Journal of Gerontology: MEDICAL SCIENCES
2007, Vol. 62A, No. 9, 1010–1015

Physical Fatigue Affects Gait Characteristics in Older Persons

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Background. Fatigue affects self-reported functioning in older persons. Balance and gait problems increase fall risk. The effect of physical fatigue in the elderly population in general, and on balance control during walking in particular is not well known. This study investigates how a repeated sit-to-stand task affects gait control in older persons.

Methods. Twenty-two persons (mean age 78 years) took part in a fatigue group (FG), and 22 persons (mean age 80 years) in a matched control group (CG). Participants walked back and forth on a walkway at different walking speeds. Gait data were adjusted for pretest–posttest differences in walking speed. The FG participants were physically fatigued by a repeated sit-to-stand task. Trunk data were obtained by a triaxial accelerometer and foot level data by an electronic walkway.

Results. There were no group differences in preferred gait speed ($p = .96$) or in step length ($p = .47$) following the fatiguing task, but there were significant increases in step width ($p = .023$) and in mediolateral trunk acceleration amplitude ($p = .038$) in the FG group. Step-length variability ($p = .004$) and interstride trunk acceleration variability in the vertical direction ($p = .002$) increased, and tended to increase in the anteroposterior direction ($p = .10$) and to decrease in the mediolateral direction ($p = .10$) in the FG only.

Conclusion. Gait changes following a physical fatiguing task agree with changes previously found in older persons at risk of falling, suggesting that physical fatigue may represent a risk factor for falls in elderly persons.

FATIGUE is an unspecific and loosely defined symptom associated with chronic diseases (1,2), and may strongly interfere with daily life functioning (3). Self-reported fatigue implies a feeling of tiredness, reduced energy, and reduced muscle strength (4). Fatigue is also associated with muscle fatigue, measured as a loss of muscle performance during repeated or continuous activation (5), where fatigability is calculated as the rate of decline in performance (6,7). Research on muscle fatigue has primarily focused on isometric work for specific muscle groups (8). Less attention has been paid to performance of everyday motor tasks.

About 30% of persons older than 65 years and 50% of those older than 80 years fall annually (9). Most falls happen during walking, and balance problems are risk factors for falls (10,11). An important research issue is therefore to identify underlying factors contributing to balance loss.

Studies on standing balance in young healthy adults conclude with an effect of muscle fatigue on body sway (12,13) and larger balance disturbances after fatiguing proximal compared with distal leg muscles (14,15). Thus, a relationship between muscle fatigue in the lower extremities and balance control is likely. Also one recent study that assessed the effect of muscle fatigue on balance control during walking concluded with changes in trunk and head movements following fatigue (16).

Muscle fatigue is sparsely documented in older persons. However, Petrella and colleagues (6) found greater fatigability during knee extension in older persons than in young, and Katsiaras and coworkers (7) reported greater fatigability during knee extension and flexion in older men compared to older women.

Gait requires the body's center of mass to be within the boundaries of the supporting foot and where the next foot hits the ground (17). Step width and step-width variability have been suggested as measures of lateral gait balance control (18), and step-length variability has been found to distinguish fallers from nonfallers (19,20). Increased interstride variability of trunk movements in the sagittal plane and decreased mediolateral (ML) variability have been reported to discriminate frail from healthy older persons (21). Thus, both trunk and foot level characteristics may be of clinical relevance for gait control in elderly persons.

Given the high impact of balance control during walking on fall risk in older persons, surprisingly little attention has been paid to the fatiguing effect of daily activities on gait. In the present study we therefore wanted to fatigue older persons physically by use of a repeated sit-to-stand task and investigate the effect on trunk and foot level gait characteristics.

Methods

Design

A controlled experimental design was used. The intervention group, here called the fatigue group (FG), performed pre- and posttests with a repeated sit-to-stand task between tests. The control group (CG) performed pre- and posttests without being fatigued between tests.

