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ORIGINAL ARTICLE

Sprint performance and mechanical outputs computed with an iPhone app: Comparison with existing reference methods

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Abstract

The purpose of this study was to assess validity and reliability of sprint performance outcomes measured with an iPhone application (named: *MySprint*) and existing field methods (i.e. timing photocells and radar gun). To do this, 12 highly trained male sprinters performed 6 maximal 40-m sprints during a single session which were simultaneously timed using 7 pairs of timing photocells, a radar gun and a newly developed iPhone app based on high-speed video recording. Several split times as well as mechanical outputs computed from the model proposed by Samozino et al. [(2015). A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scandinavian Journal of Medicine & Science in Sports*. <https://doi.org/10.1111/sms.12490>] were then measured by each system, and values were compared for validity and reliability purposes. First, there was an almost perfect correlation between the values of time for each split of the 40-m sprint measured with *MySprint* and the timing photocells ($r = 0.989-0.999$, standard error of estimate = 0.007–0.015 s, intraclass correlation coefficient (ICC) = 1.0). Second, almost perfect associations were observed for the maximal theoretical horizontal force (F_0), the maximal theoretical velocity (V_0), the maximal power (P_{max}) and the mechanical effectiveness (DRF – decrease in the ratio of force over acceleration) measured with the app and the radar gun ($r = 0.974-0.999$, ICC = 0.987–1.00). Finally, when analysing the performance outputs of the six different sprints of each athlete, almost identical levels of reliability were observed as revealed by the coefficient of variation (*MySprint*: CV = 0.027–0.14%; reference systems: CV = 0.028–0.11%). Results on the present study showed that sprint performance can be evaluated in a valid and reliable way using a novel iPhone app.

Keywords: Acceleration, technology, biomechanics, testing

Introduction

Sprint speed, power output and forward acceleration are key physical determinants of performance in many activities in sport (Cronin & Sleivert, 2005; Faude, Koch, & Meyer, 2012; Morin et al., 2012). The entire spectrum of linear force, velocity and power output capabilities of an athlete may be described and studied through the force–velocity (F–v) and power–velocity (P–v) relationships (Morin & Samozino, 2016; Rabita et al., 2015). Furthermore, the importance of the mechanical

effectiveness of ground force application has been shown as paramount for a horizontally oriented force production during sprint acceleration (Hunter, Marshall, & McNair, 2005; Kawamori, Nosaka, & Newton, 2013; Morin et al., 2012; Rabita et al., 2015). These mechanical factors of sprint acceleration performance have been the focus of a recently published review (Haugen & Buchheit, 2016), and they are of interest to sport practitioners in designing effective training programmes.

The analysis of sprint performance (i.e. mainly split times and average speed over sprint intervals) has

traditionally been performed utilising reference methods which are measuring either the runner's displacement (e.g. timing gates) or velocity (e.g. radar and laser systems) as a function of time (Haugen & Buchheit, 2016). However, the underlying mechanical determinants of performance (sprint kinetics; i.e. external forces acting upon the athlete's body) are usually measured and computed by means of considerably more costly and complex devices (e.g. force platforms or instrumented treadmills (Morin, Samozino, Bonnefoy, Edouard, & Belli, 2010; Rabita et al., 2015)). Therefore, the possibility for many coaches and/or sports clubs to measure sprint kinetics becomes unavailable or impractical. Thus, a detailed analysis of sprint performance remains exclusive to research laboratories or high-performance centres.

In order to analyse sprint kinetics in field conditions, a simple method has been designed to accurately estimate the theoretical maximal force (F_0), velocity (V_0), maximal power output (P_{\max}) and mechanical effectiveness of ground force application (ratio of force, RF, and decrease in the RF over acceleration, DRF) during sprint acceleration (Samozino et al., 2015). This 'simple method' is based on the measurement of either five split times or the velocity-time data and basic laws of motion applied to the centre-of-mass and has been shown valid in comparison to force platform measurements the 'gold standard' method for running kinetics (Samozino et al., 2015). The main advantage of this method is that it allows an accurate estimation of sprint performance and mechanics in a more affordable way than using several force platforms or instrumented treadmills. It has also been used in the sport science research context in several recent studies (Buchheit et al., 2014; Cross et al., 2015; Marrier et al., 2016; Mendiguchia et al., 2014; Pantoja, Saez de Villarreal, Brisswalter, Peyré-Tartaruga, & Morin, 2016). This method, although simple, still requires at least seven pairs of timing gates (for measuring split times and the distance-time input) or a radar system (for measuring speed-time input). Although considered as reference methods for sprint performance monitoring (Haugen & Buchheit, 2016), timing gates and radar guns are still costly and not available for the majority strength and conditioning professionals. In addition, and most importantly, the computations required to process data with this simple method are substantial and require significant skills. Therefore, a low-cost, user-friendly and accurate device or application could have significant practical applications for coaches with no advanced instrumental or biomechanics education required.

