Concurrent Validity of Clinical Balance Tests and Falls Risk for Older Adults with Cognitive Impairment

Normala Mesbah *BSc (Hons) (Physiotherapy), MSc (GeronRehabStud), PhD*
Lecturer, Physiotherapy Programme and Center for Healthy Ageing and Wellness, Faculty of Health Sciences, University Kebangsaan Malaysia, Kuala Lumpur, Malaysia

Meredith Perry *BPhty, MManipTh (Distinction), PhD*
Associate Professor, Centre for Health, Activity and Rehabilitation Research, School of Physiotherapy, University of Otago, Wellington, New Zealand

Keith D. Hill *BAppSc (Physio), Grad Dip Physio (Neurology), PhD*
Professor and Director, Rehabilitation Ageing and Independent Living (RAIL) Research Centre, Monash University, Melbourne, Australia

Donald Manlapaz *BSc (Physical Therapy), MSc (Physical Therapy), PhD*
Assistant Professor and Chair, Department of Physical Therapy, College of Rehabilitation Sciences, University of Santo Tomas, Philippines

Leigh Hale *BSc (Physio), MSc (Physio), PhD*
Professor and Dean, Centre for Health, Activity and Rehabilitation Research, School of Physiotherapy, University of Otago, Dunedin, New Zealand

ABSTRACT

Older adults with cognitive impairment frequently have reduced balance and are at high risk for falling. We investigated the concurrent validity of the Physiological Profile Assessment (PPA) and the Timed Up and Go (TUG) test with computerised posturography in 13 older adults (mean (*SD*) age, 80 (8) years) with mild-to-moderate cognitive impairment (mean (*SD*) Mini-Mental State Examination score, 19 (9)). Spearman's rho demonstrated moderately good positive correlation between PPA (muscle strength) and posturography rising index ($r_s = 0.699$, $p = 0.01$) and posturography mediolateral sway during eyes open standing on a foam surface ($r_s = 0.604$, $p = 0.04$); good negative correlations between PPA anteroposterior sway (eyes closed) and posturography sway velocity (eyes open) standing on foam ($r_s = -0.745$, $p = 0.01$) and Romberg ratios of PPA and posturography ($r_s = -0.698$, $p = 0.02$); moderately good positive correlations between TUG and posturography (left step quick turn *time;* left turn *sway*; $r_s = 0.548$, $p = 0.04$; 0.646, $p = 0.02$); and good-to-excellent negative correlation between TUG and posturography (rising index $r_s = -0.719$, $p = 0.01$). Both tests appear valid measures of balance in older adults with mild-to-moderate cognitive impairment; however, we suggest both are used.

Mesbah, N., Perry, M., Hill, K. D., Manlapaz, D., & Hale, L. (2023). Concurrent validity of clinical balance tests and falls risk for older adults with cognitive impairment. *New Zealand Journal of Physiotherapy, 51*(2), 188–198. https://doi.org/10.15619/nzjp.v51i3.277

Key Words: Balance, Cognitive Impairment, Concurrent Validity, Falls Risk, Older Adults, Postural Stability

INTRODUCTION

Older adults with cognitive impairment frequently have reduced balance and are at high risk for falling (Allali et al., 2017). Cognitive impairment in older adults forms part of the syndrome of dementia, an overarching term for a clinical syndrome "characterised by progressive cognitive decline that interferes with the ability to function independently" (Duong et al., 2017, p. 118). Changes in cognition, function, and behaviour vary greatly between those living with dementia and are insidiously progressive, starting with mild cognitive impairment typically not assigned a diagnosis (Duong et al., 2017). A major concern for older adults living with dementia is that of falling, with an increased falls risk of two to three times that of older adults without cognitive impairment and an annual falls rate of around 60% (Allali et al., 2017; Goldup, 2017).

Risk factors for falling associated with dementia include poorer executive function and visuospatial scores, use of centrally acting medications, high number of medications, psychiatric comorbidities, such as anxiety or depression, and reduced mobility and balance (Goldup, 2017). Further to this, postural stability and balance have been shown to be impaired in older adults with mild to moderate Alzheimer's disease (AD), the most common type of dementia, with decreasing visual input and ability to concentrate on multiple tasks found to particularly impact postural stability (Mesbah et al., 2017). Some aforementioned risk factors are unmodifiable; however, exercise and/or physical activity has shown promise to reduce the rate of falls in people with dementia, theorised to mediate falls risk by reducing the rate of physical decline through maintaining or improving balance and mobility (Goldup, 2017). Arguably, addressing balance and mobility concerns is likely to be more effective before cognitive decline progresses. Interventions targeting balance and mobility, commonly prescribed and delivered by physiotherapists, are therefore recommended but require appropriate clinical measures of outcome, with demonstrated properties of validity, reliability, utility, and safety (Suttanon et al., 2011).

Several measurement tools have been recommended for evaluation of balance in older adults with dementia. These tools include both clinical tools such as the Timed Up and Go (TUG) test (Goldup, 2017; Mesbah et al., 2017; Suttanon et al., 2011) and one component of the Physiologic Profile Assessment (PPA) (Lord et al. 2003), and laboratory-based tools like computerised posturography (Lorbach et al., 2007). While the advantage of clinical balance tests is their ease of execution, their variable execution and subjective scoring systems can render these tools sub-optimal (Jacobs et al., 2006; Munhoz et al., 2004). As such, a clinical outcome measure of balance provides a limited understanding of postural instability. The advantages of laboratory-based tests, such as computerised posturography are their objectivity and detailed results that can guide clinical management (Chaudhry et al., 2011), but their limitations include poor accessibility, cost, time to set up and administer, and size of the equipment.

Many authors consider laboratory measures, such as computerised posturography, to be the "gold standard" (Versi, 1992) in measuring balance due to their reliable, comprehensive, and objective measurement (Dodd et al., 2003; Furman et al., 1994; Ionescu et al., 2005; Mancini & Horak, 2010; Trueblood et al., 2018). Indeed, the NeurocomTM force plate tests of the modified Clinical Test of Sensory Interaction on Balance, Walk Across (step width, step length parameters), and sit to stand (rising index parameter) demonstrated excellent retest reliability ($ICC_{3,1}$ ranging from 0.75 to 0.91) in 14 older people with mild to moderate AD (Suttanon et al., 2011). Such measures, however, are not readily available in a physiotherapy community or primary health care setting, nor are practical or easily transportable, and can be time consuming to execute.

