Validity of various portable devices to measure sit-to-stand velocity and power in older adults

Samuel T. Orange[a], James W. Metcalfe[b], Andreas Liefeith[c], Alastair, R. Jordan[c].

[a]Department of Sport, Exercise and Rehabilitation, Faculty of Health and Life Sciences, Northumbria University, Newcastle Upon Tyne, UK.

[b]Sport, Health and Exercise Science, School of Life Sciences, University of Hull, UK.

[c]School of Sport, York St John University, York, UK.

Corresponding author:

Dr Samuel T. Orange

Department of Sport, Exercise and Rehabilitation, Faculty of Health and Life Sciences, Northumbria University, Northumberland Building Room 430A, Newcastle Upon Tyne, UK, NE1 8SG.

Telephone: +44 (0)191 227 3056

Email: orange_1@hotmail.co.uk

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations of interest: None

Acknowledgements: The authors would like to thank Ray Schofield and Christopher Jones for their help in recruitment and data collection. We would also like to thank all the volunteers whom volunteered to take part in this study.

Word count: 2998

ABSTRACT

Background: Movement velocity and power in a single STS are related to functional performance in older adults. Identifying accessible tools that provide valid measures of STS velocity/power would allow practitioners to evaluate physical function in clinical settings where time, space and finances are limited.

Research question: Does a linear position transducer (LPT), iPhone application (App), and inertial measurement unit (IMU) obtain valid measurements of velocity and power during a single STS compared with 3D motion capture?

Methods: Twenty-seven community-dwelling older adults aged ≥60 years completed a single STS test with mean velocity and power simultaneously measured with 3D motion capture, an LPT, IMU and App. Acceptable validity was established if the Pearson correlation coefficient (r) was very high (≥0.7) and bias as a standardised effect size (ES) was small (<0.6). The relationship between STS velocity/power and 30-s chair STS performance was also evaluated.

Results: Measures of STS velocity obtained by the LPT (r = 0.94, ES = -0.21) and App (r = 0.89, ES = -0.19) were very highly valid when compared to 3D motion capture, and were very strongly related to 30-s STS performance (r ≥0.74). The LPT (r = 0.87, ES = 0.13) and App (r = 0.74, ES = -0.12) also showed very high correlations and negligible bias for measuring STS power. Data collected by the IMU failed to meet our pre-determined threshold of acceptable validity for STS velocity (r = 0.72, ES = 1.00) or power (r = 0.61, ES = 0.34).

Significance: The LPT and iPhone App, but not the IMU, are valid tools for measuring STS velocity and power in community-dwelling older adults. Clinicians can use STS velocity obtained by either the LPT or App as a simple and valid proxy for functional status, which could help identify patients at high-risk of incident disability.

Keywords: Physical function, functional screening, validity, velocity, power, older adults.

1. INTRODUCTION

Aging is associated with reduced physical functioning [1], which has negative implications for independence and quality of life. Poor physical function is associated with depressive symptoms, incident disability and all-cause mortality in older adults [2-4]. It is therefore crucial that clinicians have access to tools that can accurately assess physical function so that appropriate interventions can commence as early as possible.

Lower-limb movement velocity and power reduce precipitously throughout aging [5, 6] and are important factors underpinning age-related impairments in function [7, 8]. Recently, velocity and power recorded during a single sit-to-stand (STS) have shown high correlations with several measures of physical function in older adults [9]. A single STS is quick and simple to perform, is not a fatiguing task, and the power generated during the movement is relevant to functional daily activities. Thus, it has been proposed that a single assessment of STS power could be used as a functional screening tool in clinical settings where limited time and space preclude clinicians from administering a battery of tests [9, 10]. However, evaluating velocity and power typically involves sophisticated measurement tools, with three-dimensional (3D) motion capture widely considered the gold standard [11]. Three-dimensional motion capture has restricted use within clinical settings due to transportation issues, time-consuming analyses and high costs.

Advancements in smartphone software have given rise to the development of iPhone applications (Apps) that measure velocity and power from a video recording. Indeed, an iPhone App has been purpose-built to measure time, velocity and power during a single STS. One internal validation study reported high correlations between STS measurements obtained by the App and those collected by a force plate (Pearson correlations: 0.85-0.91) [12]. However, the large inter-individual variation that inevitably exists in a sample of adults aged 21 to 87 years can inflate correlations because the correlation coefficient is sensitive to the spread of values between participants [13]. It is necessary to independently evaluate the App in a more homogenous sample of older adults before it can be used by clinicians who are working with this population.

There are portable devices commercially-available that provide kinetic and kinematic information during the STS, such as linear position transducers (LPTs) and inertial measurement units (IMUs). Despite their use in the research literature [9, 10, 14], STS data obtained by LPTs and IMUs have not yet been compared to data collected by 3D motion capture, meaning that their validity currently is unknown. Determining the validity of these portable devices together in the same sample will inform practitioners about which method(s) can be used as a functional screening tool. Therefore, the purpose of this study was to evaluate the validity of an LPT, iPhone App, and wearable IMU for measuring STS velocity and power in community-dwelling older adults. We also examined whether velocity and power recorded in a single STS were related to performance in a well-established measure of functional mobility (30-s chair STS test).

