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# 6th vital sign app: Testing validity and reliability for measuring gait speed

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ABSTRACT

*Background:* Gait speed tests are useful predictors of different health outcomes in people. These tests can be administered by the convenience of one's smartphone.
*Research Question:* Is the 6th Vital Sign app valid and reliable for measuring gait speed?
*Methods:* The study used a prospective test-retest design. Fifteen college subjects were asked to walk at their normal pace for 2 min. Each subject performed two trials. Speed was recorded by the 6th Vital Sign app, Brower timing gates, and by hand-measurement of distance walked divided by the 2 min. Criterion validity was assessed by paired t-tests, Cohen's D effect sizes, and Pearson correlation tests. Inter-trial reliability within each device was assessed with Pearson correlation tests.
*Results:* Speed measured by the app was significantly lower than speed measured by gates ($p = 0.004$) and by hand-measurement ($p = 0.009$). The difference between gates and hand-measurement was not significant ($p = 0.684$). The speed measured by gates and hand-measurement were very highly correlated ($r = 0.974$), but speed measured by app was only moderately correlated with gates ($r = 0.370$) and hand-measurement ($r = 0.365$). The inter-trial reliability was fairly high with correlations $r = 0.916$, 0.944, and 0.941 when speed was measured by the app, gates, and hand-measurement, respectively.
*Significance:* The app tended to underestimate speed when compared to gate and hand-measurements. Therefore, we conclude that the 6$^{th}$ Vital Sign app is not valid for use for clinical diagnosis or prognosis.

## 1. Introduction

In the United States (US), there have been ongoing trends across many measures indicating that the population is becoming less healthy and physically active [1–3]. Over half of adults were either overweight or obese in 2014 [3], and only about 1 in 5 adults met the 2008 Physical Activity Guidelines [2]. As disease burden related to physical inactivity increases [4], allied healthcare professionals will need to test individuals in order to perform primary and secondary prevention interventions. A walking speed test is an economic, simple, and useful tool to screen individuals for functional status and risk of health issues [5,6]. Walking speed tests can predict current functional independence and future health deterioration, screen for chronic lifestyle diseases such as hypertension, and help with clinical decision making such as whether they will be homebound, the likelihood of hospitalization, and the location of release after hospital visits [5–7].

Typical laboratory or clinical gait testing often uses sophisticated kinematic equipment such as optoelectronic motion capture systems, force plates, instrumented walkways, and timing gates [8–11]. Although these devices are highly valid and reliable, their expense and size make them prohibitive for use outside of a research laboratory. These types of equipment are not regularly accessible and call for trained personnel. An additional limitation of many of the above mentioned devices is that they can only measure up to a few steps of overland walking, which may not represent longer duration gait ability in individuals. Accelerometers are more accessible because they are cheaper and more portable. They are practical for measuring a long period of movements, complicated movements, and movements outdoors or over varied terrain. Today, most smartphones come installed with a three-dimensional accelerometer, gyroscope, and a compass with equal sensitivity as research-grade biomechanical equipment [10,12]. Using a smartphone as a testing device for movement velocity has become an appealing option for researchers and clinicians, and it can be used by a patient to track one's own health [13–15].

Recently there has been a growing interest in using smartphone applications to assess gait speed, along with other fitness indications as well [15,16]. Smartphone usage is feasible, and when used as a fitness tracker, it can encourage the user because they can easily track their

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progress on their own phone. In 2016, researchers at Duke University launched the 6th Vital Sign app on iTunes as a free app. They created and disseminated a simple tool for measuring walking speed and assessing public health in individuals of all ages and functional status [17]. This app is only available for use on the iOS operating system. Using the built-in accelerometers of the smartphone the app is downloaded onto, the app measures the walking distance and speed for 2 min and compares the result to the average of the US population. However, with their initial launch, they did not assess validity and reliability of the app. Therefore, the purpose of our study was to test the reliability and validity of the 6th Vital Sign smartphone app as an independent and unbiased research group. The three research questions were:

1. Is the 6th Vital Sign app valid relative to the criterion standards of using timing gates and hand-measurements of gait speed?
2. Is the 6th Vital Sign app reliable relative to the criterion standards of using timing gates and hand-measurements of gait speed?
3. What is the inter-trial reliability of the 6th Vital Sign app for measuring gait speed?

