Original article

Assessment of an APP to measure lift velocity during bench press exercises: preliminary results

Javier Peláez Barrajón, Alejandro F. San Juan

Laboratorio de Biomecánica Deportiva. Departamento de Salud y Rendimiento Humano. Facultad de Ciencias de la Actividad Física y del Deporte – INEF. Universidad Politécnica de Madrid.

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Summary

Introduction: It's becoming more common to find sports mobile applications that have easy access and are easy to use. Nevertheless their general measure precision still needs improvement. The objective of this study was to determine the precision that a Smartphone application (APP) and a Smartphone accelerometer can provide to measure the mean velocity of a bench press (BP) on Smith machine.
Material and method: 5 subjects participated in the study (age 23,8 ± 2,94 years), they had a minimum lifting experience of 1 year. All of them did 3 repetitions with a load of 70% and 90% of the estimated value of 1 Repetition Maximum (1RM), and a lift with their 1RM. In each repetition mean velocity was measured by a validated linear encoder and the APP.
Results: there was a strong positive correlation in mean velocity between linear encoder and the APP (r= 0,685, $p<0.001$, SEE=0,09 m • s_{-1}). Intraclass correlation coefficient (ICC = 0,707) showed a good agreement between both devices. The APP showed significant differences in the mean velocities of lifts with the 90% 1RM (APP= 0,44±0,08 m • s_{-1}; Encoder= 0,30 ± 0,03 m • s_{-1}), not showing significant differences in mean velocities of lifts with 70% 1RM (APP= 0,54±0,13 m • s_{-1}; Encoder= 0,51 ± 0,10 m • s_{-1}).
Discussion: At this moment the APP is not totally reliable and valid at low velocity lifts. Nevertheless, with proper signal filters it could be a precise, accessible and easy to use tool to measure lifts velocity in an easy and proper way.

Key words:
Accelerometer. Smartphone. Resistances. Training. Technology. Strength. APP. Test.

Evaluación de una APP para medir la velocidad de levantamientos de *press* banca: resultados preliminares

Resumen

Introducción: Cada vez es más frecuente encontrar aplicaciones móviles relacionadas con el deporte de fácil acceso y uso. Sin embargo, su precisión general de medida tiene aún mucho margen de mejora. El objetivo de este estudio fue determinar la precisión de una Aplicación móvil (APP) Android y del acelerómetro del teléfono móvil, para medir la velocidad media de un levantamiento de *Press* Banca (PB).
Material y método: Participaron en el estudio 5 sujetos (edad 23,8 ± 2,94 años), con una experiencia mínima de un año en el entrenamiento con resistencias en PB. Todos realizaron 3 repeticiones con un 70% y 90% del valor estimado de 1 Repetición Máxima (1RM). En cada repetición se midió y comparó la velocidad media simultáneamente con un Encoder lineal validado y la APP.
Resultados: Observamos una correlación positiva fuerte de la velocidad media entre el *Encoder* lineal y la APP (r= 0,685, $p<0.001$, SEE=0,09 m • s_{-1}). El coeficiente de correlación intraclase (ICC= 0,707) mostró un buen acuerdo entre ambos dispositivos. La APP mostró diferencias significativas en las velocidades medias de levantamientos del 90% 1RM (APP= 0,44±0,08 m • s_{-1}; Encoder= 0,30 ± 0,03 m • s_{-1}), no encontrando diferencias significativas en velocidades medias con cargas del 70% 1RM (APP= 0,54±0,13 m • s_{-1}; *Encoder*= 0,51 ± 0,10 m • s_{-1}).
Discusión: La APP no es por el momento totalmente válida y fiable a bajas velocidades de ejecución. Sin embargo, con filtros de señal específicos puede llegar a ser una herramienta de medición suficientemente precisa, accesible, fácil de usar, y que permitirá estimar la velocidad de los levantamientos de forma cómoda y adecuada.

Palabras clave:
Acelerómetro. Teléfono móvil. Resistencias. Entrenamiento. Tecnología. Fuerza. APP. Test.

Correspondence: Javier Peláez Barrajón
E-mail: javi.pelaezb@gmail.com

Introduction

Resistance or weight training has been the method most used to increase muscle strength in athletes[1]. In order to prescribe a resistance training programme based on the capabilities of each individual athlete, it is first necessary to determine the maximum load that this person can move during an exercise or the lift velocity[2].