Such an application (*MyJump*) has recently been developed and validated to measure flight time during vertical jumping from slow-motion (120 fps)

video recordings using an iPhone 5s (Balsalobre-Fernández, Glaister, & Lockey, 2015; Gallardo-Fuentes et al., 2016); providing easy and accurate computation of the jumping F-v profile and other complex mechanical determinants of jumping performance (Morin & Samozino, 2016; Samozino et al., 2014; Samozino, Morin, Hintzy, & Belli, 2008; Samozino, Rejc, Di Prampero, Belli, & Morin, 2012). Using the same approach, now with a higher frame rate recording (240 fps for the iPhone 6 or newer and iPad Air or newer), an Apple application called *MySprint* has been designed for the measurement of 40-m sprint acceleration performance and the computation of all the aforementioned sprint mechanical outputs in field conditions and for a much lower cost (iPhone around \$500 + \$9 of the App compared to about \$4000 for photocells or radar). In order to test the validity of *MySprint*, the aim of this study was to assess validity and reliability of performance inputs (split times and velocity-time curves) and computed mechanical variables to the current two reference methods in this context (Haugen & Buchheit, 2016): timing gates and radar.

Methods

Athletes

Twelve trained male sprinters (age, 21.4 ± 3.9 years; body-mass, 71.5 ± 4.5 kg; body-height 1.80 ± 0.05 m; body-fat, $7.2 \pm 3.3\%$) voluntarily participated in the study. Their best performances over 100 m were in the range 10.74–11.57 s and each athlete had participated in national or regional level before this study, thus, all of them were highly trained and familiarised with the testing exercise. None of the athletes had suffered any lower-extremity injury during the six months preceding the study. Before commencing of the study, all athletes signed an informed consent according the Declaration of Helsinki and approved by the ethical committee of the Catholic University of San Antonio.

Procedures

All athletes performed a 15-min warm-up consisting of 5 min of jogging, 5 min of lower limb dynamic stretching and 5 min of progressive sprints (i.e. 40-m at 50%, 70% and 90% effort). Following the warm-up, athletes performed 6 maximal effort 40-m sprints, with 5-min rest between trials, on a synthetic outdoor track. Athletes started from a crouching position (staggered-stance) with the right hand on the track. The six trials were assessed by recording each sprint using an iPhone 6 and *MySprint* app (Apple

Inc., USA), a radar gun (Stalker ATS ProII; Applied Concepts, Plano, TX, USA) and seven pairs of timing photocells (Microgate, Bolzano, Italy) simultaneously. In order to synchronise the three devices, the start of the sprint was determined as the moment in which the right thumb of the athlete took off the ground (this was detected by visual inspection with *MySprint*, pressure pad for timing gates and the centre-of-mass velocity above an arbitrary speed of 0.2 m s^{-1} for the radar). Split time and velocity–time data were used along with subjects' body-mass and body-height as inputs to calculate F_0 , V_0 , P_{\max} and DRF according to Samozino's method (Samozino et al., 2015). Data were compared between the *MySprint* app, radar gun and timing photocells. This comparison to the two reference methods included the inputs of the method (i.e. split times or velocity–time data) and the outputs (i.e. sprint mechanics) of the sprint effort.