The types of outcome measures used to evaluate balance in older populations with dementia were found in a published systematic review to be inconsistent across studies (Mesbah et al., 2017). A more consistent approach to outcome measures used to evaluate changes of balance has been recommended (Howe et al., 2011). Although a consensus statement on tools and measures most useful to evaluate balance in adult populations has been published (Sibley et al., 2015), the applicability of this to older adults with dementia is unclear (Sibley et al., 2015). For populations with dementia, it is recommended that outcome measures should be quick to execute and instructions easy for the person being tested to follow (Horak, 2006).

Two clinically applied measurement tools of falls risk including balance, the PPA and the TUG, potentially meet the requirements of being "quick to execute" and "easy to follow instructions" and have been shown to have reasonable reliability in older adults with cognitive impairment. For example, the TUG's retest reliability in 14 older people with mild to moderate AD was moderately high (intraclass correlation coefficient ($ICC_{3,1}$) = 0.5 and 0.7) (Suttanon et al., 2011). The PPA demonstrated a range of test-retest reliability data in 21 older adults with mild to moderate AD: excellent for high- and low-contrast visual acuity, contrast sensitivity, knee extension strength, coordinated stability, and maximal balance range tests (ICCs 0.78–0.90); fair-to-good for tactile sensitivity, ankle dorsiflexion strength, hand reaction time, sway on foam with eyes closed, and the overall falls risk score (ICCs 0.43–0.75), but poor for proprioception, foot reaction time, sway on floor (eyes open and closed), and sway on foam with eyes open (ICCs 0.18–0.39) (Lorbach et al., 2007).

In addition to reliability, a further clinometric property of outcome measurement to consider is that of concurrent validity. This construct measures how tests compare against a criterion or "gold standard" test. The aim of this study was to evaluate the concurrent validity of the PPA and the TUG tests with computerised posturography in older adults with cognitive impairment. If found to be concurrently valid, the TUG and the PPA could be used as valid measures of falls risk and balance in older adults with dementia in a community or clinical setting when computerised posturography was not available or impractical to use.

METHODS

Study design, recruitment, and study setting

This cross-sectional study was approved by the University of Otago Human Ethics Committee (reference number, H14/035). Participants were recruited through community advertisement such as newsletters distributed by the local Alzheimer's association. Volunteers contacted the primary researcher (NM) and were screened for eligibility by telephone. Information sheets and consent forms were then sent (by post or email) to potentially eligible participants. Testing occurred at two sites, at a university-based balance clinic and at a local rest home that offered a day care out-reach programme specifically for older adults with dementia living in the community.

Participants

Participants with the following criteria were included: (a) aged 65 years or older, (b) mild to moderate severity of cognitive impairment based on the Mini-Mental State Examination (MMSE) score ≥ 10 but ≤ 28/30 (Folstein et al., 1975; Ries et al., 2010; Shigemori et al., 2010), (c) community dwelling, (d) self-reported ability to understand verbal instruction sufficiently to safely undergo postural stability testing (Mozley et al., 1999), (e) independently mobile for a distance of at least 5 m (with or without walking devices), and (f) able to self-consent to participate (determining this ability was guided by steps outlined by the United Kingdom's Alzheimer's Society (Alzheimer's Society, 2023). Participants with cardiac and neurological impairments that would prevent them from doing the testing were excluded.

Procedure

Following the recruitment process, participants were provided with an appointment for testing. Participants were encouraged to have a support person accompany them. The participant was provided with an opportunity to ask questions and was then asked to sign consent. All tests were conducted by NM and assisted by a research assistant (DM).

The following processes then took place:

1. Collection of self-reported (or support person proxy reported) demographic data: age, gender, marital status, ethnicity, height, weight, education level, duration of having memory loss, medical status, number of falls in the past 12 months, and medications. In this study, a fall was defined as "an unexpected event in which the person comes to rest inadvertently on the ground, floor, or other lower level" (Lamb et al., 2005, p. 1618).
2. Testing of cognitive function using the MMSE (Folstein et al., 1975). The MMSE is divided into two sections. The first section requires verbal responses to test orientation, memory, and attention; 21 is the maximum score. The second section tests the ability of an individual to name, follow verbal and written commands, write a sentence spontaneously, and copy a complex polygon similar to a Bender-Gestalt figure; 9 is the maximum score (Folstein et al., 1975). The score range has been divided into normal (27–30), mild (18–26), moderate (10–17), and severe (< 10) cognitive function (Folstein et al., 1975). For this study, and given the variability of cut-off in the literature, a cut-off ≥ 10 and ≤ 28/30 was employed to indicate mild to moderate severity of cognitive impairment (Folstein et al., 1975; Ries et al., 2010; Shigemori et al., 2010). A license for use of the MMSE was obtained for this study.
3. Each participant was then tested using computerised posturography using the Neurocom long plate (0.5 m x 1.5 m) (Neurocom Balance Master, Neurocom International Inc., USA), the PPA and the TUG. These tests were carried out in a random order assigned by a computerised random programme and are described below.

Tests

The protocol for testing was based on the standardised procedures published for each test and standardised instructions were used with each participant. Each test was demonstrated to the participant before the actual test was performed to increase their understanding of it. The score of the PPA and TUG performance were recorded on the study scoring sheet. Data from the posturography testing were computer generated, thus the scores were saved in a PDF file downloaded from the computer linked to the posturography system.

Computerised posturography using the long-plate equipment

Five tests were undertaken on the computerised posturography using the NeuroCom International Balance Manager System^{TM} (the long-plate equipment) (Neurocom Balance Master, Neurocom International Inc., USA): (a) modified Clinical Test of Sensory Interaction on Balance (mCTSIB), (b) sit to stand, (c) step quick turn (to the left and the right), (d) walk across, and (e) limits of stability. The tests were first demonstrated to participants. The key elements in the instructions were the use of simple commands with cues and gestures provided when necessary. The testing procedures followed those used by Suttanon et al. (2011) and are briefly described in Table 1.

