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ORIGINAL ARTICLE

Loaded and unloaded timed stair tests as tools for assessing advanced functional mobility in people with stroke

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ABSTRACT

BACKGROUND: The Timed Stair Test (TST) was originally designed to measure advanced functional mobility in patients who have undergone a total hip replacement. Its psychometric properties have not been examined systematically in people with stroke.
AIM: The aims of this study were to: 1) determine the intra-rater reliability of TST under loaded and unloaded condition; 2) identify the minimal detectable changes (MDCs) in TST completion times; 3) investigate the concurrent validity between TST completion times and stroke-specific outcome measures; and 4) determine the cut-off TST completion time to differentiate the performance between people with stroke and healthy older adults.
DESIGN: Cross-sectional study.
SETTING: A university-based rehabilitation center.
POPULATION: Ninety-four people with stroke and 34 healthy older adults.
METHODS: TSTs were conducted under loaded and unloaded conditions. Two trials of the TST for each of the two conditions were performed on the same day. The Fugl-Meyer Assessment of Lower Extremity (FMA-LE), lower-limb muscle strength test assessed by a hand held dynamometer, Berg Balance Scale (BBS), Limit of Stability (LOS) Test, Timed Up and Go (TUG) Test, and the Cantonese version of the Community Integration Measure (CIM) were also used to assess the subjects.
RESULTS: Excellent intra-rater reliability was demonstrated for TST completion times under loaded (intraclass correlation coefficient [$ICC_{2,1}$]=0.991) and unloaded ($ICC_{2,1}$=0.985) conditions. The MDCs in TST completion times were 6.55 seconds and 7.25 seconds under loaded and unloaded conditions, respectively. FMA-LE scores, mean strength of the affected-side dorsiflexors and plantar flexors, BBS scores, and LOS movement velocity and maximum excursion scores demonstrated fair to excellent negative correlations with TST completion times under both loaded (r=-0.314 to -0.786) and unloaded (r=-0.296 to -0.794) conditions. TUG results demonstrated good to excellent positive correlations with TST completion times under both loaded (r=0.875, P<0.001) and unloaded (r=0.872, P<0.001) conditions. The TST completion times of 26.3 seconds and 23.4 seconds under loaded and unloaded conditions, respectively, differentiated between people with stroke and healthy older adults.
CONCLUSIONS: The TST is a reliable clinical tool for evaluating advanced functional mobility in people with stroke.
CLINICAL REHABILITATION IMPACT: TST is a fast and simple test that does not require sophisticated equipment, making it suitable for busy hospital and rehabilitation settings.

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KEY WORDS: Stroke; Arthroplasty, replacement, hip; Recovery of function.

Community-dwelling people with stroke are likely to perform daily activities requiring the synthesis of various components of mobility, including sit-to-stand, walking, walking up and down stairs, and turning. Additionally, the need to carry a load, such as a backpack, may arise in daily life. Although several tests have been developed to assess the mobility function of people with stroke, they did not focally and comprehensively capture all these components of day-to-day mobility activities simultaneously. For example, the Timed Up and Go (TUG)[1] is able to assess the sit-to-stand, walking and turning but the stair climbing ability is not evaluated. The timed up and down stair test[2] aims at measuring the maximum speed of stair climbing but it does not simulate the real life situations that people often carry a load and walk in comfortable speed. A validated measure assessing the series of components of functional mobility simultaneously can provide better understanding of the locomotor recovery of community-dwelling people with stroke.

The Timed Stair Test (TST) was originally designed to measure advanced functional mobility in patients who have undergone a total hip replacement.[3] The TST combines multiple components, including rising from a chair, walking for 3 m, and stair-climbing, with and without carrying a load. Stair climbing with additional loading requires significantly more lower-limb muscle activity and is therefore a more difficult movement to perform.[4] The TST simulates the daily advanced functional mobility necessary for living in a community setting.

Despite the potential utility of the TST for evaluating advanced functional mobility during the rehabilitation of people with stroke, its psychometric properties, including intra-rater reliability and correlation with stroke-specific impairments, have not been examined systematically in people with stroke. Thus, the objectives of this study were to: 1) determine the intra-rater reliability of TST completion times under loaded and unloaded condition; 2) identify the minimal detectable changes (MDCs) in TST completion times; 3) investigate the concurrent validity between TST completion times and stroke-specific outcome measures; and 4) determine the optimal cut-off TST completion time to differentiate the performance between people with stroke and healthy older adults.