2. METHODS

2.1. Participants

Community-dwelling older adults were recruited from North Yorkshire, UK, between March and May 2019. Inclusion criteria were: aged ≥60 years, body mass index of 18.5-34.9 kg/m^2, and ability to stand up from a chair without assistance. Exclusion criteria were: unstable chronic disease state, resting hypertension (≥200/≥100 mmHg), tachycardia (≥100 bpm), and any contraindication to exercise testing [15]. Participants were informed of the study procedures before providing written informed consent and the Cross-School Ethics Committee at York St

John University provided ethical approval the study. This study was pre-registered on AsPredicted (#21725/21727 [16]).

2.2. Study design and procedures

This study used a cross-sectional design. Participants were initially screened for eligibility using a medical questionnaire and evaluations of blood pressure, heart rate, and anthropometrics. Self-reported physical activity was assessed with the International Physical Activity Questionnaire – Short Form [17]. Participants then performed the single STS test with 3D motion capture (Oqus 300, Qualisys, Gothenberg, Sweden), an LPT (GymAware PowerTool, Kinetic Performance Technologies, Canberra, Australia), IMU (PUSH, PUSH Inc., Toronto, Canada) and iPhone App (Sit To Stand App, v1.1) simultaneously measuring mean velocity and power (Figure 1).

2.3. Single sit-to-stand test

Femur length was measured as the distance between the superior aspect of the greater trochanter and femoral lateral condyle on the participant's right side. A spherical reflective marker was placed on the greater trochanter for reference. Participants sat in a firm, armless chair, without wearing footwear and crossed their arms against their chest. The chair was countersunk into a custom-made, weighted platform that was individually adjusted in height so that all participants began with their hip, knee and ankle joints at approximately 90°. Participants were positioned on the edge of the seat to minimise trunk flexion/horizontal displacement. We instructed participants to stand upright as quickly as possible (hips and knees fully extended), to stay stood upright for two seconds, and then to sit back down at a comfortable pace. Participants performed two practise repetitions to practise correct technique. Subsequently, three repetitions were completed, separated by 60-seconds rest. The repetition with the maximum mean velocity (determined by 3D motion capture) was used for analysis. Additional trials were performed if their arms moved away from their chest.

2.4. Data analysis

2.4.1. Three-dimensional motion capture

To maximise coverage of a calibration volume (average residual <1mm), eleven high-speed (240 Hz) infra-red cameras were used to track 3D displacement coordinates of the greater trochanter marker. The vertical displacement of the greater trochanter from a seated position (where the knee joint is 90° and femur is parallel to the floor) to standing height was a proxy for femur length, and therefore vertical displacement during the STS. This landmark is also consistent with the landmark used by other measures (iPhone App). Marker trajectory was smoothed by taking a moving average of 11 frames. The cameras were synchronised with a force plate (Kistler Instruments, Sindelfingen, Germany) to determine the rising phase of the STS, where the movement starts with peak vertical ground reaction force ('seat-off') and ends when vertical force reaches body weight prior to the overshoot [12, 18]. Seat-off represents the beginning of the extension phase and the transition from horizontal to vertical force [18]. Instantaneous velocity was estimated by differentiating displacement time data between each frame. Mean velocity was calculated by averaging all the instantaneous velocities measured from the start to the end positions of the STS. Mean power was estimated as the product of mean vertical velocity and ground reaction force of body weight [18]. Data processing and acquisition were performed using Visual3D software (Visual3D v6.01.36, C-Motion, Germantown, USA).

2.4.2. Linear position transducer

The LPT was positioned on the floor directly underneath the participant's right greater trochanter. The retractable cable was vertically attached to a belt that was secured around the participant's waist using a Velcro strap. Displacement data during the rising phase of the STS were time-stamped every 20 milliseconds then down-sampled to 50 Hz for analysis. Sampled data were not filtered. Instantaneous velocity was estimated as change in displacement over time, and acceleration was calculated as the change in velocity over the change in time [19]. Force was estimated by the product of body mass and acceleration, and power was calculated as the product of force and velocity. Mean velocity and power were determined as the average of all instantaneous data. Data were transmitted to an iPad App (v2.6) via Bluetooth.

2.4.3. Inertial measurement unit

The IMU was placed on the participant's right forearm, 1-2 cm distal to the elbow, as per manufacturer's instructions [20]. The device consists of a 3-axis accelerometer and gyroscope that provides six degrees of freedom. Acceleration data were recorded at 200 Hz and smoothed with a Butterworth filter. Instantaneous vertical velocity was calculated by integrating acceleration with respect to time. Force was then calculated as the product of acceleration and body mass, and power was estimated by multiplying force with velocity. Mean velocity and power were calculated as the average of all instantaneous data. Data were transmitted via Bluetooth to a tablet using the PUSH App (v4.4.8).