Participants

Participants were recruited from a study on the effect of cataract surgery on balance and gait. All participants were

70 years old or older, able to walk 10 m independently, and had no stroke or lower limb surgery during the last 6 months. Cognitively impaired [Mini-Mental Status Examination score (22) of $< 20/30$] or terminally ill persons were excluded. Potential participants were invited to a 6-week postsurgery assessment. Participants in the CG ($N = 22$) were recruited after the FG participants and were matched for gender and age at a group level with the FG ($N = 22$). All participants had been assessed by a geriatrician, and those in the FG were found to have no medical contraindications for performing a fatiguing task. The study was run according to the Declaration of Helsinki and was approved by the Regional Ethical Committee.

Test Procedures

Testing took about 15 minutes. The fatigue procedure took another 5–15 minutes. FG participants started to walk immediately after having been fatigued. CG participants had approximately 10 minutes between pre- and posttest.

Fatigue protocol.—FG participants were asked to rise from a 46-cm hardback chair without arm rests. Participants were instructed to cross arms and repeatedly rise to an erect position and sit down again at a fast speed. During fatiguing they were verbally encouraged by the examiner to continue until they felt too exhausted to do any more repetitions. Two persons were not able to have arms crossed and were therefore allowed to rise with arms free.

Pretest walking trials.—Participants walked along a 7-m walkway, where time and gait characteristics were registered for the middle 4.7 m. Pretest included a warm-up walking trial and walking back and forth three times at different instructions on walking speed, giving six sequences of data for each participant. Instructions were as follows and were always followed by ''go back and forth once'': (i) ''Walk slowly as if you were waiting at a bus stop,'' (ii) ''Walk at your preferred speed,'' and (iii) ''Walk as fast as you can safely do without running.''

Posttest walking trials.—FG participants walked back and forth at their preferred speed. CG participants repeated the pretest protocol which was necessary for another study in which they also participated. Warm-up was not performed. The two walks at preferred speed were used in the analyses.

Outcome Measures

During fatiguing, time and vertical displacement of each sit-to-stand movement was measured by a line fixed to a belt at waist level, connected to a reel at floor level (MuscleLab; Ergotest Technology, Langesund, Norway). Number of sit-to-stand repetitions was registered and mean and peak velocity of each repetition calculated. Walking speed was calculated from time registered by photocells.

Trunk acceleration was measured along three orthogonal axes using a triaxial piezoresistant accelerometer (15 g) mounted to the participant by a belt over the L3 region of the spine and connected to a portable data logger. Data were stored on interchangeable Personal Computer Memory Card International Association (PCMCIA) cards and subsequently transferred to a computer for offline processing. The accelerometer may register a static component due to tilt out of the horizontal plane. This component was corrected for to assess dynamic acceleration during gait (23).

Footfalls were identified by a 4.7-m-long electronic walkway (GAITRite; CIR Systems Inc., Havertown, PA). Step length, step width, step-length variability, and step-width variability were used as outcome measures.

Data Analysis

Signal processing of acceleration data was performed in MATLAB 7.1 (MathWorks Inc., Natick, MA). Statistical analyses were performed in Microsoft Excel 11.0 (Redmond, WA) and SPSS 13.0 (Chicago, IL). An alpha level of 0.05 was chosen for statistical significance.

Fatigue was calculated as the difference of average velocity and also of peak velocity between the first and the last five sit-to-stand trials. Trunk acceleration amplitudes for each walking trial were expressed by root mean square (RMS) values. Trunk acceleration variability was assessed by an autocorrelation procedure. A perfect replication of the gait cycle signal between neighboring strides will return an autocorrelation coefficient of 1, and no association a coefficient of 0, meaning that the higher the autocorrelation coefficient, the lower between-stride variability. Procedures for obtaining autocorrelation coefficients are described elsewhere (24).

The electronic walkway's software (GAITRite34sg 2005) was used to calculate footfall parameters. Step width and step length were registered from footprints, and step-width variability and step-length variability were calculated as standard deviation of step width and step length for each trial.