Materials and methods

Study design

This was a cross-sectional study conducted in a university-affiliated neurorehabilitation laboratory. A detailed explanation of the study was provided to potential study participants. Written consent was then obtained from the participants before participating in the study. Ethical approval (HSEARS20210110002) was obtained from the University Ethics Committee of the local institution. The study protocol followed the principles of the Declaration of Helsinki.[5]

Sample size calculation

As no previous study has investigated the reliability of TST completion times for people with stroke, we estimated the required sample size based on a previous study[6] that found good test–retest reliability (intraclass correlation coefficient [ICC]=0.880) for the TST in people with obesity. Thus, we also assumed excellent reliability (ICC=0.90) of the TST completion time in people with stroke, and determined that a sample size of 22 was required to achieve 80% power at a significance level of 0.05. The sample size was estimated using an online calculator.[7] To increase the power of the study, we increased the sample size to 30 to determine intra-rater reliability in our study.

No previous study has investigated the correlations between TST completion times and stroke-specific outcome measures in people with stroke. Therefore, we assumed a medium level of correlation between TST completion times and stroke-specific outcome measures in people with stroke (ρ=0.30). A minimum sample size of 64 was required to achieve 80% power at a significance level of 0.05. The sample size calculation was performed using G*Power 3.1.9.7 (Franz Faul, University of Kiel, Kiel, Germany). To draw a more reliable conclusion, a sample size of 94 was used to assess the correlations between TST completion times and stroke-specific outcome measures.

Participants

We recruited 94 community-dwelling people with stroke and 34 healthy older adults. The demographics of the participants are shown in Table I. People with stroke were eligible if they 1) were aged 50 years or above; 2) had experienced a single stroke, verified by computed tomography or magnetic resonance imaging, at least 12 months prior to the beginning of the study; 3) were able to climb stairs independently or with assistance from walking aids or a handrail; 4) scored at least 7/10 on the Hong Kong version of the Abbreviated Mental Test;[8] and 5) had a stable general medical condition. Subjects were excluded if they had any comorbid medical conditions, such as neurological disorders or musculoskeletal conditions, that would affect their accurate assessment. Healthy older adults with the same inclusion and exclusion criteria for stroke participants were recruited as the control group except for a history of stroke. A total of 34 healthy older adults (9 male, 25 female) older than 50 years with a stable health condition were recruited as the control group. People with any neurological or cardiovascular disease that might affect proper assessment were excluded.

Table I.—*Demographics of the people with stroke and the healthy older adults.*

Characteristics	Stroke (N.=94)	Healthy (N.=34)	P-value
Age, years, mean (SD)	63.17 (6.19)	60.97 (7.39)	0.282
Sex, M/F, N.	53/41	9/25	0.003*
Height, cm, mean (SD)	162.41 (12.06)	161.88 (8.08)	0.644
Weight, kg, mean (SD)	64.59 (9.34)	59.12 (9.99)	0.911
BMI, mean (SD)	24.25 (11.73)	22.53 (3.20)	0.402
Post-stroke duration, months, mean (SD)	80.87 (53.68)	N/A	N/A
Type of stroke, N.			
Ischemic	66	N/A	N/A
Hemorrhagic	28	N/A	N/A
Stroke-affected side, N.			
Left	38	N/A	N/A
Right	56	N/A	N/A
Mobility status, N. (%)			
Walks without gait aids	30 (32%)	34 (100%)	
Walks with gait aids	64 (68%)	0	
FMA-LE, mean (SD)	26.41 (4.31)	/	
Ankle dorsiflexor strength, kg, mean (SD)			
Affected	11.30 (6.41)	/	
Unaffected	16.76 (5.92)	/	
Ankle plantarflexor strength, kg, mean (SD)			
Affected	8.73 (5.03)	/	
Unaffected	13.58 (5.94)	/	
BBS, mean (SD)	51.51 (4.20)	/	
TUG, s, mean (SD)	14.97 (8.46)	/	
CIM, mean (SD)	40.76 (7.29)	/	

*Significant difference at the P≤0.05 level of confidence; SD: standard deviation; M: male; F: female; N/A: not applicable.

Outcome measures

Procedures

Subjects with stroke were required to complete the TST along with stroke-specific outcome measures, which included the Fugl-Meyer Assessment of Lower Extremity (FMA-LE), a lower-limb muscle strength test, the Berg Balance Scale (BBS), Limit of Stability (LOS) Test (Balance Master), the TUG Test, and the Cantonese version of the Community Integration Measure (CIM), on the same day. The inclusion of these stroke-specific outcome measures were based on the International Classification of Functioning, Disability and Health (ICF) framework to provide a comprehensive view of the recovery of functional mobility in relation to the health condition, personal factors and environmental context of people with stroke. We conceptualized that functional mobility would have dynamic interactions and mutually affect the recovery and health status of people with stroke. According to our conceptualization, the measures of body structure and function domain included the FMA-LE and lower-limb muscle strength test. The measures of the activity domain included the BBS, LOS and TUG test. The relationship between the participation domain and functional of mobility was measured by the CIM.