## 2. Methods

This project was approved by the Institutional Review Board and complies with the principles laid down in the Declaration of Helsinki. All participants provided written informed consent before commencing the assessments. Participants were full-time or part-time students at the university where the study was conducted who could walk without any aid. Data were collected between September and November of 2017. Participants were asked to attend one session at the Exercise Physiology laboratory. Participants were instructed to refrain from eating, smoking, or ingesting caffeine or alcohol within 3 h of their testing session, or from exercise prior to their testing session, and to wear athletic shoes and clothing. After 5 min of seated rest, participants were assessed for resting blood pressure and heart rate. Their heights were measured by a stadiometer, and weight and body fat percentage were measured by a Tanita BF-350 Total Body Composition Analyzer (Tanita, Tokyo, Japan). Participants were then equipped with a Polar Heart Rate (HR) Monitor (Polar Electro Inc., Kemple, Finland).

Next, participants were brought outside to a flat 400 m oval running track to complete the walk test. The track was permanently marked at the point where the timing gates needed to be set, the point where participants started. Additionally, the track was marked at meter intervals from 150 m to 300 m to ensure accurate and reliable hand-measurements of distance. Brower Timing Gates (Brower Timing Systems, Draper, USA) were placed at the starting line and at 100 m. Though it was likely that participants would exceed 100 m during their 2 min of walking, 100 m was chosen as it would provide a long enough sample to indicate average normal walking speed while still ensuring it was within the range all participants would be able to walk. Timing gates were set to a height of one meter to approximate center of mass in most adults and ensure reliable use of the equipment across all trials [8]. For the test, participants wore a belt with a d-ring buckle. Attached to the belt was a pouch custom fitted to the smartphone used during data collection and the belt was adjusted so that the pouch fit snugly over the participants' left iliac crest to minimize extraneous movement. The 6th Vital Sign smartphone app was powered by Apple's ResearchKit [17]. In this study, the app was downloaded to an iPhone 7 plus, measuring 158.2 mm × 77.9 mm × 7.3 mm and weighing 188 g. The same smartphone was used at all testing sessions.

After fitting the belt, participants were informed of the walking test procedures. Participants were instructed to begin walking when they heard the starting signal from the app, to walk at their normal pace in the indicated lane for two minutes, and stop when they heard the stopping signal from the app. Participants were instructed to stand still at the exact place they stopped until measurements were recorded. When ready, participants started with their toes on a line marked 30 cm from the first timing gate per standard procedure [18]. After confirming the participant's understanding and their readiness to start, the start button for the app was pressed and then the smartphone was placed in the pouch. The app provided a countdown timer that allowed a period for the participant to place the smartphone and then prepare to start the trial. When the app announced "start walking," participants began the trial. If the participant did not have the smartphone in the pouch or were otherwise not ready to begin, the trial did not proceed and the app was reset. The app required participants to walk for 2 min at their normal pace. After the 2 min, participants stopped in place and researchers placed a cone at the participant's toes. The distance from the last meter mark on the track to the front edge of the cone (i.e. where the participant's toes ended) was measured with a tape measure marked at every millimeter; total distance from the first timing gate to this point was recorded as hand-measured distance. After measurements were recorded, participants returned to the start and sat down until their heart rate returned to resting level or 5 min had elapsed. After the rest period, this procedure was repeated for a second trial.

Speed was measured by the 6th Vital Sign app, the Brower timing gates, and by calculating speed based on the hand-measurement of distance. The 6th Vital Sign app reported speed over the 2 min period in feet per second, which was converted to meters per second for data analysis. The hand-measured distance in meters divided by 2 min (the time the app instructed participants to walk) generated the variable hand-measured speed. The speed to 100 m, as determined by the Brower timing gates, and hand-measured speed were used as criterion standards to compare against app speed.