2.4.4. iPhone App

An iPhone 6 was attached to a tripod (height: 0.7 m) and positioned 3-metres from the force plate on the right side of the participant. Participant femur length was entered into the App before executing the STS test, and each STS was recorded by the App at 240 frames per second/720 pixels. After recording the STS, the researcher identified the start and end positions of the movement by pressing a start and stop button in the App, respectively. A visual grid of 3.8 x 3.8 pixels is built into the App as an overlay, and the first frame was selected when the reflective marker on the greater trochanter crossed the first horizontal grid line [12]. The final frame was chosen when the greater trochanter was at its highest point i.e. the participant was stood upright with full hip and knee extension. The App calculates time between the first and final frames selected by the user and estimates mean vertical velocity as femur length (m) divided by time (s) [12]. Mean vertical power was calculated based on a regression equation created from 17 healthy participants aged 26-81 years:

Mean power ($W \cdot kg^{-1}$) = 2.773 - 6.228·time + 18.224·femur length

The App presents values of power relative to body mass ($W \cdot kg^{-1}$). For validity analyses, we multiplied the value by the participant's body mass to attain the absolute value (W).

2.5. Thirty-second chair sit-to-stand test

The 30-s chair STS is a well-established measure of functional mobility [21, 22]. The same chair as the single STS test was used and participants began seated with hip, knee and ankle joints at 90°, without wearing footwear and with their arms crossed against their chest. The total number of stands participants performed in 30-s was recorded.

2.6. Statistical analysis

Data were analysed using R (R Foundation for Statistical Computing, Vienna, Austria). Normality of data was inspected via Q-Q plots/histograms and homoscedasticity was assessed with Bland-Altman plots. Power data were log transformed due to evidence of non-normality. The strength of relationships was assessed with the Pearson correlation coefficient (r). The size of r was interpreted as: negligible (<0.1), small (0.1-0.29), moderate (0.3-0.49), high (0.5-0.69), very high (0.7-0.89) or almost perfect (≥0.9) [23]. Systematic bias was evaluated with the standardised effect size (ES) using the formula: mean bias / SD of criterion. The magnitude of the ES was rated as (±): trivial (<0.2), small (0.2-0.59), moderate (0.60-1.19), large (1.2-2.0) and very large (≥2.0) [23]. Negative ESs represent underestimations compared to 3D motion capture, whereas positive ESs represent overestimations. The devices were considered valid if the following criteria were met: very high correlation ($r \geq 0.7$) and small bias (ES<0.6). We reported the standard error of estimate (SEE) using the formula: $\sqrt{\frac{\Sigma(\mathrm{Y}-\hat{Y})^2}{N}}$, where the numerator is the residual sum of squares from the prediction model. SEE was also presented as a percentage of predicted values. Sample estimates were reported with 95% confidence intervals (CIs). Raw data and statistical code are available online [16].

3. RESULTS

We initially intended to recruit 30 participants [16]. However, 28 were recruited due to unforeseen logistical constraints. One participant did not complete the STS test because of concerns the devices would interfere with their implantable cardioverter defibrillator. Thus, 27 participants completed the study and were included in the analyses (Table 1).

3.1. Validity of portable devices

Data collected by each device are presented in Figure 2 (see supplementary material for descriptive statistics). Measures of STS velocity obtained by the LPT (r=0.94, ES=-0.21) and iPhone App (r=0.89, ES =-0.19) showed almost perfect and very high associations with 3D motion capture, respectively (Figure 3). The LPT (r=0.87, ES=0.13) and App (r=0.74, ES =-0.12) also showed very high correlations and negligible bias for measuring STS power (Table 2). Data collected by the IMU failed to meet our pre-determined threshold of acceptable validity for STS velocity (r=0.72, ES=1.00) or power (r=0.61, ES=0.34). There was no evidence of heteroscedasticity (see supplementary material).

3.2. Relationship with 30-s chair STS performance

Measures of STS velocity obtained by 3D motion capture, the LPT and App were very strongly related to 30-s chair STS performance ($r \geq 0.74$). There were moderate to high correlations between 30-s chair STS performance and STS power obtained by all devices (Table 3).

4. DISCUSSION

The main finding of this study was that the LPT and iPhone App were highly valid for measuring STS velocity and power. Estimates of STS velocity obtained by the LPT and App were very strongly related to performance in the 30-s chair STS test. Conversely, data collected by the IMU failed to meet our pre-determined criteria for acceptable validity. These findings suggest that the LPT and App are useful tools for evaluating physical function in community-dwelling older adults, which has important implications for clinicians working in settings where time, space, and finances are limited.

