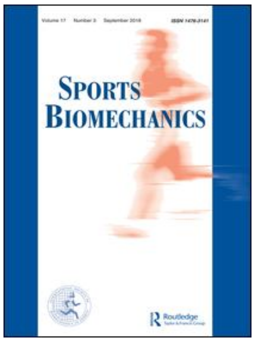

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ARTICLE

Validation of an opto-electronic instrument for the measurement of weighted countermovement jump execution velocity

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ABSTRACT

The purpose of this study was to analyse the reliability and validity of an opto-electronic sensor system (Velowin) compared to a linear velocity transducer (T-Force System) considered as the gold standard. Mean velocity (MV) and peak velocity (PV) generated in the Smith machine bar placed on the shoulders in counter-movement jump exercise (CMJ) were analysed. The study was conducted with a sample of 21 men with experience in resistance training. Five measurements were analysed for CMJ exercise in concentric phase using a progressive loading increase. Three jumps were made per load with a 3–4 min recovery between loads. The analysis of the variance confirmed that there were no significant differences (p > 0.05) in the execution velocity between Velowin and T-Force with each of the loads. The reliability analysis showed, with each of the loads, high values of the intraclass correlation coefficient (ICC = 0.95–0.99) and a 'substantial' Lin´s concordance coefficient in MV (CCC ≥0.96) and between 'substantial' (CCC = 0.98) and 'almost perfect' (CCC = 0.99) in PV. These results confirm the reliability and validity of the Velowin device is reliable for measuring the execution velocity in loaded CMJ exercise.

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KEYWORDS
Strength; reliability; evaluation; kinematic; performance

Introduction

Vertical jump performance is considered a key indicator of the rate of force development of the lower limbs (Eagles, Sayers, Bousson, & Lovell, 2015) and, therefore, is directly related to the neuromuscular aptitude of the participant. Accordingly, any favorable change in the vertical jump ability may be reflecting a significant improvement in the neuromuscular performance of the lower limbs (i.e. sprint ability) (Loturco et al., 2015). It is for this reason that its performance measurement is used for the assessment of the neuromuscular aptitude of sports populations, the functional ability of non-athletic populations of different ages, the discrimination between sporting levels and, even, the detection of talents (Loturco et al., 2015). In addition, the loss of countermovement jump ability (CMJ) pre-post exercise has been proposed as an excellent

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indicator for neuromuscular fatigue monitoring (Gathercole, Sporer, Stellingwerf, & Sleivert, 2015; Gorostiaga et al., 2010; Sánchez-Medina & González-Badillo, 2011). Hence, the loss of height in the CMJ is equivalent to the loss of mean, peak and take-off velocity, so that neuromuscular fatigue can be measured by means of this pre-post percentage loss (González-Badillo, Sánchez-Medina, Pareja-Blanco, & Rodríguez-Rosell, 2017).

Vertical jump performance is therefore a explored topic in scientific literature (Davis, Briscoe, Markowski, Saville, & Taylor, 2003; Hasson, Dugan, Doyle, Humphries, & Newton, 2004; Eagles et al., 2015) and valuable for its application to physical performance training, control and assessment of any population. Due to the relevance of the vertical jump assessment, it is important to know the validity of different measurement instruments and techniques used for their estimation, such as force plates, contact platforms, infrared optical platforms, accelerometers, video-analysis, and smartphone apps. Howerver, the economic cost, portability and assembly of force transducer instrumented force plates are the main disadvantages for the measurement of vertical jump performance outside the laboratory. Moreover, most of these electronic devices determine jump height by flight time as a criterion, having shown to be a procedure of great validity in various studies (García-López, Morante, Ogueta-Alday, & Rodriguez-Marroyo, 2013; García-Ramos et al., 2015; Requena, Requena, García, De Villarreal, & Pääsuke, 2012). However, despite being the most frequently tested method in scientific literature to assess vertical jump performance, this procedure has some drawbacks. On the one hand, the detection of the right moment of takeoff and landing is a complex aspect to be able to validate these instruments with respect to jump height, flight time and vertical takeoff velocity (Monnet, Decatoire, & Lacouture, 2014). On the other hand, it is assumed that the vertical position of the participant´s centre of mass is the same at the time of landing as at the moment of takeoff, so that the time to the vertex of flight is equal to the time of descent. But this assumption may result in the estimated jump heights hiding measurement errors if the participant alters the execution technique, especially during landing (i.e.: not having fully extended knees). The previous would increase flight time 'artificially', and consequently would increase the estimated jump height (Aragon-Vargas, 2000; Musayev, 2006; Nuzzo, Anning, & Scharfenberg, 2011).