Many gait variables are speed related and should therefore be assessed at comparable speeds (25). Based on the six walking trials at pretest, we calculated an individual quadratic curve estimate of the gait variable of interest, over the speed range demonstrated by that participant. We could then compare the performance of that participant at posttest with point estimates from the curve representing equivalent walking speeds during pretest. The difference between posttest at preferred gait speed and pretest point estimate at an equivalent speed was used as a measure of change, as exemplified in Figure 1. Outcome scores were calculated as the mean of two trials.

Parametric and nonparametric tests for independent samples were used to test group differences in sample characteristics. A repeated-measures general linear model was used to test changes in gait characteristics from pre- to posttest for the FG relative to the CG (Time * Group interaction) and for the total sample (main effect of time), where it was controlled for preferred gait speed at pretest as well as for previous stroke, due to the fact that the number of persons having an earlier stroke was 8 in the FG and 4 in the CG. A paired sample t test was used to test fatigability during the sit-to-stand task.

Results

Sample characteristics are shown in Table 1 and baseline gait characteristics in Table 2. No significant group differences were found.

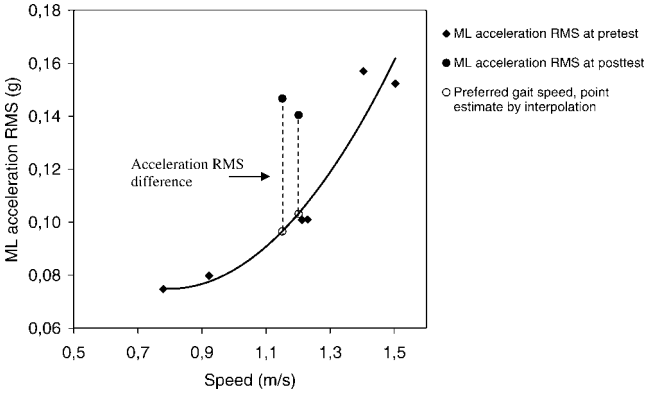

Figure 1. Curvilinear relationship of mediolateral (ML) acceleration root mean square (RMS) plotted against walking speed for a participant walking back and forth at three different instructions on walking speed at pretest (◆). *Solid line*, quadratic curve estimate; ●, ML acceleration RMS for the two walking trials at preferred gait speed at posttest; ○, point estimates representing ML acceleration RMS at equivalent speeds at pretest.

Median number of sit-to-stand trials in the FG was 25 (interquartile range: 20.0–34.5). One participant managed 249 trials, which is 150 repetitions more than for the second best. Average and peak sit-to-stand velocity decreased from the first five to the last five trials ($p = .003$ and $< .001$, respectively) (Table 3). Figure 2 demonstrates a linear relationship ($R^2 = .37$, $p = .006$) between change in peak velocity per repetition versus number of completed sit-to-stand repetitions, indicating higher fatigability in persons with low capacity in performing the fatiguing task. Data for the participant who did 249 sit-to-stand trials and one participant who was believed to be pacing, thus improving performance throughout the test, which is highly unlikely in a fatiguing task (7), were included in the significance tests but not in the figure.

There was a significant pre- to posttest increase in preferred gait speed for the total sample ($p = .003$), but no Time * Group interaction ($p = .96$) (Table 4). Figure 3 demonstrates a large between-participant change in anteroposterior (AP), vertical (V) and ML trunk acceleration RMS in the FG. We found, however, a significant Time * Group interaction for the ML acceleration amplitude ($p = .038$), indicating a larger pre- to posttest increase in the FG compared to the CG. The significant Time * Group interaction found for interstride trunk acceleration variability in the V direction, and the near significant interactions in the AP and ML directions ($p = .10$) indicate increased variability for the FG relative to the CG in the direction of progression (AP and V) and decreased variability in the ML direction at posttest (Figure 4). At foot level we found significant Time * Group interactions for step width and for step-length variability, indicating increases in the FG from pre- to posttest (Figures 5 and 6). Controlling for previous stroke actually strengthened group differences, but did not affect conclusions of the statistical tests.

