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Validity and reliability of an iPhone App to assess time, velocity and leg power during a sit-to-stand functional performance test

Juan Diego Ruiz-Cárdenas[a, *], Juan José Rodríguez-Juan[a], Rowan R. Smart[b], Jennifer M. Jakobi[b], Gareth R. Jones[b]

[a] ECOFISTEM Research Group, Faculty of Health Sciences, Catholic University of Murcia, Murcia, Spain
[b] Healthy Exercise and Aging Laboratory Group (HEAL), School of Health and Exercise Sciences, University of British Columbia Okanagan, Kelowna, BC, Canada

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ABSTRACT

The purposes of this study were: (i) Analyze the concurrent validity and reliability of an iPhone App for measuring time, velocity and power during a single sit-to-stand (STS) test compared with measurements recorded from a force plate; and (ii) Evaluate the relationship between the iPhone App measures with age and functional performance. Forty-eight healthy individuals (age range: 26–81 years) were recruited. All participants completed a STS test on a force plate with the movement recorded on an iPhone 6 at 240 frames-per-second. Functional ability was also measured using isometric handgrip strength and self-paced walking time tests. Intraclass correlation coefficients (ICC), Pearson’s correlation coefficient, Cronbach's alpha (α) and Bland-Altman plots with 95% confidence intervals (CI) were used to test validity and reliability between instruments. The results showed a good agreement between all STS measurement variables; time (ICC = 0.864, 95%CI = 0.77–0.92; α = 0.926), velocity (ICC = 0.912, 95%CI = 0.85–0.95; α = 0.953) and power (ICC = 0.846, 95%CI = 0.74–0.91; α = 0.917) with no systematic bias between instruments for any variable analyzed. STS time, velocity and power derived from the iPhone App show moderate to strong associations with age (|r| = 0.63–0.83) and handgrip strength (|r| = 0.4–0.64) but not the walking test. The results of this study identify that this iPhone App is reliable for measuring STS and the derived values of time, velocity and power shows strong associations with age and handgrip strength.

1. Introduction

The sit-to-stand (STS) test is a reliable tool to measure functional mobility [1], which declines considerably with increased age [2], disease and disability [3] and has been considered a physical marker of ageing along with handgrip strength or walking speed [4,5]. Sit-to-stand time increases with age, likely the consequence of slower leg velocity and reduced muscle power [6,7]. Leg velocity and power are often correlated with changes in handgrip strength and walking speed, both influence age-related decline in functional mobility [8,9]. Therefore, changes in STS performance may be considered as an important measure of physical independence.

Although time to complete the STS is the primary measure of function, leg velocity and muscle power also contribute to understanding physical performance [10]. However, measurement of velocity and power require more sophisticated assessment tools such as a force plate [11,12], accelerometer [13,14], force transducers [7] and/or motion capture systems [15]. This technology, although sensitive to small changes in STS performance is not readily available or affordable for clinical or field-based testing environments and some current methods remain complex, difficult and time consuming to analyze [5]. Recent advances in hand-held technology offer an opportunity to assess leg velocity and power through a smartphone mobile application (App). Recently App technology was used to justify the validity and reliability of the Timed-Up and Go [14,16] and the five-time STS [16] assessment protocols. However, these Apps do not provide analysis of leg velocity or power [14,16]. Leg power is a product of the force (Newtons; N) × the velocity (meters/second; m/s) generated during the move-

* Corresponding author at: Physiotherapy Department, Faculty of Health Sciences, Catholic University of Murcia, Campus Los Jerónimos, 30107 Murcia, Spain.
Email address: jdruiz@ucam.edu (J.D. Ruiz-Cárdenas)

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ment, and is considered a good measure of fall risk [13] and age-related functional decline [7]. To our knowledge, there is no App technology currently available to objectively measure time, velocity and power during a single STS test captured from a video recording using a smartphone device.

The primary objective of this study was to determine the concurrent validity and reliability of an iPhone App for measuring time, velocity and power during a single-STS test compared with established measurements recorded from a force plate. The secondary objective was to ascertain whether these measurement variables were related to age, handgrip strength, and self-selected walking speed.