For these reasons, it is considered then that the most reliable and sensitive variable, and which best expresses and explains vertical jump performance, is peak velocity (González-Badillo & Marques, 2010; González-Badillo et al., 2017; Jiménez-Reyes, Pareja-Blanco, Rodríguez-Rosell, Marques, & González-Badillo, 2016). In addition, using peak velocity as a criterion or performance indicator of vertical jump—and not flight time or jump height—has the advantage of not being affected by alterations in the jumping technique and, therefore, allowing to discriminate and to express in a better way the variables that determine the true jump performance (González-Badillo & Sánchez-Medina, 2010).

Currently, linear transducers are considered by different researchers as reference gold-standard devices for measuring the bar execution velocity in linear movements (Cormie, Deane, & McBride, 2007; González-Badillo & Sánchez-Medina, 2010; Jidovtseff, Harris, Crielaard, & Cronin, 2011). Recently, a type of 'optical' transducer has been developed (Velowin, Deportec, Murcia, Spain). This novel device can directly measure the position of any body-point at any time frame by means of an infrared camera, which allows to obtain peak velocity and jump height by derivation: height = $(v_{peak})^2/2g$ ($g = 9.81$ m/s^2) (Linthorne, 2001). This device also allows determining mean velocity, peak velocity and mean propulsive velocity for any type of linear trajectory of the load, showing the records of the most determining variables (displacement, phase times, power, etc.) in real time through a graphic and numerical analysis accomplished by its own software. So, this device could exclude some limitations and disadvantages of other type of electronic instruments previously explained when measuring height or execution velocity.

Despite the possible advantages of this new device, its validation is a prerequisite in order to use this tool with confidence for the evaluation of vertical jump performance. Generally, to analyse the reliability and validity of a new assessment device, a 'gold-standard' is used, that is, a different device that measures with proved reliability. Subsequently, the obtained data in both devices (those from the 'gold-standard' and those from the new device to be tested) are compared and subjected to statistical treatment to demonstrate their reliability and content validity. In this sense, there are several statistical tests to assess reliability, such as the Intra-class Correlation Coefficient (ICC) and the Standard Error of the Measurement (SEM). Both procedures, along with other types of statistical indicators such as the Coefficient of Variation (CV) and the Lin`s Concordance Correlation Coefficient (CCC), are statistical procedures that verify the reliability of each of the measurements of the evaluated device. Consequently, it would be convenient to present not only an indicator of reliability, but all of them together, since the interpretation of results will be much more objective and accurate (Atkinson & Nevill, 1998).

Therefore, the purpose of this study was to analyse the differences in execution velocity in loaded CMJ exercise, measured simultaneously by means of a linear velocity transducer and an opto-electronic device placed on the bar over the shoulders, and in this way, establish the reliability and concurrent validity of the opto-electronic system as an instrument for measuring CMJ's performance. In this regard, it was hypothesised that the Velowin opto-electric system is reliable and valid for recording kinematic variables (mean and peak velocity) compared to the T-Force System linear velocity transducer.

Methods

Experimental design

A unifactorial intra-subject design was used, in which all the participants execute the same jumping exercise (CMJ) to obtain mean velocity data (average bar velocity during the whole concentric phase in m/s) and maximal or peak velocity (maximal instantaneous bar velocity reached at a particular instant during the concentric phase in m/s) measured with the Velowin opto-electronic device and the T-Force linear velocity transducer. This was done with the aim of comparing the behavior of both devices for the CMJ exercise, taking as independent variable both devices, and as dependent variables the mean velocity (MV) and the maximal or peak execution velocity (PV). In this way, the opto-electronic device reliability to measure the exposed kinematic parameters could be tested. The investigation statistical power was evaluated with the statistical program G*Power 3.1.9.2, according to the levels proposed by Cohen (Cohen, 1988) $\alpha = 0.03$; β (1-β) = 0.80 and β error prob. = 0.20 for N = 21.

