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Physical and Psychological Factors Associated With Stair Negotiation Performance in Older People

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Background. An inability to negotiate stairs is a marker of disability and functional decline and can be a critical factor in loss of independence in older people. There is limited research on the underlying factors that impair performance in this important activity of daily living. We examined which physical and psychological factors are associated with stair climbing and stair descending performance in older people.

Methods. Six hundred sixty-four community-dwelling people aged 75–98 years (mean age = 80.1 years, standard deviation (*SD*) = 4.4 years) underwent stair negotiation tests as well as tests of lower limb strength, vision, peripheral sensation, reaction time, and balance and completed questionnaires measuring psychological and health status.

Results. Many physiological and psychological factors were significantly associated with stair negotiation speed. Multiple regression analyses revealed that knee extension and knee flexor strength, lower limb proprioception, edge contrast sensitivity, reaction time involving a foot-press response, leaning balance, fear of falling, and the Short-Form 12 Health Status Questionnaire (SF-12) pain and vitality scores were significant and independent predictors of stair ascent and descent performance. The combined set of variables explained 47% of the variance in stair ascent performance and 50% of the variance in stair descent performance. Measures of strength, balance, vision, fear, and vitality also significantly discriminated between persons who did and did not require the use of the handrail when performing the tests.

Discussion. In community-dwelling older people, impaired stair negotiation is associated not only with reduced strength but also with impaired sensation, strength, and balance; reduced vitality; presence of pain; and increased fear of falling.

STAIR negotiation (ascent and descent) is an important activity of daily living (ADL). An inability to undertake this task is an indicator of disability (1) that can have extensive implications for the health, well-being, and independence of older people. Many falls in public places occur on steps, and 80% of these occur during stair descent (2), making this a particularly important functional task for community-dwelling older people.

There is strong evidence that the ability to negotiate stairs is dependent on adequate lower limb strength (3,4) and power (5). Stair descent also requires the correct visual processing of the stairs, as well as adequate motor planning and kinesthetic feedback for safe and coordinated movement (6). Furthermore, as previous research has found associations between psychological variables (vitality, anxiety, and fear of falling) and functional tasks and ADLs in older people (7,8), it is possible that these psychological factors may also influence stair negotiation.

As previous studies have examined possible determinants of stair negotiation ability in isolation, it has not been possible to establish their relative importance in influencing this important functional task. In this study, we investigated the contributions of a broad range of physical and psychological factors to performance (speed and handrail use) in a stair climbing and descending task in a sample of older, community-dwelling people.

Methods

Participants

Six hundred sixty-four community-dwelling participants (233 men, 431 women) aged 75–98 years (mean 80.1 years, standard deviation (*SD*) = 4.4) took part in the study. Potential participants were randomly drawn from a health insurance company membership database, and were excluded from the study if they had minimal English language skills, were blind, had Parkinson's disease, or had a Short Portable Mental Status Questionnaire (SPMSQ) score < 7 (9). To maximize participation rates of older people with mobility limitations, transportation was provided for participants who could not make their own way to the falls assessment clinic. Of the 2468 persons initially contacted, 700 (28%) agreed to participate; of these, 664 (233 men, 431 women) aged 75–98 years (mean = 80.1 years, *SD* = 4.4) met the inclusion criteria and completed the stair negotiation tests. The prevalence of medical conditions, medication use, physical activity and mobility limitations

Table 1. Prevalence of Major Medical Conditions, Medication Use, Participation in Physical Activity and Mobility, and ADL Limitations in the Study Population

Condition	Number (%)
Medical conditions	
Poor vision	166 (25.0)
Stroke	46 (6.9)
Lower limb arthritis	273 (41.1)
Diabetes	46 (6.9)
Incontinence	100 (15.1)
Depression	68 (10.2)
Health rated as fair or poor	57 (8.6)
Medication use	
≥4 medications	363 (54.7)
Cardiovascular system medications	461 (69.4)
Psychoactive medications	102 (15.4)
Musculoskeletal system medications	154 (23.2)
Physical activity	
Planned walks < once per week	294 (44.3)
Physical activity < 1 h/d	193 (29.1)
Limited in climbing stairs	201 (30.3)
Mobility and ADL limitations	
Used a walking aid	109 (16.4)
Wore multifocal spectacles	456 (68.7)
Difficulty with home maintenance	402 (60.5)
Difficulty with housework	217 (32.7)
Difficulty cooking	103 (15.5)
Difficulty shopping	97 (14.6)
Difficulty dressing	15 (2.3)

Note: ADL = Activity of Daily Living.

are shown in Table 1. The Human Studies Ethics Committee at the University of New South Wales gave approval for this study, and written informed consent was obtained from all individuals prior to their participation.

