Journal of Associated Medical Sciences 2019; 52 (2): 139-145

JAMS
Journal of Associated Medical Sciences

Thai-Journal Citation Index Centre (TCI) & ASEAN Citation Index (ACI)

Journal of Associated Medical Sciences

Journal homepage: https://www.tci-thaijo.org/index.php/bulletinAMS/index



Test-retest Reliability of the Five Times Sit-to-Stand Test measured using the kinect in older adults

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ARTICLE INFO

Article history:
Received 15 December 2018
Accepted as revised 25 May 2019
Available online 25 May 2019

Keywords:
Five Times Sit-to-Stand Test, kinect, psychometric properties

ABSTRACT

Background: The Kinect camera system is a low-cost portable device that can be used to time the Five Times Sit-to-Stand Test (FTSST). However, there is insufficient information and limited studies concerning the reliability of the Kinect measurements when compared with standard clinical stopwatch measurements.

Objectives: The aims of this study were to investigate the test-retest reliability of the FTSST as measured using a Kinect camera and to determine its agreement with standard clinical stopwatch measurements.

Materials and methods: Thirty older adults were timed while performing four repeated FTSSTs under two conditions: with and without their arms crossed. There were 10-minute breaks between the four tests. The times were simultaneously recorded by a Kinect camera system and by a research assistant using a stopwatch.

Results: The intraclass correlation coefficient (ICC) values for the test-retest reliability were 0.664 with the arms crossed and 0.843 with the arms free. In addition, the determination of the agreement between the Kinect and the stopwatch measurements in this study produced ICC values of 0.944 with the arms crossed and 0.954 with the arms free.

Conclusion: The test-retest reliability of the FTSST as measured using the Kinect system was good to excellent, and its agreement with the standard clinical stopwatch was excellent.

Introduction

Fall prevention is a very important strategy used to protect older adults from injuries, disabilities, and premature deaths. Falls can devastate the quality of life of older adults by compromising their activities of daily living. In addition, they can affect an individual's socioeconomic status, and they can have implications on government resource allocations. There are several methods that physical therapists use in clinics to assess the functional mobility of older adults in order to predict their fall risks, such as the Berg Balance Scale, the Timed Up and Go (TUG) test, and the Short Physical Performance Battery test. However, previous research has suggested that due to their good psychometric properties and clinical utility, the Five Times Sit-to-Stand Test (FTSST) and other clinical tests, such as the Alternate Step Test and the Six-meter Walk Test, are the best tests of general mobility.[1]

Moving from sitting to standing is a critical movement task performed in daily life. It involves the functional ability to control the center of gravity while moving the base of support from the hips to the feet in order to attain an upright standing posture.[2] Even individuals with functional deficits

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doi: 10.14456/jams.2019.22
E-ISSN: 2539-6056

commonly perform sit-to-stand tasks more than 45 times daily.[3] Older adults who have reported multiple falls have been found to perform poorly in tests of functional ability, such as the FTSST.[4] Moreover, the FTSST also reflects the functional strength of the lower extremities, and thus, it is commonly used in the clinic for functional assessments of various populations.[5,6] Due to the ease of its application in the clinical setting, there are several studies that have reported the value of the FTSST in predicting the potential for future falls in older adults.[7,8] However, comparing clinical studies is difficult because there are many variables that can affect the results, including the seat height of the chair, the arm positions, the movement speed, the patient's balancing ability, and the patient's psychological status.[9,10]

The original FTSST used in clinical settings involves the use of manual timing devices, such as a stopwatch, but these cannot be used for isolated assessments, and they do not report the kinematic movements of the lower extremities. However, new technology has been developed to enhance the test by obtaining additional information about the kinematic movements themselves and the timing of the movement phases. For example, excellent measurement consistency has been reported when using a smartphone application for the laboratory assessment of an FTSST.[11] In addition, a sensor-based sit-to-stand movement test was also found to have excellent validity in older adults.[12] Kinect-based systems have also become increasingly popular when used for functional clinical assessments. They are commonly used for gait assessments in various populations, but they can also be used for other clinical tests, such as the TUG test and the FTSST.[13,14] A Kinect-based system is a valuable clinical tool due to its ability to discriminate between fallers and non-fallers in the FTSST, as well as its correlation with the Physiological Profile Assessment, which indicated that the Kinect was feasible to use in clinical practice.[14]