PPA

The PPA was developed by Lord and colleagues (2003) from Neuroscience Research Australia, to evaluate balance and risk of falling among older adults (Lord et al., 2003). The PPA measures five components: (a) postural sway: performed under four sensory conditions of eyes open or eyes closed on both a firm surface and a foam surface, (b) hand reaction time, (c) quadriceps muscle strength, (d) knee joint proprioception, and (e) vision edge contrast sensitivity. The details of the execution of the PPA can be found in Lord et al. (2003) but are briefly described in Table 1.

TUG test

The TUG, as described by the developers, can be used as a descriptive tool, providing information about an individual's balance, gait speed, and functional ability (Podsiadlo & Richardson, 1991), and as such was used in this study to measure balance and falls risk. This test has been shown to be feasible and reliable to use with older adults with mild to moderate dementia, despite the multi-step instructional nature of this test (Goldup, 2017; Mesbah et al., 2017; Suttanon et al., 2011). The shorter the time to complete the task the better the functional balance (Mancini & Horak, 2010). This test is described in Table 1.

Data analysis

SPSS software Windows version 23 (IBM Corporation, United States of America) was used to analyse the data. Descriptive analysis was used to calculate means, standard deviations, and the range of the continuous data, and percentage was used for categorical data.

Concurrent validity between the PPA, the TUG, and the computerised posturography was calculated using the Spearman rank order correlation (r_s) because all values violated the assumption of normality and linearity. As there are similarities and differences between the characteristics of balance evaluated by the three chosen tests, and none have a composite score of balance per se, concurrent validity between variables from within each test that had similar properties were correlated, as shown in Table 2. The strength of correlation coefficient was categorised according to the criteria by Portney and Watkins (2015): $r_s \geq 0.75$ demonstrated a good to excellent relationship, 0.50–0.75 moderate to good, 0.25–0.50 fair, and < 0.25 represented little or no relationship (Portney & Watkins, 2015; Portney & Watkins, 2000). The significance level was set at $p < 0.05$.

For the balance evaluation in the eyes open and eyes closed condition, the Romberg ratio (on firm and foam surface) was calculated by dividing the score of eyes closed with that of eyes open (Fujita et al., 2005) for both the PPA and computerised posturography sway. A value exceeding 1.0 indicates a greater amount of postural sway during the eyes closed condition (Tjernström et al., 2015). Romberg's ratio assesses visual dependency in postural stability and indicates the proprioceptive contribution to postural stability (Tjernström et al., 2015).

Table 1

Brief Description of Tests Used in this Study

Description of tests
Computerised posturography using the long-plate equipment
Modified Clinical Test of Sensory Interaction on Balance (mCTSIB): This test was used to measure postural sway under four sensory conditions: (a) eyes open and (b) eyes closed while standing on (c) a firm surface and (d) a foam surface; each participant undertook three trials, standing still for 10 s on each of the four test conditions. The smaller the sway velocity, the greater the stability. The best result from each test was used for statistical analysis (Suttanon et al., 2011).
Sit to stand: The sit to stand test measures the ability of the participant to stand up from a seated position without losing balance. The participant was asked to sit on a box that was placed at the centre of the measurement platform with the knees positioned in 90° flexion. On seeing a visual cue generated by the computer the participant had to stand up and hold a standing position for 5 s. Three trials were undertaken and the best score for each variable measured during this task was computed for statistical analysis. The outcome variables from this test were: (a) weight transfer time (s), (b) rising index (%), and (c) sway velocity (degree/s) (Suttanon et al., 2011).
Step quick turn: This is a test of stability during turning, measured in turn time (s) and turn sway (degree/s). The participant takes two steps then turns to one direction (left or right) and returns to the starting position. Performance was evaluated based on turning to both sides (left and right). The best measures of turn time (s) and turn sway (degree/s) were reported for turning in both directions from three trials in each direction and were used for analyses. The short turn time and low sway score indicate high stability (Suttanon et al., 2011).
Walk across: Walk across is a test of walking at a comfortable speed across the long plate. The measurements taken were step width (cm), step length (cm), and walking speed (cm/s). Step width is an indication of the size of the person's base of support. A smaller score indicates better postural stability. Completing the task quickly indicates longer step lengths were used, which is indicative of a better performance (Suttanon et al., 2011).
Limits of stability: Limits of stability (LOS) is a test of moving in eight directions as fast as possible towards to match the cursor of the individual's movement with that of a shifting target displayed on a screen. The measurements taken were speed and oscillation of weight shift (movement of centre of gravity within the body's LOS). All eight directions were tested once. The outcome variables include: (a) reaction time (s), is the time between the trigger signal to move (the centre of gravity) and the beginning of execution of movement. A low score indicates good performance; and (b) movement velocity (degree/s), that is, the average speed of centre of gravity movement. A low score indicates good performance (Suttanon et al., 2011).
Physiological Profile Assessment
Postural sway: Participants stand with feet together either on a firm floor or on a medium-density foam rubber mat (15 cm thick) for 30 s. The degree of body sway is measured using a swaymeter (a 40 cm long rod with a vertically mounted pen at its end is attached to the participant's waist). The pen tip is located on a square paper positioned on a height-adjustable table. As the person sways, the movement is recorded visually by the pen on a sheet of millimetre graph paper. The test is performed with eyes open and closed. The total sway (number of square millimetre squares traversed by the pen) and anteroposterior and mediolateral sway are recorded.
Edge contrast sensitivity: Assessed with the Melbourne Edge Test. Participants are presented with a card with 20 circular patches with visually reducing contrast variability and the participant is scored on their ability to accurately identify the orientation of the lowest contrast patch. This contrast sensitivity is measured in decibel units (1 dB = 10log10 contrast).
Proprioception: Assessed in sitting with the participant's eyes closed. An acrylic panel marked with a protractor is placed between the participant's feet and the participant is asked to lift one foot and then match the position of this foot with the other foot. The difference in alignment between the position of the two great toes is measured in degrees. An average of five attempts is recorded.
Maximum isometric muscular strength of the quadriceps: Measured in sitting on a specially provided chair using a spring-loaded dynamometer attached to the participant's ankle and the chair. The average of 3 trials is recorded in kg.
Timed Up and Go (TUG) test
The *TUG* (Podsiadlo and Richardson, 1991) was used to measure dynamic postural stability. This test timed the duration (s) for the participant to stand up from a standard chair without an arm rest, walk 3 m at their usual pace, turn, walk back and sit down again in the chair. Participants may use a walking device as necessary, but this use needs to be recorded and the device used in subsequent testing (Shumway-Cook et al., 2000).

