Fatigue After Physical Activity in Healthy and Balance-Impaired Elderly

Thorlene Egerton, Sandra G. Brauer, and Andrew G. Cresswell

This study aimed to determine whether physical activity similar to daily living results in signs and sensations of fatigue in healthy old, balance-impaired old, and healthy young adults. Sensations of general tiredness, leg tiredness, knee-extension and hip-abduction strength, and temporospatial gait variables were measured before, immediately after, and up to 20 min after moderate-intensity physical activity. After activity, all groups reported increased levels of tiredness but showed no changes in strength. The balance-impaired had greater and more prolonged feelings of tiredness, with a mean increase before to immediately after activity of 3.6 on the visual analogue scale and no recovery at 16 min. The young and healthy old had an increase of 3 and 2.6, respectively, and had recovered before 16 min. In the balance-impaired group only, cadence slowed immediately after activity. It is proposed that these changes, in particular the prolonged feelings of tiredness, might limit daily activity.

Keywords: aging, gait, muscle strength

For older people, physical activity is a key component of independent functioning and quality of life and contributes to the prevention of diseases, disability, and falls (American College of Sports Medicine, 1998; Bauman, 2004; Drewnowski & Evans, 2001; Lord, Ward, Williams, & Anstey, 1993). One possible downside to physical activity is that it might lead to fatigue, which could compromise activity levels and performance of tasks such as balance and walking (Adlerton & Moritz, 2001; Helbostad, Leirfall, Moe-Nilssen, & Sletvold, 2007; Moore, Korff, & Kinzey, 2005).

Fatigue is a broad term used to describe a number of phenomena with a variety of causes. The literature describes exercise-induced fatigue from a biomechanical and physiological perspective as an inability of muscles to generate or maintain force or power output (Enoka & Stuart, 1992; Gandevia, 2001). The term fatigue is also used to describe sensations including tiredness, muscle ache, and increased effort for the same output (Abbiss & Laursen, 2007; St. Clair Gibson et al., 2003). The two effects are closely related, and both can affect task performance. Clearly, fatigue could directly influence a person’s ability and willingness to continue activity and might therefore indirectly contribute to limitation of function.
Exercise-induced fatigue can be considered a process commencing the moment physical activity begins, and, importantly, it is reversible by rest (Riley, Rannels, Low, Jensen, & Jacobs, 1990). The extent of fatigue and rate of recovery depend on several variables including type, intensity, and duration of activity. With intermittent, submaximal muscle contractions, there might be enough time between efforts for some aspects of the fatigue process to recover, but others might accumulate and result in subjective or objective barriers to ongoing activity (Baker, Kostov, Miller, & Weiner, 1993; Enoka & Stuart, 1992). Levels of fatigue and recovery rates after physical activity commonly undertaken by older people, such as activities of daily living (ADLs), have not yet been reported.

Fatigue, and recovery, might be important determinants of whether older adults can safely and successfully carry out requisite tasks and maintain independence and quality of life (Allman & Rice, 2002). It is therefore important to understand the effect of physical activity, of a level comparable to usual ADLs, on muscle performance and feelings of fatigue for older people including the frail elderly.

The aim of the study was to determine whether self-paced moderate-intensity physical activity leads to signs of muscle fatigue or sensations of tiredness in healthy older, balance-impaired older, and healthy young adults. A further aim was to determine whether the three groups exhibited differences in recovery.

**Methods**

**Participants**

Three groups of participants were included in this study—10 healthy older people, 10 balance-impaired elderly, and 10 young healthy adults. Inclusion criteria for the healthy older group were being over 65 years old, living independently in the community, and scoring ≥52/56 on the Berg Balance Scale (Berg, Wood-Dauphinee, Williams, & Maki, 1992). To be included in the balance-impaired group, participants needed to be over 65 years old, be hospital inpatients referred to physiotherapy for mobility or balance upgrade, score <52/56 on the Berg Balance Scale, and report feeling unsteady on their feet. The latter two criteria have previously been used to classify older people as balance impaired (Brauer, Woollacott, & Shumway-Cook, 2001) because a Berg Balance Scale score of ≤51 with self-reported unsteadiness has been shown to be predictive of falling (Shumway-Cook, Baldwin, Polissar, & Gruber, 1997). The young participants were 20–45 years old.