2. Methods

The App (*Sit-to-stand App version 1.0.8*) was developed using Xcode 8.3.2 and the Swift 3.1 programming language (*Apple Inc., USA*) for Mac OS X (*Apple Inc., USA*). For capturing, importing and manipulating high-speed videos the AVFoundation and AVKit frameworks (*Apple Inc., USA*) were used. The App was designed for analyzing STS test via high-speed video recording (240 frames-per-second) to allow the calculation of time between two frames selected by the user and subsequent calculation of the mean vertical velocity and mean vertical power relative to body weight. After the calculation of the time during STS test, the App used the following Newtonian equation for calculating mean vertical velocity:

$$V = d/t \qquad (1)$$

where the mean vertical velocity is equal to the femur length (*d*), the distance between the superior aspect of the greater trochanter and lateral condyle of the femur, divided by the time in seconds (s) to rise from the chair *(t)*, as measured between two user selected frames. Subsequently, mean vertical power (*Pmean)* was estimated from the following equation:

$$Pmean = 2.773–6.228 \times t + 18.224 \times d \qquad (2)$$

Pmean was integrated into the App software. This regression equation was developed using data previously acquired from a force plate (*AMTI SGA 6-3, MA, USA*) in a sample of 17 healthy subjects (10 males; Range: age = 26–81 years, body weight = 53.5–98.7 kg, femur length = 0.33-0.45m, time of rising phase = 0.30–1.11 s, *Pmean* = 3.26–8.86 W/kg). The *Pmean* and time *(t)* of the rising phase from the force plate and the femur length *(d)* were used to develop the multivariate regression analysis (*r^2 adjusted = 0.917; p = 0.035; standard error of estimate(SEE) = 0.45)* using SPSS Statistics 19.0 (*IBM SPSS Inc. USA, 2010*).

2.1. Participants

Forty-eight healthy individuals (25 women), (mean and [range]: age = 50.6 [21–87] years, height = 1.68 [1.5–1.85]m, body weight = 71.9 [50.2–125.5]kg, femur length = 0.389 [0.33–0.39]m, time to rising = 0.53 [0.35–0.80] sec) were recruited for the validation study. Eight males were removed for Objective 2 due to missing data from the functional test battery (handgrip and walking tests). Thus, 40 healthy individuals were used to assess the relationship between the App measurement variables with age, handgrip strength and self-selected walking speed (Table 1). All procedures conformed to the Declaration of Helsinki and this study was approved by the Behavior Research Ethics Board at the University of British Columbia and at the Catholic University of Murcia. Written informed consent was obtained from each participant in advance.

Table 1
Sample characteristics (n = 40).

	Mean	SD	Minimum	Maximum
Age (years)	53.1	23.83	21	87
Weight (kg)	69.6	13.31	50.2	113.4
Height (m)	1.66	0.085	1.50	1.85
Femur length (m)	0.38	0.039	0.33	0.49
Walking time (s)	2.81	0.52	1.98	5.04
Handgrip (kg)	66	19.94	26.8	112.3
STS App variables				
STS time average (sec)	0.50	0.09	0.375	0.7
STS time fastest (sec)	0.47	0.09	0.346	0.7
Mean vertical velocity average (m/s)	0.79	0.16	0.48	1.18
Mean vertical velocity fastest (m/s)	0.85	0.17	0.49	1.22
Pmean average (W/kg)	6.69	0.91	4.62	8.60
Pmean fastest (W/kg)	6.89	0.90	4.66	8.68

Data are given as mean, standard deviation (SD) and range. Sit-to-stand (STS). Mean power relative to body weight (*Pmean*). Average of three repetitions (average). Fastest repetition (fastest). Kilograms (kg), meters (m), seconds (sec), meters per second (m/s), Watts per kilogram (W/kg).

2.2. Objective 1–validity and reliability

Prior to the execution of STS test, the superior aspect of greater trochanter and lateral condyle of the femur on the right side of the participant were marked with colored stickers to measure the femur length. Femur length measured with an anthropometric measuring tape by JDR or JJR. Participants completed three STS repetitions to complete the test while standing without footwear on a force plate (*AMTI SGA 6-3, MA, USA*). Each STS repetition was recorded on video using the iPhone App (*Sit-to-stand App version 1.0.8*) installed on an iPhone 6 running iOS 10.2.1 (*Apple Inc., USA*). Each repetition was recorded at 240 frames-per-second at a quality of 720 pixels. The iPhone was not attached to the participant, rather it was positioned on a 0.7m-high tripod placed 3 m from the force plate on the right side of the participant (Fig. 1).

