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Validity and reliability of a novel iPhone app for the measurement of barbell velocity and 1RM on the bench-press exercise
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ABSTRACT
The purpose of this study was to analyse the validity and reliability of a novel iPhone app (named: PowerLift) for the measurement of mean velocity on the bench-press exercise. Additionally, the accuracy of the estimation of the 1-Repetition maximum (1RM) using the load–velocity relationship was tested. To do this, 10 powerlifters (Mean (SD): age = 26.5 ± 6.5 years; bench press 1RM · kg⁻¹ = 1.34 ± 0.25) completed an incremental test on the bench-press exercise with 5 different loads (75–100% 1RM), while the mean velocity of the barbell was registered using a linear transducer (LT) and Powerlift. Results showed a very high correlation between the LT and the app (r = 0.94, SEE = 0.028 m · s⁻¹) for the measurement of mean velocity. Bland–Altman plots (R² = 0.011) and intraclass correlation coefficient (ICC = 0.965) revealed a very high agreement between both devices. A systematic bias by which the app registered slightly higher values than the LT (P < 0.05; mean difference (SD) between instruments = 0.008 ± 0.03 m · s⁻¹). Finally, actual and estimated 1RM using the app were highly correlated (r = 0.98, mean difference (SD) = 5.5 ± 9.6 kg, P < 0.05). The app was found to be highly valid and reliable in comparison with a LT. These findings could have valuable practical applications for strength and conditioning coaches who wish to measure barbell velocity in the bench-press exercise.

INTRODUCTION
It has been extensively demonstrated that increases in muscular strength lead to significant enhancements in several physical activities such as jumping, sprinting, throwing, kicking or running, among others (Folland & Williams, 2007; Seitz, Reyes, Tran, De Villarreal, & Haff, 2014; Suchomel, Nimphius, & Stone, 2016). One of the most common methods to increase muscular strength is resistance training (Contreras et al., 2016; Gonzalez-Badillo, Gorostiaga, Arellano, & Izquierdo, 2005; Schoenfeld, Ogborn, & Krieger, 2016). Thus, quantifying and prescribing resistance training programmes has been widely investigated in order to optimise the desired adaptations (Brandon, Howatson, & Hunter, 2011; Gonzalez-Badillo & Sánchez-Medina, 2010; Singh, Foster, Tod, & McGuigan, 2007). Specifically, the manipulation of training intensity is considered key in the design of resistance training programmes (Folland & Williams, 2007; Fry, 2004); in fact, it seems that the neuromuscular adaptations to resistance training are highly dependent on the intensity of the training stimulus (Cormie, McGuigan, & Newton, 2010; Fry, 2004; Gonzalez-Badillo, Rodriguez-Rosell, Sánchez-Medina, Gorostiaga, & Pareja-Blanco, 2014).

Over the last few decades, the measurement of the 1-Repetition maximum (1RM; i.e., the load that can be lifted just once) has been the most widely used methodology to quantify and prescribe resistance training intensities (McMaster, Gill, Cronin, & McGuigan, 2014; Soriano, Suchomel, & Marin, 2016). However, prescribing training intensity as a percentage of the 1RM (i.e., 75% 1RM) has a major drawback: it requires performing a maximal effort that might increase the risk of injuries or overtraining, especially in untrained or weaker populations such as elderly people (Pollock et al., 1991). Therefore, several methodologies have been developed to estimate 1RM using less invasive protocols, such as performing a number of submaximal repetitions (Julio, Panissa, & Franchini, 2012; Kravitz, Akalan, Novicki, & Kinzey, 2003), registering the rate of perceived exertion (Day, McGuigan, Brice, & Foster, 2004; Robertson et al., 2008) or, more recently, measuring the barbell’s displacement velocity during the lift (Bazuelo-Ruiz et al., 2015; Conceição, Fernandes, Lewis, González-Badillo, & Jiménez-Reyes, 2016; Gonzalez-Badillo & Sánchez-Medina, 2010; Jidovtseff, Harris, Crielaard, & Cronin, 2011). Among them, velocity measurement has been demonstrated to be the best non-invasive methodology to estimate the 1RM of the participants thanks to the well-known load–velocity relationship, for which the velocity at which the bar is lifted is extremely well correlated (R² > 0.97) with the load it represents (Conceição et al., 2016; Gonzalez-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011). Therefore, measuring barbell velocity allows us to estimate the 1RM with high accuracy without conducting an actual 1RM test.