Seven pairs of timing photocells were placed at 0, 5, 10, 15, 20, 30 and 40 m to measure the 6 different split times during the six 40-m trials of each athlete. A radar gun measured instantaneous velocity at a sampling rate of 46.875 Hz. The radar gun was placed on a tripod 10 m behind the athletes at a height of 1 m, corresponding approximately to the height of athletes' centre-of-mass (Morin et al., 2012). The *MySprint* app was developed using the software XCode 5.0.5 for Mac OSX 10.9.2 and was installed on an iPhone 6 running iOS 9.3.2; filmed with the iPhone's built in 240 fps high-speed camera at a quality of 720p.

The *MySprint* app was specifically designed for analysing multiple split times from a high-speed video of a maximal 40-m sprint by registering the time-stamp for the beginning and different points where athlete is crossing the six different markers. To record the video of each sprint, the iPhone 6 was mounted to a tripod (in the frontal plane) in order to film the sprint from the side, at the 20 m marker and at 18 m from the track, in order to register the entire sprint. Since the iPhone 6 was in a fixed position, video parallax was corrected to ensure 5-, 10-, 15-, 20-, 30- and 40-m split times were measured properly (Figure 1). Since the iPhone 6 was in a fixed position, video parallax was corrected to ensure 5-, 10-, 15-, 20-, 30- and 40-m split times were measured properly (Figure 1). The correction of the parallax was done by positioning the different markers not exactly at the associated distances (i.e. 5, 10, 15, 20, 30 and 40 m from the starting line), but at adjusted positions so that the subjects were viewed by the iPhone camera to cross the markers with their hip when they were exactly at these targeted distances (5, 10, 15, 20, 30 and 40 m, Figure 1).

Two independent observers, were asked to select the first frame in which athletes' right thumb left the ground (start of the sprint) and, subsequently, the frame in which the pelvis was aligned with each of the 5 different markers for each of the 72 recorded sprints using the *MySprint* app. After this detection procedure, the *MySprint* app automatically calculated each split time in milliseconds and sprint mechanical outputs by implementing the equations developed by Samozino et al. (2015).

Statistical analyses

All data for the 72 sprints compared in total (6 trials, 12 athletes) are presented as mean \pm standard deviation (SD). An independent *t*-test analysis was used in order to compare the *MySprint* app to the radar gun and the photocells for the measurement of (i) each split time (timing gate methods) and (ii) the values of F_0 , V_0 , P_{\max} and DRF (radar method). First, to analyse the concurrent validity of the *MySprint* app in comparison with the other devices, Pearson's product–moment correlation coefficient with 95% confidence intervals (CI), the analysis of the slope and *y*-intercept of the resultant regression lines and the standard error of estimate (SEE) were used. Second, to test the level of agreement between devices on the measurement of the aforementioned variables, the intraclass correlation coefficient (ICC-2,1-) (mean values of the six trials of each individual) and Bland–Altman plots were analysed. Also, the coefficient of variation (CV) was used to analyse the level of reliability of each instrument on the measurement of the six different sprints of each athlete. In order to analyse the inter-observer reliability, the ICC (2,1) and Bland–Altman plots were used. All statistical analyses were performed using IBM SPSS statistics 22 (IBM Co, Armonk, NY, USA) and Microsoft Excel 2010 (Microsoft Corp., Redmont, WA, USA) with a level of significance of $p < .05$.

Results

MySprint app vs. timing photocells for the measurement of sprint time

An almost perfect correlation between the *MySprint* app and the photocells for the measurement of the different sprint times was observed ($r = 0.989–0.999$, $SEE = 0.007–0.015 \text{ s}$, $p < .001$) (Figure 2). Also, a perfect agreement between the values of time was obtained with both the *MySprint* app and the photocells as revealed by the ICC (ICC = 1.00, CI = 1.00–1.00) and the Bland–Altman plot

