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Sit-to-Stand Performance Depends on Sensation, Speed, Balance, and Psychological Status in Addition to Strength in Older People

Stephen R. Lord, Susan M. Murray, Kirsten Chapman, Bridget Munro, and Anne Tiedemann

Prince of Wales Medical Research Institute, New South Wales, Australia.

Background. Sit-to-stand (STS) performance is often used as a measure of lower-limb strength in older people and those with significant weakness. However, the findings of recent studies suggest that performance in this test is also influenced by factors associated with balance and mobility. We conducted a study to determine whether sensorimotor, balance, and psychological factors in addition to lower-limb strength predict sit-to-stand performance in older people.

Methods. Six hundred and sixty nine community-dwelling men and women aged 75–93 years (mean age 78.9, SD = 4.1) underwent quantitative tests of strength, vision, peripheral sensation, reaction time, balance, health status, and sit-to-stand performance.

Results. Many physiological and psychological factors were significantly associated with sit-to-stand times in univariate analyses. Multiple regression analysis revealed that visual contrast sensitivity, lower limb proprioception, peripheral tactile sensitivity, reaction time involving a foot-press response, sway with eyes open on a foam rubber mat, body weight, and scores on the Short-Form 12 Health Status Questionnaire pain, anxiety, and vitality scales in addition to knee extension, knee flexion, and ankle dorsiflexion strength were significant and independent predictors of STS performance. Of these measures, quadriceps strength had the highest beta weight, indicating it was the most important variable in explaining the variance in STS times. However, the remaining measures accounted for more than half the explained variance in STS times. The final regression model explained 34.9% of the variance in STS times (multiple R = .59).

Conclusions. The findings indicate that, in community-dwelling older people, STS performance is influenced by multiple physiological and psychological processes and represents a particular transfer skill, rather than a proxy measure of lower limb strength.

THE sit-to-stand (STS) test is a commonly used functional performance measure in clinical research and practice. The test involves measuring the time taken to stand from a seated position either one, three, five, or 10 times or recording the number of repetitions undertaken in a given period, for example 10 or 30 seconds (1,2). Performance on this test has often been seen as an indicator or proxy measure for lower limb strength in older people (1–6) and in patients with conditions such as proximal myopathy (1) and arthritis (7).

However, studies that have compared STS times with specific lower limb strength measures have found only moderate associations. The amount of variance explained ranges from 6–23% for strength of nonnormalized single muscle groups (4,7) and 12–48% for muscle groups normalized for factors such as weight, height, and age (6,8). Stronger associations (R^2 = .5–.6) have been reported between timed chair rises and a combined lower limb strength measure (i.e., a leg press involving hip extension, knee extension, and ankle plantarflexion strength [3]), but these associations may be inflated as the subject group included a mix of trained and untrained older people.

It has been reported that the STS times are associated with standing and leaning balance (9–12) and mobility (10–12). Slow STS times have also been found to predict subsequent disability (13,14), falls (15–17), and hip fractures (14).

These findings suggest that rather than comprising a specific measure of lower limb strength, performance on the STS test may also be influenced by a range of factors associated with balance and mobility. For example, fall-related factors such as postural sway, reaction time, peripheral sensation, and vision may have a significant impact on STS performance in older people. Furthermore, psychological factors could also play a role, as the presence of pain and depression has been found to reduce mobility in this population (18,19). Therefore, the aim of this study was to investigate the relative contributions of a broad range of sensorimotor, balance, and psychological factors to performance on the STS test in a large sample of older, community-dwelling people.

METHODS

Subjects

Names and addresses of people older than 75 years were randomly drawn from a membership database of a private health insurance company as part of a randomized controlled trial of tailored falls prevention strategies. These subjects were initially contacted by letter and asked to participate in the study. Subjects were then contacted by telephone and were invited to the Falls and Balance Laboratory at the Royal North Shore Hospital in Sydney, Australia.