## 3. Data analysis

Descriptive statistics of the sample were generated, and the pairwise difference between the two methods of measurements was graphically described by the Bland and Altman Method. [19] Criterion validity of the app was assessed in two ways: systematic difference and degree of agreement. For the systematic difference, the average pairwise difference was tested with t-tests among the app, hand-measurement, and Brower timing gates (hereafter referred to as gates), and the effect sizes were estimated by Cohen's $d$ [20]. For the t-tests we fixed a family-wise significance level at $\alpha = 0.05$, and we used a Bonferroni correction with an individual α-level at $\alpha/3 = 0.0167$ to account for multiple comparisons. This correction of significance level was needed in order to avoid inflation of overall Type I error rate in the three simultaneous comparisons [21]. Cohen's $d$ effect sizes are interpreted as negligible for $d < 0.2$, small for $0.2 \le d < 0.5$, medium for $0.5 \le d < 0.8$, and large for $d \ge 0.8$ [22]. Pearson correlation tests were used to examine criterion validity among the three devices, and intraclass correlations were calculated to quantity the degree of agreement among the app, hand-measurement, and gates. The absolute values of correlation are interpreted as trivial for $r < 0.1$, small for $0.1 \le r < 0.3$, moderate for $0.3 \le r < 0.5$, large for $0.5 \le r < 0.7$, very large for $0.7 \le r < 0.9$, and nearly perfect for $0.9 \le r < 1$ [22].

Pearson correlation tests were used for each device to assess inter-trial reliability (i.e., consistency between the two trials). The average difference between the two trials, within each device, was also compared using paired t-tests and Cohen's $d$.

To overcome a potential lack of statistical power due to a small sample size ($n = 15$), the three anthropometric variables (height, weight, and body fat %) were considered to reduce random error. However, it was decided not to include any of these variables, because both correlation and linear regression tests (results not shown) indicated that there was a weak relationship between any of the anthropometric variables and walking speed. Additionally, temperature and wind speed were measured during all trials, but these factors did not affect the statistical results of the current study, so they are not reported here.

All statistical analyses were performed using R Version 3.5.1 [23].

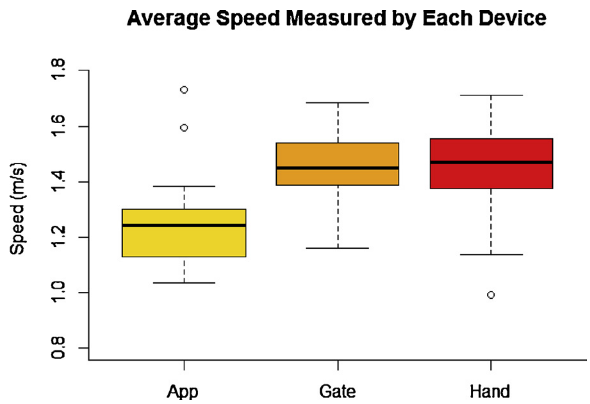


**Fig. 1.** Average Speed of the Two Trials Measured by Each of the Three Devices (App, Gates, and Hand-Measurement).

## 4. Results

Fifteen participants (4 males and 11 females; mean age 21.5 $\pm$ 2.75 years; body fat percentage 25.57% $\pm$ 12.22%; height 164.46 $\pm$ 8.90 cm) completed the assessments. For one participant, a single trial was not captured by the gates. All other devices had 100% function. When the participants were asked to walk for 2 min, the average distance was 172.1 m (SD = 24.2, range 121.3–207.3) according to hand-measurement and 151.5 m (SD = 23.4, range 126.2–206.1) according to the app in the first trial, and the average was 173.1 m (SD = 24.6, range 116.6–203.7) according to hand-measurement and 152.7 m (SD = 22.9, range 122.0–209.5) according to the app in the second trial.

The average speed of the two trials for each device is presented in Fig. 1, and the Bland-Altman plot is shown in Fig. 2. The app appears to underestimate the walking speed relative to both the gates and hand-measurement. However, the hand-measurement seems fairly consistent with the gates. The gates recorded an average speed of 1.444 $\pm$ 0.166 m/s; the hand-measurements calculated an average speed of 1.438 $\pm$ 0.200 m/s; the 6$^{th}$ Vital Sign app recorded an average speed of 1.268 $\pm$ 0.189 m/s. Comparisons between the devices are summarized in Table 1. There was a significant and large difference between the app and the gates, and a significant and medium difference between the app and hand-measured speed. In contrast, gates and hand-measured speed were similar. In the analysis of hand-measurement and gates, as shown in the Bland-Altman plot (Fig. 2), there was one potential outlying data point (outside of the bounds). To investigate the impact of this data point, the *t*-test was repeated without the data point, and the Wilcoxon test (an alternative nonparametric method which is not sensitive to outliers) was used with the data point. In the two tests, the conclusion was still a lack of evidence for the difference between gates and hand-measured speed.