STS velocity recorded by the LPT was almost perfectly related to data obtained by 3D motion capture (r=0.94, 95% CI: 0.87 to 0.97). The 95% CI of the estimate is encouraging because it suggests that the lowest correlation compatible with the data is still very high. A very high correlation was also found for measures of STS power (r=0.87). In line with these findings, previous research has shown a strong association between an LPT and cinematography for measuring STS power (r = 0.76) [14]. Our findings also showed negligible to small biases between the LPT and 3D motion capture, indicating a high level of agreement. Therefore, clinicians can use the LPT as a valid alternative to 3D motion capture for measuring STS velocity and power in community-dwelling older adults.

This is the first independent validation study of the Sit To Stand App. Our findings showed very high correlations, negligible bias and small errors between the App and 3D motion capture for both STS velocity and power (Table 2). These data agree with a previous internal validation study, which reported high Pearson correlations and no evidence of bias between the App and a force plate for all STS variables in adults aged 21 to 87 years (r=0.85-0.91) [12]. Given that our study recruited adults aged ≥60 years, we have extended their findings by showing that the App is highly valid in a homogenous sample of older adults.

Despite showing very high validity, the App calculated that one participant produced zero power (Figure 2). This is because the linear regression model it uses to determine STS power produces a straight line that extends beyond $\hat{Y}$=0 given certain parameters. For instance, given a femur length of 0.388-metres and STS time of 1.59-seconds, the model predicts a negative power value ($2.773 - 6.228 \cdot 1.59 + 18.224 \cdot 0.388 = -0.06\ W \cdot kg^{-1}$). Although it is rare the model predicts values of $\leq 0\ W \cdot kg^{-1}$, future work refining the App's regression equation to eliminate implausible values is warranted, perhaps by using a larger sample and fitting a quadratic model so its nadir is greater than $\hat{Y}$=0.

The 30-s chair STS test is routinely used as a surrogate for functional mobility in older adults [21]. Velocity data recorded by the LPT and App during a single STS were very highly correlated with 30-s STS performance ($r \geq 0.74$). In agreement with this finding, STS velocity measured with an LPT has previously been shown to significantly correlate with 10-m gait speed, 6MWT distance, TUG, and 30-s STS performance [9, 10]. Our results suggest that STS velocity recorded by either the LPT or App can be used as a quick and valid proxy for functional status in older adults. The low-cost of the App (£5) compared to the LPT (~£1800) makes the App a viable measurement tool when finances are also restricted.

Data obtained by the IMU failed to meet our threshold for acceptable validity. The IMU overestimated mean velocity by an average of $0.13\ m \cdot s^{-1}$ (ES=1.0) and did not show a very high relationship with 3D motion capture for measuring mean power (r = 0.61). The IMU prediction models also showed relatively high levels of error (SEE=17-19%), which may be due to differences in calculation techniques. The wearable IMU directly measures acceleration and estimates velocity as the integral of acceleration [20]. Conversely, 3D motion capture, the LPT and App calculate velocity as change in displacement over time. All techniques subsequently estimate power via inverse dynamics. The disparity in the initial method used to calculate velocity may have underpinned the lower validity of the IMU compared with 3D motion capture. Furthermore, unlike the LPT and App, STS velocity obtained by the IMU was not highly related to 30-s chair STS performance (r = 0.58).

Several studies have assessed STS power in older adults using different techniques, including force platforms [18, 24], LPTs [9, 25, 26] accelerometers [27], or a combination of mass, height, and manually-recorded time [28, 29]. Studies have also employed contrasting STS protocols, such as by allowing the use of armrests [26] and estimating single STS power based on a 5-repetition STS test [28]. The has led to a wide range of STS mean power values reported in the literature, from 184 to 784 W [26, 28, 29]. Future work should move towards developing a standardised method for evaluating STS velocity and power so that normative reference data are available to assist clinicians with data interpretation.

A limitation of this study is that participants were community-dwelling and most reported being physically active, which may limit the applicability of the findings to more sedentary populations or older adults in residential care. However, there was no evidence of heteroscedasticity for any device, suggesting that device error is consistent across a range of STS abilities.

5. CONCLUSION

The LPT and iPhone App, but not the IMU, were highly valid for measuring STS velocity and power in community-dwelling older adults. Velocity data obtained by the LPT and App were also very strongly related to performance in a well-established measure of functional mobility. Taken together, our findings suggest that practitioners can use STS velocity recorded by either the LPT or App to evaluate physical function in clinical settings where time and space are limited, which could help identify patients at high-risk of incident disability.

Conflict of interest statement

The authors have no conflicts of interest to declare.

References

[1] K.S. Hall, H.J. Cohen, C.F. Pieper, G.G. Fillenbaum, W.E. Kraus, K.M. Huffman, et al., Physical Performance Across the Adult Life Span: Correlates With Age and Physical Activity, J. Gerontol. A Biol. Sci. Med. 72(4) (2017) 572-578.

[2] A. Chale-Rush, J.M. Guralnik, M.P. Walkup, M.E. Miller, W.J. Rejeski, J.A. Katula, et al., Relationship between physical functioning and physical activity in the lifestyle interventions and independence for elders pilot, J. Am. Geriatr. Soc. 58(10) (2010) 1918-24.