Participants

The study sample, selected for accessibility and convenience (Azorín & Sánchez-Crespo, 1994), included 21 men (age 29.3 ± 3.5 years, height 1.78 ± 0.065 cm, body mass 75.6 ± 7.8 kg) with experience in resistance training and familiar with the CMJ exercise. The established inclusion criteria were: i) to practice intense and/or moderate physical activity at least 2–3 days a week, ii) to have accumulated experience in resistance training with isoinertial equipment ≥ 3 years in order to minimise the bias of variability by differences in technical performance, and iii) not having suffered muscle or bone injury in shoulder, spine, hip, knee, and/or ankle at least six months prior to the study. Likewise, the participants could not have performed any type of intense physical exercise that involved the lower limbs at least 48 h prior to the measurement day.

After approval by the Ethics Committee of the University of Murcia, the study's volunteer participants were informed of risks, purpose and procedures of the research before signing an institutionally approved informed consent document prior to the beginning of the evaluation sessions.

Instruments

The loaded countermovement jump exercise was performed on a Smith machine (Instrumentos y Tecnología Deportiva SL, Murcia, Spain) without any counterweight mechanism, and the reflective marker of the infrared camera of the opto-electronic device (Velowin v.1.7.232, Instruments and Sports Technology; Murcia, Spain) was fixed at the end of the bar along with the extensible cable of the linear velocity transducer (T-Force System, v 2.35; Ergotech Consulting, Murcia, Spain) at the vertical projection of the bar (Figure 1). A complete description of the T-Force System linear velocity transducer is provided in another scientific document (Sánchez-Medina & González-Badillo, 2011). The opto-electronic device Velowin is able to directly measure the position of a reflecting point at each instant of time (every 2 ms) by means of an infrared camera, obtaining by derivation the variables of velocity, acceleration, force and power.

The opto-electronic system and the linear velocity transducer collected the MV and PV data instantaneously and simultaneously with a frequency of 500 and 1000 Hz, respectively, and smoothed the signal using a 4th order lowpass Butterworth filter with no phase shift and 10 Hz cutoff frequency. The opto-electronic instrument calibration was performed according to the manufacturer's instructions. The calculations of the different variables analysed (MV and PV) are automatically made with the algorithms of each software (Velowin v.1.7.232 and T-Force System v. 2.35, respectively).

Testing procedures

The participants of the investigation made all the counter-movement jump exercise measurements in a force-analysis laboratory (Murcia University, Spain). All tests were

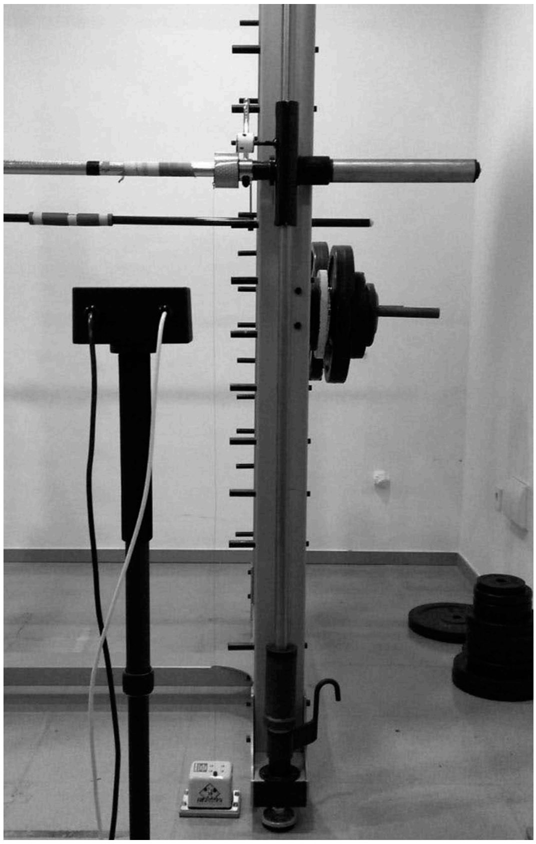

Figure 1. Installation of Velowin and T-Force devices on Smith machine bar.

performed by the same evaluator, at the same time and under similar environmental conditions (absolute atmospheric pressure 1003 hPa, relative humidity ~ 60%, height 95 m above sea level and temperature ~ 24ºC).

