Original Article

Validation of a force platform clinical for the assessment of vertical jump height

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ABSTRACT

Objective: the purpose of the present study was to analyze the concurrent validity and reliability of a force platform clinical COBS Feedback® for the estimation of the height of vertical jumps. Design: a cross-sectional correlational and comparative study. Setting: University Human Movement and Physiotherapy Laboratory. Participants: healthy university students (14 female and 13 male) aged between 18 and 25 years old (mean = 20.074 ±1.542). Main Outcome Measures: vertical jump heights, technical error and grade of agreement between methods of measurement. Results: after the 27 subjects performed a total of 135 vertical jumps on COBS Feedback®platform while simultaneously being recorded with a high-speed camera-based method, the intraclass correlation coefficient showed an almost perfect concordance between the two methods (ICC = 0.916, $CI_{95\%}$= 0.882 to 0.940, p<0.001). The technical error of the COBS Feedback® against HSC-Kinovea video analysis was at 0.310±0.223m, being higher in males than in females (t= -2.822, $CI_{95\%}$: -0.376 to -0.574, p=0.001). Conclusions: the COBS Feedback® method provided a valid measurement of the flight times for estimate the vertical jump height as a number of well-known tests and devices. **Key words:** BIOMECHANICS, SYSTEMS ANALYSIS, ATHLETIC PERFORMANCE, PHYSICAL THERAPY, TIME AND MOTION STUDIES

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INTRODUCTION

Force plates are used to quantify physical performance and to identify deficient patterns of movement during human locomotion activities. Force plate COBS Feedback® (Coordination, Balance and Strength) was designed mainly for diagnosis and treatment. This device electronic can record functional aspects of motion during the execution of certain motor tasks (i.e., static or dynamic) in neurological rehabilitation, sport recovery and aging (Physiomed, 2016).

This platform target was designed mainly for diagnosis and treatment. Its diagnostic possibilities include the evaluation and documentation of the progress made on fundamental motor skills, such as sitting and standing balance, alternating loads, slow knee flexion, lateral tilt and forward trunk flexion (Instruction Measurements Manual, 1995).

According to J. Reinhold, the Director and Cofounder of Physiomed Elektromedizin AG company, more than 550 users have acquired this device, mainly in Germany, Russia, China and Latin America (personal communication, June 2016). With an exhaustive use of this plate force multitude movement patterns can be categorized in human in different populations, favoring the precise detection of anomalies in the motor functions and the risk of injury. It is therefore important to understand all of the valid and reliable possibilities of evaluating motor functions with the COBS Feedback® method.

The usefulness of this device may increase with the addition of the assessment of vertical jump height, which is a measure of the muscular strength of the lower extremities that is of interest to physical trainers, coaches, sport clinicians and physiotherapists. The height (in meter; m) reached in a vertical jump is generally considered the gold standard of determining the muscular power of the lower extremities (Earp et al, 2010; Rouis et al, 2015) and is also an indicator of anaerobic fitness (Ostojić et al, 2010). In addition, jump height can provide information concerning the functional capacity of different populations (Amonette et al, 2012; Farias et al, 2013) and physical performance in several sports (Ziv and Lidor, 2010a; Ziv and Lidor, 2010b).

The methods used to assess jump height can be grouped according to the 1) measurement of the distance between two marks, 2) F_z-t records, and 3) measurement of the flight time (f_t). Moreover, these methods include the easy and practical Sargent jump (Sargent, 1921), the application of formulas to measure free falling motion by using an optical mat, a force platform, an infrared platform and accelerometers, as well as, complex video-based methods with and without markers and a force platform (Balsalobre-Fernandez et al, 2014; Ismail et al, 2016). Some of these methods allow for calculations of the exact position of the human body's center of mass along the execution of the jump by recording the time and reactive force on three axes (F_z, F_x, F_y). As a result, it is possible to accurately obtain the peak, average power, take off velocity, vertical acceleration, and flight time of a vertical jump (Balsalobre-Fernandez et al, 2015; Bui et al, 2015; Castagna et al, 2013; Huurnink et al, 2013; Whitmer et al, 2015).