[3] F. Landi, R. Calvani, M. Tosato, A.M. Martone, R. Bernabei, G. Onder, et al., Impact of physical function impairment and multimorbidity on mortality among community-living older persons with sarcopaenia: results from the ilSIRENTE prospective cohort study, BMJ Open. 6(7) (2016) e008281.

[4] E.G. Heiland, A.K. Welmer, R. Wang, G. Santoni, S. Angleman, L. Fratiglioni, et al., Association of mobility limitations with incident disability among older adults: a population-based study, Age Ageing. 45(6) (2016) 812-819.

[5] I.R. Lanza, T.F. Towse, G.E. Caldwell, D.M. Wigmore, J.A. Kent-Braun, Effects of age on human muscle torque, velocity, and power in two muscle groups, J. Appl. Physiol. 95(6) (2003) 2361-9.

[6] P. Aagaard, C. Suetta, P. Caserotti, S.P. Magnusson, M. Kjaer, Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure, Scand J Med Sci Sports. 20(1) (2010) 49-64.

[7] K.F. Reid, R.A. Fielding, Skeletal muscle power: a critical determinant of physical functioning in older adults, Exerc Sport Sci Rev. 40(1) (2012) 4-12.

[8] S.P. Sayers, J.M. Guralnik, L.A. Thombs, R.A. Fielding, Effect of leg muscle contraction velocity on functional performance in older men and women, J. Am. Geriatr. Soc. 53(3) (2005) 467-71.

[9] J.M. Glenn, M. Gray, A. Binns, Relationship of sit-to-stand lower-body power with functional fitness measures among older adults with and without sarcopenia, J Geriatr Phys Ther. 40(1) (2017) 42-50.
[10] S.T. Orange, P. Marshall, L.A. Madden, R.V. Vince, Can sit-to-stand power explain the ability to perform functional tasks in adults with severe obesity?, J Sports Sci. 37(11) (2019) 1227-1234.
[11] B. Pueo, J.M. Jimenez-Olmedo, Application of motion capture technology for sport performance analysis, Retos 32 (2017) 241-247.
[12] J.D. Ruiz-Cardenas, J.J. Rodriguez-Juan, R.R. Smart, J.M. Jakobi, G.R. Jones, Validity and reliability of an iPhone App to assess time, velocity and leg power during a sit-to-stand functional performance test, Gait Posture 59 (2018) 261-266.
[13] G. Atkinson, A.M. Nevill, Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine, Sports Med. 26(4) (1998) 217-38.
[14] M. Gray, S. Paulson, Developing a measure of muscular power during a functional task for older adults, BMC Geriatr. 14 (2014) 145.
[15] ACSM, ACSM's Guidelines for Exercise Testing and Prescription, 10th ed., Wolters Kluwer, Alphen aan den Rijn, South Holland, Netherlands, 2017.
[16] [dataset] S.T. Orange, J.W. Metcalfe, A. Liefeith, A.R. Jordan, Validity of portable devices to measure sit-to-stand velocity and power, Open Science Framework, v 1; 2019; DOI 10.17605/OSF.IO/C8HJ5.
[17] C.L. Craig, A.L. Marshall, M. Sjostrom, A.E. Bauman, M.L. Booth, B.E. Ainsworth, et al., International physical activity questionnaire: 12-country reliability and validity, Med Sci Sports Exerc 35(8) (2003) 1381-95.
[18] U. Lindemann, H. Claus, M. Stuber, P. Augat, R. Muche, T. Nikolaus, et al., Measuring power during the sit-to-stand transfer, Eur. J. Appl. Physiol. 89(5) (2003) 466-70.

[19] S.T. Orange, J.W. Metcalfe, P. Marshall, R.V. Vince, L.A. Madden, A. Liefeith, The Test-retest Reliability of a Commercial Linear Position Transducer (GymAware PowerTool) to Measure Velocity and Power in the Back Squat and Bench Press, J. Strength Cond. Res (2018). doi: 10.1093/gerona/glw120.

[20] S.T. Orange, J.W. Metcalfe, A. Liefeith, P. Marshall, L. Madden, C. Fewster, et al., Validity and reliability of a wearable inertial sensor to measure velocity and power in the back squat and bench press, J. Strength Cond. Res. 33(9) (2019) 2398-2408.

[21] C. Beaudart, Y. Rolland, A.J. Cruz-Jentoft, J.M. Bauer, C. Sieber, C. Cooper, et al., Assessment of Muscle Function and Physical Performance in Daily Clinical Practice : A position paper endorsed by the European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Diseases (ESCEO), Calcif. Tissue Int. 105(1) (2019) 1-14.

[22] C.J. Jones, R.E. Rikli, W.C. Beam, A 30-s chair-stand test as a measure of lower body strength in community-residing older adults, Res Q Exercise Sport. 70(2) (1999) 113-9.