Table 1. Sample Characteristics

Sample Characteristics	Fatigue Group ($N = 22$)	Control Group ($N = 22$)
Women: *N* (%)	17 (77.2)	17 (77.2)
Age (y): mean (*SD*)	78.2 (5.0)	80.4 (4.9)
Body mass index (kg/m^2): mean (*SD*)	27.5 (5.6)	27.3 (4.4)
Mental status (MMSE): mean (*SD*)	27.0 (2.3)	28.0 (1.8)
Persons with a fall the previous y: *N* (%)	9 (40.9)	7 (31.8)
Medical diagnoses: *N* (%)		
Stroke	8 (36.4)	4 (18.2)
Heart disease	4 (18.1)	2 (9.0)
Hypertension	10 (45.5)	9 (40.9)
Respiratory disease	3 (13.6)	3 (13.6)
Diabetes mellitus	4 (18.1)	1 (4.5)
Muscular/skeletal disease	3 (13.6)	3 (13.6)
Depression	2 (9.0)	2 (9.0)
Incontinence	9 (40.9)	8 (36.4)
Hearing impairment	11 (50.0)	7 (41.2)
Syncope	3 (13.6)	4 (18.2)
Osteoporosis	8 (36.4)	2 (9.0)

Note: *SD* = standard deviation; MMSE = Mini-Mental State Examination.

Table 2. Baseline Gait Characteristics Compared at Preferred Gait Speed

	Fatigue Group ($N = 22$)		Control Group ($N = 22$)		Independent Sample *t* Test	
Gait Characteristics	Mean	(*SD*)	Mean	(*SD*)	*t*	*p*
Preferred gait speed, m/s	0.99	0.23	0.98	0.20	0.74	.39
AP trunk acceleration RMS, g	0.12	0.03	0.11	0.03	0.21	.25
V trunk acceleration RMS, g	0.18	0.06	0.15	0.04	0.49	.49
ML trunk acceleration RMS, g	0.13	0.04	0.12	0.03	2.02	.16
AP trunk repeatability (autocorr.)	0.72	0.15	0.77	0.13	1.01	.30
V trunk repeatability (autocorr.)	0.69	0.18	0.75	0.16	0.29	.59
ML repeatability (autocorr.)	0.62	0.14	0.60	0.19	2.73	.11
Step length, cm	52.48	9.32	54.82	7.85	0.39	.54
Step width, cm	9.92	4.74	9.73	3.10	2.61	.11
Step-length variability, cm	3.67	1.76	2.67	1.24	1.48	.23
Step-width variability, cm	2.40	0.64	2.62	1.34	2.40	.18

Note: *SD* = standard deviation; RMS = root mean square; AP = anteroposterior; V = vertical; ML = mediolateral; autocorr. = autocorrelation.

Discussion

We have investigated how physical fatigue influences gait, and have found changes in gait characteristics at trunk and foot level, but no changes in gait speed in an FG relative to a CG.

The increased step width and ML trunk acceleration amplitude in the FG participants following fatigue indicate that participants adopted a broader base of support and

Table 3. Average and Peak Velocity (m/s) of the Repeated Sit-to-Stand Movements During the Muscle Fatiguing Task

Velocity	Mean Through all Trials	Mean of First Five Trials	Mean of Last Five Trials	*t* Values	*t* Values of Change
Average	0.31 (0.10)	0.33 (0.11)	0.29 (0.09)	3.30	.003
Peak	0.60 (0.19)	0.65 (0.21)	0.55 (0.18)	5.14	$< .001$

Note: Mean (standard deviation) with one sample *t* tests for change.