Measurement of Stair Ascent and Descent Performance

Participants were scored on the time taken to walk up and then down eight stairs, as quickly as possible. The stairs were indoors, had a handrail, were covered with linoleum, and were well lit. The participants were asked to begin the test at the bottom of the eight stairs (15 cm high, 27.5 cm deep), and a stopwatch was used to time performance. They were instructed to walk as quickly as possible (but not to run) and to take one step at a time. They were allowed to use the handrail and a mobility aid if preferred. Timing commenced for the stair ascent when the participant raised a foot off the ground to climb the first step and stopped when both feet were placed on the eighth step (a landing). After a brief rest, the participant was asked to descend the stairs. Again, timing was started when the participant raised a foot off the ground for the first step and stopped when the last step was completed. Test–retest reliability was determined from a subset of 30 participants, with the use of the intraclass correlation coefficient ($ICC_{1,3}$) model. The ICC value for stair ascent was 0.84 (95% confidence interval [CI], 0.69–0.92); for stair descent, it was 0.86 (95% CI, 0.74–0.93), indicating excellent reliability (10). A record of whether participants held the handrail during the stair negotiation tasks was also made.

Assessments of Sensorimotor Function and Balance

Visual acuity and visual contrast sensitivity were assessed using a log Minimum Angle Resolvable (logMAR) letter chart and the Melbourne Edge Test (11), respectively. Depth perception was evaluated using a Howard–Dohlman depth perception apparatus (12). Proprioception was measured using a lower limb matching task. Errors were recorded using a protractor inscribed on a vertical clear acrylic sheet (60 cm × 60 cm × 1 cm) placed between the legs. Tactile sensitivity was measured at the lateral malleolus using a Semmes–Weinstein type aesthesiometer (Balance Systems Inc., Sydney, Australia). Vibration sense at the tibial tuberosity of the knee was measured using a vibrator that produced a 200 Hz vibration under load.

Ankle dorsiflexion, knee extension, and knee flexion strength were measured in both legs. These muscle groups were assessed because (i) they have been found to be important lower limb strength measures in the prediction of falls in older people and (ii) they can be assessed using simple rigs with participants seated. The angles of the hip, knee, and ankle were 90°, 110°, and 90°, respectively, when testing ankle dorsiflexion strength, and the angles of the hip and knee were 90° when testing knee extension and knee flexion strength. The best of three trials was recorded for each muscle group, and the average of these scores for both legs was recorded. These measures were then normalized for body weight.

Two measures of simple reaction time (SRT) were made. These measures involved a light as the stimulus and either a finger press or a foot press as the response. Postural sway was measured using a sway meter that measured displacements of the body at the level of the waist. Testing was performed with participants standing with their eyes open, then closed, on the floor and then on a foam rubber mat (60 cm × 70 cm × 15 cm thick). Leaning balance was measured using the coordinated stability test (13), which measures the participant's ability to adjust body position in a steady and coordinated manner while near or at the limits of the base of support.

Psychological Assessment

Items from the Short-Form 12 Health Status Questionnaire (SF-12) were used to provide validated assessments of pain, depression, anxiety, and vitality (14). Fear of falling was assessed with a single question using a five-point scale, with ratings ranging from "not at all" to "totally."

Statistical Analysis

Pearson correlation coefficients were computed to examine the relationships between stair negotiation times and the other test variables. Hierarchical multiple regression was used to assess the associations between the stair negotiation times and the physiological and psychological variables. Because there is considerable evidence that knee extension strength is an important determinant of

Table 2. Physiological, Psychological, and Health Correlates of Stair Ascent and Descent Speed

