Validity of the Four Square Step Test to Assess Dynamic Balance, Step Velocity and Displacement

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Abstract— **The four square step test (FSST) is commonly used to assess dynamic standing balance in elderly adult populations. To date, only the time (recorded by a stop-watch) to complete the test has been used. Other important dynamic balance information such as step velocity and step displacement can be extracted. This study re-examined the validity of recording the FSST time with a stop-watch by comparing it to a "gold standard" method (Vicon) and investigated the relationship between FSST stop-watch time and measures of step velocity, step displacement, and age. After familiarization, fourty-one healthy adults (42 ± 12 yrs.) completed three FSST trials. The FSST time was recorded by a stop-watch and the participants' foot movements were simultaneously recorded by a Vicon motion system (120 Hz). Measures extracted from the Vicon system were FSST time, step velocity (four directions) and step displacement (four directions). A paired t-test was used to compare FSST time recorded by each system. Pearson's correlation analyses were conducted to identify relationships between measures. No significant difference was found between the FSST time recorded by the methods (mean difference = 0.02 ± 0.11 s). Moreover, a strong positive linear relationship ($r = 0.99$, $p < 0.0001$) was found between the FSST time recorded by the methods. A moderate linear relationship was found between the FSST time (Vicon) and step velocity ($r = 0.67$, $p < 0.0001$). Poor linear relationships were found between (1) step velocity and step displacement, (2) FSST time (Vicon) and step displacement, (3) FSST time (both methods) and age, (4) age and step velocity, and (5) age and step displacement. In conclusion, the FSST stop-watch method is valid. Moreover, it may be used to predict step velocity but not step displacement. No relationship was found between age and the FSST time, step velocity or step displacement.**

Keywords— **Dynamic balance, step velocity, aging, falls.**

I. Introduction

Falls are a major cause of injury in the elderly adult population [1-4] and commonly result from a trip or slip [5, 6] where a person has been unable to rapidly recover balance by stepping quickly to reestablish the base of support. The four square step test (FSST) is widely used to assess dynamic balance in the elderly adult population [7]. It records the time taken to step quickly in the forwards, backwards and sideways directions. The test is easy to conduct since it involves little equipment (stop-watch and a level floor space). Although it has been validated against other existing balance tests, its objective validity (accuracy of stop-watch measure) has not been assessed nor have key measures of step velocity and displacement been extracted. The primary aim of this study was to investigate the objective validity of the FSST time measure. A secondary aim was to extract measures of step velocity and displacement to determine whether these measures are related to the FSST time measure and age.

Walking speed is an important measure of a person's functional capacity [8] and is associated with survival or mortality risk [9]. Hence, it is important for an aging population to maintain step velocity. Moreover, the ability to move the feet quickly after a sudden loss of balance is critical for balance recovery to avoid a fall after a stumble, trip or misstep. Work has shown that the ability to rapidly step forward, backward, and sideways reduces with age [10] and is slower for fallers compared to non-fallers [11]. Other research has shown that the ability to move feet quickly to re-establish a base of support is critical to recover balance during a forward fall [12]. It was found that healthy older females, compared to older males and younger females were significantly less able to take a rapid forward step to regain balance during a forward fall. The reduced ability of older females to recover balance during a forward fall may be related to a reduced capacity to generate rapid ankle plantar-flexor torque [13].

For the FSST test, an assessor uses a stop-watch to measure the time taken by a person to complete the test. The test measures a person's ability to rapidly step forward, backward and sideways. The objective validity of this measure however is unknown. The accuracy of the test may be affected by human reaction time [14] since a stop-watch must be manually started and stopped. Moreover, measures such as step velocity and displacement have not been previously extracted from this test. These data can be extracted may provide additional important information about a person's dynamic balance. This study investigated the objective validity of the FSST by simultaneously capturing FSST time data with a stop-watch and a Vicon motion analysis system (gold standard). It also investigated the measures of step velocity and displacement, and the effect of age upon these outcome measures.

II. MATERIALS AND METHODS

Fourty-one healthy adults (age: 41.7 ± 11.9 yrs; mass: 73.2 ± 13.4 kg; height: 167.2 ± 8.7 cm) participated in this study. Study approval was obtained from RMIT University human ethics committee and each participant provided written informed consent. All participants were able to move unassisted and were without any pathology. After familiarization, each participant was instructed to complete the FSST in the shortest time possible (3 trials). Spherical passive reflective markers (14 mm diameter) were attached to the heels (calcaneus area) of the participants' shoes and recorded by a six-camera Vicon motion capture system (Oxford Metrics Ltd., Oxford), termed here as "gold standard" method. The capture rate was 120 Hz. The same investigator simultaneously measured the time taken to complete each FSST trial using a stop-watch. A fourth-order Butterworth low-pass filter with a cut-off frequency of 5 Hz was used to smooth marker trajectories captured by the Vicon system. Salient stationary points of the magnitude of the three-dimensional heel velocity vectors were used to determine time taken, step velocity and step displacement for each FSST trial. Numerical differentiation was used to compute the three-dimensional heel velocity vectors. Descriptive statistics were calculated for each outcome measure. Paired t-tests and Pearson's correlation analyses were conducted to assess the objective validity of the test and to identify relationships between outcome measures: 1) FSST stop-watch time and step velocity, 2) FSST stop-watch time and step displacement, 3) FSST stop-watch time and age, 4) step velocity and step displacement, 5) age and step velocity, and, 6) age and step displacement.