The performance of a 1 Repetition Maximum (1RM) strength assessment test carries a high risk of injury for novice athletes or more fragile populations such as children and the elderly[3]. Even for high-performance athletes, the 1RM test still entails a risk of injury and could affect the planning of their training sessions[4]. Consequently, different indirect methods have been proposed to estimate 1RM: methods based on muscular endurance[5-7], anthropometric measurement methods[8-11], and those based on lift velocity[12,13].

The 1RM estimation method based on sub-maximal lift velocity has been shown to be a valid and reliable method to accurately predict 1RM without actually performing the lift at maximum load[12,13]. The linear transducer is considered to be the gold standard tool for the measurement of lift velocity[12,13], however its main drawback is that it is expensive. Other methods are available for the measurement of lift velocity, such as the use of video analysis[14,15] or professional accelerometers[16,17]. Moreover, it is becoming increasingly more common to find smartphone sport-related applications, and specifically for the analysis of lift velocity[14], or jumping[18].

Given that present-day smartphones feature inertial sensors (accelerometers, magnetometers and gyroscopes) to determine the position and movement of the device, this technology could be used to measure lift velocity[19]. However, to date, and to the best of knowledge, there is no smartphone Application (APP) that uses this hardware to measure velocity and estimate strength.

The key aim of this study was to establish the reliability and validity of the APP that uses the smartphone accelerometer to obtain the mean concentric velocity of a bench-press (BP) lift on a Smith machine, compared with a validated linear transducer. Moreover, the specific objectives were as follows: 1) to determine the degree of validity of the smartphone accelerometer, 2) to verify the utility of the application in an actual test environment, and 3) to identify any potential errors and disadvantages of the APP in order to correct future software versions.

The following hypothesis is made: the APP will be valid and reliable for the measurement of the mean lift velocity compared with a validated linear transducer.

Material and method

Experimental approach to the problem

Five young male subjects took part in the study, with experience in endurance training and specifically with at least 1 year's experience in BP exercises. All subjects performed 3 BP repetitions on the Smith machine with 70% 1RM, 3 repetitions with 90% 1RM and one attempt at 1RM. These intensities-percentages were selected, given that they have proven to be useful in estimating the 1RM value through a linear equation, as described by Jaric, S.[20]. Each repetition was simultaneously measured with a validated linear transducer[19] (Speed4Lifts, Madrid, Spain), and smartphone (TEL), both attached to the bar. A running armband phone holder was used to attach the TEL (Figure 1) while the velcro strip supplied with the transducer was used to fix it in place. Statistical analysis was used to compare the mean concentric velocities for 70 lifts in order to verify the validity and reliability of the APP..

Figure 1. Position of the linear transducer and the TEL during the experiment.

Participants

5 subjects with at least one year's specific experience in BP resistance training took part in the study (Mean ± Standard deviation: Age = 23.8 ± 2.9 years; Height = 177.6 ± 9.2cm; Weight = 77.5 ± 9 kg; 1-RM BP = 80.8 ± 16.7 kg). The exclusion criteria were as follows: 1) aged under 18 years; 2) consumption of narcotic drugs and/or psychotropic substances before or during the test; 3) any cardiovascular, metabolic, neurological, pulmonary or orthopaedic disease or disorder that could limit performance in the different tests; 4) less than 12 months' experience in BP training. All participants were students at the Faculty of Physical Activity and Sports, where the test was conducted.