To examine intra-rater reliability, 30 subjects were randomly selected from the 94 subjects by drawing lots. Two trials of the TST for each of the two conditions were assessed 15 minutes apart to eliminate learning and fatigue effects by the same assessor who was an experienced research assistant in stroke rehabilitation with physiotherapy training background. The sequence of the tests was randomly determined by drawing lots, and the participants were given at least 2 minutes of rest between the tests to minimize learning and fatigue effects. Healthy older adults were only required to complete one trial of the TST.

TST

The TST is used to assess advanced functional mobility.[3] It consists of the following 4 subtasks: subtask 1, rising from a chair and walking 3 m; subtask 2, ascending a staircase; subtask 3, turning around and descending a staircase; subtask 4, walking 3 m, turning, and sitting down on the same chair (Figure 1). The staircase used in this study had 12 stairs, each with a height of 13 cm and a length of 24 cm. The subjects were instructed to walk at their usual speed, and walking aids were allowed during the test. No practice trial was performed. The time taken for each subtask was recorded using a stopwatch.

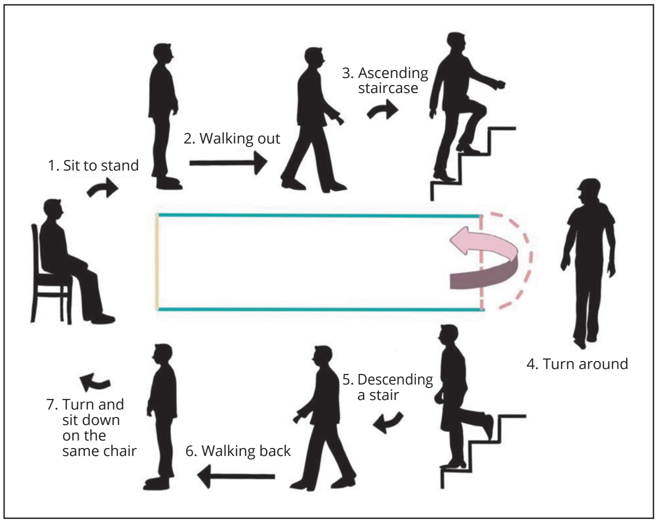

Figure 1.—Timed Stair Test (TST) setup.

The participants were required to complete the test in the unloaded condition, followed by the loaded condition, for each TST trial. For the loaded condition, the participants were required to wear a vest carrying 5% of their body weight. Metal strips weighing 0.16 kg were evenly distributed in the vest, and the number of strips was adjusted according to the participant's body weight. Two TST trials were conducted on the same day to assess intra-rater reliability by the same assessor, with 15 minutes between the two trials.

FMA-LE

The FMA-LE was used to assess post-stroke lower-limb motor function.[9] The FMA-LE score ranges from 0 to 34, with 17 items and ordinal scoring from 0 to 2. A higher score indicates better motor control of the lower extremities. The FMA-LE has shown excellent inter-rater and intra-rater reliability (ICC=0.95) in people with stroke.[10]

Lower-Limb Muscle Strength

A Nicholas handheld dynamometer (model 01160; Lafayette Instrument Company, Lafayette, IN, USA) was used to measure the strength of the dorsiflexors and plantarflexors of both the affected and unaffected sides. The maximum isometric voluntary contraction strength of the ankle dorsiflexors and plantarflexors was assessed twice on alternate sides, with 30 seconds of rest between trials. The dynamometers were placed at the dorsum and sole of the foot to assess the ankle dorsiflexion and plantarflexion strength, respectively. The participants were required to sustain maximal contraction for 3 seconds. The average strength of each muscle group across the two trials was recorded. Hand-held dynamometer has shown excellent reliability (ICC=0.95-0.99) in community-dwelling older adults who had experienced falls.[11]

BBS

The BBS was used to assess functional balance.[12] It involves 14 functional tasks, assessed using a scale of 0 to 4, with a total score of 56. A higher score indicates better balance function. The BBS has shown excellent inter-rater reliability (ICC=0.95–0.98) and intra-rater reliability (ICC=0.97) in people with stroke.[13]

LOS

The LOS test was used to assess postural balance, which was measured using a computed dynamic posturography system (Bertec Corporation, Columbus, OH, USA). The LOS test measures the maximum displacement of the center of pressure (COP) in different directions while maintaining balance. The device uses a short stable force plate surrounded by a visual projection. Participants stand bare-footed on the force plate, while wearing a harness. During the assessment, the participants attempted to move their COP towards eight target boxes projected in various directions while viewing a real-time display of their COP on a computer screen located at eye level. The reaction time (RT), movement velocity (MV), endpoint excursion (EE), maximum excursion (ME), and directional control (DC) were measured during the test. Composite scores were generated for each variable by averaging the scores for the eight targets within a trial.