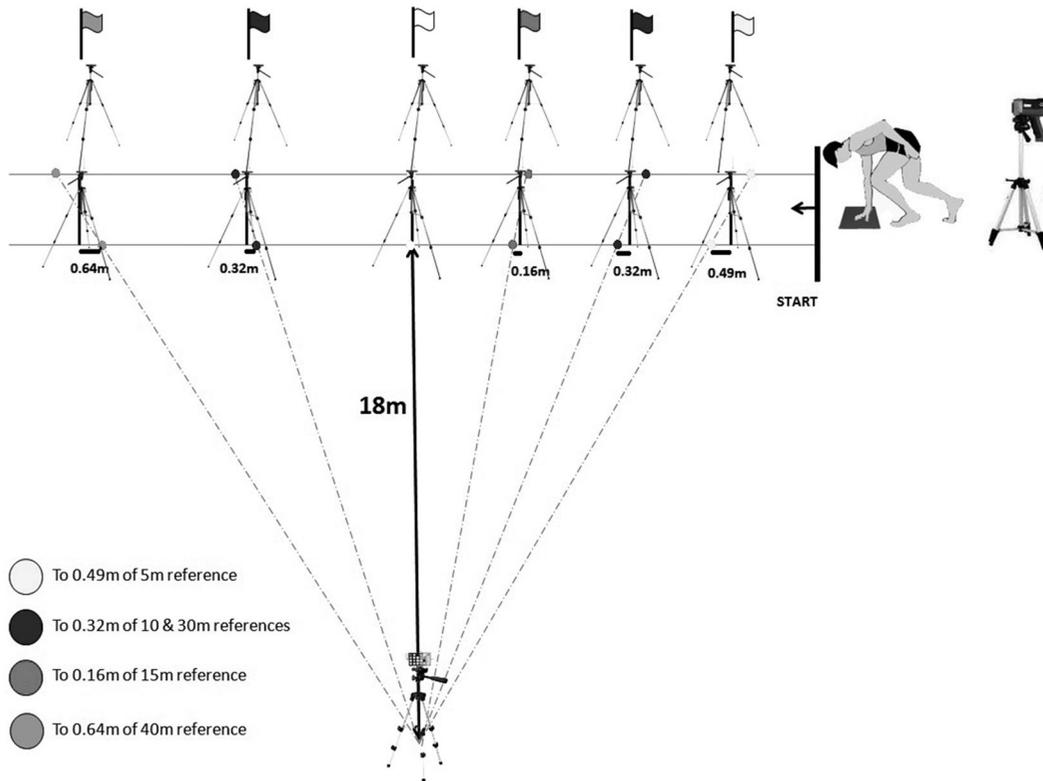


Figure 1. Proposed reference system used during the validation protocol of *MySprint*. Distances of 5, 10, 15, 20, 30 and 40 m are marked by flags.

(Figure 3). No statistically significant differences between the two instruments on the measurement of sprint time were observed, as revealed by the independent measures *t*-test (mean difference = 0.002 ± 0.01 s, $p = .952$). Also, root mean square of error was calculated for comparison between two devices

(RMSE = 0.003). When analysing the reliability of the *MySprint* app for the measurement of the six different trials, very low CV (average values of the different split times), almost identical to those obtained with the timing photocells, were observed (*MySprint*: CV = 0.027%; timing photocells: CV = 0.028%).

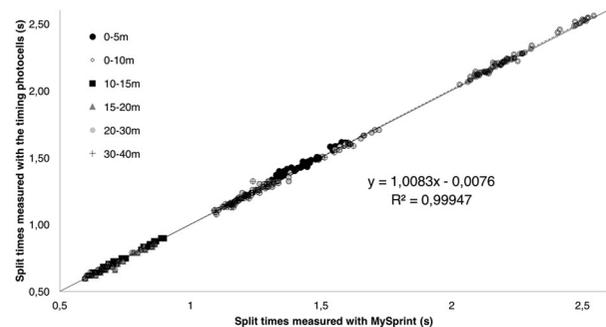


Figure 2. Concurrent validity between the *MySprint* app and the timing photocells for the measurement of the time to cover 0–5, 5–10, 10–15, 15–20, 20–30, 30–40 and 0–40 m. Each split time is represented with different markers; however, the regression equation and the value of R^2 correspond to the whole dataset. The identity line is represented by the discontinuous line, while the regression line is represented by the continuous black line.