Table 1. Age and Gender Distribution of the Study Population

	Men	Women	Total
Age Group	*n* (%)	*n* (%)	*N* (%)
75–79	124 (53.2)	225 (51.6)	349 (52.2)
80–84	69 (29.6)	143 (32.8)	212 (31.7)
85–89	29 (12.4)	57 (13.1)	86 (12.9)
90+	11 (4.7)	11 (2.5)	22 (3.3)
Total	233 (34.8)	436 (65.2)	669 (100.0)
Mean (*SD*)	80.1 (4.6)	80.1 (4.3)	80.1 (4.4)

Note: *SD* = standard deviation.

Transport was provided for those who could not make their own way to the hospital to maximize the participation rates of older people with mobility limitations. Subjects were excluded from the study if they had Parkinson's disease or a Short Portable Mental Status Questionnaire score less than 7 (20). Of the 2468 subjects initially contacted by letter and/or telephone, 669 subjects (233 men, 436 women) aged 75 to 93 years (mean 78.9, *SD* = 4.1) met the inclusion criteria and were evaluated for STS performance.

The age and gender distribution of the sample is shown in Table 1. The prevalence of major medical conditions, medication use, physical activity, mobility, and activity of daily living (ADL) limitations for those who were assessed for STS performance is shown in Table 2. The Human Studies Ethics Committee at the University of New South Wales gave approval for this study, and informed consent was obtained from all subjects prior to their participation.

Table 2. 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	168 (25.4)
Stroke	47 (7.0)
Lower limb arthritis	278 (41.6)
Diabetes	46 (6.9)
Incontinence	102 (15.2)
Depression	70 (10.5)
Health rated as fair or poor	59 (8.8)
Medication Use	
Four plus medications	377 (55.1)
Cardiovascular system medications	477 (69.7)
Psychoactive medications	105 (15.3)
Musculoskeletal system medications	161 (23.5)
Physical Activity	
Planned walks < once per week	29 (7.2)
Physical activity < 1 hour/day	196 (29.3)
Limited in climbing stairs	41 (6.1)
Mobility and ADL Limitations	
Used a walking aid	114 (17.0)
Difficulty with home maintenance	406 (61.1)
Difficulty with housework	220 (32.9)
Difficulty cooking	105 (15.7)
Difficulty shopping	100 (14.9)
Difficulty dressing	16 (2.4)

Note: ADL = activity of daily living.

Measurement of STS Performance

Subjects were asked to rise from a chair five times as fast as possible with their arms folded across their chests. The chair was of a standard height (0.43 m) without armrests. Test-retest reliability was determined from a subset of 30 subjects who took part in the trial. The intraclass correlation was 0.89 (95% CI = .79–.95).

Assessments of Sensorimotor Function and Balance

Visual acuity and visual contrast sensitivity were assessed using a logMAR chart and the Melbourne Edge Test, respectively (21). Depth perception was evaluated using a Howard-Dohlman depth perception apparatus (22). Proprioception was measured using a lower limb-matching task (23). 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 aesthesiometer (23). Vibration sense at the tibial tuberosity of the knee was measured using a vibrator that produced a 200-Hz vibration of varying intensity under load (23). A staircase method with three ascending and three descending trials was used to determine vibration thresholds.

The maximal voluntary strength of three muscle groups in both legs was measured under isometric conditions. Testing of the knee flexor and extensor muscles was performed using a strap incorporating a load cell, which was connected to an amplifier with the output recorded on a digital display. The voluntary strength of the knee flexor muscles and extensor muscles was measured with the subject sitting on a tall chair with a strap around the leg 10 cm above the ankle joint. The angles of the hip and knee joints were 90°. In three trials per muscle group, the subject attempted to pull against the strap assembly with maximal force for 2–3 seconds of duration, and the greatest force for each muscle group was recorded. The testing of ankle dorsiflexion was performed using a pivoted platform attached to a spring gauge. While the subject was sitting on a tall chair, the foot was secured to the pivoted platform with the angle of the knee at 110°. In three trials, the subject attempted maximal dorsiflexion of the ankle, and the greatest force was recorded. Strength scores were measured in kg force and were normalized for mass by dividing the strength scores by body weight (in kg).