The Kinect is a low cost device that can easily be used in the clinic and by older adults to monitor their fall risks by themselves at home. However, it requires specialized software to control the tests, collect and analyze the data, and report the psychometric property outcomes required for clinical decision-making.[15] Reliability is important when determining the consistency of an assessment tool. Even though the psychometric properties of the Kinect system used for the FTSST have been reported in a previous study[16], there is insufficient information and limited literature concerning the reliability of the Kinect measurements when compared with standard stopwatch measurements. Thus, the primary purpose of this study was to determine the test-retest reliability of the FTSST as measured using a Kinect system. The second purpose was to examine the agreement between the FTSST measured using the Kinect system and the FTSST measured using a standard clinical stopwatch in older adults. This would provide valuable reference data to inform clinical decision-making with regard to the selection of the most reliable measurement tools in the clinic.

Materials and methods

Study design

An observational design with repeated measures was used in this study.

Participants

This study was conducted at the Mae Khao Tom subdistrict hospital in Chiang Rai, Thailand. Thirty adults from the Mae Khao Tom community who were older than 60 years of age and who could stand independently participated in this study. The subjects were excluded if they had a cognitive impairment (Thai Mental State Examination score of less than 23), a balance impairment (Berg Balance Scale score of less than 45), a past medical history that could have affected their postural control (such as a stroke or Parkinson's disease), a problem with their vestibular system (as tested via the Dix-Hallpike test), or a pain score of more than 5 out of 10 on a Visual Analog Scale.

Ethical approval

A research assistant explained the study protocol to all of the participants. Each participant signed an informed consent form before participating in this study, and they understood that they could withdraw from the study at any time. The study protocol was approved by the Mae Fah Luang University Ethics Committee according to the tenets of the Declaration of Helsinki (ethical record number: REH-60093).

Equipment

The Kinect camera (Microsoft, Redmond, WA, USA) has been shown to provide valid measurements for movement analyses, such as sit-to-stand tests.[17] Therefore, a Kinect camera was used in this study in conjunction with "MFU fall risk detection" customized software. One Kinect camera was placed 2 meters lateral to the participant, on his or her right side, and the whole body movement was captured using an infrared sensor attached over the participant's humeral head. The customized software captured the motion of the shoulder throughout each movement sequence of the sit-to-stand-to-sit motion. The sequence timing was stopped automatically when the participant completed the 5 required movement sequences.

Rater quality

A research assistant conducted the FTSST using a standard stopwatch. He had previously practiced administering the test with young adults in the university laboratory before taking part in this research. For the standard stopwatch measurements, the time was recorded from the start, when the hip left the chair. It ended when, after 5 completed sit-to-sand-to-sit movement sequences, the participant was again seated in the chair with his or her trunk vertical. The intrarater reliability for the FTSST showed an intraclass correlation coefficient (ICC) of 0.960. The same research assistant conducted the stopwatch measurements for all of the participants as part of the research protocol.

Procedure

After being screened for eligibility, each participant performed the FTSST in a quiet room with suitable lighting.

The participant sat on a standard chair with a seat height of 0.46 meters. For the starting position, the participant placed his or her feet 0.1 meters behind the knees, as shown in Figure 1.[18] The participant was asked to stand up and sit down five times as quickly as possible, while ensuring that his or her hips and knees were fully extended when standing. The test was performed 4 times sequentially, twice under each of two conditions: with the participant's arms folded across the chest and with the arms unrestricted and free to move about as required. The participants were allowed one practice FTSST in order to familiarize themselves with the instructions and test requirements. The FTSST was then performed first with the arms folded across the chest, and then with the arms free, then again with the arms folded, and again with the arms free. They were given 10-minute breaks between the tests. The durations of the FTSSTs were simultaneously recorded by both the Kinect system and by a standard stopwatch. Both the software and the stopwatch were controlled by the same research assistant. The data were then used for further statistical analyses.