Table 2

Matching of Similar Variable of the Three Tests for Purposes of Correlation Analysis

Test	Variables evaluating various aspects of balance and falls risk				
Computerised posturography using the long-plate equipment	mCTSIB	Sit to stand	Step quick turn	Walk across	Limits of Stability
PPA	Postural sway. (1) eyes open; (2) eyes closed on a firm surface or a foam surface	Quadriceps muscle strength. An important prerequisite to achieve the motor task of sit to stand			
TUG test	–	TUG includes sit to stand	TUG includes turning	TUG includes walking	–

Note. mCTSIB = modified Clinical Test of Sensory Interaction on Balance; PPA = Physiological Profile Assessment; TUG = Timed Up and Go test.

RESULTS

Participants

Demographic data for the 13 participants (7 male, 6 female) are reported in Table 3. Included participants had a mean (*SD*) age of 80 (8) (range 71–94) years and a mean (*SD*) MMSE of 19 (9) (range 14–28) points. Ten participants were recruited from a day care programme that specifically catered for older adults with dementia and three participants via the local Alzheimer's Society newsletter. Three participants had diagnoses of dementia (one with AD, two with fronto-temporal lobe dementia). A history of falls in the previous year was self-reported by four participants and confirmed by their support person. One participant used a walking stick during the TUG, walk across, and step quick turn tests. One participant could not perform the walk across and step quick turn tests due to failure of the testing equipment at the time of their test.

The computerised posturography limits of stability test was only carried out on six (46%) participants as those with a history of falling declined to complete the test as they felt apprehensive of falling. One participant did not complete the PPA as she was anxious about falling and declined to participate in the last four aspects of the PPA test. There were no other safety incidents reported during or after the tests. Missing data were thus due to participants being unable to complete a test due to their concern for their safety. In these instances, the test was stopped immediately and was noted as "unable to complete".

Concurrent validity assessment

Tables 4–6 illustrate the results of the correlation coefficients of the PPA and the TUG against variables from computerised posturography, namely, mCTSIB, sit to stand, step quick turn, and walk across tests.

Concurrent validity of the Physiological Profile Assessment

To assess the concurrent validity of the PPA, the sway and quadriceps muscle strength variables were compared with tasks of a similar nature performed using computerised posturography (Tables 4 and 5). Spearman's rho indicated the presence of moderate to good positive correlation between muscle strength (PPA) and the rising index (computerised posturography) (r_s = 0.699, $p = 0.01$, $n = 12$), and mediolateral sway during eyes open standing on foam (PPA) and sway velocity during eyes open standing on foam surface (computerised posturography) (r_s = 0.604, $p = 0.04$, $n = 12$). There were good negative correlations between anteroposterior sway during eyes closed standing on foam (PPA) and sway velocity during standing on foam with eyes open (computerised posturography) (r_s = –0.745, $p = 0.01$, $n = 12$) and Romberg ratio between PPA and computerised posturography (r_s = –0.698, $p = 0.02$, $n = 12$). The other variables did not significantly correlate ($p > 0.05$).

Concurrent validity of the TUG test

Similarly, to assess the concurrent validity of the TUG, performance of the test was compared with tasks of a similar nature performed using computerised posturography. Table 6 reports the results of concurrent validity between the TUG and step quick turn, sit to stand, and walk across tests. Moderate to good positive correlations were found between the TUG and the step quick turn *time* turn to left (computerised posturography) (r_s = 0.548, $p = 0.04$, $n = 12$) and step quick turn *sway* to left (computerised posturography) (r_s = 0.646, $p = 0.02$, $n = 11$). Good to excellent negative correlation was found between the TUG and rising index (computerised posturography) (r_s = –0.719, $p = 0.01$, $n = 13$). The other variables did not significantly correlate ($p > 0.05$).

DISCUSSION

In this study, the PPA and the TUG were shown to have moderate to excellent concurrent validity compared to the criterion test of computerised posturography in older adults with mild to moderate cognitive impairment. Four pairs of variables demonstrated concurrent validity. However, as not all variables between the PPA and the TUG correlated with comparable items of the computerised posturography, we suggest that both the PPA and the TUG may be required to evaluate balance and falls risk in older adults with self-reported memory loss in a clinical setting.

Thirteen older adults aged 71 to 94 years were recruited, with self-reported memory loss. Although a confirmed diagnosis of dementia would have been ideal, only three participants had confirmed dementia and the diagnoses of the other participants remained unconfirmed. Due to recruitment difficulties, participants were selected based on self-report of memory loss as opposed to confirmed diagnostic criteria. Subsequent

Table 3

*Demographics and Health Status Characteristics of Participants (*N *= 13)*

Characteristic	*M* (*SD*)	Range	*n*	%
Age, years	80 (8)	71–94		
Male			7	54
Height, m	1.6 (1.6)	1.4–1.9		
Weight, kg	73.9 (13.0)	41.0–93.0		
Education				
High school			10	75
Tertiary diploma/degree			2	17
Other			1	8
MMSE [a]	19 (9)	14–28		
Diagnosis				
Confirmed dementia diagnosis			3	23
Corrective lenses				
Bifocal			11	85
No visual correction			2	15
History of fall				
No fall			9	69
One-time fall			4	31
Number of medical conditions [b]				
0			4	31
1			4	31
2			2	15
≥ 3			3	23
Number of medications		0–4		
Use of walking aids			1	8

Note: MMSE = Mini-Mental State Examination; TUG = Timed Up and Go test.

[a] *n* = 11, 2 participants did not have recent MMSE scores. [b] Medical conditions included hypertension, heart disease, lung disease, depression, diabetes, musculoskeletal and history of stroke.

testing of participants with the MMSE, however, confirmed that eight participants did indeed have mild to moderate cognitive impairment (mean (*SD*) 20 (3), range 14–24). Thus, the findings of this study, while not reflecting specific diagnostic conditions (such as AD or a specific dementia), are representative for older adults with mild to moderate cognitive impairment, with the caveat that the identification of mild to moderate cognitive impairment was solely from the Mini Mental State Examination. This test has demonstrated high sensitivity (87% sensitivity) to measure cognitive impairment among older adults with dementia in residential care, hospital, or presenting at memory/dementia clinics, albeit in older adults with more cognitive impairments than participants in the current study (Folstein et al., 1985; Tombaugh et al., 1992). Targeting older adults with mild to moderate cognitive decline potentially enables concerns with balance and mobility to be addressed more effectively than when cognitive decline has progressed to more advanced levels.