Two measures of simple reaction time (SRT) were made. These involved a light as the stimulus and either a finger-press or a foot-press as the response (23,24). Postural sway was measured using a sway-meter that measured displacements of the body at the level of the waist (23). Testing was performed with subjects standing on the floor and a foam rubber mat (70 cm × 60 cm × 15 cm thick) with eyes open and eyes closed. Leaning balance was measured using the coordinated stability test—a test that assessed subjects' ability to adjust their balance in a steady and controlled manner when near the limits of their base of support (24).

These tests were included because they provide direct measures of the functional capacity of the physiological systems that play important roles in the control of postural stability while standing and walking. Furthermore, these tests take into account both "normal" age-related functional declines and any additional impairments resulting from medical conditions (whether diagnosed or not). Previously, we have found that these variables preclude medical falls risk factors, such as impaired cognitive status, stroke, and age, from entering discriminant function models and discriminate between fallers and nonfallers with sensitivities and specificities more than 75% (25). Reliability coefficients calculated in previous studies of similar samples ranged from .75 to .92 for the strength measures, .73 to .85 for the vision tests, .46 to .69 for the assessments of peripheral sensation, .63 to .80 for the reaction time tasks, .57 to .85 for the sway measures, and .83 for coordinated stability test (23,24,26,27).

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 (28).

Statistical Analysis

The sensorimotor, balance, and psychological measures were continuous variables. For variables with right-skewed distributions, logs of the variables were analyzed. Pearson correlation coefficients were computed to examine the relationships between STS times and the other test variables. Partial correlations were also computed to examine these relationships while controlling for age. Hierarchical multiple regression was used to assess the associations between STS times and the sensorimotor, balance, and psychological variables. Variables were entered into the regression model in the following order: (i) knee extension strength, (ii) knee flexion and ankle dorsiflexion strength, (iii) body weight, (iv) sensorimotor and balance measures, and (v) psychological measures. Variables that were not identified as significant and independent predictors of STS time after the entry of each block of variables were eliminated from the model. To avoid the inclusion of misleading or unhelpful variables due to covariance among some independent variables, only one variable from highly correlated variables (e.g., the sway measures) was included as a possible predictor at the entry of each block. Beta weights and signs for all variables entered into the regression model were also examined to ensure they made meaningful contributions to STS performance. Change in the amount of variance (R^2) was assessed on the entry of each block of variables into the model. The standardized beta weights provided give an indication of the relative importance of the various measures entered into the model in explaining variance in STS times. The data were analyzed using SPSS for Windows (SPSS, Inc., Chicago, IL) (29).

RESULTS

STS Times and Age, Gender, and Height

STS times for men and women in 5-year age groups are shown in Table 3. Six hundred and forty-two (96.0%) subjects successfully completed the STS test. The remaining 28 subjects (4.0%) who were unable to complete the test were given scores of 30 seconds (which approximated three standard deviations above the mean) in further analyses. There was no significant difference in STS times for the men and women: 12.8 ± 5.9 s and 12.9 ± 5.1 s, respectively ($t = .99$, $df = 667$, $p = .32$). STS times were weakly but significantly correlated with age ($R = .16, p < .01$) and weight ($R = .14$, $p < .01$), but were not associated with height ($R = .00$, $p = .99$).

Table 3. STS Time (Seconds) by Age and Gender

	Men	Women
Age-group	Mean (*SD*)	Mean (*SD*)
75–79	12.1 (5.4)	12.2 (4.1)
80–84	12.9 (5.5)	13.4 (5.6)
85–89	13.7 (7.2)	14.1 (6.5)
90+	17.2 (8.0)	15.1 (6.5)
Total	12.8 (5.9)	12.9 (5.1)

Note: SD = standard deviation; STS = sit-to-stand.