Volunteers were excluded if they were unable to give informed consent or had known neurological disease, musculoskeletal problems that affected balance or mobility (e.g., chronic back pain, hip replacement, recent ankle sprain), cardiovascular problems affecting their ability to safely exercise (e.g., unstable angina), pain interfering with daily activities, vestibular symptoms, known peripheral sensation loss, or uncorrectable loss of visual acuity. Volunteers were also excluded if they exercised more than twice per week at a moderate or vigorous level of intensity or played sport competitively. Participant characteristics are summarized in Table 1. The study was approved by the local hospital and university research ethics committees, and all participants gave written informed consent before participation.
Procedure

Indications of fatigue (subjective feelings of tiredness, maximal voluntary isometric contraction torque of leg muscles, and temporospatial gait variables) were measured before and immediately after a standardized activity protocol. Participants attended one test session in which they undertook all baseline measures three times. They then carried out the activity protocol before being retested immediately after cessation of activity (Post0). Subjective feelings of tiredness and muscle-strength measures were tested again at 8 (Post8) and 16 (Post16) min after activity, and gait measures again at 10 (Post10) and 20 (Post20) min after activity. The timing was designed to minimize the impact of testing on postexercise fatigue. In the three preactivity measures, the first trial was considered a familiarization trial and the second and third trials were averaged to give the preactivity (Pre) value.

The activity protocol incorporated functional-mobility tasks including walking, stepping onto blocks in forward and sideways directions, standing up from a chair, carrying loads, minisquats and -lunges, stepping over and around obstacles, and single-leg standing. Functional-mobility tasks were used because ADLs have been reported as the main form of physical activity carried out by older adults (Brown, Fuller, Lee, Cockburn, & Adamson, 1999). The tasks chosen in this protocol include activities typically used in rehabilitation programs aimed at improving functional mobility of elderly clients (Nitz & Choy, 2004) and are purported to train the muscle groups that are essential for carrying out ADLs in task-specific ways. The tasks were set up as a circuit that was repeated for 14 min. The participants were asked to make their way around the circuit self-paced at a moderate intensity (Level 13, “somewhat hard” on the Borg rating-of-perceived-exertion scale; Borg, 1982). The tasks in the circuit were modified to suit the capabilities of each individual participant, so the number of circuits completed in the time and the workload achieved varied between participants, whereas the intensity of the experience and the duration of activity were standardized. Standing rests were permitted while endeavoring to keep the overall intensity at “somewhat hard,” but sitting rests were discouraged.

Measurements

The measures of fatigue included two subjective tiredness scales, two leg-strength measurements, and temporospatial gait recordings. In addition, heart rate (HR) was recorded continuously using a heart-rate monitor (Polar Pacer, Polar Electro Inc., Lake Success, NY) to indicate the cardiovascular demand during and after the

Table 1  Participant Characteristics, \( M \pm SD \)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Young ((n = 10))</th>
<th>Healthy old ((n = 10))</th>
<th>Balance-impaired old ((n = 10))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>34.6 ± 6.7</td>
<td>71.2 ± 5.7</td>
<td>81.6 ± 5.1</td>
</tr>
<tr>
<td>Males ((n))</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Height (m)</td>
<td>167.0 ± 10.5</td>
<td>164.2 ± 7.7</td>
<td>158.1 ± 9.4</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>61.2 ± 10.6</td>
<td>71.9 ± 9.2</td>
<td>65.5 ± 15.9</td>
</tr>
<tr>
<td>Berg Balance Scale (score/56)</td>
<td>56</td>
<td>54.5 ± 1.5</td>
<td>38.6 ± 7.2</td>
</tr>
</tbody>
</table>
activity protocol. Postactivity HR rise was also presented as a percentage of heart-rate reserve, which was calculated as maximum HR (220 – age) minus resting HR.

Sensations of fatigue were separated into general feelings of tiredness or weariness and local leg-muscle tiredness or ache and scored with different formats to help participants distinguish between the two sensations. General tiredness was scored on a vertical visual analogue scale, with 0 being no tiredness and 10 being maximal tiredness (Grant et al., 1999; Lee, Hicks, & Nino-Murcia, 1991; Miller & Ferris, 1993). Local leg-muscle tiredness was measured using a modified Borg CR-10 category-rating scale, a 12-point scale from 0 to 10 with verbal descriptors assigned to 10 of the levels (Borg, 1982; Neely, Ljunggren, Sylven, & Borg, 1992).