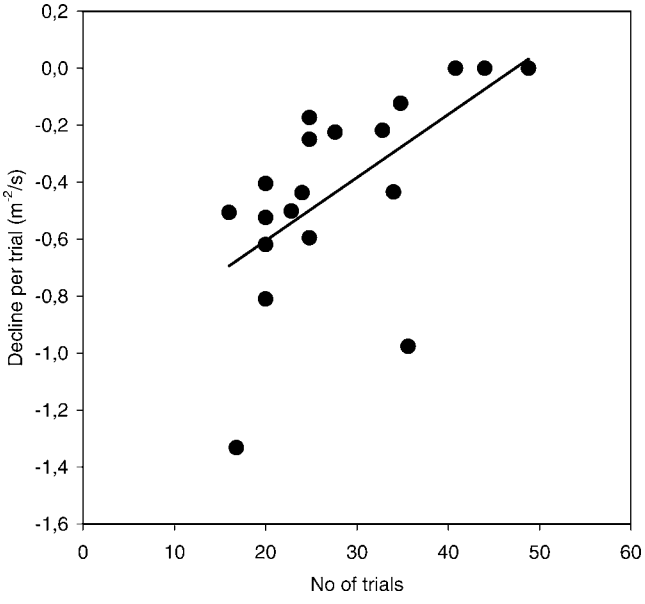

Figure 2. Fatigue group. Number of sit-to-stand trials plotted against pretest–posttest changes in sit-to-stand peak velocity per trial. *Solid line:* fit line. Negative values indicate a deline from pretest to posttest.

a concomitant increase in lateral weight shift. Interestingly, ML step-width variability and ML interstride trunk acceleration variability did not show any significant Time * Group interactions, supporting previous findings that increased ML excursions may not be accompanied by larger ML variability when capacity for balance control is challenged in older persons (25).

Trunk movements in the line of progression can be decomposed to the AP and V directions. In our study, AP and V acceleration amplitudes were not affected by the fatiguing task for the FG as a whole. At the foot level, this was also the case for step length. Lack of change in the AP and V accelerations may explain why gait speed did not differ between groups at posttest. The same phenomenon

Table 4. Repeated-Measures Analysis of Variance (ANOVA) (Wilks' Lambda *p* Values) of Pretest–Posttest Gait Differences

	Repeated-Measures ANOVA: *p* Values	
Gait Characteristics	Main Effect Time	Time * Group Interaction
Preferred gait speed, m/s	.003	.964
AP trunk acceleration RMS, g	.927	.554
V trunk acceleration RMS, g	.690	.354
ML trunk acceleration RMS, g	.656	.038
AP trunk repeatability, autocorr.	.056	.104
V trunk repeatability, autocorr.	.011	.004
ML repeatability, autocorr.	.058	.103
Step length, cm	.603	.465
Step width, cm	.129	.023
Step-length variability, cm*	.102	.002
Step-width variability, cm	.209	.184

Notes: Results are controlled for differences in baseline preferred gait speed.
RMS = root mean square; AP = anteroposterior; V = vertical; ML = mediolateral; autocorr. = autocorrelation.

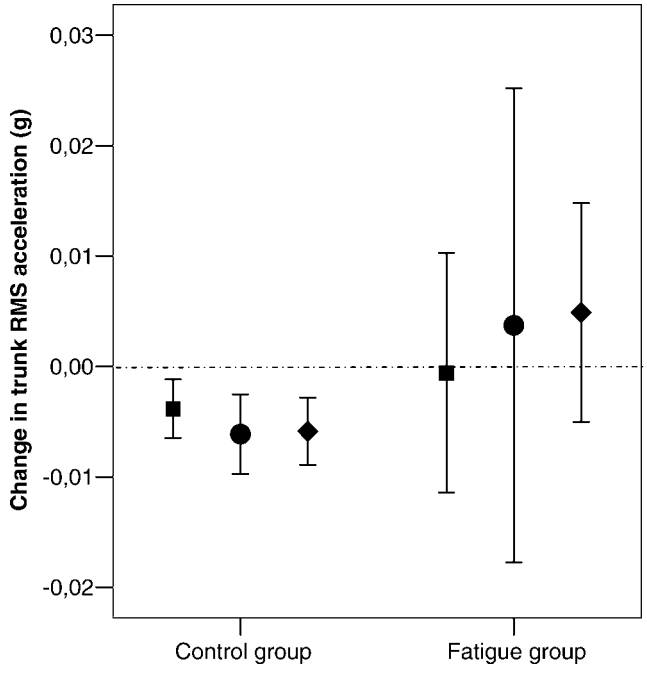

Figure 3. Pretest–posttest changes in anteroposterior (■), vertical (●), and mediolateral (◆) trunk acceleration root mean square with 95% confidence interval for the control group and the fatigue group.