Software and system overview

In order to measure the FTSST times, the Kinect was placed approximately 0.5 meters above the floor and 2 meters lateral to the participant, on his or her right side (Figure 1). The "MFU fall risk detection" software was used to detect the subject's joints by obtaining a video feed from the Kinect at 30 frames per second with a 640 by 480 image resolution. The shoulder joint was used as a reference landmark based on our findings that it was the most stable position when compared to the other landmarks, such as the head or hip joint.

The main algorithm of our software used to measure the FTSST times is briefly explained in following steps:

1. Detect the shoulder joint.
2. Check whether the subject sits still for a while and keep this shoulder position as a sitting reference. Set the current state to sitting.
3. Detect whether the subject is standing by comparing the current shoulder position with the sitting reference. If the difference is greater than the defined thresholds and the previous state was sitting, set the state to standing and start the counting time.
4. If the current state is standing and then the subject's shoulder changes to less than the sitting reference, set the state to sitting and count a complete sit-stand-sit loop.
5. Repeat steps 3 and 4. When the count of the sit-stand-sit loop reaches five, stop and record the time.
6. Compute the elapsed time for the FTSST. Reset the software and wait for the next test.

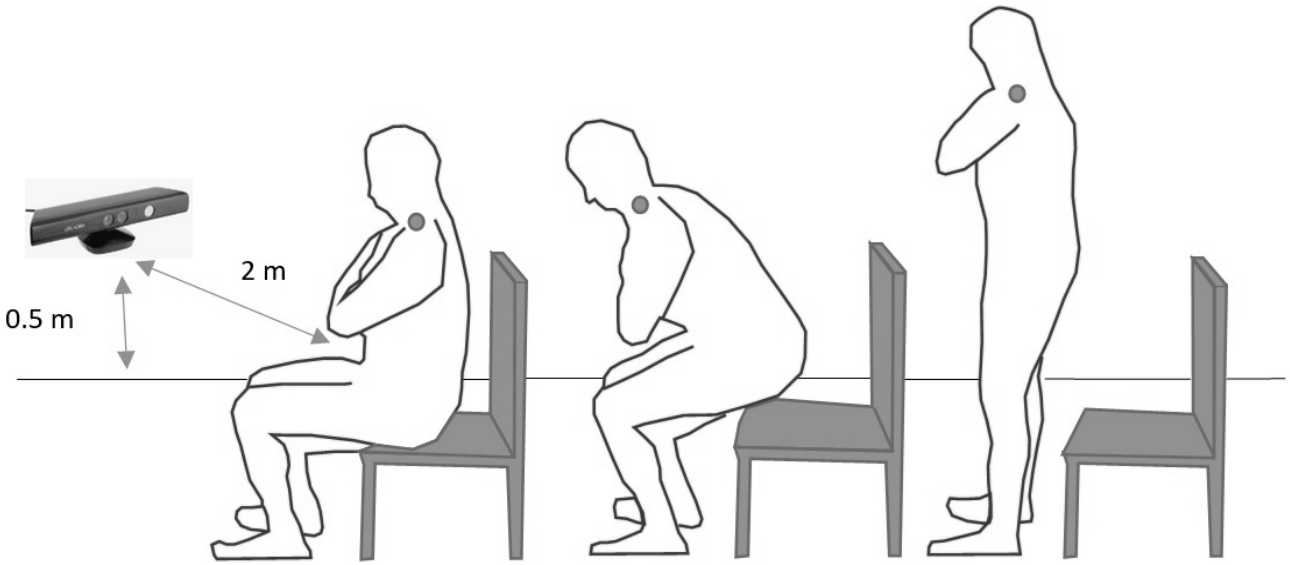


Figure 1 *Testing environment and sit-to-stand detection phases of Kinect. Right shoulder joint was a referece point.*