Maximal voluntary isometric torque of the right knee extensors (Figure 1[a]) and right hip abductors (Figure 1[b]) were recorded with load cells (250-kg limit, aluminum S-type, Amalgamated Instrument Co., Hornsby, Australia) affixed to a customized plinth. The load cells were connected to the limbs via an inelastic wire rope and limb cuffs. The position of the person on the plinth was adjusted to accommodate different leg lengths and ensure standardized angle of pull on the wire rope. The moment-arm lengths (lateral femoral condyle to ankle cuff for knee extensors and greater trochanter to knee cuff for hip abductors) were used to calculate maximum torque (Nm) from the peak force produced. The force was corrected for appropriate wire relative to leg angle before torque was calculated. Standardized verbal instructions and encouragement were given.

The temporospatial characteristics of barefoot walking at a comfortable pace (velocity, cadence, stride length, double-support phase [% of cycle], cycle-time variability, and stride-length variability) were recorded using an 8-m GAITRite mat (CIR Systems Inc., Havertown, PA). The mat has good to excellent test–retest reliability in young and older adults, with intraclass correlation coefficients (ICCs) of .82–.92 for speed, cadence, and step length (Menz, Latt, Tiedemann, Mun San Kwan, & Lord, 2004; van Uden & Besser, 2004) and has demonstrated validity, with ICCs of .91–.99 comparing GAITRite and motion-analysis systems for speed, cadence, step length, and step time (Webster, Wittwer, & Feller, 2005). Participants were asked to walk within a narrow walkway (3 times the width of one foot across the metatarsal heads) bound by 3-mm-high × 30-mm-wide barriers at their self-chosen speed. Although the walkway was 10 m long, data were only collected from the middle approximately 7 m so that the first and last steps and transition onto and off the GAITRite mat were excluded.

Statistical Analysis

To determine whether changes occurred because of the physical activity, a repeated-measures analysis of variance (ANOVA) was performed on tiredness and strength variables, with within-participant factors of time (Pre, Post0, Post8, and Post16), between-participants factors of group (young, healthy old, balance-impaired old), and Group × Time interactions. For the gait variables, the time periods investigated were Pre, Post0, Post10, and Post20. Because the two older groups differed in both age and balance ability, when a Group × Time interaction was found with a difference between the two older groups, a repeated-measures analysis of covariance (ANCOVA) was performed between only the two older groups with age as a covariate. A significant group effect with a nonsignificant age
effect would indicate that balance score accounted for the group difference rather than age. Statistical analyses were carried out using SPSS (SPSS Inc., Chicago) version 15.0. Significance level for all tests was set at $p \leq 0.05$.

**Figure 1** — (a) Maximal voluntary isometric torque of the right knee extensors was measured with the participant positioned sitting with hip at 90° and knee at 60° from full extension, pelvis stabilized with a hip belt, and arms across the chest. (b) Right hip abductors were measured with participant positioned supine with right hip in neutral, left leg supported on a stool, arms across the chest, and pelvis stabilized manually. The load cells were affixed to a customized plinth and were connected to the limbs via an inelastic wire rope and limb cuffs. Attempted movement was in the direction of the arrows.

**Results**

**HR**

A significant time effect and a significant Group $\times$ Time interaction for both HR and percentage of heart-rate reserve were found (Figures 2[A] and 2[B]). The
activity protocol resulted in all groups having a higher HR and a greater percentage of heart-rate reserve at Post0 than at Pre, Post8, and Post16, time $F(3, 24) > 62.4, p \leq .05$. This indicates that the activity protocol created cardiovascular demand that had significantly reduced by 8 min after exercise. Figures 2(A) and 2(B) show that immediately after the activity (Post0) the young participants had a higher HR and showed greater effort when HR was expressed as a proportion of heart-rate reserve than did the older groups, Group $\times$ Time $F(2, 26) > 3.0, p \leq .05$, whereas there was no difference between groups at Pre, Post8, or Post16. At Post8, the young participants still had a statistically significantly higher HR than at Pre (mean increase 10 beats/min, 95% confidence interval [CI] 4–16 beats/min) and returned to their preactivity level by Post16, whereas the two older groups had returned to their preactivity level by Post8.