This study demonstrated that participants who had stronger quadriceps muscles as measured by the PPA and were faster at completing the TUG had higher force generation from their lower legs when standing up (as measured by computerised posturography). Previous studies have evaluated the relationship of muscle strength and the sit to stand task in older adults (Lord et al., 2002; Kwan et al., 2011; Schenkman et al., 1996). For instance, among 280 community-dwelling older adults aged 65 years and above, quadriceps muscle strength was found to significantly influence ($p < 0.001$, $r_s = 0.231$) the performance of the TUG (Kwan et al., 2011). This finding is not surprising given that in sit to stand, a common daily living activity (Millington et al. 1992), the quadriceps muscles are required to generate the force to initiate the extension phase of sit to stand (Corrigan & Bohannon, 2001; Miyoshi et al., 2005).

The moderate correlation found between the TUG with the time taken and amount of sway during a turning task measured by computerised posturography was expected, but that this correlation was only significant for turning to the left was not. Turning plays a role in many upright physical activities (Lenoir et al., 2006). Turning requires asymmetrical limb movement and, through changes in the execution of knee flexion-extension and ankle dorsi-plantarflexion, the inside limb is theorised to be functionally shorter than the outside limb (Dite & Temple, 2002). The inside foot is subject to a prolonged stance phase and a

Table 4

Spearman Rank Correlation (r_s) Between Sway (Physiological Profile Assessment) and Sway in AP and ML Direction (mCTSIB From Computerised Posturography)

PPA		mCTSIB			
		Firm surface		Foam surface	
		EO SV	EC SV	EO SV	EC SV
Firm surface					
EO sway AP	r_s	0.320	–0.176	–0.291	0.056
	p	0.31	0.58	0.36	0.86
	n	12	12	12	12
EO sway ML	r_s	0.386	0.302	0.303	–0.555
	p	0.22	0.34	0.34	0.06
	n	12	12	12	12
EC sway AP	r_s	–0.484	–0.043	–0.355	0.291
	p	0.11	0.90	0.26	0.36
	n	12	12	12	12
EC sway ML	r_s	0.040	0.107	–0.267	0.039
	p	0.90	0.74	0.40	0.91
	n	12	12	12	12
Foam surface					
EO sway AP	r_s	0.018	–0.438	–0.229	0.181
	p	0.96	0.16	0.48	0.57
	n	12	12	12	12
EO sway ML	r_s	0.604*	0.463	0.011	–0.364
	p	0.04	0.13	0.97	0.25
	n	12	12	12	12
EC sway AP	r_s	–0.327	–0.219	–0.745**	0.354
	p	0.30	0.49	0.01	0.26
	n	12	12	12	12
EC sway ML	r_s	–0.104	–0.046	–0.399	–0.028
	p	0.75	0.89	0.20	0.93
	n	12	12	12	12

Note: AP = anteroposterior; EC = eyes closed; EO = eyes open; mCTSIB = modified Clinical Test of Sensory Interaction on Balance; ML = mediolateral; PPA = Physiological Profile Assessment; SV = sway velocity.

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

10% increase in vertical force in the posteromedial section of the foot compared to straight-line walking (Peyer et al., 2017). In the current study, leg dominance may explain this difference, but unfortunately leg dominance data were not collected. Future research should measure and analyse direction of turn related to the dominant and non-dominant leg.

For the correlation between sway items between the PPA and the modified clinical test of sensory interaction, on balance, the main tests were those of upright standing on foam with eyes open and closed. Given the similarities of these two tests, the poor correlation was unexpected, with only three variables demonstrating a significant correlation (mediolateral sway [eyes open, standing on foam]; PPA anteroposterior sway [eyes closed] and posturography sway velocity [eyes open] standing on foam, and Romberg ratio). The differing density of the foam (supplied by the license company as part of the test equipment) used to stand on between the two tests could account for this. The foam used in the computerised posturography may have higher elasticity, thus causing more sway. Patel et al. (2008) reported on the elasticity of the foam used in their test (with foam categorised by their elastic modulus as firm, medium, and soft) and found that there was more variance in ankle torque when standing on more elastic foam (Patel et al., 2008). Standing on a foam (high elasticity) surface is thought to amplify postural stability sway by reducing the reliability of somatosensory input from cutaneous mechanoreceptors on the base of the feet and by changing the efficiency of ankle torque (Perry et al., 2000). The amount of compression explains this

Table 5

Spearman Rank Correlation (r_s) Between the Romberg Ratio and Muscle Strength Components of the PPA and the mCTSIB and Sit to Stand Components of Computerised Posturography

PPA		Computerised posturography Romberg ratio (mCTSIB)			
		Firm surface		Foam surface	
Romberg ratio (firm surface)	r_s	0.135		–0.113	
	p	0.68		0.74	
	n	12		11	
Romberg ratio (foam surface)	r_s	0.191		–0.698*	
	p	0.55		0.02	
	n	12		11	
		Sit to stand			
		WTT	RI	SV	LRWS
Muscle strength	r_s	0.554	0.699*	–0.323	–0.189
	p	0.06	0.01	0.31	0.56
	n	12	12	12	12

Note: LRWS = left right weight symmetry; mCTSIB = modified Clinical Test of Sensory Interaction on Balance; PPA = Physiological Profile Approach; RI = rising index; SV = sway velocity; WTT = weight transfer time.

*Correlation is significant at the 0.05 level (2-tailed).

Table 6

Spearman Rank Correlation (r_s) Between Timed Up and Go and Computerised Posturography's Step Quick, Sit to Stand and Walk Across Tests

Variable		Step quick turn				Sit to stand				Walk across			
		TTL	TTR	TSL	TSR	WTT	RI	SV	LRWS	SW	SL	WS	LRS
Timed up and go	r_s	0.584*	0.245	0.646*	0.491	–0.022	–0.719**	–0.409	–0.264	0.124	–0.470	–0.470	0.109
	p	0.04	0.47	0.02	0.13	0.94	0.01	0.17	0.38	0.69	0.25	0.11	0.74
	n	12	11	11	11	13	13	13	13	13	13	13	12

Note: LRS = left right walk symmetry; LRWS = left right weight symmetry; RI = rising index; SL = step length; SV = sway velocity; SW = walk step width; TSL = turn sway left; TSR = turn sway right; TTL = turn time left; TTR = turn time right; WS = walk speed; WTT = weight transfer time.