RT was used to assess the time participants took to give a movement response after cues were provided. MV was used to assess the average center of gravity (COG) displacement speed. DC was used to assess how much of the participant's movement was in the target direction. EE was used to assess how far the participant leaned towards the target on their first attempt. ME was used to assess the maximum extent to which the participant leaned during the trial. This assessment system has shown good test–retest reliability (ICC=0.84–0.88) in people with stroke.[14]

TUG

The TUG Test was used to evaluate functional mobility.[15] The TUG test measures how long it takes participants to stand up from a chair, walk 3 m, turn around, walk back, and sit down. Each participant completes a practice trial before undergoing two timed trials, from which the mean is calculated. The TUG test has excellent reliability (ICC=0.95) in people with stroke.[16]

CIM

The CIM is a 10-item, self-reported measure used to assess community integration level.[17] Each item in the CIM is rated on a 5-point scale. The Cantonese version of the CIM has shown high internal consistency (Cronbach's alpha=0.84) and test–retest reliability (ICC=0.84) in people with stroke.[18]

Statistical analysis

SPSS (version 28; IBM Corporation, Armonk, NY, USA) was used for data analysis. Descriptive statistics were used to summarise demographic data and outcome measures. Independent t-test was used to compare people with stroke and healthy older adults. The significance level was set to α=0.05. A mixed design Analysis of Variance (ANOVA) was used to test the variation of TST completion time at unloaded and loaded conditions, and between the participants with or without stroke.

ICCs were used to assess intra-rater reliability. According to previously described guidelines,[19] $ICC_{2,1}$ (two-way random effects, absolute agreement, single rater/measurement) was applied to quantify the degree of intra-rater reliability, as the rater was randomly assigned from our trained research team and a single measurement was taken. ICC values of <0.5, 0.5–0.75, 0.75-0.9, and >0.9 represented poor, moderate, good, and excellent reliability, respectively.[19]

The MDCs in TST completion times were calculated based on test–retest reliability values and the standard deviation of the TST completion time using the following formula:[20]

$$MDC = 1.96 x SEM x \sqrt{2} \quad (1)$$

where

$$SEM = SD\sqrt{1 - r} \quad (2)$$

SEM indicates the standard error of measurement, SD indicates the standard deviation of the TST completion time, and r indicates the test-retest reliability coefficient.

Correlations between TST completion times and other outcome measures were determined using Pearson's or Spearman's correlation analysis, as appropriate. Bonferroni correction was applied to adjust the significance level to P≤0.008 (0.05/6) as there were 6 primary outcomes in this study, including FMA-LE, lower-limb muscle strength, BBS, LOS, TUG, and CIM scores. Correlations were classified as: little or no (r≤0.25), fair (r=0.25–0.50), moderate to good (r=0.50–0.75), and good to excellent (r>0.75).[20] Comparison of TST completion time between those stroke participants with low (FMA-LE Score 0 to 20) and moderate to high (FMA-LE Score 21 to 34) level of lower limb control ability would be determined by independent t-test or Mann Whitney U Test as appropriate.

Receiver operating characteristic (ROC) curves were generated to establish the cut-off scores for TST completion times under loaded and unloaded conditions, to differentiate people with stroke from healthy older adults.[21] Youden's index was used to determine the optimal cut-off score based on a trade-off between the sensitivity and 1 − specificity of each cut-off point.[22]

Results

Ninety-four people with stroke and 34 healthy older adults participated in this study. Demographic information and TST completion times are presented in Table I, II, respectively. Our mixed design ANOVA revealed that there were significant group x condition interaction effects in the total TST completion time (P=0.018). The post-hoc analysis indicated that there were significant differences of the TST total completion between the stroke participants and healthy participants in both loaded (P<0.001) and unloaded (P<0.001) condition. However, there was no significant group x condition interaction effect in any TST subtask (subtask 1: P=0.139; subtask 2: P=0.120, subtask 3: P=0.153; subtask 4: P=0.453).

Those stroke participants who were randomly drawn to participate in the intra-rater reliability (N.=30, loaded=45.48±28.07 seconds; unloaded=43.35±24.38 seconds) showed similar TST performance as those stroke participants who were not involved in the intra-rater re-

Table II.—*Mean Completion Time of TST in people with stroke and healthy older adults.*

	Stroke (N.=94) second, mean (SD)	Healthy (N.=34) second, mean (SD)
Condition 1: unloaded		
TST1	6.40 (3.68)	2.97 (0.75)
TST2	11.61 (6.50)	5.18 (1.03)
TST3	16.38 (9.13)	6.01 (1.70)
TST4	7.08 (4.40)	3.10 (0.79)
TST (composite)	41.47 (21.54)	17.26 (3.86)
Condition 2: loaded		
TST1	7.54 (6.08)	3.13 (0.73)
TST2	12.54 (7.03)	5.53 (1.15)
TST3	17.52 (9.47)	6.46 (1.78)
TST4	7.60 (5.30)	3.41 (0.77)
TST (composite)	45.20 (24.70)	18.53 (3.89)

TST: Timed Stair Test; TST 1: from the starting signal until the first foot contacted the stair; TST 2: from the first foot contact with stair to the first contact with the floor after ascending the staircase; TST 3: from turning and descending the staircase to the foot contact with the ground; TST 4: from the foot contact with the ground to the participant's back resting on the backrest of the chair.

liability (N.=64, loaded=45.07±23.20 seconds, P=0.941; unloaded=40.59±20.22, P=0.566).