The standardised warm-up consisted of 5 min jogging, joint mobility exercises, dynamic stretching, four sets of squats (2x12 with an ultralight carbon fiber bar and 2 × 10 with a 20 kg bar) and, finally, 2 sets of 6 jumps with counter-movement using the ultralight bar with a 2–3 min recovery between sets. From there, the velocity data record for the CMJ exercise was established by a progressive overload with the following dynamics for all participants (Table 1): initial external load of 3.5 kg, corresponding to the mass of a bar adapted to the Smith machine, with an increase of 10 kg (13.5, 23.5, 33.5) up to 43.5 kg for each of the consecutive measurements. Three jumps were made

Table 1. Test session protocol in CMJ exercise.

Recorded kinematic variables	MV PV	MV PV	MV PV	MV PV	MV PV
CMJ	Load 1	Load 2	Load 3	Load 4	Load 5
Load	3.5 kg	13.5 kg	23.5 kg	33.5 kg	43.5 kg
Repetitions	3	3	3	3	3
Recovery Time (min)	3	3	3	4	4

MV: Mean Velocity; PV: Peak Velocity; min: minutes; CMJ: Counter-movement jump exercise for each load with a 10 s interval between each jump. When the execution of any jump was considered incorrect, it was discarded and another repetition was performed. The recovery between each set of jumps with each load was 3–4 min.

An experienced evaluator supervised the participant correct starting position, the placement and grip of the bar, and the technical execution of the jump. The initial position of the exercise was standing with knees and hips fully extended, feet about shoulder-width apart, and the bar resting on the upper part of the back at acromion level. For the correct positioning of the participant, feet location was marked on the floor by means of a square on the vertical projection of the bar. The participants were instructed to hold the bar with a grip slightly greater than the width of the shoulders. The concentric phase of each jump was performed at the maximal possible velocity accompanied by a strong verbal encouragement to obtain the maximal effort (the instruction provided to the participants was 'jump as high as you can'). The execution of the previous eccentric phase was not subjected to any established range of movement or negative velocity. For the subsequent data analysis, the average of 3 jumps was taken for each load of the evaluated velocity variables.

Reliability and validity analysis

The methodological proposal to validate the Velowin opto-electric system involved the reliability analysis referring to the degree to which an instrument or device, in its repeated application on the same participant, produces analogous results. When analysing a continuous numeric variable (such as mean and peak velocity, in m/s), statistical procedures must be used. They include a) the Pearson correlation coefficient (*r*) with which the stability of the instrument is measured through time; b) the Coefficient of Variation (CV) or relative error that shows how reliable the estimates of the analysed variables are, and is calculated as the standard deviation (SD) value between participants divided by the mean (M) and multiplied by 100; c) the Intraclass Correlation Coefficient (ICC) that allows to evaluate the general concordance between two or more methods through an analysis of variance model (ANOVA) with repeated measures. However, the Pearson correlation coefficient, the Standard Error of the Measurement (SEM), the CV and the ICC have some limitations in that very high values can be obtained (close to 1) even though there are important differences between the measurements (if observed in a scatter plot), these being non-concordant. Therefore, Lin (1989) developed a proposal to evaluate the concordance between continuous variables through the correlation-concordance coefficient (CCC) that is defined as the product of two components: precision -represented by the correlation coefficient (P or Rc)—and accuracy -represented by the bias correction coefficient (Cb)—(Camacho-Sandoval, 2008). This coefficient can vary between −1 and 1 and its absolute value cannot be greater than the Pearson correlation coefficient. Lin´s concordance correlation coefficient (CCC) can only be zero if the Pearson correlation coefficient is also zero. Lin revealed that this method used to evaluate the reproducibility of measurements is superior to others (mentioned above) which are used for similar purposes (Cortés-Reyes, Andrés Rubio-Romero, & Gaitán-Duarte, 2010). This coefficient qualifies the strength of concordance or agreement between two variables in a more demanding way. For continuous variables, the values with this statistical indicator are classified as: 'almost perfect' >0.99, 'substantial' between 0.95 and 0.99, 'moderate' between 0.90 and 0.95, and ‘poor’ <0.90 (Cortés-Reyes, Andrés Rubio-Romero, & Gaitán-Duarte, 2010).