[23] W.G. Hopkins, S.W. Marshall, A.M. Batterham, J. Hanin, Progressive statistics for studies in sports medicine and exercise science, Med. Sci. Sports Exerc. 41(1) (2009) 3-13.

[24] F. Alvarez Barbosa, B. Del Pozo-Cruz, J. Del Pozo-Cruz, R.M. Alfonso-Rosa, B. Sanudo Corrales, M.E. Rogers, Factors Associated with the Risk of Falls of Nursing Home Residents Aged 80 or Older, Rehabil Nurs. 41(1) (2016) 16-25.

[25] J.M. Glenn, M. Gray, J. Vincenzo, S. Paulson, M. Powers, An Evaluation of Functional Sit-to-Stand Power in Cohorts of Healthy Adults Aged 18-97 Years, J Aging Phys Act 25(2) (2017) 305-310.

[26] U. Lindemann, P. Farahmand, J. Klenk, K. Blatzonis, C. Becker, Validity of linear encoder measurement of sit-to-stand performance power in older people, Physiotherapy. 101(3) (2015) 298-302.

[27] G.R. Regterschot, W. Zhang, H. Baldus, M. Stevens, W. Zijlstra, Accuracy and concurrent validity of a sensor-based analysis of sit-to-stand movements in older adults, Gait Posture. 45 (2016) 198-203.

[28] J. Alcazar, J. Losa-Reyna, C. Rodriguez-Lopez, A. Alfaro-Acha, L. Rodriguez-Manas, I. Ara, et al., The sit-to-stand muscle power test: An easy, inexpensive and portable procedure to assess muscle power in older people, Exp Gerontol. 112 (2018) 38-43.

[29] Y. Takai, M. Ohta, R. Akagi, H. Kanehisa, Y. Kawakami, T. Fukunaga, Sit-to-stand test to evaluate knee extensor muscle size and strength in the elderly: a novel approach, J. Physiol. Anthropol. 28(3) (2009) 123-8.

Figure captions

Figure 1. Placement of measurement devices during the single sit-to-stand test. The chair was placed in the middle of the laboratory and countersunk into a custom-made, weighted platform that was individually adjusted in height so that all participants began with their hip, knee and ankle joints at approximately 90°. A = three-dimensional motion capture; B = inertial measurement unit; C = linear position transducer; D = iPhone application.

Figure 2. Mean velocity (panel A) and mean power (panel B) obtained by three-dimensional motion capture (3D MoCap), linear position transducer (LPT), iPhone application (App), and inertial measurement unit (IMU) during a single sit-to-stand. Dashed horizontal line represents mean values obtained by 3D MoCap.

Figure 3. Relationship between three-dimensional motion capture (3D MoCap) and the linear position transducer (LPT), iPhone application (App), and inertial measurement unit (IMU) for measures of mean velocity (panels A-C) and mean power (panels D-F) during a single sit-to-stand. W_{log} = log transformed Watts. Area shaded in grey represents 95% confidence interval for predicted values.

Table 1. Participant characteristics (n = 27)

	Mean ± SD, number (%), or median [IQR]	Min	Max
Age (years)	72.3 ± 7.4	60	91
Male	17 (63)		
Body mass (kg)	73.8 ± 13.9	55.4	104
Height (cm)	167 ± 8.8	151	182
BMI (kg/m^2)	26.3 ± 3.8	21.4	34.9
Waist circumference (cm)	90.8 ± 11.9	71.0	116
Hip circumference (cm)	103 ± 8.6	92.2	128
Waist to hip ratio	0.89 ± 0.09	0.75	1.08
Femur length (cm)	38.8 ± 3.4	33.0	48.0
STS mean velocity (m·s^{-1})[a]	0.50 ± 0.13	0.23	0.77
STS mean power (W)[a]	321 ± 113	156	650
STS mean power (W·kg^{-1})[a]	4.32 ± 1.16	2.27	6.95
30-s chair STS test (reps)	11.7 ± 3.4	3	18
Physical activity (MET·min·wk^{-1})			
Walking	1782 [941, 2772]	297	4158
Moderate-intensity	720 [460, 1200]	0	5040
Vigorous-intensity	0 [0, 960]	0	5760

BMI = body mass index; IQR = interquartile range; MET = metabolic equivalent; STS = sit-to-stand.

[a]Values obtained by three-dimensional motion capture.

Table 2. Pearson correlation coefficient (*r*), mean bias, and standard error of estimate (SEE) with 95% confidence intervals between the portable devices and three-dimensional motion capture.

	r	Standardised bias	SEE	SEE (%)
Mean velocity ($m \cdot s^{-1}$)				
LPT	0.94 (0.87, 0.97)	-0.21 (-0.76, 0.34)	0.04 (0.03, 0.06)	8.5 (5.2, 11.8)
iPhone App	0.89 (0.77, 0.95)	-0.19 (-0.73, 0.36)	0.06 (0.04, 0.08)	11.4 (7.0, 15.7)
IMU	0.72 (0.47, 0.86)	1.00 (0.42, 1.57)	0.09 (0.05, 0.12)	17.4 (24.1, 10.7)
Mean power (W)[a]				
LPT	0.87 (0.73, 0.94)	0.13 (-0.41, 0.68)	31.5 (22.4, 40.5)	9.9 (7.1, 12.8)
iPhone App	0.74 (0.50, 0.87)	-0.12 (-0.67, 0.42)	50.7 (31.3, 70.2)	16.2 (10.0, 22.4)
IMU	0.61 (0.30, 0.80)	0.34 (-0.21, 0.89)	59.8 (44.8, 74.7)	19.2 (14.4, 24.1)

App = application; IMU = inertial measurement unit; LPT = linear position transducer.