Reliability

Excellent intra-rater reliabilities were demonstrated in TST completion times under both loaded ($ICC_{2,1}$=0.991) and unloaded ($ICC_{2,1}$=0.985) conditions (Table III). All subtasks in the loaded condition had good to excellent intra-rater reliability ($ICC_{2,1}$=0.833-0.957), and excellent reliability for the unloaded condition ($ICC_{2,1}$=0.945-0.972).

TST concurrent validity

The FMA-LE scores, mean strengths of the affected-side dorsiflexors and plantarflexors, BBS scores, and LOS MV and ME scores showed fair to excellent negative correlations with TST completion times under both loaded (r= -0.314 to -0.786) and unloaded (r=-0.296 to -0.794) conditions (Table IV, V). The TUG results demonstrated good to excellent positive correlations with TST completion times under both loaded (r=0.875, P<0.001) and unloaded (r=0.872, P<0.001) conditions. No significant correlations were found between TST completion times and the mean strength of the unaffected ankle dorsiflexors or plantarflexors, LOS RT scores, or CIM results.

Cut-off scores

The optimal cut-off TST completion times under loaded and unloaded conditions were 26.3 seconds and 23.4 seconds, respectively (sensitivity=86-88%; specificity=94-97%; area under the curve [AUC]=0.948-0.955; Figure 2, 3) (Table VI).

Table III.—*Intra-rater reliability of Timed Stair test (TST) of people with stroke.*

	$ICC_{2,1}$, Mean (95% CI)	P-value	Minimal Detectable Change
Condition 1: unloaded			
TST1	0.972 (0.943-0.987)	<0.001	1.73
TST2	0.945 (0.888-0.973)	<0.001	3.83
TST3	0.961 (0.920-0.981)	<0.001	5.03
TST4	0.970 (0.937-0.985)	<0.001	2.15
TST (composite)	0.985 (0.969-0.993)	<0.001	7.25
Condition 2: loaded			
TST1	0.833 (0.678-0.917)	<0.001	8.05
TST2	0.932 (0.862-0.967)	<0.001	4.89
TST3	0.957 (0.912-0.979)	<0.001	5.51
TST4	0.914 (0.906-0.979)	<0.001	4.37
TST (composite)	0.991 (0.981-0.996)	<0.001	6.55

*95% CI: 95% confidence interval; TST: Timed Stair Test; TST 1: from the starting signal until the first foot contacted the stair; TST 2: from the first foot contact with stair to the first contact with the floor after ascending the staircase; TST 3: from turning and descending the staircase to the foot contact with the ground; TST 4: from the foot contact with the ground to the participant's back resting on the backrest of the chair.

Discussion

This is the first study to investigate the intra-rater reliability of TST completion times in people with stroke.

Table IV.—*Correlations of performance between Timed Stair Test (TST) with stroke-specific impairments in people with stroke.*

	TST1	TST2	TST3	TST4	TST composite
Condition 1: unloaded					
FMA-LE	-0.549*	-0.476*	-0.575*	-0.396*	-0.562*
Ankle dorsiflexor strength, kg					
Affected	-0.359*	-0.383*	-0.413*	-0.276*	-0.408*
Unaffected	-0.177	-0.276*	-0.202	-0.193	-0.239
Ankle plantarflexor strength, kg					
Affected	-0.371*	-0.336*	-0.361*	-0.299*	-0.379*
Unaffected	-0.045	-0.010	-0.006	-0.030	-0.014
BBS	-0.810*	-0.611*	-0.775*	-0.697*	-0.794*
TUG, s	0.947*	0.603*	0.822*	0.882*	0.872*
CIM	0.016	-0.019	-0.027	-0.074	-0.029
Condition 2: loaded					
FMA-LE	-0.402*	-0.538*	-0.597*	-0.367*	-0.559*
Ankle dorsiflexor strength, kg					
Affected	-0.283*	-0.426*	-0.435*	-0.242	-0.410*
Unaffected	-0.122	-0.263	-0.189	-0.166	-0.213
Ankle plantarflexor strength, kg					
Affected	-0.262	-0.375*	-0.352*	-0.287*	-0.368*
Unaffected	0.119	-0.042	-0.001	-0.042	0.008
BBS	-0.601*	-0.688*	-0.777*	-0.672*	-0.786*
TUG, s	0.805*	0.693*	0.759*	0.880*	0.875*
CIM	-0.016	-0.053	-0.065	-0.070	-0.059

All correlations are Pearson's coefficients.
*Significant correlation after Bonferroni adjustment at a p-value of 0.05/6 (p ≤ 0.008); BBS: Berg Balance Scale; CIM: Community Integration Measure – Chinese version; FMA-LE: Fugl-Meyer motor assessment for the lower extremities; TUG: Timed Up and Go Test.