To execute the test, subjects sat on a rigid chair with their arms crossed over their chest with the hip, knee and ankle joints at approximately 90° as previously reported [13,17]. Both feet rested on the force plate and the subjects were instructed to stand-up as fast as possible.

2.3. Data analysis

Video analysis from the STS App was undertaken by two independent, blinded observers (JDR, JJR). To objectively determine the onset and end position of the final movement, a visual grid (3.8 × 3.8 pixels) for reference was built into the App as an overlay. The observers selected the first frame and the final frame by pressing a start and stop button, respectively. The first frame was determined when the pelvis began to move forward after anterior trunk tilt and time-matched to when the trochanter (i.e. the colored sticker) crossed the first horizontal grid line on the screen of the App. The final frame was defined as the end of the movement cycle when full extension of hip and knee were achieved in an upright stance. This position was time matched to the point when the trochanter achieved the highest vertical point during the upright movement cycle (Fig. 2).

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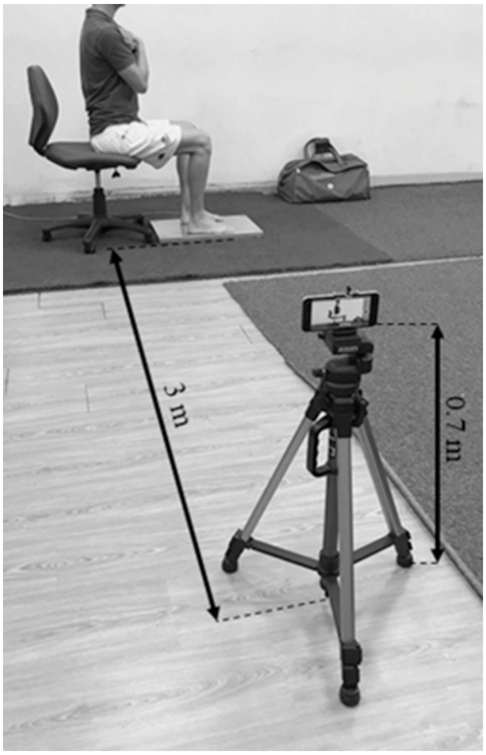

Fig. 1. Measurement environment. iPhone positioned on a 0.7 m-high tripod placed 3 m from the right side of the participant.

To validate these measures, data from the force plate was calculated from the rising phase whereby the duration of the movement starts with the peak of vertical force and ends when the vertical force curve reaches body weight after decreasing and subsequently increasing [11]. From this phase, mean power relative to body weight was calculated as the product of mean force and mean vertical velocity [Eq. (1)] divided by subject body weight. Force plate data were stored and analyzed off-line using Spike2 software *(Spike2 version 7.12 Cambridge Electronic Design, UK)*. The measures of STS time, mean vertical velocity and *Pmean* from the App were compared to those determined from the force plate.

2.4. Objective 2–construct validity relative to functional performance measures

To determine whether the STS App measurement results were indicative of functional performance the measurement variables compared against: 1) Age; 2) Handgrip strength; and 3) Self-selected walking speed.

Handgrip testing was performed in standing position with the arm at the side and the forearm and wrist placed into neutral. Using a Smedley handheld digital hand dynamometer (*Baseline Evaluation Instruments, Fabrication Enterprises Inc. White Plains, NY, USA*), subjects squeezed the device maximally. The test was repeated two times on both the right and left hand with 30-s of rest between trials of the same hand. The greater of the two trials from the right and left side were used and added together to give overall handgrip strength.

Self-selected walking speed was determined by having participants walk at a pace they consider *'normal walking speed'* over a distance of 8 m on a non-carpeted floor. To account for the time it took participants to accelerate and decelerate, markers were provided 2 m before and after the measured distance. Therefore, the total timed distance was 4 m. The timed walking test was completed twice to promote familiarity and improve accuracy.