Measures	Mean (*SD*) ($N = 664$)	Stair Ascent *r* (*p* Value)		Stair Descent *r* (*p* Value)	
Sensorimotor					
Visual acuity, high contrast (logMAR)	1.3 (1.2)	.18	.000	.18	.000
Visual acuity, low contrast (logMAR)	2.6 (2.0)	.22	.000	.22	.000
Edge contrast sensitivity (dB)	18.8 (2.5)	−.21	.000	−.24	.000
Depth perception (cm error)*	2.8 (3.7)	.16	.000	.17	.000
Proprioception (cm error)*	2.1 (1.4)	.11	.003	.13	.001
Tactile sensitivity ($\log_{10}$ mg pressure)	4.4 (0.5)	.09	.019	.10	.010
Vibration sense (microns)*	39.5 (26.6)	.10	.014	.09	.018
Ankle dorsiflexion strength/weight (Nm/kg)	1.0 (0.5)	−.22	.000	−.23	.000
Knee extension strength/weight (Nm/kg)	4.0 (1.6)	−.31	.000	−.38	.000
Knee flexion strength/weight (Nm/kg)	2.2 (0.9)	−.33	.000	−.35	.000
Simple reaction time, hand (ms)*	274 (49)	.28	.000	.32	.000
Simple reaction time, foot (ms)*	351 (62)	.32	.000	.34	.000
Balance					
Sway eyes open, floor (area)*,†	444 (416)	.13	.001	.13	.001
Sway eyes closed, floor (area)*,†	589 (611)	.20	.000	.18	.000
Sway eyes open, foam (area)*,†	1375 (1001)	.24	.000	.28	.000
Sway eyes closed, foam (area)*,†	3205 (2240)	.21	.000	.22	.000
Coordinated stability (errors)*	8.4 (8.4)	.44	.000	.46	.000
Psychological measures					
Bodily pain	1.59 (0.97)	.25	.000	.24	.000
Depression	5.27 (0.98)	−.07	.076	−.08	.043
Anxiety	2.30 (1.00)	.04	.330	.05	.233
Vitality	3.07 (1.41)	.37	.000	.37	.000
Fear of falling	3.98 (1.0)	−.33	.000	−.36	.000

Notes: High scores in the tests of visual acuity, depth perception, peripheral sensation, reaction time, balance, and psychological measures and low scores in the edge contrast sensitivity and strength scores indicate impairments.

*Data presented in raw (untransformed) units. Log_{10} transformed variables assessed in analyses due to right-skewed distributions.

†Product of maximal anterior–posterior and lateral sway scores.

SD = standard deviation; logMAR = log Minimal Angle Resolvable in minutes of arc; dB = decibel.

stair negotiation, this measure was entered into the models first. After this, other lower limb muscle group strength measures, sensorimotor and balance variables, and psychological measures were entered into the models in successive blocks. Variables that were not identified as significant and independent predictors of stair negotiation time after the entry of each block of variables were eliminated from the model. Tolerance levels were inspected to avoid the inclusion of misleading or unhelpful variables due to colinearity among some independent variables. Beta weights and signs for all variables entered into the regression model were also examined to ensure that they made meaningful contributions to stair negotiation performance. Change in the amount of variance (r^2) was assessed on the entry of each block of variables into the model. Standardized beta weights indicate the relative importance of the various measures entered into the model in explaining variance in stair negotiation times.

Independent samples *t* tests were used to determine if there were differences in physiological and psychological test performance between participants who used the handrail during the stair negotiation tasks and participants who did not. Discriminant function analyses were also performed to determine the significant and independent predictors of handrail use versus no handrail use during the stair negotiation tasks. Log transformations were performed on right-skewed variables, and the data were analyzed using SPSS for Windows (version 14.0; SPSS, Inc., Chicago, IL).

Results

Stair Negotiation Times, Age, and Sex

The average stair ascent speed was 1.6 steps/s ($SD = 0.62$) and the average stair descent speed was 1.7 steps/s ($SD = 0.55$). Men completed the stair ascent and descent significantly faster than women did: 4.8 ± 2.2 seconds and 6.0 ± 3.4 seconds, respectively, for the ascent ($t = 6.5$, $df = 662$; $p < .001$) and 4.9 ± 2.6 seconds and 6.7 ± 4.5 seconds, respectively, for the descent ($t = 7.9$, $df = 662$; $p < .001$). The men were also significantly stronger than the women in the three measures of lower limb strength ($p < .001$), but no significant differences were apparent between the men and women with respect to age or the occurrence of previous falls. Stair ascent and descent times were moderately correlated with age ($r = 0.34$, $p < .001$ and $r = 0.36$, $p < .001$, respectively).