Fair to excellent correlations were found between TST completion times and stroke-specific outcome measures. This was also the first study to investigate the optimal TST cut-off completion time to differentiate the performance between people with stroke and healthy older adults.

TABLE V.—*Correlation of performance between Timed Stair Test (TST) with Limit of Stability (LOS) test in people with stroke.*

Limit of Stability Test		TST1	TST2	TST3	TST4	TST composite
Condition 1: unloaded						
RT, s	Composite	0.237	0.092	0.197	0.183	0.189
MV, deg/s	Composite	-0.422*	-0.406*	-0.441*	-0.324*	-0.448*
EE, %	Composite	-0.492*	-0.384*	-0.478*	-0.378*	-0.480*
ME, %	Composite	-0.528*	-0.449*	-0.536*	-0.448*	-0.545*
DC, %	Composite	-0.365*	-0.264	-0.426	-0.322*	-0.389*
Condition 2: loaded						
RT, s	Composite	0.239	0.115	0.190	0.180	0.203
MV, deg/s	Composite	-0.349*	-0.410*	-0.440*	-0.272*	-0.429*
EE, %	Composite	-0.456*	-0.421*	-0.471*	-0.322*	-0.481*
ME, %	Composite	-0.488*	-0.493*	-0.523*	-0.414*	-0.549*
DC, %	Composite	-0.418*	-0.316*	-0.389*	-0.303*	-0.407*

All correlations are Pearson's coefficients.
*Significant correlation after Bonferroni adjustment at a p-value of 0.05/6 ($P \leq 0.008$).
DC: directional control; EE: endpoint excursions; LOS: Limit of Stability Test; RT: reaction time; ME: maximum excursions; MV: movement velocity.

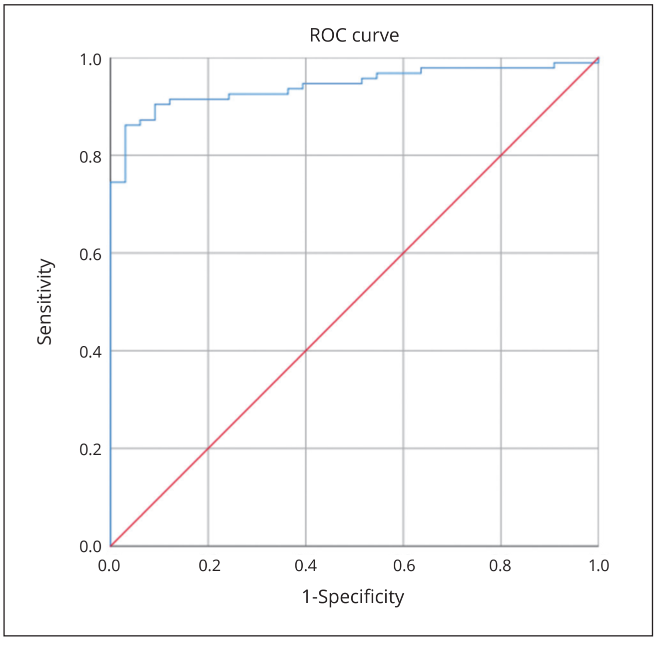

Figure 2.—Receiver operating characteristic (ROC) curves for TST for differentiating the performance of people with stroke from healthy older adults in loaded condition: AUC=0.955, sensitivity=88.5%, specificity=94.1%.

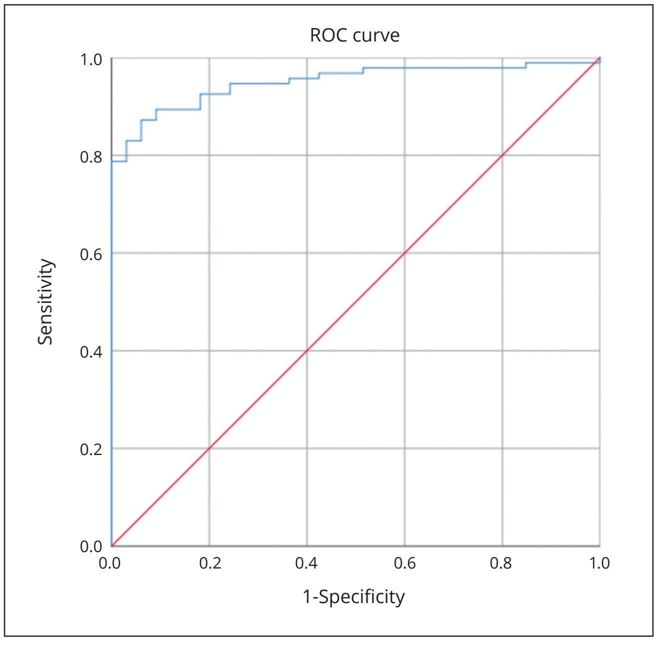

Figure 3.—Receiver operating characteristic (ROC) curves for TST for differentiating the performance of people with stroke from healthy older adults in unloaded condition: AUC=0.948, sensitivity=86.5%, specificity=97.1%.