All of the methods that employ ground reaction force when the subject jumps require the evaluator to know the values of force per unit of time to calculate vertical jump height. As mentioned earlier, the interfaces of COBS Feedback® transform the data to clinical parameters, limiting the simple access to F_Z-t records. The procedures to retrieve the real-time values for each jump in ms and estimate the jump height with this device are not widespread, and its validity and reliability have not been studied, which limit its use in fields such as clinical research and physical performance.

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The purpose of the present study was to analyze the concurrent validity and reliability of the force plate COBS Feedback® for the calculation of the flight time and height of vertical jumps. We hypothesized that this method should correlate well with the validated method that combines the use of the high-speed Sony Carl Zeiss camera (HSC), and the open-license software for video analysis Kinovea (HSC-Kinovea method) (Balsalobre-Fernandez et al, 2014).

MATERIALS AND METHODS

Study design

This instrumental reliability and validity study, with a cross-sectional correlational and comparative analysis, was conducted in the Human Movement and Physiotherapy Laboratory. We made a convenience, consecutive, non-probabilistic sample method.

Subjects

The sample consisted of healthy university students (14 female and 13 male) aged between 18 and 25 years old (mean = 20.074 ±1.542). The study was undertaken according to the Helsinki Declaration and before beginning this study, ethical approval was obtained from the University Research Ethics Board. Participation of the subjects was voluntary, and all of them signed an informed consent form. No subjects trained in vertical jumping were required. Subjects with motor deficiency that limited the correct execution of the jump were excluded from the study.

Instrumentation

Instrumentation for HSC method

A low-cost, low-resolution 720 x 576 pixel, battery-powered high-speed Sony Carl Zeiss (Vario-Tessar) camera (Sony Co., Ltd., Tokyo, Japan) was used to collect data from vertical jumps. The HSC method recordings were subsequently analyzed using the open-license video analysis Kinovea software (i.e., Kinovea 0.8.15 for Windows; available at http://www.kinovea.org) (Balsalobre-Fernandez et al, 2014)). The HSC recorded at 240fps, with a shutter speed of 1/3 - 1/3500. The methodology to estimate maximal jump height (h_{max}) was based on measuring the flight time. Using the data of the force platform and HSC-Kinovea, it is possible to account for the difference between the moment at which a subject leaf the platform (ie t_{off}) and the moment at which a subject return to it (ie. $t_{landing}$) (Bui et al 2015). The literature suggests that the measurement of flight time is the most frequently used and valid and reliable method to calculate the jump height (Casartelli et al, 2010; Dias et al, 2011; Glatthorn et al 2011; Girard et al, 2011). It was calculated by the following formula described in the literature (Aragón-Vargas, 1996): hmax = $a \times (t_{of}/2)^2 \times 2^{-1}$, where *a* is the acceleration of gravity (9.81 $m \cdot s^{-2}$).

Instrumentation for COBS Feedback®

COBS Feedback® (Physiomed Elektromedizin AG; Schnaittach, Germany) has two independent dynamometers to measure the vertical ground reaction force (F_z) in Newtons (N); it also incorporates the feedback software Physiofeedback to store, analyze and display records during motor tests. The integration of these two interfaces transforms the records related to balance, coordination, stability and posture to clinical parameters. These parameters are obtained from the sampling frequency, the body weight, and the ground reaction force *per* unit time (force-time; F_z-t) in milliseconds (ms) (Karlsson and Frykberg, 2000). The sampling frequency of COBS Feedback® is 0.25 kHz (i.e., 250 records per second or 1 datum every four ms) (Manual of hardware and software installation, 1995).

Procedures

Each of the 27 subjects selected performed 5 vertical jumps Squat Jump (SJ) on force plate COBS Feedback® while simultaneously being recorded with the HSC. As has been suggested in the literature, the number of jumps was set at 5 to find significant correlations in terms of $\alpha < 0.99$, $\beta < 0.10$, and an intensity of covariation ≥0.35 (Balsalobre-Fernandez et al, 2014). A total of 135 jumps were analyzed. Each jump recorded was measured in milliseconds and later turned into seconds, in both methods.