Different technologies, such as linear transducers (LT), professional accelerometers or advanced video systems have been used to track barbell velocity (Comstock et al., 2011; Crewther et al., 2011; Lake, Lauder, & Smith, 2012), with LT often considered the gold standard by many researchers.
An LT consists of a sensor with a cable that is attached to the barbell and measures barbell velocity by (a) recording electrical signals proportional to cable velocity (i.e., linear velocity transducers) or (b) differentiating cable displacement with respect to time (i.e., linear position transducers). However, LTs have 1 major drawback: they are still too expensive for many coaches (about 2000 US dollars). For this reason, recent studies have analysed the validity and reliability of more affordable technologies used to measure barbell velocity in resistance exercises, like low-cost accelerometers or high-speed cameras (Balsalobre-Fernández, Kuzdub, Poveda-Ortiz, & Campo-Vecino, 2016; Sañudo, Rueda, Pozo-Cruz, De Hoyo, & Carrasco, 2016). Other studies have even demonstrated that smartphones can measure different physical performance variables, such as vertical jump height or range of motion (ROM; Balsalobre-Fernández, Glaister, & Lockey, 2015; Patterson, Amick, Thummar, & Rogers, 2014), without any external device. This is thanks to the advanced sensors included in the more recent models, making the measurement process simple, practical and affordable. However, no study has analysed the use of a smartphone app to measure barbell velocity in resistance exercises. Thus, the purpose of the present study was to analyse the concurrent validity and reliability of an iPhone app based on high-speed video recording and Newtonian physics to calculate barbell mean velocity on the bench-press exercise in comparison with a LT and, subsequently, to compare the estimated 1RM of the athletes using the aforementioned load–velocity relationship with their actual 1RM. We hypothesised that the app would be highly valid and reliable for the measurement of barbell mean velocity and 1RM on the bench-press exercise.

Methods

Participants

The participants in the present study were 10 resistance trained males with at least 4 years of experience in bench-press training (mean (SD): age = 26.5 ± 6.5 years, height = 1.77 ± 0.1 m; body mass = 86.0 ± 24.3 kg; bench-press 1RM = 111.7 ± 39.7 kg (or 1.34 ± 0.25 when normalising per kg of body mass)). The study protocol complied with the Declaration of Helsinki for Human Experimentation and was approved by the ethics committee at the institutional review board. Written informed consent was obtained from each participant in advance.

Experimental approach

Athletes performed 5 sets on the bench-press exercise with loads ranging 75–100% of their 1RM while barbell mean velocity was being recorded with the Smartcoach Power Encoder (Smartcoach Europe, Stockholm, Sweden) LT and an iPhone app called PowerLift, simultaneously. Each athlete performed 3 repetitions with the 75%, 80%, 85% and 90% 1RM, and 1 repetition with the 100% 1RM for a total of 13 repetitions. Concentric mean velocities of the resultant 130 repetitions measured with both systems were compared for validity and reliability purposes using several statistical analyses. Additionally, the 1RM estimated by the app was compared to the actual 1RM measured in the aforementioned incremental test.

Instruments

App. The PowerLift app was developed using Xcode 7.3.1 for Mac OS X 10.11.5 and the Swift 2.1.1 programming language (Apple Inc., USA). The AVFoundation and AVKit frameworks (Apple Inc., USA) were used for capturing, importing and manipulating high-speed videos. Then, the app (version 2.8) was installed on an iPhone 6 running iOS 9.3.2 (Apple Inc., USA) which has a recording frequency of 240 frames per second (fps) at a quality of 720 p. To measure mean velocity, PowerLift was designed to allow calculation of the time (in ms) between 2 frames selected by the user and, subsequently, the velocity of the barbell using the well-known Newtonian equation (1):

\[ v = \frac{d}{t}, \]

where \( v \) is the mean velocity of the barbell (in m · s\(^{-1}\)), \( d \) the vertical distance from the chest of the athlete to the bar in the final position of the bench press (i.e., the full ROM – which needs to be entered in the app), and \( t \) the time of the concentric phase of the lift.

To record the videos, a researcher held the iPhone in his hand in portrait position and recorded each lift from behind the athlete (i.e., facing the head of the participant) at 1.5 m from the bench and at the same height of participant’s chest in order to see the full ROM as close as possible. See Figure 1 for more details.

The beginning of the lift was considered as the first frame in which the barbell left the chest of the athletes, and the end of the lift was considered as the first frame in which the barbell ended its vertical displacement. Since this procedure requires a manual selection by the researcher, 2 independent observers analysed the same videos to test the inter-observer reliability as proposed elsewhere (Balsalobre-Fernández et al., 2015). After recording each repetition, the app exported the velocity measure to a spreadsheet for further analysis.