TABLE VI.—*Cutoff score of Timed Stair Test (TST) between people with stroke and healthy people.*

	Area under the curve	Sensitivity (%)	Specificity (%)	Optimal cut-offs (second)
Condition 1: unloaded				
TST	0.955	88.5	94.1	23.4
Condition 2: loaded				
TST	0.948	86.5	97.1	26.3

TST performance

The mean TST completion times for people with stroke were 45.20±24.70 seconds and 41.47±21.54 seconds under loaded and unloaded conditions, respectively, which is consistent with previous findings.[23, 24] Chow *et al.*[24] reported that the increased loading of a backpack significantly decreased the walking speed, step length, and cadence of normal adolescent girls at a self-selected walking speed. Ransom *et al.*[23] demonstrated that external loading significantly decreased walking speed in the stair descending task in healthy young adults. A longer TST completion time in the loaded condition can be explained by the weaker muscle strength among people with stroke when they perform the stair task. With increasing loading, a greater demand is placed on the hip, knee, and ankle joints for propulsion and braking, which may make it challenging for people with muscle weakness to maintain trunk stability while walking.[24] In addition, it may be an adaptation strategy to reduce gait speed during the stair climbing task, to reduce joint loading.[23]

In the current study, people with stroke were required to wear a vest carrying 5% of their body weight for the loaded condition. This differed from the loaded condition used in the study conducted by Perron *et al.*,[3] in which people with total hip replacements wore a vest carrying a 10 kg load. In consideration of safety issues for participants with stroke, we used 5% of body weight as the loaded condition for the TST in our study. This condition was used because a previous study recommended a maximum load of 10% of a person's body weight in carrying tasks for healthy older adults.[25] Carrying 5% of the participants' body weight instead of a predetermined weight may lead to a more standardised loading effect suitable for different body builds of frail older adults, including those with stroke who participated in this study. In addition, these conditions are thought to better mimic the daily needs of people with stroke, whose daily activities mainly involve carrying light loads.

Based on the composite TST completion times, people with stroke took 140% longer than healthy controls to complete the unloaded TST and 150% longer to complete the loaded TST. These differences may be attributable to reduced gait speed,[26] poor limb coordination,[27] and decreased ability to stand up and walk up and down stairs[28] in people with stroke. Lesions in motor cortices and descending pathways following stroke lead to various biomechanical alterations, such as muscle weakness, spasticity, and abnormal selective control of the lower limbs,[29] which decrease walking speed and balance.[30] Reduced work production by the hip, knee, and ankle muscles significantly affects walking velocity.[31]

The healthy older adults in our study took 17.26±3.86 seconds and 18.53±3.89 seconds to complete the TST under unloaded and loaded conditions, respectively. These times are similar (P>0.05) to those reported by Charteris *et al.*[32] and indicated that the effects of additional loading on gait phase, including the time of overall contact and the time of the swing and double support phases, were minimal. We found that adding a 5% weight load did not affect the TST completion time of the healthy participants in the present study. A possible explanation is that the added weight is not sufficient to make significant impacts on the walking speed of the healthy participants. Although adding a weight bearing less than 50% of body weight could lead to increased energy expenditure to maintain the trunk stability of healthy adults,[32] it may not decrease their walking speed when undertaking the TST. This may explain the lack of a significant difference in the TST completion time between unloaded and loaded conditions for healthy older adults in our study.

TST reliability

Consistent with the stair climbing performance of healthy older adults (ICC=0.942),[33] the TST showed excellent intra-rater reliability under unloaded ($ICC_{2,1}$=0.97, 95% confidence interval [CI]: 0.95-0.98) and loaded ($ICC_{2,1}$=0.98, 95% CI: 0.97–0.99) conditions in people with stroke. The high intra-rater reliability may be attributable to the adequate training of the assessors and the use of standardized protocols and clear instructions. Our findings for unloaded TST subtasks 2 (ascending a staircase) and 3 (turning around and descending a staircase; $ICC_{2,1}$=0.95-0.97, 95% CI: 0.93-0.98) were similar to those reported by Ng *et al.*[34] for people with stroke (ICC=0.98). Similar demographic characteristics and the use of stairs of a similar standard may have contributed to this consistency.