Measurement procedure.

Before begins, the subjects were instructed on how to correctly perform each test. The instruction involved standing on the force platform and becoming familiar with the test, which consists of a demonstration by the investigator and later, technical training for 5 minutes (which is guided by a graphical real-time projection of vertical reaction forces on the platform). Next, the subject performed 3-5 minutes of a general warm-up that consisted of light continuous exercise (i.e., treadmill or overground running) followed by dynamic stretching (Amonette et al, 2012). No static stretching was performed because of its possible interference with power production, speed, agility and disruption of the elastic components (Bishop and Middleton, 2013, Kruse et al, 2015). Dynamic stretching included body weight squats, knee hugs, walking lunges, walking quadriceps stretches, high kicks, and lateral lunges (Earp et al, 2010). The total warm-up was last approximately 15 minutes.

There are several techniques for executing a vertical jump that can be categorized by prestretch loads (i.e., minimal, moderate, and large) (Earp et al, 2010). The jump selected in this study was the SJ where: I) the subject was placed on the platform and looked forward at a fixed point, II) with hands on waist and III) feet no more separated than the distance between hip joints (figures 1A and B), IV) at 90° knee flexion, and V) lands with both legs simultaneously (figures 1C and D). After holding this position for 5 seconds to remove most of the elastic energy accumulated during flexion (Kurokawa et al, 2001), the subject jumped as high as possible, avoiding any counter movement (body descent) action without releasing the hands, and lands in the same position with the feet and legs extended (figures 1E and F). If a jump did not meet the criteria of a successful jump (i.e. hands on hips, static standing position, and a takeoff and landing with both legs simultaneously), it must be repeated.

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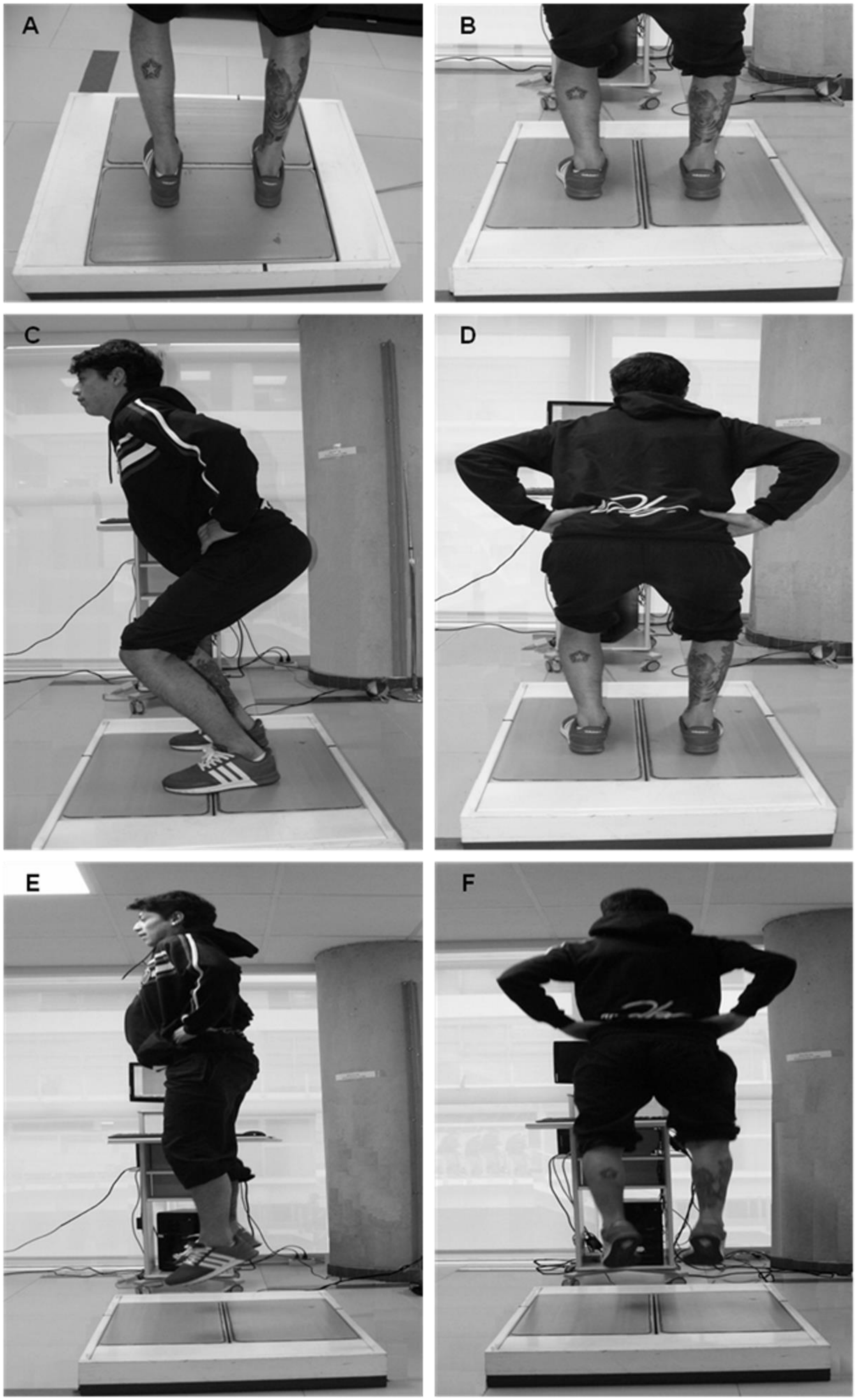