Pearson correlation analyses of speed indicated moderate but non-significant correlations between both the app and gates ($r$ = 0.370) and between the app and hand-measurements ($r$ = 0.365) (Table 2). The correlation between the hand-measurement and gates was very large with $r$ = 0.974. As described in Table 2 and Fig. 3, gates and hand-measurement show strong agreement in their measurements, but the app does not agree with the other two devices. Estimated ICCs were 0.082 (app vs. gates), 0.131 (app vs. hand-measurement), and 0.957 (hand-measurement vs. gates). The estimated ICCs involving the app were very low because of the systematic underestimation by the app when compared to the gates and hand-measurement.

Regarding inter-trial reliability, based on both the paired *t*-test and the correlation between the two trials, we have no statistical evidence for difference between the speed in the first trial and the speed in the second trial for all three devices (Table 3). It seems that subjects were able to maintain their own normal speed in the two trials. When we consider the range of gait speed observed in this study, each device measured gait speed consistently between two trials (r = 0.916 for app, r = 0.944 for gates, and r = 0.941 for hand-measurement).

## 5. Discussion

The results of this study suggest that the app is invalid when compared to the timing gates and to hand-measurement. There was a significant and large discrepancy between the app vs the timing gates for measuring gait speed. There was also a significant and medium discrepancy between the app and simple hand-measurement of gait speed. Based on this error, the app could misclassify someone's functional ability, for example whether or not they could safely cross the street [7]. Therefore, we conclude that the 6$^{th}$ Vital Sign app demonstrates poor validity when compared to the gates and hand-measurement. While correlation analysis indicated moderate criterion validity, due to the purpose of the app for providing diagnostic classification, it cannot be considered valid or reliable overall. However, the results still suggest very high inter-trial reliability of normal walking speed in college students regardless of what device is used.

The results of this study are in contrast to a recent study investigating the reliability and validity of a smartphone app for measuring gait speed in young healthy adults [10]. For their criterion standard, they used a 4.27 m long GAITRite, and found that the smartphone measurements correlated highly with the GAITRite measurements. However, their experimental distance (4.27 m) might be too short to accumulate statistical evidence for the potential difference between the two devices, whereas we used a 2 min period (about 100 m–200 m). Similarly to Silsupadol et al. [10], other studies evaluating the validity of smartphone use in measuring gait speed have used

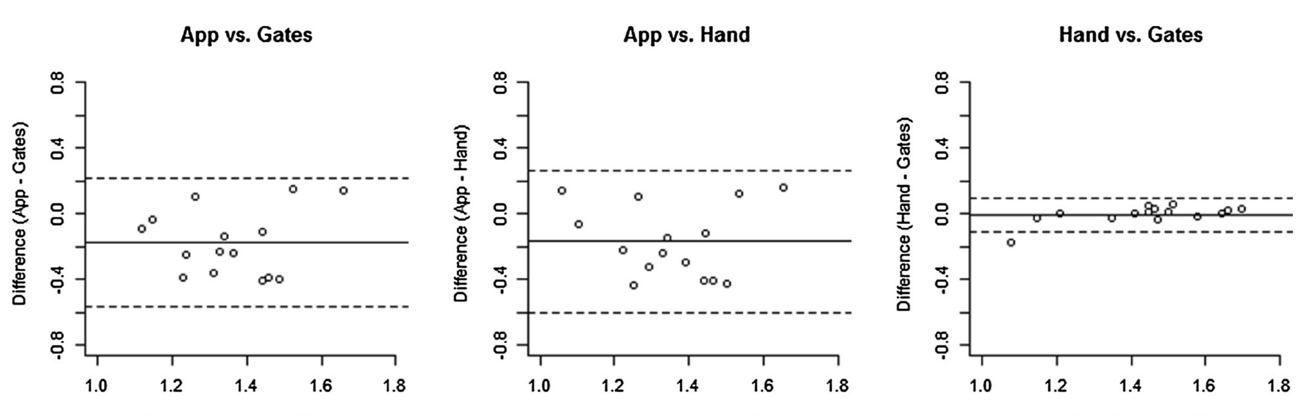


**Fig. 2.** Bland-Altman Plot of Comparing among the Three Devices (App, Gates, and Hand-Measurement).

**Table 1**
Estimated Mean Difference, 95% CI After the Bonferroni Correction, and Validity Comparisons of the Three Devices.