Sensorimotor, Balance, and Psychological Factors Associated With Stair Negotiation Performance

Table 2 shows the associations between stair negotiation speed and the sensorimotor, balance, and psychological

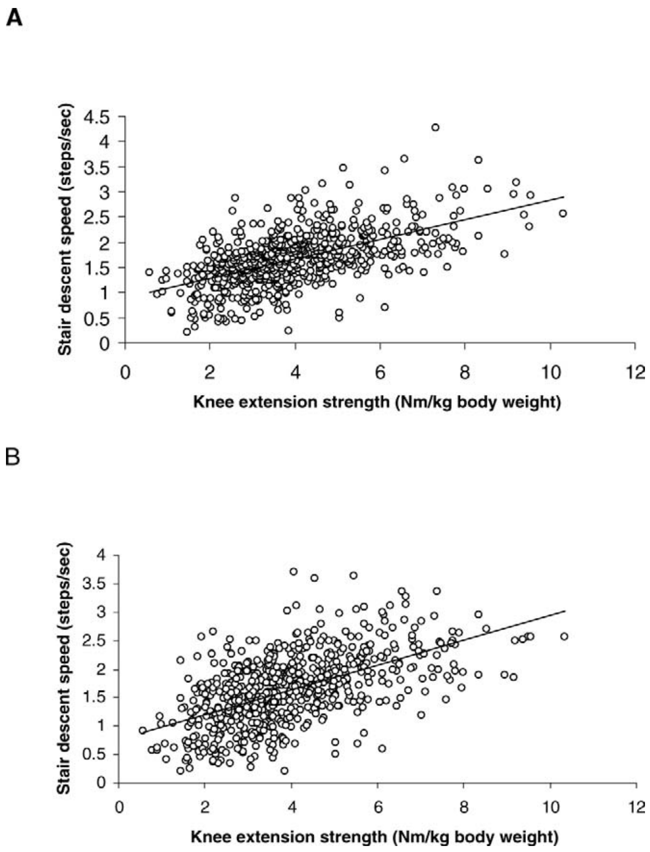

Figure 1. Association between knee extension strength and stair ascent (**A**) ($r = 0.49$) and stair descent (**B**) ($r = 0.53$) speed.

measures. All of the sensorimotor, balance, and psychological measures were significantly correlated with stair negotiation times apart from SF-12 anxiety and depression scores. Figure 1 illustrates the relationships between knee extension strength and stair ascent and descent. These associations could be described well by linear functions.

The hierarchical regression analyses revealed similar models for explaining the variance in stair ascent and descent times. In the initial steps, knee extension strength accounted for 29% of the variance in the stair ascent and 33% of the variance in stair descent times. At step 2, where other lower limb muscle group strength measures were entered into the model as possible predictors, knee flexion strength, but not ankle dorsiflexion strength, explained significant additional variance in both stair negotiation measures. The other independent predictors for stair ascent and descent times, as outlined in Table 3, were lower limb proprioception, edge contrast sensitivity, foot reaction time, coordinated stability, fear of falling, pain, and the SF-12 vitality scale score. These eight-variable models explained 47% of the variance in stair ascent times (multiple $r = 0.68$) and 50% of the variance in stair descent times (multiple $r = 0.71$).

When the study sample was categorized into two groups (indicating use or no use of the handrail during the stair ascent and descent tasks), significant differences between the groups were found for most of the vision, strength, balance, and psychological measures, as shown in Table 4. The following variables (with standardized discriminant function coefficients) were included in the discriminant function model for predicting handrail use during stair ascent: reduced knee flexion strength (–.486), poor coordinated stability (0.374), low edge contrast sensitivity (–.242), high fear of falling (.310), and low SF-12 vitality scores (.265): canonical correlation = 0.41, Wilks' $\lambda = 0.829$, $p < .001$. The variables included in the model for predicting stair descent handrail use were knee extension strength (–.547), coordinated stability (.414), low contrast visual acuity (.177), fear of falling (.291), and the SF-12 vitality scores (.201): canonical correlation = 0.455, Wilks' $\lambda = 0.793$, $p < .001$). Both models correctly classified 69% of cases with similar sensitivities and specificities.