**Sensations of Tiredness**

A significant group effect, $F(2, 25) = 6.6, p \leq .05$, and time effect, $F(3, 23) = 26.8, p \leq .05$, were found for the measure of general tiredness. The balance-impaired participants scored higher, indicating greater tiredness, than the healthy groups for all postactivity measures (Figure 2[C]). All scores postactivity were higher than those measured at Pre. Balance-impaired participants demonstrated a mean increase of 3.6 (95%CI 2.1–5.0) from Pre to Post0, healthy old showed a mean increase of 2.6 (95%CI 1.3–4.0), and the young, an increase of 3.0 (95%CI 1.7–4.4). A significant Group $\times$ Time interaction was also found, $F(6, 48) = 3.2, p \leq .05$. Before activity and at Post0 there were no differences in tiredness between groups, but by Post8 and Post16 the scores for general tiredness for the balance-impaired group were significantly higher than for the other two groups (Figure 2[C]). At Post16, the balance-impaired scored 5.8 ± 2.8 ($M \pm SD$) compared with the healthy older score of 2.7 ± 1.7 and young score of 1.4 ± 0.9 on the visual analogue scale. The young participants showed the best recovery, being the only group with Post8 and Post16 scores that were no different than their Pre levels and significantly lower than their Post0 scores (Figure 2[C]). Comparing the two older groups with age as a covariate retained a statistically significant group effect, $F(4, 12) = 4.9, p \leq .05$, with age not contributing to the difference, $F(4, 12) = 2.3, p = .12$.

The findings for leg-muscle tiredness (CR-10) showed a time course similar to that of general tiredness, time effect $F(3, 24) = 14.8, p \leq .05$. Significant increases were observed from Pre to Post0 for all groups, with a mean increase of 1–3 points. There was also a significant Group $\times$ Time interaction, $F(6, 50) = 3.4, p \leq .05$, for leg-muscle tiredness (Figure 2[D]). Again, similar to general fatigue, the young participants showed the greatest recovery, with Post8 and Post16 scores being no different than Pre. At Post16, the balance-impaired participants scored a mean of 2 points higher than at Pre, indicating a lack of recovery from their postactivity leg tiredness. At this final time the leg-muscle tiredness of the balance-impaired equated to moderate tiredness or aching (3 ± 2), whereas the means for the healthy old and young participants equated to slight (2 ± 1) and very slight tiredness (1 ± 1), respectively.

**Leg-Muscle Strength**

There were significant group effects for hip-abduction torque and knee-extension torque in that the young were the strongest and the balance-impaired the weakest
Figure 2 — (A) Heart rate, (B) percentage heart-rate reserve, (C) visual analogue scale (VAS) scores for general tiredness, and (D) CR-10 scores for leg-muscle tiredness before activity (Pre) and at the three postactivity time points—immediately after (Post0), 8 min after (Post8), and 16 min after (Post16)—for healthy young (□), healthy old (■) and balance-impaired older (▲) participants, $M \pm SD$. 
across all time periods (Table 2). No Group × Time interaction or time effect for either strength measure was found. Although knee-extensor torque measures after physical activity were not significantly different than at Pre, all groups displayed a tendency to be weaker by 2–10% of their preactivity measure.

Gait

All gait parameters showed significant group effects, with healthy old and, to an even greater extent, balance-impaired older people walking slower, with decreased cadence, shorter stride lengths, greater proportion of gait cycle in double support, and greater variability (SD) of stride length and cycle time than the young participants (Table 3). There were no significant time effects for any of the variables, but there was one significant Group × Time interaction, with cadence being significantly slower for the balance-impaired participants immediately after activity (mean decrease of 7.4 steps/min, CI 3.4–11.5, a decrease of 7% ± 7% from Pre). For the balance-impaired elderly, cadence remained significantly lower at both Post10 and Post20 than at Pre (Table 3). No age effect was found between the two older groups, group $F(4, 12) = 3.2, p ≤ .05$ with age as a covariate, age $F(4, 12) = 2.3, p = .11$.