2.5. Statistical analyses

2.5.1. Objective 1

To determine the reliability and validity of STS time, mean vertical velocity and *Pmean* between the App and force plate measures a Pearson's correlation coefficient (r) with 95% confidence intervals (CI), the intra-class correlation coefficient ($ICC_{2\text{-}1}$) with 95% CI and Cronbach's alpha was performed. Standard error of the estimate (SEE) was also used to report the typical error in the measurements. Paired samples *t*-test and Bland-Altman plots were also conducted to identify potential systematic bias. Furthermore, to test the inter-observer reliability in the measurement of STS time, mean vertical velocity and *Pmean* as well as to identify potential systematic differences, the $ICC_{2\text{-}1}$ coefficient with 95% CI and the independent sample *t*-test were used.

2.5.2. Objective 2

To evaluate the relationship between the App measurement variables and age and functional performance as assessed using handgrip strength and self-selected walking times. The average of three STS repetitions and the fastest STS repetition were recorded and a Pearson's correlation coefficient was used to examine relationships. The level of statistical significance was set at $p \leq 0.05$.

3. Results

3.1. Objective 1–reliability and validity of APP: concurrent validity of the STS app

Pearson's correlation coefficients revealed a very strong relationship between the STS App assessed variables for STS time ($r = 0.86$; 95% CI = 0.76–0.91; SEE = 0.055 s; $p < 0.001$), mean vertical velocity ($r = 0.91$; 95% CI = 0.84–0.94; SEE = 0.062 m/s) and *Pmean* ($r = 0.85$; 95% CI = 0.74–0.913; SEE = 0.49W/kg) and those determined using the force plate (Fig. 3).

3.2. Reliability and accuracy of the measurements with the App vs force plate

There was strong agreement between time ($ICC_{2-1} = 0.864$, 95%CI = 0.77–0.92; $\alpha = 0.926$), mean vertical velocity ($ICC_{2-1} = 0.912$, 95%CI = 0.85–0.95; $\alpha = 0.953$) and *Pmean* ($ICC_{2\text{-}1} = 0.846$, 95% CI = 0.74–0.91; $\alpha = 0.917$) assessed with the App and the force plate. The paired sample *t*-test revealed no systematic bias between instruments for any variable analyzed (mean difference of time = −0.001; 95% CI = −0.02–0.01; p = 0.816. mean difference of vertical velocity = 0.002; 95%CI = −0.02–0.02; p = 0.834. mean difference of *Pmean* = 0.08; 95% CI = −0.24–0.08; p = 0.322).

3.3. Inter-individual reliability

No significant differences existed between the App variables of STS time (mean difference = 0.004; 95%CI = −0.03–0.04; p = 0.814), mean vertical velocity (mean difference = −0.007; 95%CI = −0.71–0.05; p = 0.829) and *Pmean* (mean difference = 0.009; 95% CI = −0.37–0.36; p = 0.954) collected by the two observers. Moreover, there was strong agreement between the STS time ($ICC_{2-1} = 0.982$, 95%CI = 0.97–0.99; $\alpha = 0.991$), mean vertical velocity ($ICC_{2-1} = 0.984$, 95%CI = 0.97–0.99; $\alpha = 0.992$) and *Pmean* ($ICC_{2-1} = 0.993$, 95%CI = 0.98–0.99; $\alpha = 0.996$) when measured between both observers.