TST concurrent validity

FMA-LE scores showed moderate to good negative correlations with TST completion times under unloaded and loaded conditions. The FMA-LE is widely used to assess the neurological recovery of motor function in the lower extremities after stroke.[35] Better performance in the FMA-LE indicates better motor control of the lower extremities in people with stroke.[36] Therefore, it is reasonable to expect that people with better FMA-LE performance would perform better in the TST.

The strength of the affected ankle dorsiflexors and plantarflexors showed fair correlations with TST completion times. During stair ascent, the ankle plantar flexors provide a propulsive force to lift the body to the next step, and the ankle dorsiflexors work to clear the leading foot. During stair descent, co-activation of the ankle dorsiflexors and plantarflexors is required for controlled ankle dorsiflexion of the stance leg.[37] A previous study demonstrated that the affected ankle plantarflexor, the affected hip extensor, and the unaffected knee extensor account for 50.3%, 70.9%, and 62.3% of the changes in the stair-climbing speed of people with stroke.[38] However, in addition to ankle dorsiflexors and plantarflexors, other muscle groups in the hip and knee also contribute to force generation during stair ambulation in people with stroke.[28, 39] This may explain the fair correlation between TST completion times and ankle dorsiflexor and plantarflexor strength observed in this study.

BBS scores showed good to excellent correlations with TST completion times. The BBS evaluates functional balance performance, which is required for ambulation. The high correlation may be attributable to the similarity between items in the two tests. For instance, sitting to standing in subtask 1 of the TST and turning 180 degrees in subtask 3 of the TST require balance. Better balance performance may also contribute to better performance at stair climbing, resulting in shorter TST completion times.

The lack of a significant correlation between TST completion times and LOS RT scores may be the result of the small ratio of the RT duration to the entire TST time course duration, and the different actions assessed in the two tests. RT is measured in milliseconds,[40] whereas the mean TST completion times were 45 to 50 seconds. Thus, RT had a relatively insignificant influence on the TST completion time. The LOS RT is related to COG movement towards targets with fixed footing, whereas the TST RT is related to rising from sitting.

Negative correlations were found between the LOS MV and LOS ME composite scores and TST completion times under unloaded and loaded conditions, respectively. This finding may due to the similar nature of the test requirement of the TST and LOS test to displace the COG during double-limb support at the participants' preferred speed. The participants who were more capable of shifting their COG had higher LOS MV and LOS ME composite scores and took a shorter time to complete the TST.

Significantly good to excellent positive correlations were identified between the TUG results and TST completion times under both unloaded and loaded conditions. Both the TST and TUG test require participants to rise from a chair, walk forward, turn around, and sit down on the chair, but the TST further challenges participants with a stair ambulation component. Therefore, a strong correlation between the completion times of these two tests was expected.

The CIM scores showed no significant correlation with TST completion times in this study, possibly due to differences in the domains of measurement and data collection methods between the two assessment tools. The TST measures physical mobility, while the CIM measures community integration. Community integration is determined by physical functioning and factors such as depression and the perception of overall stroke recovery.[41] Moreover, the TST is an objective test that measures the physical ability of an individual, whereas the CIM measures the subjective perception of the individual.[42]

Optimal cut-Off TST completion times

The TST completion times showed excellent ability to differentiate the performance between people with stroke and healthy older adults, with AUC values of 0.948 and 0.955 for the unloaded and loaded conditions, respectively. Thus, the TST completion times had a likelihood of 94.8-95.5% to distinguish the performance between people with stroke and healthy older adults. The optimal cut-off TST completion time (loaded: 26.3 seconds; unloaded: 23.4 seconds) was much longer than the MDC (loaded: 6.55 seconds; unloaded: 7.25 seconds) in the TST completion time in both the loaded and unloaded conditions; thus, the optimal cut-off TST completion time in this study detected the true difference between people with and without stroke rather than a measurement error.

Limitations of the study

This study has several limitations. Firstly, although knee extensors are critical for stairs, sitting down and standing up from a chair, we only selected the muscle strength of ankle dorsiflexor and plantarflexor only due to limited resources in manpower. Secondly, in the stair task of the TST, only the completion time of the task was measured. The quality and strategy of the movement was not assessed. To assess the stair task comprehensively, future studies should assess the quality of movement during the TST by video recording. Finally, the TST is a sequential task, which requires the cognitive capacity to sequence the information. However, the mechanism responsible for the connection between cognitive function and TST performance was not investigated in this study. Future studies are warranted to explore the role of cognitive function in TST performance.

Conclusions

The TST is a reliable and valid clinical tool to evaluate advanced functional mobility and the ability to cope with daily activities in people with stroke. In addition to its good reliability and correlations with other measures, the TST is a fast and simple test that does not require sophisticated equipment, making it suitable for busy hospital and rehabilitation settings.

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