| | Mean Difference | Family-wise 95% CI | *p*-value | Absolute Cohen's *d* |
|---|---|---|---|---|
| App – Gates | −0.177 | (−0.317, −0.036) | 0.004 | 0.882 |
| App – Hand | −0.171 | (−0.325, −0.017) | 0.009 | 0.778 |
| Hand – Gates | −0.006 | (−0.043, 0.032) | 0.684 | 0.107 |

**Table 2**
Estimated Pearson Correlation among the Three Devices.

| | App | Gates | Hand |
|---|---|---|---|
| App | 1.000 ($p$ = NA) | – | – |
| Gates | 0.370 ($p = 0.174$) | 1.000 ($p$ = NA) | – |
| Hand | 0.365 ($p = 0.181$) | 0.974 ($p < 0.001$) | 1.000 ($p$ = NA) |

shorter times (45 s used by Manor et al. [12]) or distances (26 m used by Ellis et al. [15]). It is possible that the longer time of the test required by the 6th Vital Sign app allowed for the accumulation and compounding of small errors up to a meaningful amount, which may have not been detected in other apps using much smaller sampling windows. A recent review highlighted that the variety of protocols used in walking speed tests has negatively impacted the usefulness of walking speed as a clinical indicator [5].

There are other differences in procedures between this study and other that may account for the discrepancies in results. For example, model of phone and operation system were different between the current study (iPhone 7 plus) and others: Silsupadol et al. [10] used a Vivo X5 running Android 4.4.4, Ellis et al. [15] used an iPod Touch running iOS 6.1, and while Manor et al. [12] only specified the app was developed for iPhones, it can be assumed multiple exact models were used because the participants tried the app in their homes. Other procedural conditions such as having the participants walk barefoot [10] or having a turn at the half-way point [15] likely have reduced comparability.

Other studies using smartphones to assess speed at both walking and running gaits [15,24], as well as other clinical measures of function [16], have also shown fair to good validity. Furthermore, other studies have demonstrated good use in low-cost equipment such as Nintendo Wii Hand Controllers [25]. Therefore, the lack of accuracy of the current app is surprising, and it appears that the error may be primarily explained by the programming of the 6$^{th}$ Vital Sign app itself, as opposed to inherent limits in the technology.

The current study had several limitations. Ideally, all measures would have been taken for the same amount of time, but due to the unknown and variable nature of the distance participants would walk on any given trial, the timing gates did not capture the full 2 min of walking time required when using the app. While it was a strength of the study to use the exact same smartphone for all testing sessions, the converse limitation is that the results are only specific to the iPhone 7 plus, and may not represent the app's function on another model. To enhance accessibility, the smartphone was placed on the iliac crest. While this was close to the center of mass, other studies have used the landmark of the third lumbar vertebrae to represent the center of mass. However, Silsupadol et al. [10] demonstrated excellent reliability when placing a smartphone near the iliac crest during gait speed testing, and placement at this position demonstrated high validity ($r = 0.837$) for all gait speeds when compared to their criterion standard of the GAITRite system. Permanent marks on the track were used at every testing session to help ensure consistent placement of the Brower Timing Gates, however it is possible that there was human error in placing the gates on the exact marks. However, since the gates were not touched between a participant's trials, any error should have had minimal skewing of the analysis. Finally, this study had a small sample size. Major caveats of a small sample size are a lack of statistical power in the hypothesis testing and a lack of precision in the interval estimation (i.e., confidence interval). Despite the small sample size, we were able to detect the difference between the app and gates and the difference between the app and hand-measurement. This informs us that the effect size is practically large. Still, we could obtain a more precise estimate if the sample size was larger.

Based on the findings of this study in comparison to others that have used smartphones, we recommend that the makers of the 6th Vital Sign App revisit their data capture and processing algorithms. Future development and research will be needed to validate any future versions of the software. In general, future research and professional discussions should determine a standard set of, if not optimal, procedures for walking speed tests to make results comparable across individual studies and situations.