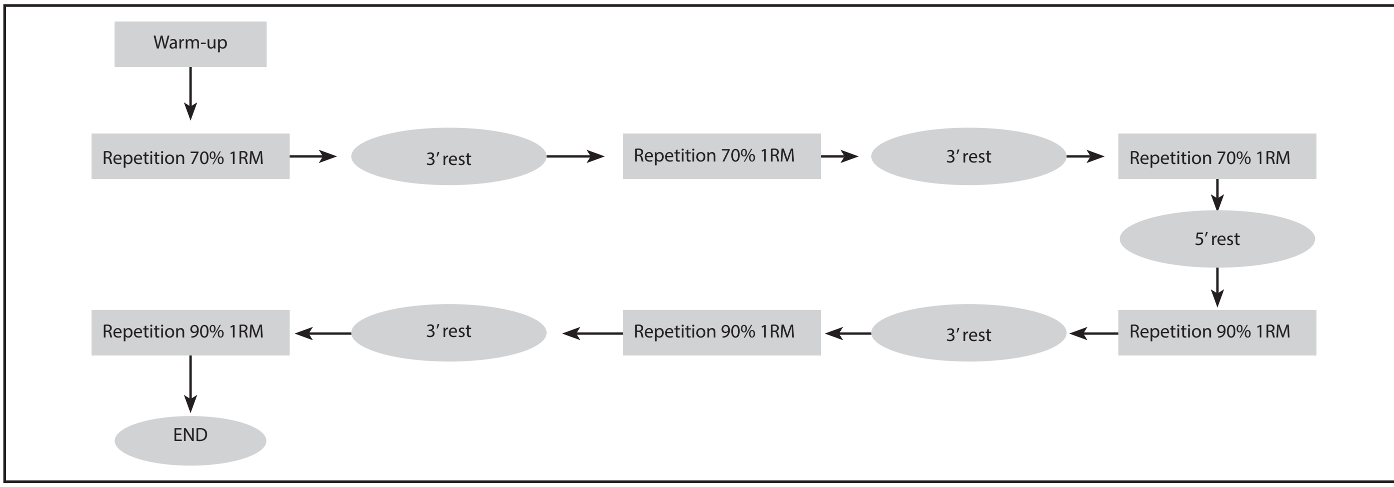
The study was approved by the Ethics Committee of the Universidad Politécnica de Madrid and complies with the principles of the Declaration of Helsinki for research involving human subjects. The purpose of the study was explained to each participant, both orally and in writing through an information sheet, and all participants signed an informed consent form.

Procedure

BP test

All subjects performed a warm-up based on the literature[18,21]. They started with 5 minutes of aerobic exercise and went on to do dynamic stretching (e.g. internal and external shoulder rotations, elbow extensions and wrist rotations), and upper-body joint mobility exercises. This was followed by 2 sets of 5 BP repetitions at approximately 50% of the subject's 1RM and a two-minute rest between sets. To complete the warm-up, the subjects performed two sets of 1 repetition at 50% of their 1RM at maximum velocity in order to suitably prepare the body's muscles.

Figure 2. Flow diagram with the implementation of the BP test.



During the test, each subject performed 3 repetitions at 70% 1RM and a three-minute rest between each repetition. After the final repetition with 70% 1RM, they rested for 5 minutes and then began the 3 repetitions at 90% 1RM, with a three-minute rest between each repetition (Figure 2).

Each repetition started with a 3 second pause after unhooking the bar. The APP gave a beep ("LETS GO") and the subjects performed the eccentric phase of the lift, until the bar touched the chest. After a 1 second pause, the application gave a second beep and the subjects performed the concentric phase of the lift at the maximum possible velocity. Both the APP and the transducer recorded the mean concentric lift velocity. All the lifts were performed on a Smith machine.

All subjects were requested not to train the muscle groups involved in the lift for at least 2 days before the test.

Instruments

The APP was developed at the Android Studio integrated development environment (Google, California, USA), using the Java programming language (Oracle, California, USA). The sensorManager library was used to capture the acceleration values. The APP was installed in a Huawei G620S smartphone (Huawei Technologies Co., Guangdong, China), with an Android operating system (Google, California, USA), and a lis3dh three-axis accelerometer (STMicroelectronics, Geneva, Switzerland). The acceleration sampling frequency was set at 50 Hz. To calculate the mean lift velocity, accelerations were taken from the concentric phase on the smartphone Z axis and the integration principle was used for the integration of these values:

$$v = \int a\,dt$$

A trapezoidal rule was developed in code to obtain the approximation of the integration value:

$$\int_b^a f(x)dx \sim h/2\,[f(a)+2f(a+h)+2f(a+2h)+\cdots+f(b)]$$

Where $h = \frac{(b - a)}{n}$ and n is the number of divisions.

The trapezoidal rule divides the area under the curve for the plot of the different acceleration values into n trapezoids of different areas. The sum of the area of all the trapezoids under the curve will give the approximated value of the integral of the said curve. The greater the number of trapezoids, which is in keeping with the number of acceleration events taken during the concentric phase, the greater the precision of the integral approximation[22].

Given the considerable noise of the TEL accelerometer, various signal filtering processes were used. These processes included the use of a "mechanical" filter to eliminate those residual values that ought to be 0 but which were given a higher or lower value by the accelerometer. Furthermore, a low pass filter was used with a filter factor that would smooth-out the acceleration curve, the greater the value.