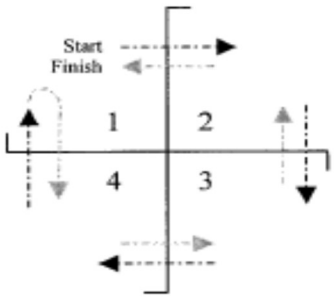

Fig 1. FSST setup. The participant starts in square 1, facing square 2, The participant steps forward into square 2, sideways to square 3, backward to square 4, sideways to square 1, sideways to square 4, forward to square 3, sideways to square 2, and backward to square 1 (figure taken from Dite et al., p. 1568).

III. RESULTS

The average time difference between the recorded FSST times was 0.02 ± 0.11s (table 1). The mean Vicon and stop-watch FSST times were 5.58 ± 0.81 s and 5.60 ± 0.81 s respectively. This difference was found to be non-significant.

A strong positive linear relationship ($r = 0.99$, $p < 0.0001$) was found between the FSST time recorded by the methods (table 1, figure 1). A moderate linear relationship was also found between the FSST time (Vicon) and step velocity ($r = 0.67$, $p < 0.0001$). Poor linear relationships however were found between (1) step velocity and step displacement, (2) FSST time (Vicon) and step displacement, (3) FSST time (both methods) and age, (4) age and step velocity, and (5) age and step displacement.

Table 1 Pearson correlation analyses. L: left; R: right; V: velocity ($mm \cdot s^{-1}$; S: displacement (mm); t: time (s)

y	x	Regression	r	p-value
FSST Time Relationships				
t_{Vicon}	$t_{Stop\text{-}Watch}$	y = 0.99x + 0.03	0.99	0.0001
t_{Vicon}	$V_{step(L)}$	y = -0.0049x + 9.2	0.68	0.0001
t_{Vicon}	$V_{step(R)}$	y = -0.0043x + 8.8	0.67	0.0001
t_{Vicon}	$S_{step(L)}$	y = 0.00057x + 3.3	0.33	0.03
t_{Vicon}	$S_{step(R)}$	y = 0.00034x + 4.2	0.22	0.16
Age Relationships				
Age	$t_{Stop\text{-}Watch}$	y = 3.727x + 19.9	0.27	0.09
Age	t_{Vicon}	y = 3.884x + 19.1	0.28	0.07
Age	$V_{step(L)}$	y = -0.0496x +76.6	0.49	0.01
Age	$V_{step(R)}$	y = -0.03x + 62.9	0.34	0.03
Age	$S_{step(L)}$	y = -0.0062x+ 65.5	0.27	0.09
Age	$S_{step(R)}$	y = -0.0024x + 50.6	0.12	0.47
Step Velocity/Displacement Relationships				
$V_{step(L)}$	$S_{step(L)}$	y = 1.996x +2529.03	0.46	0.003
$V_{step(R)}$	$S_{step(R)}$	y = 2.409x +2281.04	0.57	0.001

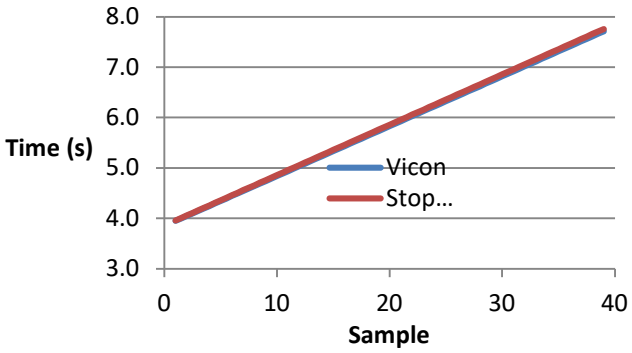

Fig 1. Plot of linear regression relationship for FSST time between Vicon and stop-watch methods.

IV. Discussion

Step velocity and walking speed are important measures of a person's functional capacity with the latter measure associated with survival or mortality risk [8,9]. Hence, it is important for an aging population to maintain or improve walking speed and step velocity. Step velocity, or the ability to rapidly move the feet, is critical for maintaining dynamic balance, or recovering balance after a trip, stumble or misstep, especially for the elderly adult population [12].

This study investigated the validity of recording FSST time with a stop-watch by comparing it to a "gold standard" method. It also investigated the measures of step velocity and displacement, and the effect of age upon these outcome measures. These measures have not been previously extracted from the FSST.

The FSST time recorded with a stop-watch exhibited high objective validity since strong agreement was found with the "gold standard" method. On average, the method of recording the FSST with a stop-watch was found to differ by 20 milliseconds. This difference was non-significant. A strong positive linear relationship ($r = 0.99$, $p < 0.001$) was also found between the methods. The results also show that the FSST time recorded with a stop-watch can be used to predict step velocity since a strong positive linear relationship was found ($r = 0.79$, $p < 0.001$). This finding is important since step velocity is critical to recover balance during a forward fall.

Poor linear relationships were found between (1) step velocity and step displacement, (2) FSST stop-watch time and step displacement, (3) FSST stop-watch time and age, (4) age and step velocity, and (5) age and step displacement. Hence, with these findings the FSST cannot be used to predict these parameters. A limitation of this study was that fact that that average age of the participants was 42 years and it was a sample size of forty-one healthy adults. Future work should involve older adults and a larger sample size to further investigate the effect of age on the FSST and measures of step velocity and displacement.

V. Conclusions

The FSST time recorded with a stop-watch was found to exhibit high objective validity. Importantly, the FSST may be used to partly predict step velocity. This finding is significant since the ability to step quickly is critical in order to recover balance during a forward fall. This test is easy to conduct in clinical or non-clinical settings and requires little equipment. No relationship was found between: 1) FSST time and step displacement; 2) age and the FSST time; and, 3) age and step velocity or step displacement.

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