Discussion

The main finding of this study was that moderate levels of physical activity resulted in prolonged sensations of tiredness and reduced cadence in the balance-impaired elderly group in the absence of physiological signs of fatigue (leg-muscle strength). The healthy young and older participants showed immediate postactivity tiredness but no alteration in postactivity strength or gait measures and better recovery of subjective general tiredness than the balance-impaired elderly.

Activity

The activity protocol was designed to be similar to the physical activity demands of daily activity of older people. The 14-min period for the activity protocol was chosen on the basis of durations of nonexercise activity periods of 15 older community-living people (Egerton, unpublished data), showing that they are upright and active for a median duration of 6 min at a time, with the 75th percentile of activity-period durations, representing the upper end of normal activity, being 14 min. A moderate level of physical activity was chosen because healthy older adults report that they undertake some of their daily activities at moderate intensity, but rarely vigorously (Brown, Fuller, Lee, Cockburn, & Adamson, 1999). In addition, studies of energy expenditure in older people have shown that energy is expended at moderate intensity during a range of ADLs (Ainsworth et al., 2000; Weller & Corey, 1998). Finally, the types of activities included in the circuit were designed to challenge the lower limb musculature in ways similar to ADLs. The level of physical activity was deemed comparable to what a healthy older person could reasonably be expected to achieve during daily living. The findings offer a possible explanation for why some older people choose not to achieve this level.
Table 2  Knee Extension and Hip Abduction Maximum Voluntary Isometric Torque at the Four Time Points and for the Three Participant Groups, $M \pm SD$

<table>
<thead>
<tr>
<th>Variable, group</th>
<th>Pre</th>
<th>Post0</th>
<th>Post8</th>
<th>Post16</th>
<th>Group effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee-extension maximal isometric torque (Nm)</td>
<td>$F(2, 23) = 26.0, p \leq .05$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>healthy young</td>
<td>173.4 (35.3)</td>
<td>170.1 (38.7)</td>
<td>152.1 (38.5)</td>
<td>171.1 (43.7)</td>
<td></td>
</tr>
<tr>
<td>healthy old</td>
<td>117.9 (29.7)</td>
<td>106.0 (29.5)</td>
<td>113.4 (38.1)</td>
<td>122.8 (51.5)</td>
<td></td>
</tr>
<tr>
<td>balance-impaired old</td>
<td>57.9 (25.1)</td>
<td>55.2 (22.5)</td>
<td>53.1 (31.6)</td>
<td>53.6 (23.5)</td>
<td></td>
</tr>
<tr>
<td>Hip-abduction maximal isometric torque (Nm)</td>
<td>$F(2, 23) = 5.7, p \leq .05$</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>healthy young</td>
<td>61.2 (31.3)</td>
<td>61.5 (33.5)</td>
<td>60.7 (30.5)</td>
<td>58.5 (28.0)</td>
<td></td>
</tr>
<tr>
<td>healthy old</td>
<td>45.9 (14.7)</td>
<td>46.2 (10.7)</td>
<td>46.7 (17.9)</td>
<td>45.7 (11.7)</td>
<td></td>
</tr>
<tr>
<td>balance-impaired old</td>
<td>25.5 (13.6)</td>
<td>24.5 (9.4)</td>
<td>21.3 (12.6)</td>
<td>25.8 (10.4)</td>
<td></td>
</tr>
</tbody>
</table>
Table 3  Gait Variables at the Four Time Points and for the Three Participant Groups, $M \pm SD$