Statistical analysis

The Shapiro-Wilk test was used for the data normality analysis. Once the normality of the dependent variables had been confirmed, ($p > 0.05$), the results were presented as a mean (M), and standard deviation (SD). Various statistical analyses were used to demonstrate the validity and reliability of the APP in comparison with the linear transducer in the BP exercise on the Smith machine. Firstly, the concurrent validity of the APP was tested using the Pearson correlation coefficient (r). The *Intraclass Correlation Coefficient* (ICC) was used to calculate the APP measurement reliability compared to that of the linear transducer. The calculation of the mean differences between the two measurements was made using a paired-sample *t* test. The standard error of estimate (SEE) was used to show the standard deviation in the measurements. The significance cutoff was set at $p = 0.05$. All calculations were performed using IBM® SPSS® Statistics 23 software (IBM Co., USA).

Results

The concurrent validity of the APP

Following the analysis of all the data for the 30 mean velocities, Pearson's correlation showed a strong positive relationship between the velocities taken simultaneously with the transducer and the APP (r= 0.685, p<0.001, SEE=0.09 $m \cdot s_{-1}$) (Figure 3).

Measurement reliability

There was good agreement between the mean velocity values obtained with the APP and the linear transducer, as shown by the ICC and Cronbach's *alpha* (ICC= 0.707; CI= 0.076- 0.886; α = 0.812).

The paired-sample t test used to compare the mean lift velocities obtained by the linear transducer and the APP showed a significant difference in velocities (APP= 0.49±0.12 $m \cdot s_{-1}$; Transducer= 0.41 ± 0.13 $m \cdot s_{-1}$; $p < 0.001$) with higher mean velocities measured by the APP (mean difference: 0.08 $m \cdot s_{-1}$).

The paired-sample t-test was performed to compare the mean velocities at each percentage of 1RM, finding no significant differences between the mean velocities at 70% 1RM measured by the APP and the linear transducer ($p > 0.05$). However, significant differences were found in the mean velocities measured for lifts at 90% 1RM, with the APP measurements being clearly higher ($p > 0.001$) (Table 1).

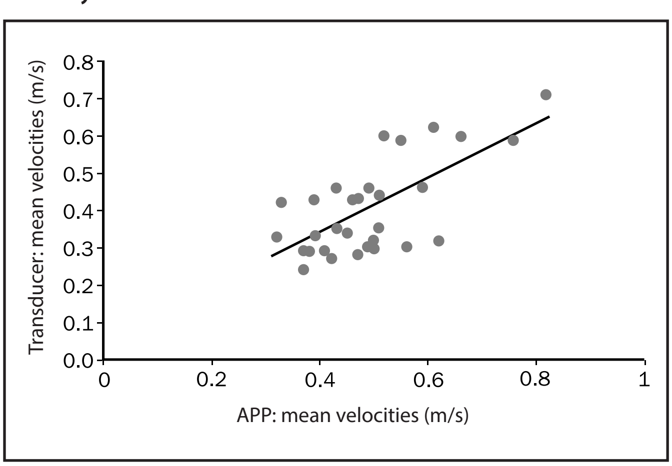
Discussion

The APP did not prove to be totally valid and reliable for the measurement of the mean velocity of a BP exercise on the Smith machine, compared with a validated linear transducer. The mean lift velocity values obtained with the APP were shown to have a strong positive correlation

Table 1 Mean lift velocity ($m \cdot s_{-1}$) based on the 1RM percentage. The data are presented as mean ± SD (standard deviation).

	App Mean ± SD	Transducer Mean ± SD
Mean velocity 70% 1 RM	0.54 ± 0.13	0.51± 0.10
Mean velocity 90% 1 RM	0.44 ± 0.08	0.30± 0.03

Figure 3. Pearson's correlation between the mean velocities measured by the linear transducer and the APP for the 30 velocities.



(r=0.685) with a good level of agreement (ICC = 0.707) compared with the linear transducer. It was also observed that the means velocities measured with the APP were significantly higher than those obtained with the linear encoder (mean difference: 0.08 $m \cdot s_{-1}$).

Specifically analysing the differences in the velocity measurements at the different 1RM percentages, no significant differences between the mean measurements of the APP and the transducer were observed for lift velocities close to 70% 1RM (APP= 0.54±0,13 $m \cdot s_{-1}$; Encoder = 0.51 ± 010 $m \cdot s_{-1}$). However, for velocities close to 90% 1RM, significant differences were found in the mean velocities of the APP compared to the transducer (APP= 0.44±0.08 $m \cdot s_{-1}$; Encoder = 0.30 ± 0.03 $m \cdot s_{-1}$).