Discussion

The factors that were found to be predictors of both stair ascent and descent speed were knee extension and flexion strength, proprioception, edge contrast sensitivity, SRT, dynamic balance, fear of falling, pain, and vitality. The two lower limb strength measures explained more than

Table 3. Hierarchical Multiple Regression of Stair Ascent and Stair Descent Speed Showing Standardized Beta Weights and r^2 after the Entry of Each Successive Block of Variables into the Model

	Stair Ascent			Stair Descent		
Predictor Variables	Beta Weights	p Value	r^2	Beta Weights	p Value	r^2
Knee extension strength	.247	< .001	.318*	.247	< .001	.319*
Knee flexion strength	.172	< .001	0.342*	.144	.002	.339*
Proprioception	−.066	.022	.420*	−.076	.007	.433*
Edge contrast sensitivity	.101	.001		.117	< .001	
Reaction time, foot press	−.074	.018		−.077	.011	
Coordinated stability	−.168	< .001		−.177	< .001	
Fear of falling	−.110	< .001	.468*	−.173	< .001	.498†
Pain	−.074	.014		−.055	.043	
Vitality	−.153	< .001		−.159	< .001	

Notes: $*p < .001$.
$^{\dagger}p < .01$.

Table 4. Mean (*SD*) Scores for the Physiological, Psychological, and Health Measures for Participants Categorized in Relation to Handrail Use in the Stair Ascent and Descent Tests

Measures	Stair Ascent: No Handrail Use ($N = 365$) Mean (*SD*)	Stair Ascent: Handrail Use ($N = 299$)* Mean (*SD*)	Stair Descent: No Handrail Use ($N = 316$) Mean (*SD*)	Stair Descent: Handrail Use ($N = 348$)* Mean (*SD*)
Sensorimotor				
Visual acuity—high contrast, logMAR	1.2 (0.5)†	1.4 (1.8)	1.2 (0.5)‡	1.4 (1.7)
Visual acuity—low contrast, logMAR	2.3 (1.0)†	2.9 (2.7)	2.3 (1.1)†	2.8 (2.5)
Edge contrast sensitivity, dB	19.2 (2.4)†	18.3 (2.4)	19.2 (2.5)†	18.4 (2.4)
Depth perception, cm error§	2.3 (3.0)‡	3.4 (4.3)	2.4 (3.0)‖	3.2 (4.1)
Proprioception, cm error§	2.1 (1.4) NS	2.1 (1.4)	2.0 (1.4) NS	2.1 (1.4)
Tactile sensitivity, $\log_{10}$mg pressure	4.4 (0.5) NS	4.4 (0.5)	4.4 (0.5) NS	4.4 (0.5)
Vibration sense, microns§	39.2 (26.1) NS	39.9 (27.2)	39.6 (26.6) NS	39.4 (26.6)
Ankle dorsiflexion strength/weight, Nm/kg	1.1 (0.5)†	0.9 (0.4)	1.1 (0.5)†	0.9 (0.4)
Knee extension strength/weight, Nm/kg	4.4 (1.7)†	3.4 (1.3)	4.6 (1.7)†	3.4 (1.3)
Knee flexion strength/weight, Nm/kg	2.5 (0.9)†	1.9 (0.7)	2.5 (0.9)†	2.0 (0.7)
Simple reaction time—hand, ms§	267.5 (43.1)†	282.2 (54.9)	266.7 (44.0)†	280.8 (52.7)
Simple reaction time—foot, ms§	341.7 (55.4)†	363.7 (68.1)	341.7 (57.4)†	360.6 (65.4)
Balance				
Sway eyes open—floor, area§	423 (364) NS	471 (470.8)	406 (338.8)‖	480 (472.8)
Sway eyes closed—floor, area§	543 (561)‡	646 (664.3)	5340 (566.7)‡	634 (646.4)
Sway eyes open—foam, area§	1267 (964)‡	1505 (1031.8)	1245 (973.8)†	1492 (1012.6)
Sway eyes closed—foam, area§	3008 (2163)‖	3445 (2310.4)	2916 (2133.5)‡	3466 (2303.6)
Coordinated stability, errors§	6.3 (7.2)†	10.9 (9.0)	5.7 (6.6)†	10.8 (9.0)
Psychological				
Body pain¶	1.8 (1.3) NS	1.9 (1.3)	1.8 (1.3) NS	1.9 (1.3)
Depression¶	5.3 (1.0)‖	5.2 (1.0)	5.3 (1.0) NS	5.2 (1.0)
Anxiety¶	2.2 (1.1)‖	2.4 (1.0)	2.3 (1.1) NS	2.4 (1.0)
Vitality¶	2.8 (1.3)†	3.4 (1.4)	2.8 (1.3)†	3.3 (1.4)
Fear of falling¶	1.8 (0.9)†	2.2 (1.0)	1.8 (0.9)†	2.2 (1.0)

Notes: *Includes 21 participants who used a mobility aid as well as the handrail.