<table>
<thead>
<tr>
<th>Variable, group</th>
<th>Pre</th>
<th>Post0</th>
<th>Post10</th>
<th>Post20</th>
<th>Group effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>healthy young</td>
<td>1.39 (0.09)</td>
<td>1.44 (0.13)</td>
<td>1.38 (0.11)</td>
<td>1.38 (0.10)</td>
<td>$F(2, 24) = 74.2, p \leq .05$</td>
</tr>
<tr>
<td>healthy old</td>
<td>1.19 (0.15)</td>
<td>1.22 (0.17)</td>
<td>1.21 (0.15)</td>
<td>1.26 (0.18)</td>
<td></td>
</tr>
<tr>
<td>balance-impaired old</td>
<td>0.59 (0.20)</td>
<td>0.54 (0.19)</td>
<td>0.55 (0.20)</td>
<td>0.58 (0.23)</td>
<td></td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>healthy young</td>
<td>119.2 (4.0)</td>
<td>122.0 (6.0)</td>
<td>120.2 (7.0)</td>
<td>120.8 (4.8)</td>
<td>$F(2, 24) = 8.8, p \leq .05$</td>
</tr>
<tr>
<td>healthy old</td>
<td>115.3 (9.9)</td>
<td>116.5 (11.5)</td>
<td>117.5 (9.6)</td>
<td>119.0 (11.7)</td>
<td></td>
</tr>
<tr>
<td>balance-impaired old</td>
<td>103.1 (16.0)</td>
<td>95.7 (15.3)</td>
<td>98.4 (18.5)</td>
<td>98.9 (19.0)</td>
<td></td>
</tr>
<tr>
<td>Stride length (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>healthy young</td>
<td>1.42 (0.12)</td>
<td>1.44 (0.14)</td>
<td>1.38 (0.09)</td>
<td>1.40 (0.13)</td>
<td>$F(2, 24) = 53.7, p \leq .05$</td>
</tr>
<tr>
<td>healthy old</td>
<td>1.24 (0.11)</td>
<td>1.22 (0.18)</td>
<td>1.25 (0.12)</td>
<td>1.28 (0.13)</td>
<td></td>
</tr>
<tr>
<td>balance-impaired old</td>
<td>0.72 (0.23)</td>
<td>0.72 (0.24)</td>
<td>0.72 (0.24)</td>
<td>0.70 (0.22)</td>
<td></td>
</tr>
<tr>
<td>Double-support phase (% of cycle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>healthy young</td>
<td>19.7 (1.9)</td>
<td>19.2 (1.5)</td>
<td>20.1 (1.7)</td>
<td>19.8 (1.4)</td>
<td>$F(2, 24) = 47.5, p \leq .05$</td>
</tr>
<tr>
<td>healthy old</td>
<td>24.1 (2.6)</td>
<td>24.2 (5.0)</td>
<td>23.3 (2.6)</td>
<td>23.0 (2.3)</td>
<td></td>
</tr>
<tr>
<td>balance-impaired old</td>
<td>34.9 (5.6)</td>
<td>35.5 (8.7)</td>
<td>36.6 (8.5)</td>
<td>37.1 (6.9)</td>
<td></td>
</tr>
<tr>
<td>Cycle-time variability (ms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$F(2, 23) = 19.0, p \leq .05$</td>
</tr>
<tr>
<td>healthy young</td>
<td>13.4 (3.8)</td>
<td>16.2 (4.0)</td>
<td>17.7 (8.4)</td>
<td>16.2 (6.0)</td>
<td></td>
</tr>
<tr>
<td>healthy old</td>
<td>31.2 (17.3)</td>
<td>34.2 (31.2)</td>
<td>35.7 (32.9)</td>
<td>23.8 (10.1)</td>
<td></td>
</tr>
<tr>
<td>balance-impaired old</td>
<td>78.5 (27.8)</td>
<td>88.0 (52.4)</td>
<td>75.5 (39.1)</td>
<td>86.7 (56.3)</td>
<td></td>
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<tr>
<td>Stride-length variability (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$F(2, 23) = 11.0, p \leq .05$</td>
</tr>
<tr>
<td>healthy young</td>
<td>2.7 (1.2)</td>
<td>2.3 (1.0)</td>
<td>2.6 (1.0)</td>
<td>2.9 (1.8)</td>
<td></td>
</tr>
<tr>
<td>healthy old</td>
<td>4.2 (2.4)</td>
<td>3.0 (1.4)</td>
<td>5.0 (3.6)</td>
<td>4.6 (3.8)</td>
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</tr>
<tr>
<td>balance-impaired old</td>
<td>6.2 (1.8)</td>
<td>5.2 (2.3)</td>
<td>5.1 (2.2)</td>
<td>5.4 (2.0)</td>
<td></td>
</tr>
</tbody>
</table>