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

theory; if the compression of the foam surface that has low elasticity was large, participants would be able to feel some of the hard surface (i.e., floor) beneath the foam, thus the accuracy of sensory information from the mechanoreceptors on the base of the feet may increase (Patel et al., 2008), and therefore stability is increased. Even though Patel's study was conducted among healthy adults aged 19 to 43 years (Patel et al., 2008), the suggestion that different foam elasticity might give rise to the different results in the performance of postural stability may account for our findings.

The precision limitation of the sway measure by the PPA could be another reason for the lack of significant correlation, as measuring the distance of trajectory of the sway measure is done "manually" using the graph paper provided and may introduce error. It is now recommended to use the new software of the PPA that directly digitally measures the distance during the test (https://www.neura.edu.au/, Prince of Wales Medical Research Institute, Randwick, Sydney, NSW, Australia). Notwithstanding, our finding was dissimilar to that of a previous study that measured the validity of measuring postural sway with the sway meter device of the PPA compared to that measured by a force plate (Sturnieks et al., 2011). Sturnieks et al. (2011) found moderate to good correlations between the sway meter and the force plate sway measures across all four conditions (r = 0.560–0.865): eyes open and eyes closed standing on firm surface; and eyes open and eyes closed standing on foam surface. Although their study suggested the sway meter has good agreement with the force plate centre of pressure (COP) measures for anterior-posterior ($r > 0.743$)

and medio-lateral displacement (*r* > 0.692), it was conducted among 29 older adults without neurological problems, aged 71 to 83 years (mean = 78, *SD* = 3), with a mean (*SD*) MMSE score of 27.8 (1.7) (Sturnieks et al., 2011). The difference of the populations might explain the variance in results.

The TUG did not show any significant agreement with the walk across test measured by computerised posturography. The nature of the test might explain this discrepancy. While performing the TUG, a participant may need to accelerate and decelerate twice, while transferring positions, and before and after turning, while the walk across only requires one acceleration–deceleration execution. The earlier construction of the TUG by Podsiadlo and Richardson (1991) showed good correlation between time score in the TUG and gait speed. However, this study was conducted among older patients with no more than mild cognitive impairment (mean MMSE = 28) referred to a day hospital (Podsiadlo & Richardson, 1991), many of whom had reduced overall functional capacity (participants had history of stroke (38%), Parkinson's disease (17%) and osteoarthritis (15%)). In a study by Wall et al. (2000), the researchers suggested isolating each component of the TUG to further investigate which functional component was impaired. These authors measured the time taken at six points: sit to stand, gait initiation, walk, turn around, walk again, slow down, stop, and sit down. It might be that the components of turning and standing up are compromised among older adults with cognitive impairment, thus increasing the time taken to complete these tasks, explaining the findings of a significant correlation between the TUG and the step quick turn test.

Participants had difficulty in completing two of the computerised posturography tests: (a) eyes closed standing on the foam, and (b) the limits of stability test in all eight directions. This is not surprising as these two tests are particularly challenging for individuals' postural stability (Suttanon et al., 2011), the first because of the limited sensory information available to the participant during the test procedure, and the second because it involves moving towards outer points of stability for an individual. The value of the computerised posturography limits of stability test for use with older adults with cognitive impairment is, however, debatable as participants with a history of falling in our study declined to do the test due to fear of falling. Suttanon et al. (2011) investigated 14 older adults with similar cognitive impairment and all their participants were able to complete the same limits of stability test; however, only four of the 14 had a history of falling.

Study limitations

The findings of this study need to be interpreted within the context of its limitations. The first limitation was its small sample size; this was because recruitment of participants using our study's "mild-to-moderate impairment" eligibility criteria proved challenging. Although the low recruitment may partly be due to the small overall population in the region where the data collection was done (approximately 130,000), it may also be due to possibly eligible older adults' denial of potential cognitive problems and potential diagnosis, and thus failure to volunteer for our study (Cohen et al., 1984). This leads to the second limitation, that of heterogeneity of the population. Our sample was heterogeneous in that it likely included people with AD, other forms of dementia, frontotemporal, and cognitive impairment. We minimised the exclusion criteria to maximise participant recruitment, a strategy recommended when there are limited resources (Hardy et al., 2009). A third limitation was not collecting leg dominance data, which would have assisted evaluation and interpretation of the turn data.

CONCLUSION

The results of this study showed that the PPA and the TUG had moderate to excellent concurrent validity compared to the criterion test of computerised posturography in older adults with mild to moderate cognitive impairment. However, as not all variables between the PPA and the TUG correlated with comparable items of the computerised posturography, we suggest that both the PPA and the TUG may be required to evaluate balance and falls risk in older adults with mild to moderate cognitive impairment in a clinical setting. Recognising the limitations of the current study, further exploration is needed of clinical-based outcome measures to use with older adults with mild to moderate cognitive impairment.

KEY POINTS

1. Older adults with cognitive impairments frequently have balance impairments and thus are at a high risk for falling.
2. The types of outcome measures used to evaluate balance in cognitively impaired older populations vary across studies.
3. For cognitively impaired populations, it is recommended that outcome measures should be quick to execute and instructions easy for the person being tested to follow.
4. This study suggests that the Physiological Profile Assessment and the Timed Up and Go test might be practical to use in combination to measure balance in older people with mild to moderate cognitive impairment.

DISCLOSURES

This study was a part of Doctor of Philosophy degree project. It was funded by the Ministry of Higher Education, Malaysia, and the University of Otago School of Physiotherapy's graduate research fund. The preliminary data were presented at the Watch Your Step: 2016 National Fall Prevention Conference – Applying Integrated Approaches, Calgary, Canada (May 14–25, 2016).

The authors have no conflicts of interest.

PERMISSIONS

No permissions were required.

ACKNOWLEDGEMENTS

The authors wish to acknowledge all participants and their support people for their involvement in this study.

CONTRIBUTIONS OF AUTHORS

Design, conceptualisation, and methodology, NM and LH; formal analysis, NM; data curation, NM and LH; writing—original draft preparation, NM; writing—review and editing, NM, LH, MP, KH, and DM; funding acquisition, NM.