Figure 1. Positions for executing the squat jump by using COBS® Feedback

Recording Conditions.

To simulate a field-training situation of the HSC-Kinovea method, recording was performed under nonprofessional conditions. Thus, no multi-camera and lighting systems were used for the recording. To capture a close-up of each subject's feet, a tripod was used holding the camera at 1.0 m from the platform and oriented in front of the sagittal plane of the subject being assessed in the COBS Feedback® (figure 2). The testing environment was designed such the two systems simultaneously measured the flight time.

Figure 2. Positions for record the squat jump by using HSC-Kinovea method

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Measuring the Flight Time Using the HSC-Kinovea Method.
To measure the flight time, one observer untrained in video analysis selected the first frame in which both feet had left the floor completely and the first frame in which at least 1 foot was touching the floor again and then used the software's "Timer" tool to obtain the final value. If the subjects lifted off or touched down with 1 foot in a different frame to the other, the observer recorded the first frame in which no foot was touching the floor (lift off) or the first frame in which 1 foot was touching the floor (touch down) (Balsalobre-Fernandez et al, 2014).

Measuring the Flight Time Using the COBS Feedback® Method.
To determine the t_{off} and $t_{landing}$, it is necessary to consider a value of vertical force (F_z) equal to "0", but this value is rarely recorded because of vibrations during the jumps. Therefore, an F_z threshold was used as described below. The t_{off} was represented by the last or closer moment just before F_z<3N (in the leg that last leaves the platform), while $t_{landing}$ was the moment just before F_z>3N (in the leg that returns first to the platform) (figures 3A and B) or in its absence the moment not considered vibration. The time between t_{off} and $t_{landing}$ characterizes the flight phase (figure 3C).