*The balance-impaired older participants had significantly lower cadence at all postactivity tests than at preactivity, Group $\times$ Time interaction, $F(6, 46) = 2.7$, $p \leq .05$. 
Measurement of HR was intended as both a physiological indicator of work and a measure of the effect of activity on the cardiovascular system (Strath et al., 2000). According to this measure, all groups did perform physical work, although the amount, reflected by the percentage of heart-rate reserve, varied between individuals and groups as a result of self-pacing and other factors such as medications used. In this study, the time and intensity of activity was controlled, rather than the workload, to better reflect actual activity, and despite self-pacing, the older groups still showed higher levels of tiredness. Self-pacing might explain the finding that leg strength remained unchanged, because pacing has been shown to enable participants to maintain the same level of voluntary effort (Ansley, Robson, St. Clair Gibson, & Noakes, 2004; Noakes, St. Clair Gibson, & Lambert, 2005; Weir, Beck, Cramer, & Housh, 2006).

**Sensations of Tiredness**

All participants reported feelings of general and leg tiredness immediately after the physical activity, which were more persistent for the balance-impaired elderly than the other participants. Age did not account for the differences between the two older groups for changes in general tiredness.

Several studies have reported fatigue in older people, only some of which can be explained by illness or medications (Avlund, Rantanen, & Schroll, 2007; Avlund, Vass, & Hendriksen, 2003; Bautmans, Gorus, Njemini, & Mets, 2007; Liao & Ferrell, 2000; Schultz-Larsen & Avlund, 2007; Wick & LaFleur, 2007). In older adults, general tiredness has been shown to be related to increased fatigability and decreased muscle strength (Bautmans et al.). Tiredness has also been shown to be predictive of future disability and mortality (Avlund, Rantanen, & Schroll, 2006; Avlund, Schultz-Larsen, & Davidsen, 1998). Although the balance-impaired participants in this study did report higher levels of general tiredness postactivity, they were not different from the healthy groups at baseline. Therefore, the tiredness in this group appears to have been brought on by physical activity.

Failure of the balance-impaired group to recover, in terms of the sensations of tiredness after activity, is an important finding. These prolonged feelings of tiredness might lead frailer people to find physical activity unappealing. This might in turn limit their physical activity in terms of both household tasks and leisure-time exercise, leading to inadequate levels to maintain general health and independent functioning. This study is the first to our knowledge to show the prolonged feelings of tiredness directly related to performance of physical activity in balance-impaired older people.

For all groups, the sensations of general tiredness and leg-muscle tiredness did not recover as quickly or completely as HR. Moreover, the feelings of tiredness do not appear to be linked to leg-muscle fatigue, because feelings of leg-muscle tiredness showed large increases after exercise and gradual recovery, whereas minimal changes in strength were observed. As such, the feelings of tiredness appear not to be directly caused by a decrease in the muscles’ ability to generate force. Causes might be central in origin or originate from other peripheral factors such as reduced peripheral circulation and levels of blood glucose along with increased metabolite buildup (Allman & Rice, 2002; Enoka & Stuart, 1992).
Leg-Muscle Performance

Little change in maximal voluntary isometric torque of knee-extensor muscles and no change in hip-abductor muscles were found as a result of the physical activity. This was not unexpected for the young participants, given the duration and intensity of the activity protocol. We could find no studies that would indicate whether fatigue would be apparent in the elderly after such an activity protocol, but a reduction in strength was hypothesized. The intensity or type of activity might have been insufficient to lead to changes in maximal torque production of the muscles measured. The sensations of local muscle and general tiredness have been reported to occur before there are obvious defects in muscle performance (Gandevia, 2001). Based on these findings and the capability of older people to self-pace their physical activity during everyday life, levels of fatigue at which muscle strength is compromised might not be reached during normal everyday living situations.

The differences in preactivity leg strength are consistent with the literature reporting age- and frailty-related decreases in strength in both knee-extensor and hip-abductor muscle groups (Bohannon, 1997; Johnson, Mille, Martinez, Crombie, & Rogers, 2004; Murray, Duthie, Gambert, Sepic, & Mollinger, 1985). This study limited leg-strength measurement to two muscle groups, and only maximal isometric torque, rather than dynamic strength, was measured. Our choice of muscles was based on the findings that peripheral muscle fatigue of more proximal leg musculature (hip and knee) affects postural control more detrimentally than that in distal musculature (ankle; Gribble & Hertel, 2004). The reliability and validity problems of measuring voluntary maximal muscle strength have long been recognized and might have contributed to the findings (Rothstein, 1985). In this study we endeavored to maximize reliability by controlling participant position, standardizing instructions, and using one assessor for all testing. Further investigation of other muscle groups and types of muscle performance such as power or endurance is warranted, however.