The APP seems to accurately measure mean velocities for loads close to 70% 1RM, with extremely small errors (0.03 $m \cdot s_{-1}$). At 90% 1RM, the error in the lift velocity measurements remains constant at around 0.15 $m \cdot s_{-1}$. This may be due to the fact that the accelerometer signal filtering was not programmed correctly for lower velocities. On the positive side, the results obtained in this exploratory study will make it possible to make finer adjustments to the filtering process for these velocities and thereby obtain results that are closer to, or even as good as those obtained at 70% 1RM lift velocities.

The linear transducer used in this study to compare the accuracy of the APP, measures the velocity of the vertical displacement of the cable attached to the bar through electric signal transduction. For this reason, many authors consider linear transducers to be the gold standard[23] for the measurement of lift velocity. Other systems to measure lift velocity[16,24] and muscle strength (25), based on accelerometers, have been shown to be valid and reliable.

Earlier literature has shown APPs to be valid and reliable for the measurement of lift velocity[14]. The disadvantage of these applications is that it is necessary to correctly select the frames marking the start and end of the lift in order to measure the athlete's range of motion in the exercise. For example, the Powerlift[14] application requires a camera with a high-speed recording capacity, given that the higher the frames/second sampling rate, the greater the accuracy obtained when determining the duration of the lift. Even so, information is always lost with regard to the space between frames, causing data loss in relation to the bar displacement velocity. Measurement of the range of motion must be made following the same procedure and as accurately as possible in order to prevent differences between lifts. This, together with the decisions taken by the observer (which frames are valid and which are not), increases the probability of error and complicates the measurement reproducibility.

This study has combined the use of the smartphone accelerometer with the development of a mobile application (APP) to treat the accelerations obtained during the lift and thereby directly measure lift velocity. In earlier literature, studies were made of the reliability and validity of other accelerometers[19] such as the Beast Sensor, reporting lower reliability and validity at low velocities, in addition to mean velocities that were higher than those of a linear transducer and a considerable loss of repetitions that were not detected correctly by the sensor. APPs such as Powerlift[14] have been shown to give an accurate measurement, yet slightly higher than the mean velocity measured by a linear transducer, while the reliability and validity of the results depend on the Hz recording recording and on the correct measurement of the range of motion. For this reason, these technologies are consistent with our APP in overestimating the mean lift velocity despite the fact that they use accelerometers of a higher quality or manual frame selection and range-of-motion processes.

This study was unable to ensure the validity and reliability of the APP, possibly due to the decision to set the sampling frequency at 50Hz, which is lower than the frequencies adopted by other systems for the measurement of velocity using an accelerometer (e.g. 200 Hz to 500 Hz)[16,24]. Furthermore, the quality of the accelerometers used in these devices (such as Push band, Beast)[16,24], and their price (around USD 350-250), are higher than those used in present-day smartphones, which are not designed to analyse motion with such accuracy and whose price is generally under USD5. Therefore, although in the future it is difficult to expect the APP tested in this study to obtain better measurement accuracy results than those of higher quality accelerometers or linear transducers, the aim of the study was to get as close as possible and to outclass the APPs based on estimations through the use of frames. The APP in this study is an inexpensive approximation of a transducer, making it possible to measure multiple movements. It is easily accessible and will prove useful for trainers and coaches, allowing them to have an approximate idea of the velocity at which a subject is moving a load.

In conclusion, the APP used in this study, which is based on the TEL accelerometer, is not yet valid or reliable for all the mean concentric velocity ranges of a BP lift on the Smith machine, compared with a validated linear transducer.

In future studies, the accelerometer signal filtering will be improved for lifts at low velocities in order to improve the measurement results for ranges close to 90% 1RM and to permit a good estimate of the 1RM value. Moreover, the performance of the APP will be tested with other smartphones and other accelerometers and operating systems, directed at improving and more efficiently adjusting the APP sampling frequency.

Future lines of investigation will explore the use of the accelerometer and inertial sensors within the area of expertise relating to biomechanics in sports and healthcare, as well as at an educational level.

Practical application

This APP makes it possible to measure the mean lift velocity as accurately as possible, thereby offering trainers and coaches an inexpensive, quick and simple way of suitably planning a strength training session, with no additional material required.

Conflict of interest

The authors have no conflict of interest at all.

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