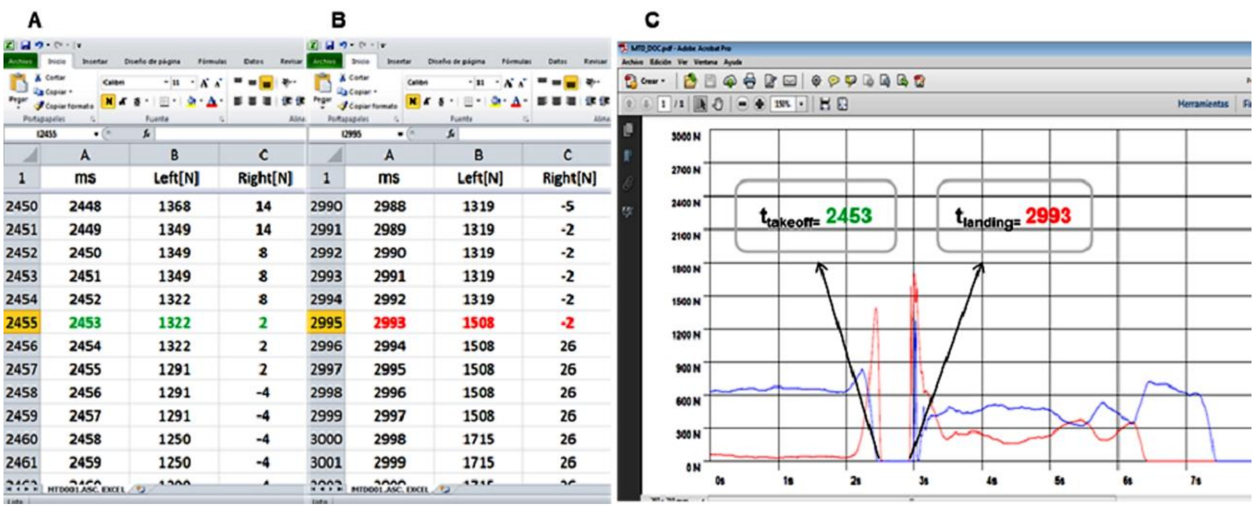

Figure 3. Retrieval of real-time values for a squat jump through COBS Feedback®

Analyses
All jumps were combined to give a total of 135 data points. After checking the normal distribution assumption by applying the Kolmogorov-Smirnov test, the validity of the COBS Feedback® method was determined by intraclass correlation coefficient (ICC), Bland-Altman graphical and technical error statistics methods. The ICC was calculated between the jump height using the HSC-Kinovea method and that obtained using the COBS Feedback® platform. These ICC values were later complemented with Bland-Altman graphical statistics. A one-sample t-test was used to determinate the grade of agreement between the difference generated by 2 methods of measurement and the acceptable referential value the 0.012m. The limits of agreement were sufficiently narrow to allow for the bedside method (ie. COBS Feedback®) to replace the reference method when encompass 95% of all measured values. A multiple regression analysis using the Enter method was performed to determine the moderating effect of the mean of bedside and reference methods over the difference generated by these 2 methods. The technical error of the reading made with both methods was also calculated as follow, square root of $[1/2n \times \sum(X_i-y_i)^2]$, where X_i and y_i are the jump values obtained with each method in each subject, «i» represent each subject (i = 1,2,3... n) and «n» is the total number of subjects. Finally, to assess the differences between sex of technical error and vertical jump

height, unpaired-sample t student and two-way mixed ANOVA test were used, respectively. The level of statistical significance for data was defined at α = 0.05, and the 95% confidence intervals ($CI_{95\%}$) are presented when appropriate. All statistical analyses were conducted in SPSS, version 22.0 (Statistical Package for Social Sciences; IBM Corporation, Armonk, New York). Data are presented as mean ± SD unless stated otherwise.

RESULTS

The results obtained using ICC showed an almost perfect concordance when estimating the jump height by HSC-Kinovea video analysis and when obtaining its using the COBS Feedback® (ICC = 0.916, $CI_{95\%}$= 0.882 to 0.940, *p*<0.001).

With the method of Bland-Altman we observed that the graphical representation of the differences between the two methods against their mean showed an excellent agreement for a 96.30% (130) of the 135 jumps (figure 4). The bivariate Pearson product-moment coefficient revealed a low but significant and positive correlation between the difference generated by 2 methods of measurement and the mean of vertical jump height obtained by these methods (*r* = 0.230, p =0.004). It can be seen in the figure (figure 4) that there was a tendency to increase the differences between methods when the height of the jump is greater. This significant correlation suggested that a proportional bias existed (figure 4). On the other hand, the regression analysis showed that the mean generated by this 2 method explained 5% of the differences obtained between the HSC-Kinovea and the COBS Feedback® method (R^2 = 0.053, p =0.007).