was observed by Kavanagh and colleagues (16) in young healthy persons following fatigue. However, for variability measures in the direction of progression, results indicate larger variability for the FG at posttest. So even if mean

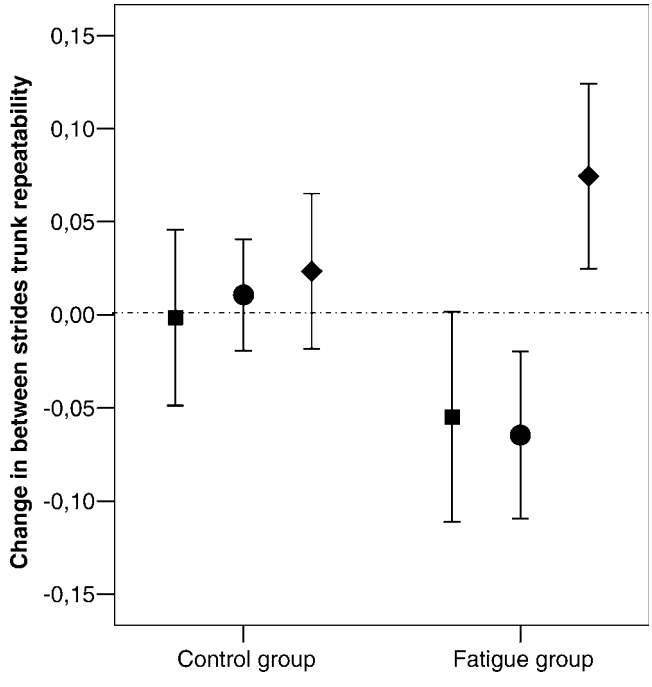

Figure 4. Pretest–posttest changes in interstride trunk variability in anteroposterior (■), vertical (●), and mediolateral (◆) trunk acceleration with 95% confidence interval for the control group and the fatigue group.

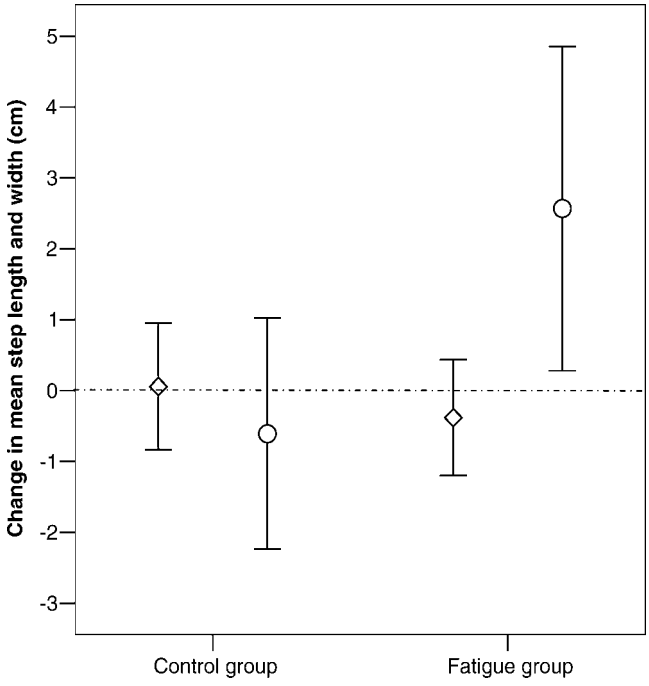

Figure 5. Pretest–posttest changes in step length (◇) and step width (○) with 95% confidence interval for the control group and the fatigue group.