Statistical analysis

The baseline characteristics were presented using descriptive statistics. ICCs (two-way mixed model, type consistency, single measurement) were used to measure the consistency of each condition. One sample t-test was used to determine the difference between the means of trial 1 and trial 2 for each condition. The absolute reliability was measured using the standard error of the measurement (SEM) and the minimal detectable change at the 95% confidence interval (MDC95). Bland-Altman plots were used to determine the systematic bias between the test and retest. The values were computed using the following formulas:

$$SEM = SD \times \sqrt{(1-ICC)}$$

$$MDC95 = 1.96 \times \sqrt{2} \times SEM$$

Additionally, ICCs (two-way random model, type absolute agreement, average measurement) and Bland-Altman plots were used to assess the agreement between the two measurement methods. Between the repeated measures and between the methods, ICCs between 0.75 and 1.00

could be interpreted as excellent, ICCs between 0.60 and 0.74 could be interpreted as having good reliability, ICCs between 0.40 and 0.59 could be interpreted as having fair reliability, and ICCs of less than 0.40 could be interpreted as having poor reliability.[19] IBM SPSS Statistics for Windows (version 20.0; IBM Corp., Armonk, NY, USA) was used to analyze the data, with a significance level set at 0.05.

Results

Test-retest reliability of the FTSST measured using the Kinect

The baseline characteristics are presented in Table 1. As shown in Table 2, there were no differences between the means of trial 1 and trial 2 for both the FTSST with arms crossed (p=0.696) and with arms free (p=0.778). The test-retest reliability results showed good reliability [ICC=0.664, 95% confidence interval (CI)=0.404–0.824, SEM=0.808] to excellent reliability [ICC=0.843, 95%CI=0.697–0.843, SEM=0.389) with arms crossed and arms free, respectively. In addition, the test-retest reliability for the arms free condition was higher than that for the arms crossed condition. The Bland-Altman plot showed a positive bias of 0.170 seconds for the arms crossed condition (95% limits of agreement, from -2.561 seconds to 2.907 seconds; Figure 2) and a negative bias of -0.130 seconds for the arms free condition (95% limits of agreement, from -2.057 seconds to 1.799 seconds; Figure 2), indicating an overestimation of the repeated measurement for the arms crossed condition and an underestimation of the repeated measurement for the arms free condition. The MDC95 of the FTSST as measured using the Kinect system for the arms crossed condition was 2.239 seconds; for the arms free condition it was 1.078 seconds.

Table 1 Baseline characteristics.

Characteristics	Older adults (n=30)
Gender, n (%)	
Males	8 (26.67)
Females	22 (73.33)
Age in years, mean (SD)	65.80 (5.72)
Weight in kg, mean (SD)	58.48 (10.12)
Height in m, mean (SD)	1.56 (0.07)
Number of education years, mean (SD)	3.60 (1.22)
Thai Mental State Examination, mean (SD)	25.58 (1.61)
Berg Balance Score, mean (SD)	55.57 (0.67)
Dix-Hallpike test, n (%)	
Negative	30 (100)
Positive	0 (0)

SD: standard deviation

Table 2 Reliability and minimum detectable change for the FTSST using the Kinect.

	Trial 1	Trial 2	Different (SD_{diff})	$ICC_{3,1}$	95% confidence interval	SEM	MDC_{95}
	Mean (SD)						
Arms crossed (seconds)	9.536 (1.658)	9.363 (1.744)	0.173 (1.395)	0.664	0.404 to 0.824	0.808	2.239
Arms free (seconds)	9.184 (1.663)	9.313 (1.845)	-0.129 (0.984)	0.843	0.697 to 0.922	0.389	1.078

FTSST: Five Times Sit-to-Stand Test, SD: standard deviation, ICC: intraclass correlation coefficient, SEM: standard error of the measurement, MDC95: minimal detectable change at the 95% confidence interval