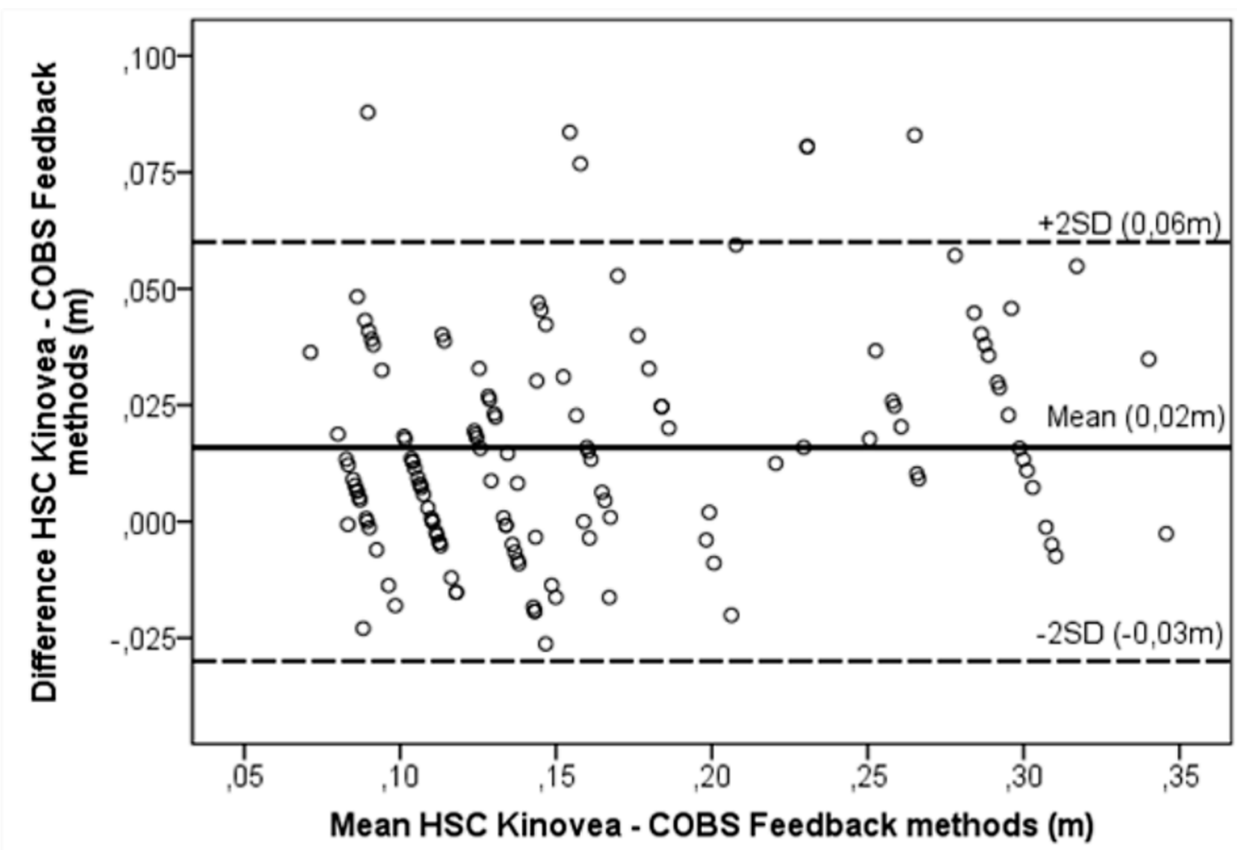

Figure 4. Bland Altman plot between beside and reference methods

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The technical error of the COBS Feedback® against Kinovea video analysis was at 0.310±0.223m, being higher in males (0.422±0.229m) than in females (0.205±0.162m) (t= -2.822, $CI_{95\%}$: -0.376 to -0.574, p=0.001).