Linear transducer. The Smartcoach Power Encoder LT (Smartcoach Europe, Stockholm, Sweden) was used as the criterion for measuring barbell velocity. To register mean velocity using the Smartcoach LT, its cable was attached to the barbell following the criteria described by the manufacturer, which basically require the cable to be aligned with the vertical axis. It should be noted that this LT measures velocity just in the vertical axis and does not register horizontal displacements that occurs while bench-pressing (Van Den Tillaar & Ettema, 2009). Then, the LT was connected to the Smartcoach software 5.0.0 installed on a personal computer running the Windows 10 operating system. Mean velocity values in m · s\(^{-1}\) were recorded for each repetition in the aforementioned software. The LT had a sampling frequency of 1000 Hz.

1RM incremental test

After conducting a 15-min warm-up consisting of dynamic stretching and preparatory exercises (i.e., glenohumeral joint external rotations, scapular retractions and bench presses with...
the 50% 1RM), participants performed 5 different sets on the bench-press exercise with increasing loads corresponding approximately to their 75%, 80%, 85%, 90% and 100% 1RM. For the first 4 sets (i.e., loads ranging 75–90% 1RM), athletes performed 3 repetitions, while for the last set athletes performed 1 repetition (i.e., the 1RM). If some participant could perform more than 1 repetitions with the fifth load, an additional set with a heavier load was performed in order to reach the 1RM. Sets were separated by 5 min of passive rest. Athletes were instructed to perform each repetition as fast as possible, and all of them were experts on the bench-press exercise.

**Estimation of the 1RM using the load–velocity relationship**

In addition to barbell velocity measurement, the PowerLift app was also designed to estimate the 1RM using the well-known force (load)–velocity relationship (Gonzalez-Badillo & Sanchez-Medina, 2010; Jidovtseff et al., 2011). To do this, the algorithm of the app needs 4 different submaximal loads with their corresponding barbell velocity and the velocity of the 1RM \((v-1RM)\) which, as demonstrated elsewhere, is almost identical for different resistance-trained participants (Conceição et al., 2016; Gonzalez-Badillo & Sanchez-Medina, 2010; Sanchez-Medina, Gonzalez-Badillo, Perez, & Pallares, 2014). Then, an individual load–velocity profile is created using least squares to obtain a linear regression equation as follows (2):

\[
v = sm + i,
\]

where \(v\) is the velocity of the barbell \((\text{in m} \cdot \text{s}^{-1})\), \(m\) the mass of the load \((\text{in kg})\), \(s\) the slope of the straight-line equation and \(i\) the y-intercept. Thus, if \(m\) is isolated (3):

\[
m = \frac{v - i}{s},
\]

the 1RM \((m\) in this case) can be calculated by replacing \(v\) with the value of \(v-1RM\).

In order to compare the actual 1RM with the 1RM estimated with the app, the loads performed in the test ranging 75–90% 1RM were used for the regression analysis. Furthermore, for comparison purposes, the same approach was used to estimate the 1RM with the velocities obtained from the LT.

**Range of motion measurement**

As mentioned above, the ROM in the bench-press exercise needs to be entered in the app to calculate the mean velocity for the barbell. To measure the athletes’ ROM, participants held the final position on the bench-press exercise with an empty barbell (i.e., elbows fully extended) while an experienced researcher measured the vertical distance from the bar to the chest with a metric tape.

**Statistical analyses**

First, the app’s concurrent validity was tested using Pearson’s product–moment correlation coefficient \((r)\) with 90% confidence intervals \((CI)\) via bootstrapping. Second, to analyse the level of agreement (reliability) of the app to measure mean velocity in comparison with the LT, the intraclass correlation coefficient \((ICC \text{-} 2.1)\) with 90% CI and Cronbach’s alpha were used. Also, paired samples \(t\)-test and Bland–Altman plots were used to identify potential systematic bias, reported via mean bias, standard deviations and the analysis of the regression line on the Bland–Altman plots. Furthermore, standard error of estimate \((SEE)\) was also used to report the typical error in the measurements. Third, to test the inter-observers’ reliability in the measurement of mean velocity using the app, as well as to identify potential systematic differences between observers, the ICC \((2.1)\) with 90% CI and the independent measures \(t\)-test were used. Finally, to compare the actual 1RM of the athletes with the one estimated with the app, the non-parametric Wilcoxon signed-rank test was used. The level of significance was set at 0.01. All calculations were performed using IBM® SPSS® Statistics 22 software (IBM Co., USA).
Results

Concurrent validity of the app
When analysing the whole data set (130 individual velocities), Pearson’s product–moment correlation coefficient showed a significant, very high relationship between the values of mean velocity measured with PowerLift and the LT \( r = 0.94, \) CI = 0.92–0.96; \( \text{SEE} = 0.028 \text{ m} \cdot \text{s}^{-1}, \) slope of the regression line = 0.97, \( P < 0.001 \). See Figure 2 for more details.