Sensorimotor, Balance, and Psychological Correlates of STS Times

Table 4 shows the associations between STS times and the sensorimotor, balance, and psychological measures. All the sensorimotor and balance measures were significantly associated with STS performance in univariate analyses,

Table 4. Strength, Sensorimotor, Balance, and Psychological Correlates of STS Times

Measures	Mean (*SD*)	*R*	Partial *R*
Strength			
Knee extension strength[†]	0.50 (0.19)	−.43[‡]	−.42[‡]
Knee flexion strength[†]	0.28 (0.10)	−.43[‡]	−.42[‡]
Ankle dorsiflexion strength[†]	0.13 (0.06)	−.37[‡]	−.36[‡]
Other Sensorimotor			
Visual acuity—high contrast (logMAR)	1.32 (1.34)	.08[§]	.04
Visual contrast sensitivity (dB)	18.8 (2.5)	−.22[‡]	−.17[‡]
Depth perception (cm error)	2.8 (3.6)	.13[‡]	.10[‡]
Proprioception (cm error)	2.1 (1.4)	.15[‡]	.13[‡]
Tactile sensitivity ($\log_{10}$mg pressure)	4.4 (0.5)	.18[‡]	.17[‡]
Vibration sense (microns)	40 (27)	.12[‡]	.09[§]
Simple reaction time—hand (ms)	274 (49)	.25[‡]	.23[‡]
Simple reaction time—foot (ms)	352 (63)	.30[‡]	.28[‡]
Balance			
Sway eyes open—floor (area)[‖]	460 (496)	.17[‡]	.15[‡]
Sway eyes closed—floor (area)[‖]	597 (631)	.21[‡]	.19[‡]
Sway eyes open—foam (area)[‖]	1386 (1009)	.26[‡]	.23[‡]
Sway eyes closed—foam (area)[‖]	3224 (2243)	.22[‡]	.18[‡]
Coordinated stability (errors)	8.41 (8.37)	.28[‡]	.25[‡]
Psychological Measures			
Bodily pain	1.60 (0.98)	.23[‡]	.24[‡]
Depression	5.25 (1.00)	−.04	−.04
Anxiety	2.31 (1.06)	−.00	.01
Vitality	3.07 (1.41)	.23[‡]	.27[‡]

Notes: High scores in the visual acuity, depth perception, sensation, reaction time, balance, pain, anxiety, and vitality measures, and low scores in the strength, contrast sensitivity, and depression measures indicate poor functioning or performance. *SD* = standard deviation; STS = sit-to-stand.

[*] Partial correlation controlling for age.

[†] Corrected for body weight: kg force/weight in kg.

[‡] $p < .01$.

[§] $p < .05$.

[‖] Product of maximal anterior-posterior and lateral sway scores.

Table 5. Hierarchical Multiple Regression of STS Times Showing Standardized Beta Weights and R^2 After the Entry of Each Successive Block of Variables Into the Model

Predictor Variables	Beta Weights	*p* Value	R^2
Knee extension strength	−.167	.002	.165*
Knee flexion strength	−.122	.025	.201*
Ankle dorsiflexion strength	−.081	.046	
Body weight	.141	.001	.219*
Contrast sensitivity	−.073	.030	.317*
Proprioception	.102	.002	
Tactile sensitivity	.122	.001	
Simple reaction time (foot)	.111	.002	
Sway eyes open—foam	.130	.001	
Anxiety	−.093	.006	.349*
Vitality	.122	.001	
Pain	.117	.001	

Note: STS = sit-to-stand.

*Indicates change in R^2 when blocks of variables were entered into the model ($p < .01$).

and with the exception of visual acuity, all remained significantly associated with STS performance after controlling for age. Of the four psychological measures used in this study, bodily pain and vitality items were significantly associated with STS times, both before and after controlling for age.

The hierarchical regression analysis indicated that when knee extension strength (corrected for body weight) was entered into the model at the initial step, it accounted for 16.5% of the variance in STS times ($p < .01$). However, as indicated in Table 5, the subsequent inclusion of the blocks of variables pertaining to strength in other lower limb muscle groups, body weight, sensorimotor and balance function, and psychological status all added significantly to the amount of variance explained in STS times. In contrast, age was not identified as an independent and significant predictor of STS times ($\beta = .01$, $p = .74$).

The final regression model revealed that visual contrast sensitivity, lower limb proprioception, tactile sensitivity, reaction time involving a foot-press response, sway with eyes open on the foam rubber mat, body weight and SF-12 pain, anxiety, and vitality scores in addition to knee extension, knee flexion, and ankle dorsiflexion strength were significant and independent predictors of STS performance. Quadriceps strength had the highest beta weight, indicating it was the most important variable in explaining the variance in STS times. Nonetheless, the remaining 11 measures provided important information and accounted for more than half of the variance explained in STS times. Overall, the model explained 34.9% of the variance in STS times (multiple $R = .59$).