## 6. Conclusion

The findings of this study are that the 6th Vital Sign app demonstrated good inter-trial reliability but poor validity. Therefore, the app has demonstrated to be inaccurate compared to hand-measurements and using timing gates. We conclude that the 6$^{th}$ Vital Sign app is not valid for use for clinical diagnosis or prognosis.

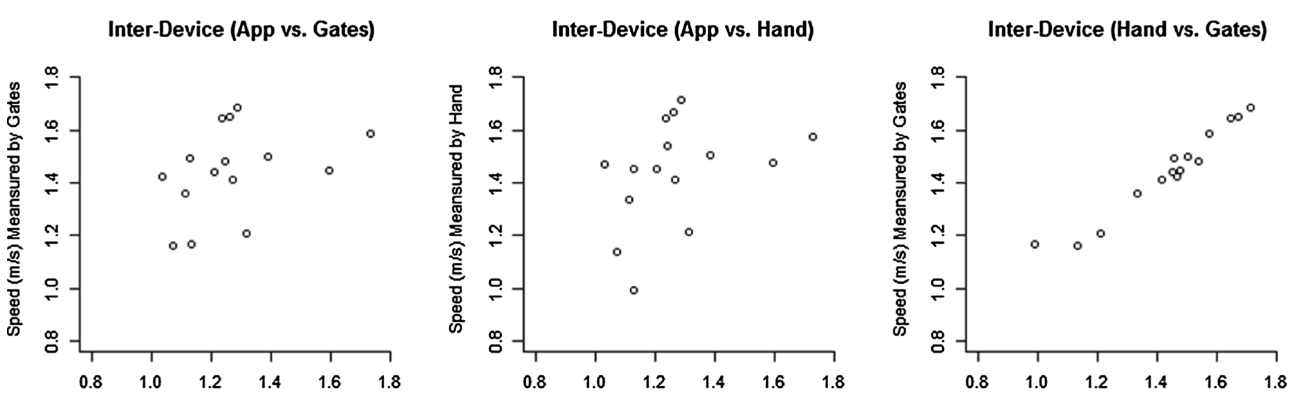


**Fig. 3.** Scatter Plots of the Average Speed for Paired Devices (App vs. Gates, App vs. Hand-Measurement, and Hand-Measurement vs. Gates).

**Table 3**
Inter-Trial Reliability of Each Device.

| | Mean Difference (Family-wise 95% CI) | *p*-value from t-test | Correlation (Family-wise 95% CI) | *p*-value from Correlation Test |
|---|---|---|---|---|
| App | 0.010 (−0.046, 0.065) | 0.641 | 0.916 (0.702, 0.978) | < 0.001 |
| Gates | 0.010 (−0.030, 0.050) | 0.506 | 0.944 (0.782, 0.986) | < 0.001 |
| Hand | 0.008 (−0.041, 0.057) | 0.653 | 0.941 (0.785, 0.985) | < 0.001 |

## Conflict of interest statement

All authors declare no conflict of interest related to this study.