The ANOVA analysis shows a significant interaction for the vertical jump height between methods and gender (table 1). It was found lower height of the jump in female than male for HSC-Kinovea (difference= -0.101±0.021m, $CI_{95\%}$: -0.148 to -0.060; p<0.001) and COBS Feedback® (difference= -0.091±0.020m, $CI_{95\%}$: -0.132 to -0.049; p<0.001) methods. Additionally, there was a difference between the COBS Feedback® and the HSC-Kinovea method (mean difference= -0.016±0.002m, $CI_{95\%}$: -0.021 to -0.011; p<0.001), indicating that in average with the COBS Feedback® the vertical jump height was undervalued by the observer (table 1).

Table 1. Results of the interaction and principal effect for difference between gender and methods in vertical jump height

Gender	HSC-Kinovea *vs* COBS Feedback® method		F	*p*
	M±SD (m)	M±SD (m)		
Female	0.123±0.024	0.110±0.025	8.479	0.007†
Male	0.224±0.076	0.201±0.070		
Total	0.170±0.075	0.154±0.069	50.071	0.000‡

Note. The mean of the 5 jumps was using for this analysis

†Interaction and ‡principal effect

DISCUSSION

The results obtained using ICC showed an excellent agreement between HSC-Kinovea and force plate COBS Feedback® methods (p<0.001). Similar result was reported in previous study evaluating the agreement between 2 observers using the HSC-Kinovea and the values obtained using the infrared (IR) platform (ICC = 0.997, p<0.0001) (Balsalobre-Fernandez et al, 2014). The main difference with the present study was that we reached agreement values between methods of moderate to high ($CI_{95\%}$= 0.882 to 0.940), while the Balsalobre-Fernandez et al, (2014) obtained high agreement values ($CI_{95\%}$= 0.995 to 0.998).

The method of Bland-Altman showed an excellent agreement for 130 of the 135 jumps (figure 4). The ideal bedside method would demonstrate narrow limits of agreement, around a mean bias of an acceptable referential value. These five outliers can be explained by poor quality image because neither professional lighting system was used with the HSC-Kinovea methods and a possible loss of focus or shadow generated by the subject could have decreased the sharpness of the image (Balsalobre-Fernandez et al, 2014). Interestingly, also it seems that when kinetic techniques (force plate) are compared with kinematic reference methods (video analysis) wide limits of agreement could be observed, when the vertical jumping is performance by non-trained subjects in this kind of motor skill.

The calculations of the jump height based on the corresponding flight times have one major drawback, explicitly that the measurement error increases with jump height (Balsalobre-Fernandez et al, 2014; Bui et al, 2015). This disadvantage was observed, as well, in this study. The differences between methods tended to increase when the height of the jump was greater (r = 0.230, p = 0.004) (figure 4). Also when comparing the technical error of the COBS Feedback® between genders, and the measurement error was greater in males at 0.422m than in females at 0.205m (p = 0.001).

On the other hand, the observer with the COBS Feedback® underestimated the height by about 0.016m on average (table 1). This can partially be explained by the same fact that the poor quality image using the HSC-Kinovea methods. Other explanations could be objective of a new research line.

The main problem in the biomechanical analysis of vertical jumps is to determine the time-of-takeoff (t_{off}) and time-of-landing ($t_{landing}$). In the present study the COBS Feedback® method has been validated for a precision in the flight time record of 250Hz (i.e., 1 datum every four ms). This is an inherent limitation to determine the flight time of this method, considering whereas the theoretical precision of other devices (i.e., Optojump system) is very high (e.g., 1.8 mm with a sampling frequency of 1000 Hz) (Castagna et al, 2013; Glatthorn et al, 2011). According to Kibele (1998), an error of 5 to 10 ms is acceptable in determining the start of the jump without substantially affecting the integration calculations, but errors larger than 2 to 3 ms in determining the t_{off} greatly affect the speed (V_z) and displacement of the center of mass.