DISCUSSION

In this study, we found that STS performance was significantly associated with a range of sensorimotor, balance, and psychological factors in older, community-dwelling people. Specifically, we found that nine measures (visual contrast sensitivity, lower limb proprioception, tactile sensitivity, simple foot reaction time, postural sway, body weight, and reported pain, anxiety, and vitality) in addition to knee extension, knee flexion, and ankle dorsiflexion strength were significant and independent predictors of STS performance. This diverse array of parameters suggests that multiple sensorimotor, balance, and psychological processes underpin STS performance, and it is not simply a proxy measure of lower limb strength.

However, strength was found to be important in explaining a considerable part of the variance in STS performance, as indicated by the three strength measures being included in the final regression model. Quadriceps strength had the highest beta weight. This is consistent with the findings of Schenkman and colleagues (9), who found that strength was relatively more important than balance in predicting the time to stand once in functionally impaired older people. The independent contributions from the knee extensor, knee flexor, and ankle dorsiflexor flexor muscle groups indicate that all these muscle groups play roles in this test that involves both rising and lowering components (3).

It has previously been found that, in addition to detecting hazards in the environment, vision plays an important role in judging distances (26) and maintaining stability when standing (23), leaning (24), and stepping (30). Thus, it appears that good vision (in particular good contrast sensitivity and depth perception) provides an additional cue for safely and quickly undertaking the STS test. Two complementary sensory measures, lower limb proprioception and tactile sensitivity, were also found to augment STS performance. With respect to other measures, ability to react quickly and maintain balance control assisted in the carrying out of this task, as it is timed and requires rapid and coordinated balance transfers. The inclusion of both reaction time and "challenged" balance measures as predictors of STS performance is consistent with previous work that has shown that these factors are important in another whole body transfer task that requires fast and appropriate stepping responses (30).

Anxiety, vitality, and pain were also associated with STS performance. The independent contribution of psychological factors in explaining variance in STS times suggests that subject motivation and apprehension affect test performance. In a related study, we have found that a similar measure to vitality (i.e., positive affect) was an independent and significant predictor of another performance test—6-minute walking distance (18). 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. The inclusion of pain in the final regression model suggests that this factor has an independent effect on STS performance over and above the other physiological and psychological measures.

Interestingly, body weight was an independent predictor of STS times, as the strength measures were normalized for this measure. This indicates that more work is required to raise and lower heavier bodies than is explained by the simple correction of strength to weight. In contrast, STS performance was not significantly associated with height or gender, which indicates that the test chair height was not an impediment to either shorter or taller people and that adjusting chair height for standing height appears unwarranted for tests of STS performance in older people. The bivariate association between STS performance and age was weak, and age could not account for any variance over and above that provided by the sensorimotor and balance measures in the multiple regression model.

It is acknowledged that, despite this broad range of measures available as possible predictors, much of the variance in STS times was left unaccounted for. It may be that other important factors, such as foot abnormalities, muscle endurance, and rate of force development in lower limb muscle groups and more precise measures of psychological factors such as mood and pain, may have added additional information about STS performance. It is also possible that the tests of peripheral sensation undertaken in weight-bearing positions may have been more appropriate for this weight-bearing task (31). Similarly, the strength tests used only approximate functional strength, as no current test can measure strength as it is functionally used (32).

In conclusion, the findings indicate that in community-dwelling older people, STS performance is influenced by multiple sensorimotor, balance, and psychological processes and represents a particular transfer skill, rather than a proxy measure of lower limb strength. The findings have implications for exercise interventions involving older people, in that interventions that produce improvements in STS times may be achieving this via multiple means.

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Address correspondence to Assoc. Professor Stephen R. Lord, Prince of Wales Medical Research Institute, Barker Street, Randwick, N.S.W., 2031, Australia. E-mail: S.Lord@unsw.edu.au

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