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## References

[1] D. Ding, K.D. Lawson, T.L. Kolbe-Alexander, E.A. Finkelstein, P.T. Katzmarzyk, W. van Mechelen, et al., The economic burden of physical inactivity: a global analysis of major non-communicable diseases, Lancet 388 (2016) 1311–1324.
[2] Centers for Disease Control and Prevention, Facts about Physical Activity. https://www.cdc.gov/physicalactivity/data/facts.htm, (Accessed 10 August 2018).
[3] Trust for America's Health and Robert Wood Johnson Foundation, Obesity Rates & Trends Overview, (2018) (Accessed 10 August 2018), https://stateofobesity.org/obesity-rates-trends-overview.
[4] J.A. Knight, Physical inactivity: associated diseases and disorders, Ann. Clin. Lab. Sci. 42 (2012) 320–337.
[5] D.J. Fonseca Alves, J. Bartholomeu-Neto, E.R. Júnior, B.S. Ribeiro Zarricueta, O.T. Nóbrega, C. Córdova, Walking speed, risk factors, and cardiovascular events in older adults—systematic review, J. Strength Cond. Res. 31 (2017) 3235–3244.
[6] S.E. Hardy, S. Perera, Y.F. Roumani, J.M. Chandler, S.A. Studenski, Improvement in usual gait speed predicts better survival in older adults, J. Am. Geriatr. Soc. 55 (2007) 1727–1734.
[7] A. Middleton, S.L. Fritz, M. Lusardi, Walking speed: the functional vital sign, J. Aging Phys. Act. 23 (2015) 314–322.
[8] S. Altmann, M. Spielmann, F.A. Engel, R. Neumann, S. Ringhof, D. Oriwol, et al., Validity of single-beam timing lights at different heights, J. Strength Cond. Res. 31 (2017) 1994–1999.
[9] S. Lord, T. Howe, J. Greenland, L. Simpson, L. Rochester, Gait variability in older adults: a structured review of testing protocol and clinimetric properties, Gait Posture 34 (2011) 443–450.
[10] P. Silsupadol, K. Teja, V. Lugade, Reliability and validity of a smartphone-based assessment of gait parameters across walking speed and smartphone locations: body, bag, belt, hand, and pocket, Gait Posture 58 (2017) 516–522.
[11] K.E. Webster, J.E. Wittwer, J.A. Feller, Validity of the GAITRite® walkway system for the measurement of averaged and individual step parameters of gait, Gait Posture 22 (2005) 317–321.
[12] B. Manor, W. Yu, H. Zhu, R. Harrison, O.-Y. Lo, L. Lipsitz, et al., Smartphone app–based assessment of gait during normal and dual-task walking: demonstration of validity and reliability, JMIR Mhealth Uhealth 6 (2018) e36.
[13] A.M. Hickey, P.S. Freedson, Utility of consumer physical activity trackers as an intervention tool in cardiovascular disease prevention and treatment, Prog. Cardiovasc. Dis. 58 (2016) 613–619.
[14] C.-T. Liu, C.-T. Chan, Exercise performance measurement with smartphone embedded sensor for well-being management, Int. J. Environ. Res. Public Health 13 (2016) 1001.
[15] R.J. Ellis, Y.S. Ng, S. Zhu, D.M. Tan, B. Anderson, G. Schlaug, et al., A validated smartphone-based assessment of gait and gait variability in parkinson's disease, PLoS One 10 (2015) e0141694.
[16] J.D. Ruiz-Cárdenas, J.J. Rodríguez-Juan, R.R. Smart, J.M. Jakobi, Validity and reliability of an iphone app to assess time, velocity and leg power during a sit-to-Stand functional performance test, in: G.R. Jones (Ed.), Gait Posture 59 (2018) 261–266.
[17] M.C. Morey, S. Ryan, J. Kelly, C. Liu, K. Hawkins, K. Schwartz, et al., The 6th vital sign: a mobile app for population health surveillance of walking speed, Innov. Aging 1 (2017) 669.
[18] S. Altmann, M. Hoffmann, G. Kurz, R. Neumann, A. Woll, S. Haertel, Different starting distances affect 5-m sprint times, J. Strength Cond. Res. 29 (2015) 2361–2366.
[19] J.M. Bland, D.G. Altman, Statistical methods for assessing agreement between two methods of clinical measurements, Lancet 1 (8476) (1986) 307–310.
[20] J. Cohen, Statistical Power Analysis For The Behavioral Sciences, 2nd ed., Lawrence Erlbaum Associates, Hillsdale, NJ, 1988.
[21] M. Kutner, C. Nachtsheim, J. Neter, W. Li, Applied Linear Statistical Models, 5th edition, McGraw-Hill/Irwin, New York, NY, 2004.
[22] W.G. Hopkins, A Scale Of Magnitude For Effect Statistics, (2006) (Accessed 19 August 2018), http://sportsci.org/resource/stats/effectmag.html.
[23] R Core Team, R: A Language And Environment For Statistical Computing, (2018) (Accessed 14 August 2018), https://www.R-project.org/.
[24] N. Romero-Franco, P. Jiménez-Reyes, A. Castaño-Zambudio, F. Capelo-Ramírez, J.J. Rodríguez-Juan, J. González-Hernández, et al., Sprint performance and mechanical outputs computed with an iphone app: comparison with existing reference methods, Eur. J. Sport Sci. 17 (2017) 386–392.
[25] R.A. Clark, K. Paterson, C. Ritchie, S. Blundell, A.L. Bryant, Design and validation of a portable, inexpensive and multi-beam timing light system using the Nintendo Wii hand controllers, J. Sci. Med. Sport 14 (2011) 177–182.