Reliability and accuracy of the measurements with the app vs. LT
There was a very high agreement between the values of mean velocity measured with PowerLift and those measured with the LT as revealed by the ICC, Cronbach’s alpha and Bland–Altman plots (ICC = 0.965, CI = 0.952–0.974; \( \alpha = 0.967 \)). See Figure 3 for more details.

The paired samples \( t \)-test revealed a systematic bias by which the values obtained with the app tended to be slightly higher than those measured with the LT (\( P < 0.05; \) mean difference (SD) between instruments = 0.008 ± 0.03 m · s\(^{-1}\), 90% CI = 0.004–0.014). Moreover, when analysing the value of \( R^2 \) between the mean of the 2 instruments vs. the difference between the 2 instruments (i.e., the X and Y axis on the Bland–Altman plot, respectively), a null relationship was observed (\( R^2 = 0.011 \)), indicating that the difference between instruments is similar across the entire range of velocities measured.

Intra-observers’ reliability
Independent measures \( t \)-test revealed no significant differences between the values of mean velocity measured by the 2 observers (\( P = 0.549; \) mean (SD) difference between observers = −0.0007 ± 0.02 m · s\(^{-1}\)). Moreover, the ICC (ICC = 0.941, 90% CI = 0.922–0.955) and the Bland–Altman plot (\( R^2 = 0.022 \)) showed a very high agreement between both observers in the measurement of mean velocity using PowerLift. See Figure 3 for more details.

Estimated vs. actual 1RM comparison
There was a very high, significant correlation between the actual 1RM and the 1RM estimated using PowerLift (\( r = 0.98, \) CI = 0.97–0.99, \( P < 0.001 \)). 1RM values estimated by the app were significantly different from the actual 1RM values of the athletes as revealed by Wilcoxon’s signed-rank test (mean (SD): actual 1RM = 111.7 ± 39.7 kg; estimated 1RM = 106.2 ± 45.2 kg; mean difference = 5.5 ± 9.6 kg; \( P = 0.008 \)). Nine out of 10 participants had actual 1RMs higher than the value estimated from the app, while 1 participant’s actual 1RM was lower than estimated 1RM. See Figure 4 for more details. However, there were no significant differences between the 1RM estimated with the app or with the LT (mean (SD): app’s estimated 1RM = 106.2 ± 45.2 kg; LT’s estimated 1RM = 107.6 ± 48.6 kg; mean difference = −1.1 ± 5.6 kg; \( P = 0.45 \)).

Discussion
The app was found to be highly valid and reliable for the measurement of mean velocity in comparison with a LT. Data showed a very high correlation between the values obtained with the app vs. the LT (\( r = 0.94 \)). Bootstrapping analysis (\( N = 1000 \)) calculated a very narrow CI for Pearson’s product–moment correlation coefficient (CI = 0.92–0.96), highlighting the good association between both devices for measuring mean velocity. Moreover, the slope of the regression line between the velocity values obtained with both devices (\( s = 0.97 \)) was very close to the identity line (i.e., the straight line represented by the equation: \( y = x \)), meaning that the values measured with both devices were very similar. However, there was a systematic bias (\( P < 0.05 \)) between the 2 devices as revealed by the paired samples \( t \)-test by which the velocities measured with PowerLift tended to be slightly higher than those measured with the LT (mean difference = 0.008 m · s\(^{-1}\)). This might be due to the fact that the LT (which works at 1000 Hz) captured the concentric vertical displacement of the barbell before it could be visually detected with the 240 Hz video recorded by the app, making the final mean velocity slightly lower. This is in line with previous research that observed that video systems registered higher velocities than LTs in resistance exercises (Sañudo et al., 2016). Finally, the level of agreement between PowerLift and the LT was also very high, as revealed by the ICC (ICC = 0.965) and the Bland–Altman plot. The analysis of the regression line between the data points on the Bland–Altman plot showed a very low \( R^2 \) value (\( R^2 = 0.011 \)) with a slope very close to 0, meaning that the differences between instruments were almost the same across the whole range of velocities (and, subsequently, loads) analysed. However, since small differences (i.e., <0.1 m · s\(^{-1}\)) in mean velocity could represent variations of about 5% in training intensity (Gonzalez-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2014), it is recommended not to use PowerLift and a LT interchangeably.