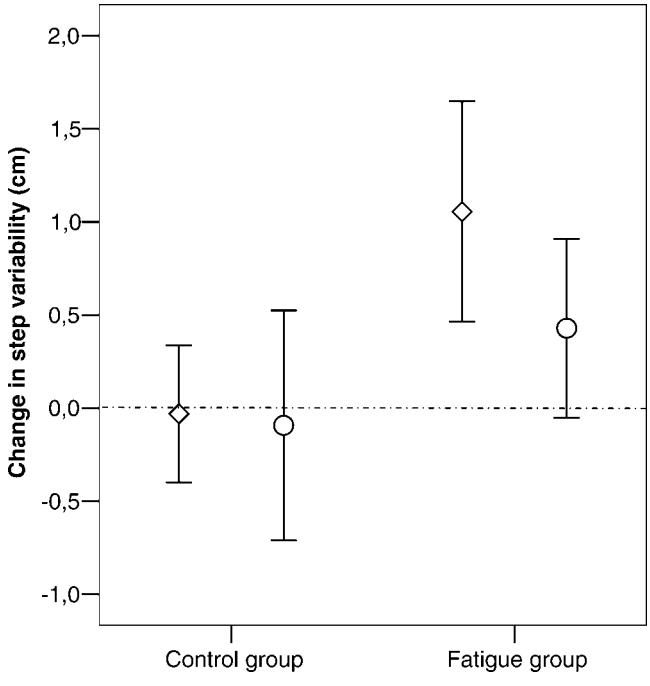

Figure 6. Pretest–posttest changes in step-length variability (◇) and step-width variability (○) with 95% confidence interval for the control group and the fatigue group.

measures of progression were not affected, consistency of progression was.

A shift in walking strategy without change in gait speed might be understood as an attempt to keep a constant or optimal output, but at the price of a higher cost of compensation (26). It is thus reasonable to suggest that this shift in movement strategy may increase risk of balance loss during walking.

The increase in step-length variability in the FG may be explained by fatigue in muscles controlling movements in the sagittal plane, and is in line with earlier studies that found step-length variability to distinguish between older persons with and without risk of falling (19,20,27).

A higher interstride trunk acceleration variability in the AP and V directions and lower in the ML direction in frail persons compared with fit older persons has been reported earlier (21). The findings in the present study suggest that, after being fatigued, the older individuals adopted gait characteristics resembling those of the frail persons. The opposing patterns of change for ML versus V and AP variability is interesting, because increased variability often is regarded as a general sign of decreased gait control (19,28–30). However, our findings are supported by those of some earlier studies (16,21), and they indicate that variability in ML trunk movements may be necessary for effectively controlling the center of mass during walking.

Unlike most muscle fatigue studies, in our study individual load during fatigue was not graded relative to each participant's maximal capacity, possibly resulting in an increased range in number of sit-to-stand trials between participants. The highly significant decrease in sit-to-stand velocity from the first five to the last five trials and larger fatigability found in those participants with fewest repetitions also indicate that participants who performed few repetitions were fatigued. However, we cannot conclude whether fatigue was caused by muscle fatigue or fatigue in other body systems (e.g., the lungs or the circulatory system).

We found an overall increase in gait speed from pre- to posttest that could possibly explain changes in gait characteristics. However, we have controlled for the effect of gait speed on all gait variables and found that the increase in gait speed was the same for the FG and the CG, thus strengthening our findings that the changes in gait characteristics in the FG from pre- to posttest are likely to be a result of change in movement strategy and not due to increased gait speed.

This study has some limitations. We did not randomize participants to the FG and CG. However, baseline gait characteristics demonstrated no significant group differences. At posttest, the CG walked back and forth at a slow speed before the two counting trials at preferred speed. Thus, this study cannot answer whether these two slow walks may have affected gait characteristics at posttest for the CG. We have also used more than one gait outcome parameter, which may have increased the risk of false-positive findings.

To our knowledge, this is one of the first studies to assess the effect of physical fatigue on gait and the first study to investigate how fatigue through a physical everyday activity affects gait control. We have demonstrated changes in gait control following physical fatigue, even if gait speed did not change. For the sample as a whole, the changes were in the direction of what frail older persons and persons at risk of

falling are demonstrating, even if changes in trunk acceleration RMS varied between participants in the FG. More studies on physical fatigue in older persons should be performed, using complex motor tasks of relevance to daily life.

Acknowledgment

This study was supported by grants from the Central Norway Regional Health Authority.

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Received August 10, 2006
Accepted December 3, 2006
Decision Editor: Luigi Ferrucci, MD, PhD