Gait

The only group whose gait was affected by the physical activity protocol was the balance-impaired elderly participants. This group had reduced cadence directly after activity that was still observable 20 min postactivity. Contrary to expectations, the healthy older participants in the current study walked faster within the narrow walkway, with faster cadence and longer strides, than comparable healthy older groups measured with unconstrained walkways (Laufer, 2005; Lord, Lloye, & Li, 1996; Verghese et al., 2007). Comparisons between this balance-impaired group and other frail samples are more difficult because of variations in sample selection and definitions of frailty (Ahmed, Mandel, & Fain, 2007; Fried et al., 2001; Walston et al., 2006). The balance-impaired participants in the current study walked more slowly with reduced cadence and stride length and greater double-support percentage than healthy older people and the “transitioning to frail” participants of Kressig et al. (2004). They walked faster, however, than patients on discharge from an elderly rehabilitation ward (Gorgon, Said, & Galea, 2007) and nursing home patients who showed decreases in leg strength, gait, and balance but could still walk without an aid (Sauvage et al., 1992).
The narrow walkway was used during this study to increase the demand of the walking task while still being achievable for the frailest participants (Brown et al., 2002; Gage, Sleik, Polych, McKenzie, & Brown, 2003). Our method of altering the walking task to increase the required level of attention was an attempt to resemble the cognitive demands of walking in a home environment. Narrow walkways have been shown to increase the level of anxiety and attention required and lead to altered kinematics consistent with a more conservative gait pattern (Brown et al., 2002; Gage et al.). This increased cognitive demand might have led to post-activity changes that would not have occurred had an unconstrained walking task been used. Other studies have shown that healthy older people alter their gait when walking is combined with increased cognitive demands (dual-task conditions), with decreases in cadence being greater than decreases in velocity (van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007; Verghese et al., 2007). Both age-related and fear-related slowing of gait have been shown to be largely a result of decreases in stride length rather than cadence (Maki, 1997). Thus, the feelings of tiredness might have exacerbated the effect of the more cognitively demanding walking in the balance-impaired participants, who responded with an alternative strategy to increase stability when fatigued because of the narrow walkway. Alternatively, the slowing of cadence might be a strategy to reduce cardiovascular effort in the presence of the feelings of tiredness despite a rapid recovery of HR. Either way, it seems that the sensations of fatigue are likely responsible for the gait changes rather than any changes in the muscles.

To our knowledge, only one other study has investigated the effect of physical activity on gait in older adults (Helbostad et al., 2007). In that study, participants increased their step-width and step-length variability after activity. The baseline gait characteristics of the participants in the fatigued group were similar to the healthy older participants in the current study who did not show any changes in gait. The differences in findings might be a result of differences in the intensity of the activity protocols, because in Helbostad et al.’s (2007) study, participants performed a sit-to-stand task as fast as possible until too exhausted to continue.

Although providing valuable initial information, this study has several limitations. The activity used was unlikely to be exactly the same as ADLs carried out at home, and because of the encouragement to keep going for 14 min, some participants in this study might have reached levels of fatigue that they would normally avoid. Thus, elders might have experienced greater deterioration in the study than they usually would at home. Although our methods might be more sensitive to showing an effect than if participants were measured at home, they give a better indication of what older people’s response is when they are asked to carry out a reasonable level of activity. It is not possible from just this study to know whether it was the type of activity, the duration, or the intensity that contributed most to the findings of prolonged feelings of tiredness. Future research should address these issues and also relate fatigue to functional abilities and balance.

Conclusion

This study found that balance-impaired older people had greater and more prolonged sensations of tiredness after physical activity than healthy older and younger people and that there were corresponding changes in their gait. These
effects occurred despite the physical activity being self-paced and of moderate intensity and short duration. This might contribute to frailer older people self-limiting the amount of time spent on ADLs and exercising, thereby compromising health and independence in the longer term. Gait alterations might put them at greater risk of falling, and the fatigue experienced might also compromise older people’s ability to maintain postural control, an issue that requires further investigation.

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References


