HR and BP (40–42). An increase in the excitation of muscle afferent receptors (43) will cause greater increases in HR and BP during resistance exercise, utilizing either a larger muscle mass (31,42) or a higher relative exercise intensity (44). The greater increase in cardiovascular stress with greater active muscle mass may explain the increased HR, MAP, and RPP associated with CON exercise in our study, as several investigators have reported an increase in motor unit recruitment with CON compared to ECC exercise (14,36,37). In addition, although physiological responses to CON exercise are greater, so too is subjective perceived exertion. In our study, RPE for both young and older adults were significantly greater after CON than ECC exercise, despite the fact that ECC exercise was performed at the same torque output.

We made an a priori decision to study CON and ECC isokinetic exercise at the same absolute torque. We knew that ECC peak torque would likely be higher than CON peak torque for both young and older subjects, thus the relative workload associated with CON exercise would likely be greater than for ECC exercise. A pragmatic reason for our a priori decision was based on the greater use of CON exercise programs used in both rehabilitation and training and on the greater accessibility of CON exercise apparatus. Perhaps more importantly, however, physical tasks frequently have fixed, rather than relative, metabolic demands. This is a disadvantage for older people with lower maximal capacities. Functionally, older adults are often faced with the chal-
Although the same and young subjects, respectively. Thus, for both age groups, equivalent to 31% and 35% of ECC peak torque for the old and young people (6,10,11), clinical observation indicates that older adults have more difficulty performing ECC exercise.

In our study, the CON and ECC exercise bouts were not performed at the same relative exercise intensity. The target torque output for both CON and ECC exercise was set at 50% of the CON peak torque. This target torque output was equivalent to 31% and 35% of ECC peak torque for the old and young subjects, respectively. Thus, for both age groups, although the same absolute torque levels were maintained during the 2-minute CON and ECC exercise bouts, the actual relative ECC intensity was considerably less than the CON intensity. This could explain the differences in HR, MAP, and RPP responses to ECC and CON exercise that we observed in our study. Further research comparing HR and BP responses at the same relative level of exercise intensity (i.e., exercise at 50% of ECC peak torque vs 50% of CON peak torque) is thus warranted to provide additional insight into the differences in cardiovascular response to these two types of muscle contractions. Previous work has indicated that there may be such a difference for maximal work, reporting that 60 seconds of maximal ECC knee exercise elicited significantly lower heart rate and blood pressure responses compared to the same period of maximal CON knee exercise (25). Conversely, it has also been reported that CON and ECC exercise at the same relative intensity elicited a similar pressor response despite different absolute torque outputs (44). There are no previous data comparing cardiovascular responses to submaximal CON and ECC isokinetic exercise at the same relative intensity.

It has been suggested in some (6,10,12) but not all (45,46) previous papers that in comparison to younger adults, older adults may preserve ECC force generating capacity to a greater degree than CON. A cross-sectional study with male and female subjects from 18 to 80 years of age showed that although there was a significant loss of isometric and isokinetic CON strength over time, the decline in isokinetic ECC strength was minimal (9 newtons per decade) (6). CON peak torque in the knee extensors has also been reported to decline more with age than ECC peak torque (10). However, a large cross-sectional study has reported that gender may also play a role in this preservation of ECC capacity (45). In women, age accounted for less of the variance in ECC peak torque, and muscle quality (specific tension) was better preserved with age, compared to men (45). More recently, a second large study has also reported that although muscle quality is affected by age and gender, the magnitude of the effect is dependent upon the type of muscle action (CON or ECC) and the muscle group studied (upper vs lower extremity) (46). In this study, CON and ECC peak torques for arms or legs were calculated as the sum of both flexion and extension movements (46).

Our study has supported an age-related preservation of ECC force-generating capacity. The ratio of ECC:CON peak torque was significantly higher in the older subjects (p=0.033), and in fact, ECC peak torque in the older adults was actually greater than CON peak torque in the younger adults. Possible mediators for the relative preservation of eccentric strength during aging include an increased contribution of connective tissue to force production, a reduction in weak or unstable sarcomeres, and changes in the detachment and reattachment of crossbridges during lengthening contractions (6). This relative preservation of ECC force-generating capacity with aging has implications for development of appropriate training and rehabilitation programs for older adults.

Previous studies investigating the cardiovascular responses to maximal isokinetic work have, with but one exception (25), recommended that caution be exercised before performing isokinetic strength assessments (3–5,30,31). We have demonstrated that submaximal isokinetic exercise (particularly of the CON type) elicits significant cardiovascular system stress in older adults. We studied healthy, recreationally active older adults who are not representative of a typical older population. Although the increases in cardiovascular stress in our older adults were only moderate, the large variation in response suggests that for some of our older adults, clinically significant levels of HR, MAP, and RPP may have been attained. The risk in an older population is greater given the increased incidence of “silent” hypertension and heart disease, thus the need for a careful cardiovascular screening prior to isokinetic exercise for fitness or rehabilitation may be warranted.

In summary, we have shown that, at the same absolute torque output, greater cardiovascular stress is elicited by submaximal isokinetic CON compared to ECC exercise in both young and older adults. In addition, we did not observe any age-related differences in cardiovascular stress elicited by our protocol of submaximal isokinetic CON and ECC exercise. Finally, because ECC strength may be preserved with aging, and ECC isokinetic exercise appears to be more protective of cardiovascular responses in both maximal and submaximal protocols, it may be a very appropriate form of resistance exercise for assessment, training, or rehabilitation in older adults.

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