†$p < .001$.

‡$p < .01$.

§Data are presented in raw (untransformed) units. Log_{10}-transformed variables are assessed in analyses due to right-skewed distributions.

‖$p < .05$.

¶Mann–Whitney *U* test.

SD = standard deviation; logMAR = log Minimal Angle Resolvable in minutes of arc; NS = no significant difference.

one-third of the variance in the performance of the tasks. This finding supports previous studies that have examined the relationship between strength and stair-climbing ability (3,4) and is in accordance with other studies of predictors of walking speed (8), chair standing (7), and stepping (15), which show that lower limb strength is a vital component of everyday functional activities and that deficits in strength can lead to immobility and activity restriction. The associations were described well by linear relationships, indicating that increases in strength were associated with continued gains in speed of performance and no evidence of a ceiling effect in this population of older community-dwelling people.

Good leaning balance, as measured by the coordinated stability test, was also an important factor in being able to perform the stair ascent and descent tasks quickly. An association has been found between impaired balance and slow walking speed (16,17) and also between impaired balance and deficits in a range of other functional tasks (7,18,19). It is apparent that balance deficits also result in slower, more tentative performance of stair ascent and descent, which are relatively difficult functional tasks for older people. Similarly, the independent contribution of simple foot-press reaction time in the final regression models may indicate that older people with slow reaction times are less confident in negotiating stairs, where there is a risk of tripping. The finding that proprioception was a predictor of performance in both the stair descent and ascent tasks supports the findings of Startzell and colleagues (20), who suggested that proprioception is important at the start of the stair descent for locating the position of the first step and that it assists in the midstair region after the first few stairs have been navigated successfully and the dimensions of the stairs have been ‘‘learned.’’

Vision is required throughout stair negotiation for judging step dimensions and detecting hazards (21). This reliance on vision indicates why this factor was identified as an independent predictor of stair negotiation speed (22). Previous studies have also shown that vision is important for judging distances (23) and maintaining stability during standing (24,25) and stepping (26).

Vitality and pain were included in both regression models, suggesting that both independently affect an older person's ability to move quickly to complete an assigned task. In older people, chronic pain is common, with 18% of the current study population stating that pain interfered at least moderately with their activities in the past month. These findings support previous work that has shown an association between measures of pain and vitality and performance in other functional tasks (7,8).

The inclusion of fear of falling as an independent predictor of stair negotiation is consistent with previous research showing that fear of falling is associated with frailty and reduced mobility (27), impaired gait (28,29), impaired balance (30,31), and restriction of activity (32) in older people. Decreased confidence in stair negotiation also leads to slower speed and an increased reliance on handrail support, particularly during stair descent (33).

Our study also found that participants who used the handrail during the stair negotiation tasks were also more likely to perform poorly in the vision, strength, and balance tests, as well as have a higher fear of falling and reduced vitality. It is interesting that the discriminant function analyses found the strongest strength predictor of handrail use for stair ascent was knee flexor strength whereas the strongest strength predictor for stair descent was knee extensor strength. We postulate that this is due to the role of the knee flexors (hamstrings) in extending the hip during stair ascent and due to the importance of the braking or eccentric activity of the quadriceps muscle during stair descent. Those individuals unable to produce sufficient force for these aspects of unaided stair climbing are more likely to use the handrail to compensate for this muscle weakness (34).

It is acknowledged that, despite the range of factors available as possible predictors, approximately half of the variance in stair negotiation speed was left unaccounted for. Other factors that may have added additional information about performance in the tasks include strength of other lower limb muscle groups, ankle and knee joint range of motion (35), lower limb power (5), cardiovascular fitness (36), and foot abnormalities (37).

The overall finding of this study is that people who perform stair negotiation tasks slowly or require handrail support may not only be lacking adequate lower limb strength, but may also have other physiological impairments, reduced vitality, pain, and an increased fear of falling. These results imply that exercise training, which improves lower limb strength and balance, in addition to visual interventions for older people, may also result in an increased ability to negotiate stairs in a safe and efficient manner.

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