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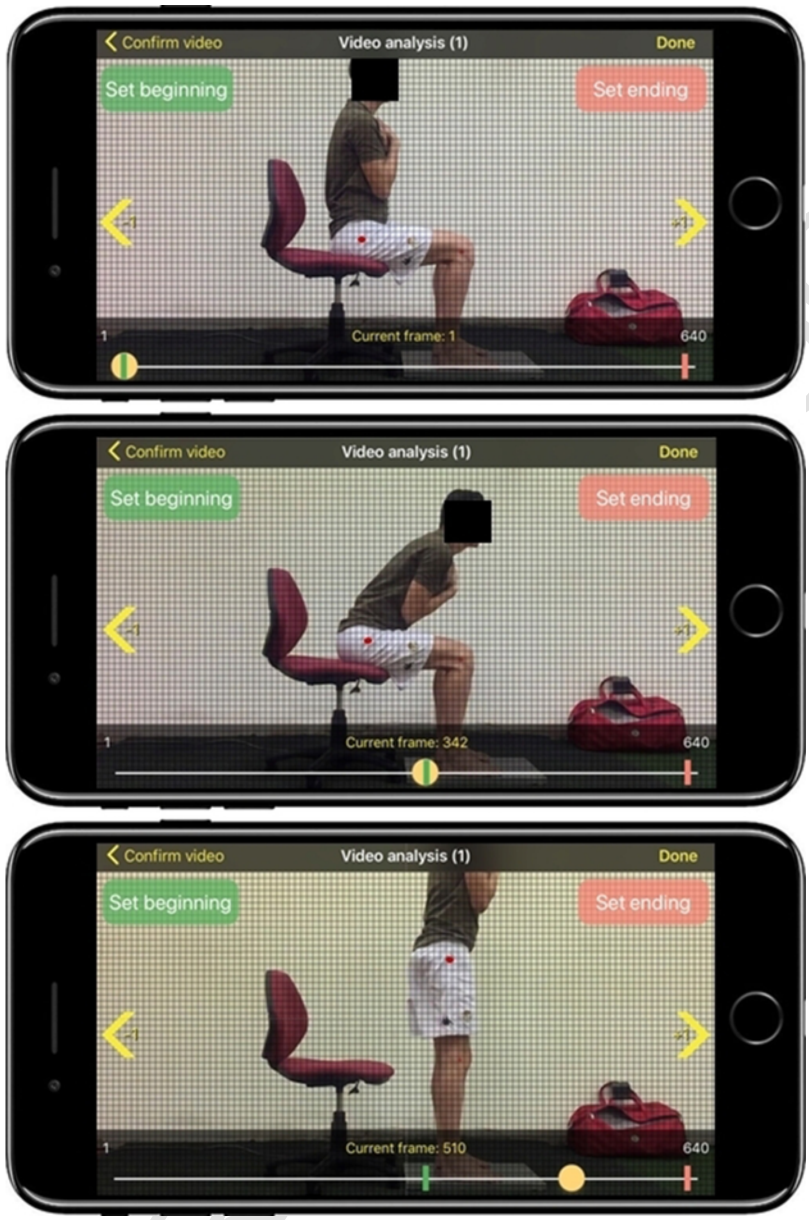

Fig. 2. User interface of the App. Red dot represents the colored sticker placed on the greater trochanter while the subject was at rest (top panel), at the beginning of the vertical movement when red dot crossed the first horizontal grip line on the screen (middle panel), and at the end of the vertical movement, when it achieved the highest point (lower panel). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.3.1. *Objective 2–construct validity relative to functional performance measures*

Pearson's correlation coefficient showed a strong to very strong relationship between age and STS time, mean vertical velocity, and *Pmean* values. Handgrip strength was related to the STS time, mean vertical velocity and *Pmean*, but only when assessed against values derived from the fastest STS repetition completed and not the average STS time. There was no relationship between the STS App variables and self-selected walking speed (Table 2).

4. Discussion

To our knowledge, this is the first study to validate an App for measuring time, velocity and leg power using video-capture analysis during a single STS test. The STS App was a valid and reliable instrument for measuring STS time, vertical velocity and leg power, compared with those determined by a force plate. The mean difference between instruments was very small, indicating a high level of agreement between these measurement tools. Inter-individual reliability was strong for all variables and no bias reported between observers. The App variables were strongly correlated between advancing age and handgrip strength, but not self-selected walking speed. The App is valid and reliable for determining STS time, velocity and power regardless of sex and age.

4.1. *Objective 1–reliability and validity of APP*

Prior studies have reported on the development of smartphone Apps to assist with other functional performance measurements such as; the Timed-Up and Go [14,16], and the repetitive 5x STS test [16] but unlike our STS App these tools only analyzed time and/or acceleration values and the results demonstrated an overestimation of time of