ADDRESS FOR CORRESPONDENCE

Leigh Hale, School of Physiotherapy, University of Otago, PO Box 56, Dunedin, New Zealand.

Email: leigh.hale@otago.ac.nz

REFERENCES

Allali, G., Launay, C. P., Blumen, H. M., Callisaya, M. L., De Cock, A.-M., Kressig, R. W., Srikanth, V., Steinmetz, J.-P., Verghese, J., Beauchet, O., & Biomathics Consortium. (2017). Falls, cognitive impairment, and gait performance: Results from the GOOD Initiative. *Journal of the American Medical Directors Association, 18*(4), 335–340. https://doi.org/10.1016/j.jamda.2016.10.008

Alzheimer's Society. (2023). *Assessing the mental capacity of a person with dementia*. https://www.alzheimers.org.uk/get-support/legal-financial/assessing-mental-capacity-dementia

Chaudhry, H., Bukiet, B., Ji, Z., & Findley, T. (2011). Measurement of balance in computer posturography: Comparison of methods – a brief review. *Journal of Bodywork and Movement Therapies, 15*(1), 82–91. https://doi.org/10.1016/j.jbmt.2008.03.003

Cohen, D., Kennedy, G., & Eisdorfer, C. (1984). Phases of change in the patient with Alzheimer's dementia: A conceptual dimension for defining health care management. *Journal of the American Geriatrics Society, 32*(1), 11–15. https://doi.org/10.1111/j.1532-5415.1984.tb05143.x

Corrigan, D., & Bohannon, R. W. (2001). Relationship between knee extension force and stand-up performance in community-dwelling elderly women. *Archives of Physical Medicine and Rehabilitation, 82*(12), 1666–1672. https://doi.org/10.1053/apmr.2001.26811

Dite, W., & Temple, V. A. (2002). Development of a clinical measure of turning for older adults. *American Journal of Physical Medicine and Rehabilitation, 81*(11), 857–866. https://doi.org/10.1097/00002060-200211000-00010

Dodd, K., Hill, K., Haas, R., Luke, C., & Millard, S. (2003). Retest reliability of dynamic balance during standing in older people after surgical treatment of hip fracture. *Physiotherapy Research International, 8*, 93–100. https://doi.org/10.1002/pri.276

Duong, S., Patel, T., & Chang, F. (2017). Dementia: What pharmacists need to know. *Canadian Pharmacists Journal, 150*(2), 118–129. https://doi.org/10.1177/1715163517690745

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198. https://doi.org/10.1016/0022-3956(75)90026-6

Folstein, M. F., Anthony, J. C., Parhad, I., Duffy, B., & Gruenberg, E. M. (1985). The meaning of cognitive impairment in the elderly. *Journal of the American Geriatrics Society, 33*(4), 228–235. https://doi.org/10.1111/j.1532-5415.1985.tb07109.x

Fujita, T., Nakamura, S., Ohue, M., Fujii, Y., Miyauchi, A., Takagi, Y., & Tsugeno, H. (2005). Effect of age on body sway assessed by computerized posturography. *Journal of Bone and Mineral Metabolism, 23*(2), 152–156. https://doi.org/10.1007/s00774-004-0554-7

Furman, J. M. (1994). Posturography: Uses and limitations. *Baillieres Clinical Neurology, 3*(3), 501–513.

Goldup, H. (2017). Falls prevention in dementia: Literature review. *Journal of Dementia, 2*(1), 105.

Hardy, S. E., Allore, H., & Studenski, S. A. (2009). Missing data: A special challenge in aging research. *Journal of the American Geriatrics Society, 57*(4), 722–729. https://doi.org/10.1111/j.1532-5415.2008.02168.x

Horak, F. B. (2006). Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age and Ageing, 35*(Suppl 2), ii7–ii11. https://doi.org/10.1093/ageing/afl077

Howe, T. E., Rochester, L., Neil, F., Skelton, D. A., & Ballinger, C. (2011). Exercise for improving balance in older people. *Cochrane Database of Systematic Reviews.* https://doi.org/10.1002/14651858.CD004963.pub3

Ionescu, E., Dubreuil, C., & Ferber-Viart, C. C. (2005). Physiological changes in balance control of adults aged 20 to 60 years assessed with Equitest. *Annales d'Oto-Laryngologie et de Chirurgie Cervico-faciale, 122*(5), 231–235. https://doi.org/10.1016/s0003-438x(05)82354-0

Jacobs, J. V., Horak, F. B., Tran, V., & Nutt, J. G. (2006). Multiple balance tests improve the assessment of postural stability in subjects with Parkinson's disease. *Journal of Neurology, Neurosurgery and Psychiatry, 77*(3), 322–326. https://doi.org/10.1136/jnnp.2005.068742

Kwan, M. M.-S., Lin, S.-I., Chen, C.-H., Close, J. C., & Lord, S. R. (2011). Sensorimotor function, balance abilities and pain influence Timed Up and Go performance in older community-living people. *Aging Clinical and Experimental Research, 23*(3), 196–201. https://doi.org/10.1007/BF03324960

Lamb, S. E., Jørstad-Stein, E. C., Hauer, K., & Becker, C., & Prevention of Falls Network Europe and Outcomes Consensus Group (2005). Development of a common outcome data set for fall injury prevention trials: The Prevention of Falls Network Europe consensus. *Journal of the American Geriatrics Society, 53*(9), 1618–1622. https://doi.org/10.1111/j.1532-5415.2005.53455.x

Lenoir, M., Van Overschelde, S., De Rycke, M., & Much, E. (2006). Intrinsic and extrinsic factors of turning preferences in humans. *Neuroscience Letters 393*(2–3),179–183. https://doi.org/10.1016/j.neulet.2005.09.061

Lorbach, E. R., Webster, K. E., Menz, H. B., Wittwer, J. E., & Merory, J. R. (2007). Physiological falls risk assessment in older people with Alzheimer's disease. *Dementia and Geriatric Cognitive Disorders, 24*(4), 260–265. https://doi.org/10.1159/000107101

Lord, S. R., Menz, H. B., & Tiedemann, A. (2003). A physiological profile approach to falls risk assessment and prevention. *Physical Therapy, 83*(3), 237–252.