[a]Data were log transformed prior to analysis due to evidence of non-normality.

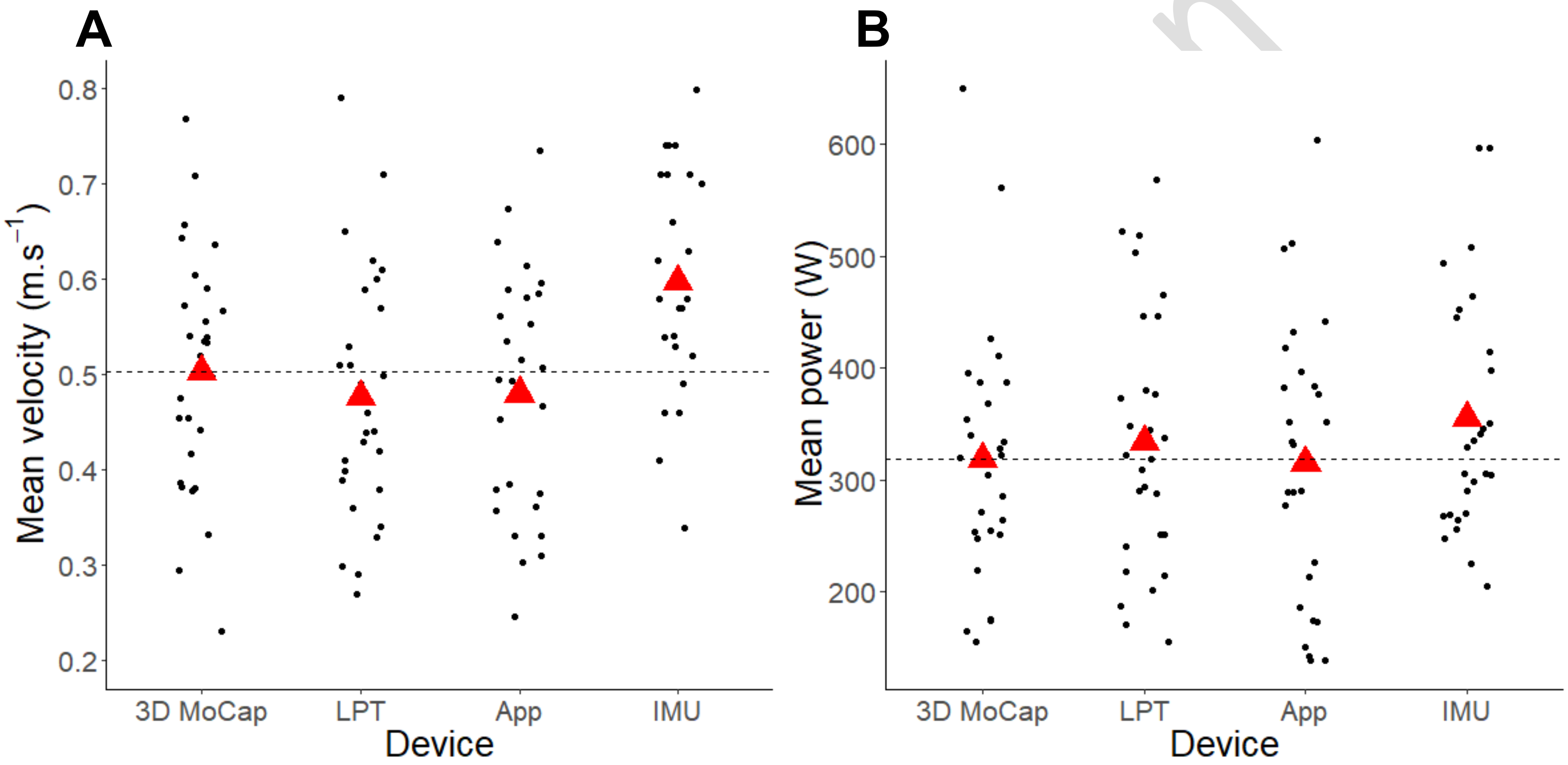
Table 3. Relationship between velocity and power during a single STS and 30-s chair STS performance. Data are presented as Pearson correlation coefficient (*r*) with 95% confidence intervals.