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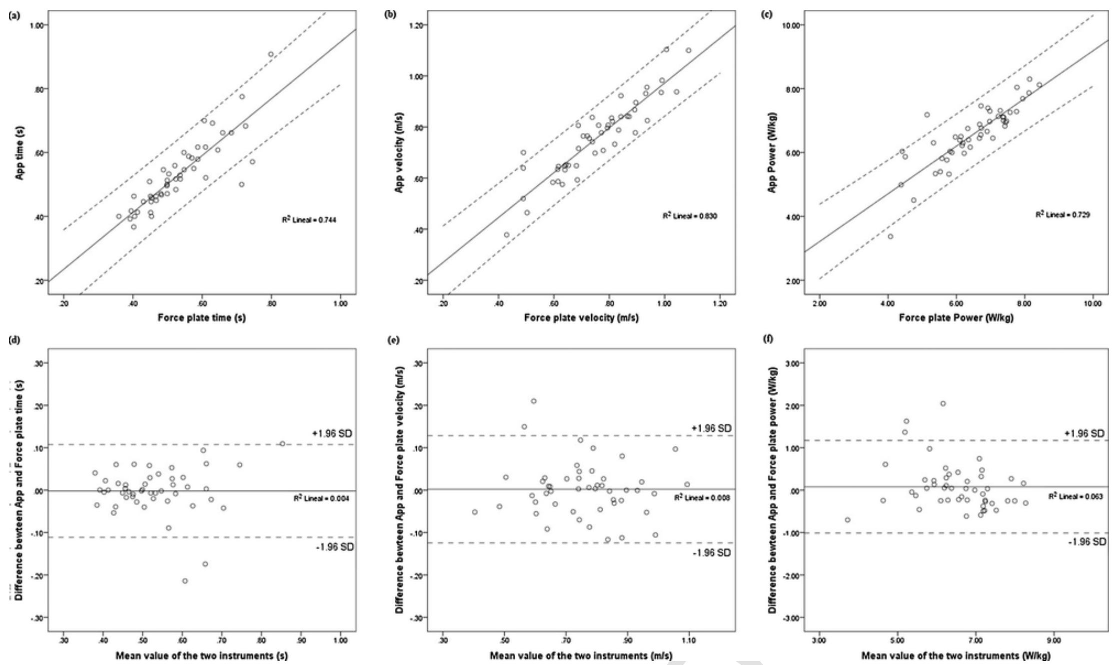

Fig. 3. Pearson's correlation coefficients explain the relationship between the iPhone App and the force plate for rising time (a), mean velocity (b) and *Pmean* (c). Bland–Altman plots reflect the differences for rising time (d), mean velocity (e) and *Pmean* (f) between the iPhone App and the force plate. The horizontal thin line represents the systematic bias while the dashed line represents the ±1.96 standard deviations (SD).

Table 2
Relationship between App variables and age, grip strength and walking time (n = 40).

App variables		Age			Grip strength			Walking time		
		r	95% CI	p-value	r	95% CI	p-value	r	95% CI	p-value
STS time	Average	0.626	0.391 to 0.784	< 0.001	−0.293	−0.553 to 0.02	0.66	0.188	−0.131 to 0.471	0.24
	Fastest	0.715	0.52 to 0.839	< 0.001	−0.398	−0.631 to −0.099	0.011	0.221	−0.097 to 0.498	0.17
Mean vertical velocity	Average	−0.744	−0.856 to −0.563	< 0.001	0.494	0.216 to 0.698	0.001	−0.237	−0.51 to 0.08	0.14
	Fastest	−0.837	−0.91 to −0.711	< 0.001	0.586	0.336 to 0.758	< 0.001	−0.271	−0.537 to 0.044	0.09
Pmean	Average	−0.701	−0.831 to −0.499	< 0.001	0.577	0.324 to 0.753	< 0.001	−0.231	−0.506 to 0.086	0.15
	Fastest	−0.750	−0.86 to −0.573	< 0.001	0.644	0.416 to 0.795	< 0.001	−0.250	−0.52 to 0.066	0.12

The results are given for average of three repetitions and for the fastest repetition. Time to complete the rising phase of sit-to-stand (STS time). Mean power relative to body weight (*Pmean*). 95% confidence interval (95% CI).

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0.48 and 0.27 s, respectively [16]. The added benefit of the STS App is its ability to determine movement velocity and leg power generated during a single STS coupled with a short assessment duration and data processing response (~5 min). The use of an intuitive interface and the automatic data processing makes this App a useful tool for measuring time, velocity and power within a clinical or field-based environment.