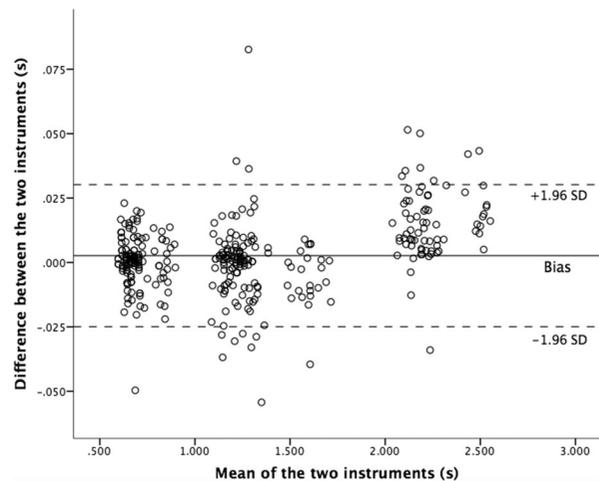


Figure 3. Bland–Altman plots for the timing photocells and *MySprint* app split time data. The central line represents the absolute average difference between instruments, while the upper and the lower lines represent ± 1.96 SD.

MySprint app vs. radar gun for the calculation of sprint mechanics

An almost perfect correlation between the mechanical variables computed with the *MySprint* app and the radar gun time data was also observed ($r = 0.974\text{--}0.999$, $p < .001$). Also, the ICC revealed very high to perfect agreements between the mechanical variables computed with the *MySprint* app and the radar gun (ICC = 0.987–1.00). Furthermore, no statistically significant differences between the two instruments on the measurement of the different mechanical variables were observed, as revealed by the independent measures *t*-test ($p > .05$). Moreover, when analysing the reliability of the *MySprint* app for the measurement of mechanical variables computed from the six different trials, very low CV, almost identical to those obtained with the radar gun, were observed (*MySprint*: CV = 0.14%; radar gun: CV = 0.11%). See Table I for more details.

Inter-observer reliability

Finally, when analysing the values of sprint time measured by the two independent observers, an almost perfect agreement, with no significant differences between raters was observed, as revealed by the independent measures *t*-test (mean difference = 0.004 ± 0.03 , $p = .999$) and the ICC (ICC = 0.998, CI = 0.997–0.998).

Discussion

The present investigation was aimed to analyse the validity and reliability of a new iPhone app (*MySprint*) for the measurement of sprint mechanics under field conditions. Results showed that the agreement of the *MySprint* app with reference methods for the measurement of sprint time (i.e. timing photocells) revealed almost perfect Pearson's product-moment correlation coefficient ($r = 0.999$) and the very low SEE (0.013 s), with no statistically

significant differences. Moreover, the analysis of the Bland-Altman plot provided valuable information about the agreement between *MySprint* and the timing photocells which, as revealed by the ICC, was perfect (ICC = 1.0). First, the limits of agreement of the Bland-Altman plot (± 1.96 SD) were just ± 0.028 s, with the majority of the points close to 0. Moreover, the value of R^2 of the linear regression on the Bland-Altman plot was very low ($R^2 = 0.119$) meaning that the differences between devices were the same at all ranges of speeds measured (i.e. there was no proportional bias). Finally, when analysing the six sprints of each athlete with both the *MySprint* app and the timing photocells, almost identical CV was observed, meaning that the measures obtained with *MySprint* were as reliable as those measured with the timing photocells. In conclusion, *MySprint* can be used to time 40 m sprints and its different splits (0–5, 5–10, 10–15, 15–20, 20–30 and 30–40 m) in a very valid, reliable and accurate way. These results are in line with a recent study that demonstrated that video-analysis is indeed the most stable timing system when analysing the variability of different sprints of the same subject, with lower SDs than photocells or laser systems (Bond, Willaert, & Noonan, 2016).

Although sprint time is an important variable related to other measures of physical performance, analysing other sprint-related mechanical variables (e.g. F_0 , V_0 , P_{\max} and DRF) has been highlighted as paramount over the last decade (Samozino et al., 2015). Specifically, it has been shown that the ability to produce horizontal force via a high mechanical effectiveness is key to understand the success of highly trained sprinters (Morin et al., 2012; Rabita et al., 2015) and, moreover, it was observed that measuring horizontal forces during acceleration sprints could provide relevant information in the context of hamstring injury prevention (Mendiguchia et al., 2014, 2016). To date, measuring these mechanical variables requires advanced equipment such as force platforms, radar guns, laser system or timing photocells and a significant knowledge of