Lord, S. R., Murray, S. M., Chapman, K., Munro, B., & Tiedemann, A. (2002). Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 57*(8), M539–M543. https://doi.org/10.1093/gerona/57.8.m539

Mancini, M., & Horak, F. B. (2010). The relevance of clinical balance assessment tools to differentiate balance deficits. *European Journal of Physical Rehabilitation Medicine, 46*(2), 239–248.

Mesbah, N., Perry, M., Hill, K. D., Kaur, M., & Hale, L. (2017). Postural stability in older adults with Alzheimer disease. *Physical Therapy, 97*(3), 290–309. https://doi.org/10.2522/ptj.20160115

Millington, P. J., Myklebust, B. M., & Shambes, G. M. (1992). Biomechanical analysis of the sit-to-stand motion in elderly persons. *Archives of Physical Medicine and Rehabilitation, 73*(7), 609–617.

Miyoshi, K., Kimura, T., Yokokawa, Y., Cheng, G. A., Fujiwara, T., Yamamoto, I., & Kondo, Y. (2005). Effect of ageing on quadriceps muscle strength and on the forward shift of center of pressure during sit-to-stand movement from a chair. *Journal of Physical Therapy Science, 17*(1), 23–28.

Mozley, C. G., Huxley, P., Sutcliffe, C., Bagley, H., Burns, A., Challis, D., & Cordingley, L. (1999). 'Not knowing where I am doesn't mean I don't know what I like': Cognitive impairment and quality of life responses in elderly people. *International Journal of Geriatric Psychiatry, 14*(9), 776–783. https://doi.org/10.1002/(SICI)1099-1166(199909)14:9<776::AID-GPS13>3.0.CO;2-C

Munhoz, R., Li, J.-Y., Kurtinecz, M., Piboolnurak, P., Constantino, A., Fahn, S., & Lang, A. (2004). Evaluation of the pull test technique in assessing postural instability in Parkinson's disease. *Neurology, 62*(1), 125–127. https://doi.org/10.1212/wnl.62.1.125

Patel, M., Fransson, P.-A., Lush, D., & Gomez, S. (2008). The effect of foam surface properties on postural stability assessment while standing. *Gait and Posture, 28*(4), 649–656. https://doi.org/10.1016/j.gaitpost.2008.04.018

Perry, S. D., McIlroy, W. E., & Maki, B. E. (2000). The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. *Brain Research, 877*(2), 401–406. https://doi.org/10.1016/s0006-8993(00)02712-8

Peyer, K. E., Brassey, C. A., Rose, K. A., & Sellers, W. I. (2017). Locomotion pattern and foot pressure adjustments during gentle turns in healthy subjects. *Journal of Biomechanics, 60*, 65–71. https://doi.org/10.1016/j.jbiomech.2017.06.025

Podsiadlo, D., & Richardson, S. (1991). The timed "Up & Go": A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society, 39*(2), 142–148. https://doi.org/10.1111/j.1532-5415.1991.tb01616.x

Portney, L. G., & Watkins, M. P. (2000). *Foundations of clinical research: Applications to practice* (2nd ed.). Prentice Hall Health.

Portney, L. G., & Watkins, M. P. (2015). *Foundations of clinical research: Applications to practice* (3rd ed.). FA Davis Company.

Ries, J. D., Drake, J. M., & Marino, C. (2010). A small-group functional balance intervention for individuals with Alzheimer disease: A pilot study. *Journal of Neurologic Physical Therapy, 34*(1), 3–10. https://doi.org/10.1097/NPT.0b013e3181d00f2e

Schenkman, M., Hughes, M. A., Samsa, G., & Studenski, S. (1996). The relative importance of strength and balance in chair rise by functionally impaired older individuals. *Journal of the American Geriatrics Society, 44*(12), 1441–1446. https://doi.org/10.1111/j.1532-5415.1996.tb04068.x

Shigemori, K., Ohgi, S., Okuyama, E., Shimura, T., & Schneider, E. (2010). The factorial structure of the Mini Mental State Examination (MMSE) in Japanese dementia patients. *BMC Geriatrics, 10*, 36. https://doi.org/10.1186/1471-2318-10-36

Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the Timed Up and Go Test. *Physical Therapy, 80*(9),896–903. https://doi.org/10.1093/ptj/80.9.896

Sibley, K. M., Howe, T., Lamb, S. E., Lord, S. R., Maki, B. E., Rose, D. J., Scott, V., Stathokostas, L., Straus, S. E, & Jaglal, S. B. (2015). Recommendations for a core outcome set for measuring standing balance in adult populations: A consensus-based approach. *PLoS One, 10*(3), e0120568. https://doi.org/10.1371/journal.pone.0120568

Sturnieks, D. L., Arnold, R., & Lord, S. R. (2011). Validity and reliability of the Swaymeter device for measuring postural sway. *BMC Geriatrics, 11*, 63. https://doi.org/10.1186/1471-2318-11-63

Suttanon, P., Hill, K. D., Dodd, K. J. & Siad, S. M. (2011). Retest reliability of balance and mobility measurements in people with mild to moderate Alzheimer's disease. *International Psychogeriatrics, 23*(7), 1152–1159. https://doi.org/10.1017/S1041610211000639

Tjernström, F., Björklund, M., & Malmström, E.-M. (2015). Romberg ratio in quiet stance posturography – Test to retest reliability. *Gait and Posture, 42*(1), 27–31. https://doi.org/10.1016/j.gaitpost.2014.12.007

Tombaugh, T. N., & McIntyre, N. J. (1992). The Mini-Mental State Examination: A comprehensive review. *Journal of the American Geriatrics Society, 40*(9), 922–935. https://doi.org/10.1111/j.1532-5415.1992.tb01992.x

Trueblood, P. R., Rivera, M., Lopez, C., Bentley, C., & Wubenhorst, N. (2018). Age-based normative data for a computerized dynamic posturography system that uses a virtual visual surround environment. *Acta Oto-Laryngologica, 138*(7), 597–602, https://doi.org/10.1080/00016489.2018.1429653

Versi, E. (1992). "Gold standard" is an appropriate term. *British Medical Journal, 305*(6846), 187. https://doi.org/10.1136/bmj.305.6846.187-b

Wall, J. C., Bell, C., Campbell, S., & Davis, J. (2000). The Timed Get-Up-and-Go test revisited: Measurement of the component tasks. *Journal of Rehabilitation Research and Development, 37*(1), 109–113.