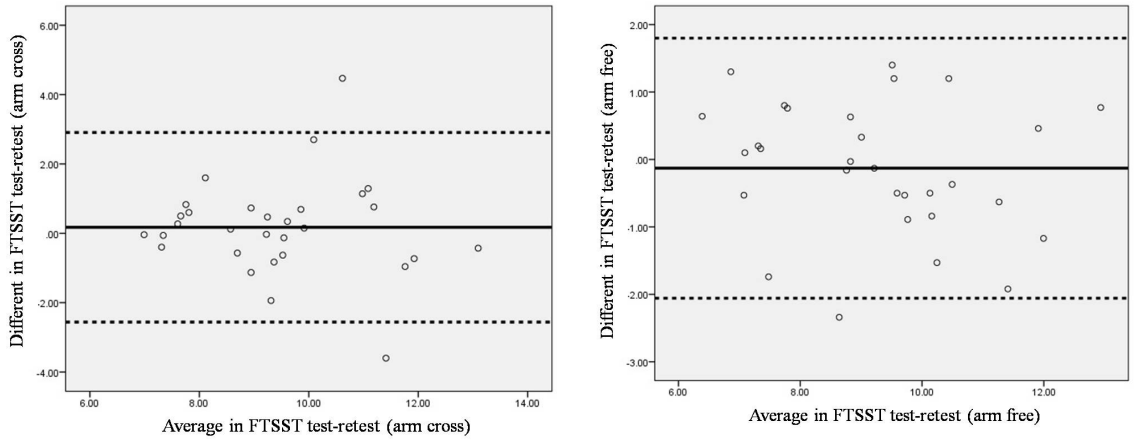


Figure 2 *Bland-Altman plot representing the average of two trials for test-retest for FTSST for the arms crossed and arms free conditions.*

Agreement of the FTSST measured using the Kinect system and a standard stopwatch

The measurement consistency between the Kinect system measurements and the standard stopwatch measurements was excellent, which was indicated by the ICCs for the Kinect system and standard stopwatch measurements for both the arms crossed condition and the arms free condition, which were 0.944 (95%CI=0.224–0.986) and 0.954 (95%CI=0.222–0.989), respectively (Table 3). The Bland-Altman plots represented negative biases of -0.464 seconds (95% limits of agreement, from -1.056 seconds to 0.128 seconds; Figure 3) for the arms crossed condition and -0.462 seconds (95% limits of agreement, from -1.015 seconds to 0.090 seconds; Figure 3) for the arms free condition, indicating an underestimation of the time by the Kinect system.

Table 3 The FTSST agreement analysis between the Kinect and the standard stopwatch measurements.

	FTSST using Kinect (seconds)*	FTSST using standard stopwatch (seconds)*	$ICC_{2,k}$	95% confidence interval	SEM
Arms crossed	9.452 (1.552)	9.915 (1.658)	0.944	0.224 to 0.986	0.071
Arms free	9.251 (1.687)	9.713 (1.797)	0.954	0.222 to 0.989	0.062

**Values are expressed as mean (SD)*
FTSST: Five Times Sit-to-Stand Test, SD: standard deviation, ICC: intraclass correlation coefficient, SEM: standard error of the measure

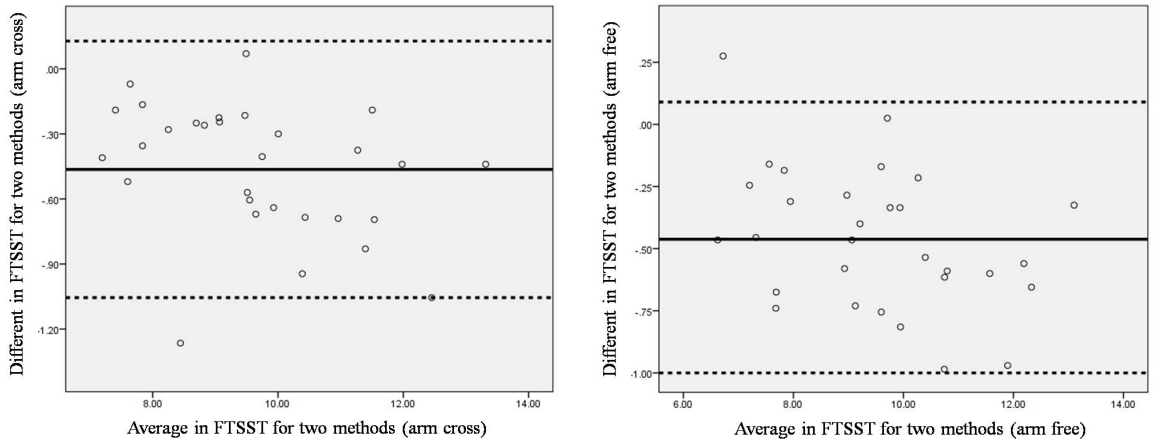


Figure 3 *Bland-Altman plot representing the agreement between two methods for the FTSST.*