An additional limitation of this device is the inability to obtain the jump height values in real time or instant data outputs. This aspect does not seem to be overly problematic in small samples because the time required to obtain the data is quite reasonable. An untrained observer takes approximately 30 seconds to determine the flight time of each jump. However, this condition offers a restriction for fields in which broad jumping measurements are required (e.g. professional sports team); suggesting that Physiomed Elektromedizin AG company should develop a registration system (software) that provides advantages in the collection and processing of data.

To the best of our knowledge, this is the first study which aimed to validate the COBS Feedback® method, by offering objective, reliable and easily interpretable information on the procedures used to estimate the height of a jump. Therefore, the results of the present study increase the ecological validity and improve widespread use of this device in fields such as clinical research and physical performance. In addition, the study shows that is possible a good reliability when the values of the F_Z-t are retrieved by one observer untrained in the determination of the t_{off} and $t_{landing}$ using the COBS Feedback® records.

Study limitations

According with the analysis of Bland-Altman the principal limitation of this study was that a significant agreement between the 2 methods of measurement was not possible with a referential value < 0.012m. In the literature it does not exist an ideal agreement value for the comparison of the methods for assessment the vertical jump. However, we consider that this referential value is acceptable for improve the clinical practice of the physical therapist and the performance of athletes.

Future research lines

Future studies should confirm these finding using other technologies such as the application of formulas to measure free falling motion by using an optical mat, a force platform, an infrared platform and accelerometers, and complex video-based methods with and without markers (Balsalobre-Fernandez et al, 2015; Bui et al, 2015; Castagna et al, 2013; Huurnink et al, 2013; Ismail, Osman et al, 2016; Whitmer et al, 2015). Moreover,

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new measurements with instructed subjects in vertical jump (e.g., professional athletes) could pin down the drawbacks of the COBS Feedback® (i.e., a measurement error and a wide limit of agreement that increases with jump height) for a most favorable validity of this method.

Due to the reproducibility of the findings presented in this study, this methodology could be included in future research lines of biomechanical analysis during a vertical jump. For example, by using two independent dynamometers, COBS Feedback® would be considered to assess 1) the symmetry load (to analyze the force behavior between legs), 2) the kinematics in the symmetry of the task (to compare the speed and acceleration between legs), and 3) the proportion of effort capacity (to determine the variation in the legs' efficiency, considering the jump height and heart rate response).

Clinical implications

Clinical physical therapy and performance settings could benefit from practical application of the COBS Feedback® for jump height assessment. During the training process the selection of the optimal physical load is essential for the desired adaptation and injury risk reduction (Halson, 2014). The associations between different fatigue conditions and jump height can provide biomechanical knowledge and potential recommendations regarding strategies for training and the prevention of injuries. Recent observations have shown that different impact loads and effort progressions affect jumping ability and muscular or tendon adaptation, and it is therefore believed that daily jump height monitoring may potentially provide the essential information necessary to adjust training loads in athletes. Although there are contradictory results (Edouard et al, 2015; Twist and Highton, 2013), Kamandulis et al (2016) recently found that in basketball players under different conditions of fatigue, the reduction in jump height is associated with muscle damage in response to acute strenuous exercise and neuromuscular fatigue after a competitive season. These results suggest that land-based jump programs characterized by repetitive high impact exercises require planning and supervised execution to reduce the risk of injury and to achieve the desired physical adaptation. Jump height assessment with the COBS Feedback® could be a suitable tool for the screening programs that determine the injury risk for the lower limbs and for the objective examination of the athletic performance (e.g. required planning and supervised execution).

CONCLUSSIONS

The results of the present study demonstrated that the COBS Feedback® platform provides a good valid and reliable alternative to measure the flight time and vertical jump height as a number of well-known tests and devices. The measurement error and disagreements with video analysis method increased when the height of the jump was greater, and COBS Feedback® method underestimated the vertical jump height. Therefore, caution should be exercised when interpreting data obtained from different height of the jump and instruction level in vertical jump.

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