Table I. Concurrent validity and reliability of the radar gun vs. *MySprint* on the measurement of sprint mechanics

	Radar method	<i>MySprint</i> method	SEE	<i>r</i>	<i>s</i>	<i>i</i>	ICC (95% CI)
F_0 (N/kg)	6.8 ± 0.6	6.9 ± 0.6	0.09	0.999 (0.998–0.999)	1.04	–0.22	0.999 (0.999–1.000)
V_0 (m/s)	8.28 ± 1.0	8.35 ± 1.0	0.03	0.988 (0.974–0.999)	0.992	0.14	0.987 (0.979–0.992)
P_{\max} (W/kg)	14.1 ± 2.4	14.5 ± 2.5	0.19	0.988 (0.974–0.999)	1.032	–0.09	0.998 (0.997–0.999)
DRF (%s/m)	-0.077 ± 0.01	-0.078 ± 0.01	0.001	0.994 (0.990–0.9979)	0.97	–0.001	0.994 (0.991–0.996)

Notes: F_0 , theoretical maximal force; V_0 , theoretical maximal velocity; P_{\max} , maximal power output; DRF, slope of the linear decrease on ratio of force as sprint velocity increases; *r*, Pearson's product-moment correlation coefficient; *s*, slope of the regression line; *i*, *y*-intercept of the regression line; ICC, intraclass correlation coefficient; CI, confidence interval; SEE, standard error of estimate.

biomechanics and data processing (Samozino et al., 2015). However, since the validated reference method by Samozino et al. (2015) for measuring sprint mechanics uses 6 splits times of a 40-m sprint, it was expected that the *MySprint* app (which implements Samozino et al.'s equations) would provide valid and reliable estimations of those mechanical variables provided that the main input of the model (sprint time) was successfully validated. This was confirmed by the almost perfect Pearson's product-moment correlation coefficients ($r = 0.974$ – 0.999), the almost perfect agreement (ICC = 0.979 – 1.0) or the small bias ($< 2.5\%$) between the *MySprint* app and the radar gun for the measurement of the main sprint mechanical outputs of F_0 , V_0 , P_{\max} and mechanical effectiveness. Therefore, this study demonstrates that *MySprint* is highly valid and reliable for measuring both sprint time and key acceleration mechanics.

The main limitation of the methodology used by the *MySprint* app to measure the sprint performance is the fact that the user has to manually select the frames in which the athlete passes for different markers, making the measurement process subjective which may produce some error. To address this issue, we analysed the values of sprint times measured by two independent observers using the *MySprint* app, in order to test if significant differences occurred. Our results showed that the difference between both observers was negligible, with no statistically significant differences between the values of time measured with *MySprint* by two observers independently and an almost perfect ICC. These results are in line with another study that analysed the validity of the *MyJump* app which measures flight time of vertical jumps by the manual selection of the take-off and landing frames (Balsalobre-Fernández et al., 2015; Stanton, Kean, & Scanlan, 2015). These small differences between observers are due to the fact that the distance between one frame and the next or previous one is just 0.004 s thanks to the 240 fps video recording of the iPhone 6; therefore, taking into consideration that observers typically differed on one or two frames, the absolute difference in seconds between observers could not be high. In fact, our results showed that the mean difference between observers was 0.004 ± 0.03 s, that is, one frame.

Summarising, the present study demonstrated that the *MySprint* app shows a very high agreement with the current main reference methods for sprint performance analysis (Haugen & Buchheit, 2016) for the measurement of 40-m sprint times and its different splits. Therefore, in addition to its low cost compared with the aforementioned reference methods, it can be considered valid to calculate mechanical variables such as F_0 , V_0 , P_{\max} and DRF while keeping in

mind that the measurement process is based on the manual selection of different frames in which the athletes pass several markers. To the best of our knowledge, this is the first study analysing the validity and reliability of an iPhone application for measuring sprint performance. Physiotherapists, coaches and athletes may benefit from this easy-to-use, portable and affordable tool that provides advanced sprint mechanics measurements under field conditions. Therefore, the development of this app could be of great interest in the context of sport performance and injuries management.

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Disclosure statement

The second author is the main designer of the app covered in this manuscript. To guarantee the independency of the results, two independent observers collected and analyse the data.

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