Although STS time can be easily measured using a stop-watch, measurement error from manual recordings are greater, compared with more sophisticated wearable technology [18]. Mean vertical velocity can be calculated through the distance traveled as a function of time whereas muscle power is the ability to perform muscular work per unit of time and can be measured as *Work/Time or Force* × *Distance/Time or Force* × *Velocity*. However, a number of studies have adapted the standard calculation of power in the quantification of STS test [11,19,20]. Lindemann et al. [11,19] calculated power from a single STS test as *Body weight*× *Distance (body height standing* − *body height sitting)* × *Time* using a force plate, whereas Takai et al. [20] proposed that leg muscle power could be determined using a stopwatch from *Body weight* × *Distance (leg length* − *chair height)* × *Gravity* (9.8 m/sec^2) × *10* (repetitions)/*Time* (time to complete 10 repetitions). Although these equations have been correlated with cross-sectional area of knee extensor muscles [20] or other devices for power measurements such as the Nottingham power rig [11], these methods fail to report specific values of muscle power that would be useful for screening large population samples. This interpretation is supported by the fact that mean power values range from 184 to 647 Watts (W) between studies [11,20]. In our study, power was ascertained from a regression equation derived from Force (applied to a force plate) × Velocity (vertical; sampled during the rising phase of STS test) relative to body weight. Power ranged between 6.7 W kg^{-1}–6.9 W kg^{-1} for the average of three STS repetitions and for the fastest repetition, respectively. Differences between this study and previous investigations likely relate to the different equations applied between studies. Similar to our study, Smith et al. [15] developed a linear regression equation to estimate muscle power during STS test using data collected from a force plate and a high-speed photography system (*Vicon, Lake Forest, CA*) and reported values of 6.4 $W\,kg^{-1}$. However, we have advanced this regression model approach through use of a common device (iPhone) and validated the equation applied for the design of this portable tool.

A limitation to our study was that the regression equation used to determine leg power was created from a small sample (n = 17); however, the equation was validated using 48 healthy individuals whose femur length and STS execution time was representative of the adult population [19,21,22]. Thus, the values and findings are likely applicable to the general adult population.

4.2. Objective 2–construct validity relative to functional performance measures

The results of this study demonstrate that a strong relationship exists between age and STS time, velocity and power regardless if the measures were sampled from an average of 3 STS or the fastest STS repetition. Velocity determined from the fastest STS repetition, was most associated with age, although STS time and power were also strongly related with age. Recently Glenn et al. [6] demonstrated that STS velocity and power calculated from a force plate was able to disassociate between age groups. Similar to our results, these authors also reported that velocity sampled from the fastest STS test was a more sensitive measure, compared to average velocity of 5 trials, when detecting differences between age-groups. These results suggest that using the fastest STS repetition rather than the average of 3 or 5 STS repetitions is a better protocol for evaluating STS time, velocity and power.

A moderate, but significant relationship was also observed between handgrip strength and STS time, velocity, and power, but only when these measures were determined using the fastest STS repetition protocol. Although all variables were related to handgrip strength, it was *Pmean* that was most closely related. This relationship is reported by others who suggest that both handgrip strength and lower leg power are most effective at evaluating overall functional performance in older adults [23]. However, similar to other studies [6,24] no relationship existed between self-selected walking speed and the STS variables regardless of how these variables were collected. We speculate that the STS variables are measures of leg movement velocity and muscle power which are generated using the anaerobic system as it moves a load through a greater range of motion, which is not the case for walking, as the range of motion and thereby load moved would be much less. Therefore, the STS may not replace measures of walking speed, but rather complement this assessment protocol so that all physiological systems, aerobic and anaerobic, might be assessed.

5. Conclusion

Our study demonstrates that the STS App was reliable and valid assessment tool that can be easily used within a field-based setting where space and technology are often constrained. The values from the App were moderate to very-strong associated with age and grip strength but not for walking speed. The iPhone App could be a useful tool for assessment large populations in short-time period within the environmental context of daily living.

Conflict of interest

The second author of the article is the creator of the App and may benefit financially from purchases of the app. Nevertheless, to guarantee the objectivity of the results, two independent, blinded authors performed data analysis from the App.

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