Discussion

The aim of this study was to investigate the reliability of the Kinect system for the measurement of the FTSST in older adults and its agreement with standard clinical stopwatch-measured tests. This research represents the development of customized software using a low-cost device. The results showed good to excellent test-retest reliability for the FTSST by the Kinect system for both conditions. In addition, excellent agreement was found between the Kinect system and the standard clinical stopwatch measurements.

Reliability of the Kinect system for the FTSST

The results of this study showed that there was good to excellent test-retest reliability, indicating that the FTSST timed by the Kinect system is the optimal choice for clinical use. One previous study suggested that an ICC of more than 0.6 was a useful consideration in clinical outcome measurements.[20] Our results were not found to be different from those of other studies, and this is supported by a previous systematic review that reported a test-retest reliability for the FTSST in which the ICC values ranged between 0.64 and 0.96.[21] However, a higher test-retest reliability for the arms free condition than the arms crossed condition indicated that the arm position affected the outcome measurements. This is in contrast to the results from the study by Ng et al., who found that there was no difference between the times obtained by older adults while performing a FTSST with different arm positions.[22] This may be due to the "MFU fall risk detection software" used with the Kinect system, which timed the movement pathway of the shoulder. Thus, the motion capture by the Kinect system may have been affected when the arm position was out of neutral alignment.

In this study, the smallest change that could be considered to be a true change was found to be different for each arm condition: 2.239 seconds and 1.078 seconds for the arms crossed and arms free conditions, respectively. This is in contrast with the results from the study by Goldberg et al. in 2012, who found a minimal detectable change that exceeded 2.5 seconds in older adults[7]; however, the measurement protocol in our study was different.

FTSST agreement between the Kinect system and the standard stopwatch measurements

A strong correlation between the Kinect system and clinical standard measurements, such as those obtained using a Vicon motion analysis system, for timed sit-to-stand tests can be found in Parkinson's disease studies (r=0.999).[17] Therefore, the measurements of the time taken in the sit-to-stand studies using the Kinect camera system are considered to be valid. The FTSST test is easily performed, and tests using a standard stopwatch to measure the time have been commonly used in clinical practice.

This study found agreement between the Kinect system and the standard stopwatch measurements for the FTSST, indicating that the Kinect system is an optimal tool for this clinical test, even though there was a difference in the measurement methods: the standard stopwatch measurements were obtained by focusing on the hip movement, while the Kinect system focused on the shoulder movement. This is supported by a previous study that found a high correlation for the FTSST using the Kinect system and standard stopwatch measurements (r=0.704 to 0.931).[14] The Kinect camera is superior to the standard stopwatch measures because it can provide a self-assessment method to determine the risk of falling. Older adults can monitor their own risk of falling at home by themselves. Moreover, Kinect cameras can also provide kinematic joint data during movement; therefore, they are useful tools for clinical analyses conducted by both physical therapists and researchers.

Study limitations

The older adults who participated in this study were healthy older adults. Therefore, the reliability of these tests in various populations, such as older adults with balance impairments and health problems as well as patients suffering from strokes or Parkinson's disease, is unknown. The other psychometric properties of the Kinect system used for the FTSST, such as the test-retest reliability between days and a cut-off score for the prediction of falls in older adults, are also unknown. Further studies should aim to fill these gaps in the knowledge.

Conclusion

A good-to-excellent within-day test-retest reliability was found for the FTSST measured using the Kinect system. The excellent agreement of the measurements between the Kinect system and a standard stopwatch could inform the decision-making of the management of clinical practices, such as the promotion of FTSST self-assessments using the Kinect at home.

Acknowledgements

The authors would like to thank research assistant Mr. Jirawut Yafan for collecting the data.

Conflict of interest

The authors declare no conflicts of interest.

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