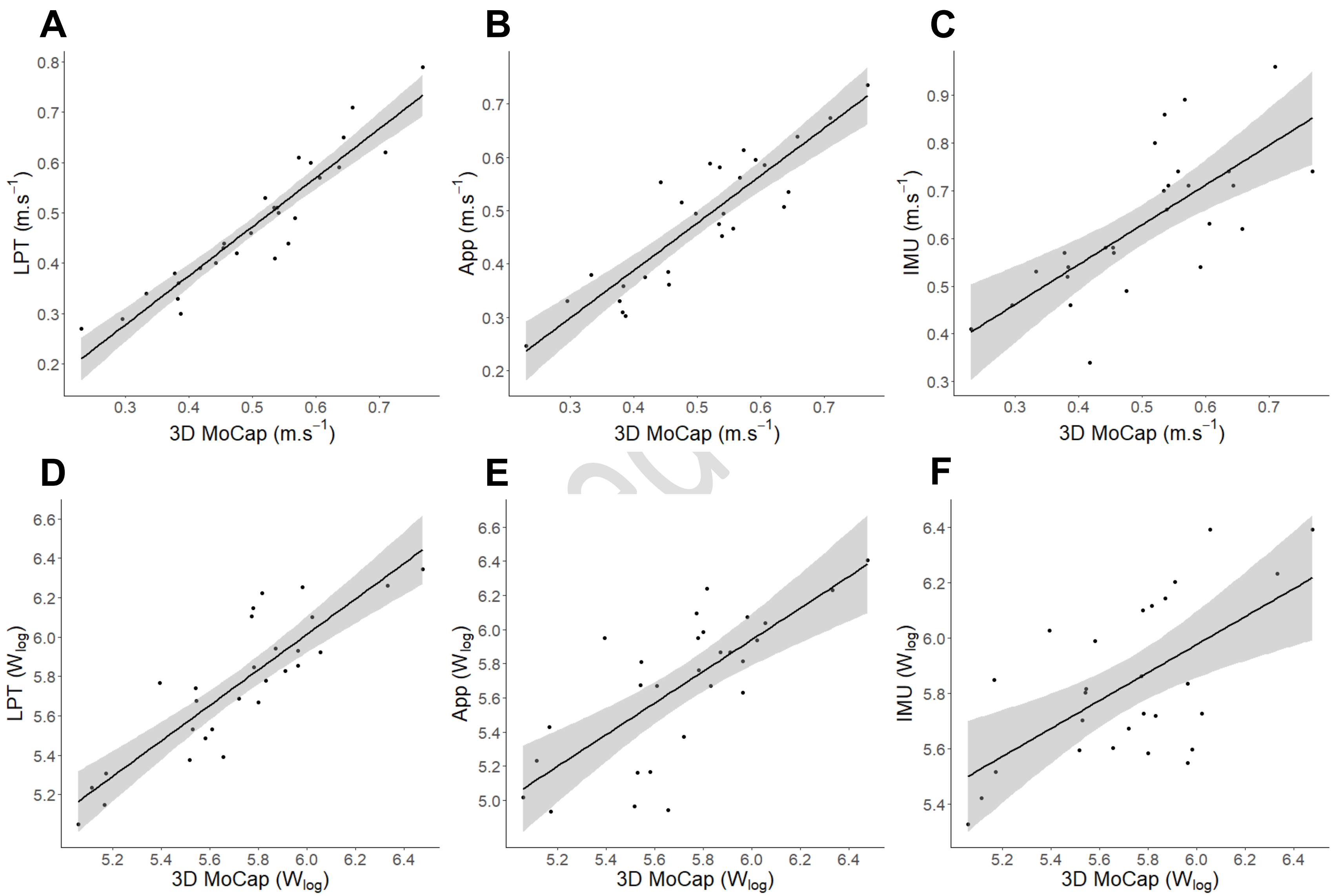
	3D MoCap (n = 28)	LPT (n = 28)	iPhone App (n = 28)	IMU (n = 27)
Mean velocity	0.75 (0.51, 0.88)	0.78 (0.57, 0.90)	0.74 (0.50, 0.87)	0.58 (0.26, 0.79)
Mean power[a]	0.40 (0.02, 0.67)	0.49 (0.14, 0.73)	0.57 (0.24, 0.78)	0.39 (0.01, 0.67)

App = application; IMU = inertial measurement unit; LPT = linear position transducer; 3D MoCap = three-dimensional motion capture.

[a]Data were log transformed prior to analysis due to evidence of non-normality.


A
B
C
D


A
B
Mean velocity (m.s^{-1})
0.8
0.7
0.6
0.5
0.4
0.3
0.2
3D MoCap
LPT
App
IMU
Device
Mean power (W)
600
500
400
300
200
3D MoCap
LPT
App
IMU
Device



A
B
C
D
E
F
LPT (m.s^{-1})
App (m.s^{-1})
IMU (m.s^{-1})
3D MoCap (m.s^{-1})
LPT (W_{log})
App (W_{log})
IMU (W_{log})
3D MoCap (W_{log})