Previous studies have successfully validated low-cost technologies such as wearable devices or open-source video
software with LT (Balsalobre-Fernández et al., 2016; Sañudo et al., 2016). Specifically, 1 previous study showed that video analysis can provide valid measurements of barbell velocity on the bench-press exercise (Sañudo et al., 2016); however, the accuracy of the video software observed in that study was much lower than that found in our study, with mean differences ranging from 0.14 to 0.59 m · s$^{-1}$ compared with a LT. This was probably due to the fact that these authors used 50 Hz (i.e., normal speed) video recording instead of high-speed recording, which allows a much better frame-by-frame measurement (Balsalobre-Fernández et al., 2015).

An additional aim in the present study is the accuracy of the app to estimate the 1RM of the athletes. The app uses the well-known load–velocity relationship to predict the 1RM using least squares as proposed elsewhere (Gonzalez-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011). Several investigations have observed that this approach can provide accurate estimations of the 1RM in different exercises (Bazuelo-Ruiz et al., 2015; Jidovtseff et al., 2011; Picerno et al., 2016); however, although we observed very high correlations between actual and estimated 1RM values ($r = 0.98$), significant differences between participant’s actual and estimated 1RM were found ($P < 0.05$). Specifically, 9 from 10 participants’ 1RM values were significantly underestimated.

This might be due to the fact that the app’s algorithm uses a value of $v$-1RM equal to 0.17 m · s$^{-1}$ as reported elsewhere (Gonzalez-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2014). As described in the materials and methods section, the $v$-1RM value is needed to estimate the 1RM using the slope and the y-intercept of the linear regression equation. However, the value of $v$-1RM of the athletes on our study was 0.14 m · s$^{-1}$ on average. For this, the linear regression

Figure 3. Bland–Altman plots for the measurement of mean velocity between: (a) instruments and (b) observers. The horizontal thin lines represent the observed bias with 1.96 standard deviations (SD), while the thick line is the regression line of the data points.
computed by *PowerLift* underestimated the value of 1RM. Furthermore, we computed the same linear regression using velocities from the LT, and we observed that the estimated 1RM was not significantly different from the 1RM estimated using the app (mean difference = −1.1 kg; \( P = 0.45 \)). Thus, both instrumentals underestimated the 1RM very similarly in our study. In any case, the app was proven to estimate the 1RM in the bench-press exercise, with levels of precision similar to those obtained with LT (Bosquet, Porta-Benache, & Blais, 2010; Jidovtseff et al., 2011) or submaximal repetitions to failure (Julio et al., 2012; Kravitz et al., 2003) (=5 kg), as observed in previous studies. Thus, the app could be used to estimate the 1RM with submaximal loads (i.e., 75–90% 1RM) without the need to perform an actual 1RM test or repetitions to failure, which might impair performance and recovery due to its maximal intensity (Davies, Orr, Halaki, & Hackett, 2016; Pareja-Blanco et al., 2016).

The major drawback of the app is the manual selection of the beginning and end of the movement by inspecting the high-speed videos on the app. However, to address this issue we compared the reliability of 2 observers who independently analysed each video with *PowerLift* to measure mean velocity. A very high agreement between observers’ measured velocities was observed, as revealed by the ICC (ICC = 0.969), the independent measures t-test (\( P = 0.549 \)) and the Bland–Altman plot where no systematic bias was identified (Bias = 0.0007 m · s\(^{-1}\); \( R^2 = 0.022 \)). These results confirm the good inter-observers agreement when analysing high-speed videos (Balsalobre-Fernández et al., 2015). Also, it is worth noting that the app, due to the very simple method used to calculate velocity, cannot provide measures of peak or mean propulsive velocity (MPV), the latter being especially relevant since it can better detect the neuromuscular capabilities of the participant (Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010). However, if medium to high submaximal loads are used (i.e., 75–90% approximately), the braking phase on the bench-press exercise drops to 0%

and, therefore, mean velocity equals MPV (Sanchez-Medina et al., 2010); thus, if coaches want to calculate MPV with the app, medium to high loads should be used.

In conclusion, the *PowerLift* app was proven to be a highly valid, reliable and accurate instrument to measure mean velocity and, subsequently, to estimate the 1RM on the bench-press exercise. However, since a systematic bias was observed, the *PowerLift* app should not be used interchangeably with a LT. To the best of our knowledge, this is the first study analysing the validity of an iPhone app for measuring mean velocity in resistance exercises.

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**Disclosure statement**

The first author of the article is the developer of the app mentioned. The data from the app were obtained from two independent observers not related to the app development.

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**References**


**Figure 4.** Actual and *PowerLift*’s estimated 1RM values of each athlete.