Statistical analyses

The data analysis was performed using the statistical program SPSS (IBM SPSS version 21.0, Chicago, IL, USA). All variables met the assumption of normality (Shapiro-Wilk test). Standard statistical methods were used to obtain the mean as a measure of central tendency and standard deviation as a measure of dispersion expressed in terms of means ± standard deviation. In addition, the confidence intervals (CI; probable limits between which the true difference between two means lies) between the means of the MV and PV variables of each device (Velowin and T-Force) in the CMJ exercise for each of the registered loads (3.5 kg, 13.5 kg, 23.5 kg, 33.5 kg and 43.5 kg) were calculated. To test the concurrent validity of Velowin with respect to the ‘gold standard’ T-Force, in addition to the description of mean values, standard deviation and distribution values, an analysis of variance (ANOVA) was performed to verify the existence of significant differences in the means of each variable analysed. The calculation of the reliability was obtained through the Intraclass Correlation Coefficient (ICC), the Coefficient of Variation (CV) and the Lin´s Concordance Correlation Coefficient (CCC). A significance level of $p < 0.05$ was accepted for all the analysis.

Results

Preliminary test of normality

To verify the normality of the MV and PV variables with each of the loads evaluated (3.5, 13.5, 23.5, 33.5 and 43.5 kg) in both devices (Velowin and T-Force), the *Shapiro Wilk test* was used and it confirmed that all the variables under study have a normal distribution of $p > 0.05$. Also, the skewness and kurtosis values were between 0 and 2 (Azorín & Sánchez-Crespo, 1994).

Reliability

The reliability test obtained through the ICC shows a mean absolute value of 0.98 and values from 0.95 to 0.99 (95% Confidence Interval) based on the MV or PV variable for Velowin and T-Force. The Pearson correlation coefficient showed values from $r \geq 0.66$ to $r = 0.96$. The Coefficient of Variation (CV) values for the analysed variables with each one of the loads were less than 3% (Table 2).

Lin´s concordance correlation coefficient (CCC) values confirm a ‘substantial’ agreement or concordance (CCC = 0.96 for 13.5, 23.5, and 33.5 kg, CCC = 0.97 for 3.5 kg) and ‘almost perfect’ (CCC = 0.98 with 43.5 kg) for MV (Table 2). For PV, the CCC presents a ‘substantial’ concordance (CCC = 0.98 for 3.5, 23.5 kg) and ‘almost perfect’ (CCC = 0.99 for 13.5, 33.5 and 43.5 kg). This corroborates the concordance (precision and accuracy) of the measurement in the Velowin device for MV and PV kinematic variables in CMJ exercise.

Table 2. Coefficient of Variation (CV), Intra-class Correlation Coefficient (ICC) and Lin Concordance Coefficient (CCC) for each analysed variable with both devices in CMJ exercise.

Variables_load	Test	CV (%)	ICC	(95% CI)	SEM	CCC
MV_3.5 kg	VW	2.41	0.98	(0.95 –0.98)	0.0025	0.97
	TF	2.15	0.97	(0.93 –0.99)	0.0024	
PV_3.5 kg	VW	1.77	0.98	(0.95 –0.99)	0.0021	0.98
	TF	1.62	0.98	(0.96 –0.99)	0.0017	
MV_13.5 kg	VW	1.70	0.97	(0.94 –0.99)	0.0021	0.96
	TF	1.63	0.98	(0.95 –0.99)	0.0022	
PV_13.5 kg	VW	1.68	0.99	(0.97 –0.99)	0.0014	0.99
	TF	1.92	0.98	(0.96 –0.99)	0.0026	
MV_23.5 kg	VW	2.56	0.95	(0.88 –0.98)	0.0033	0.96
	TF	2.53	0.96	(0.91 –0.98)	0.0033	
PV_23.5 kg	VW	2.38	0.97	(0.94 –0.99)	0.0023	0.98
	TF	2.36	0.98	(0.95 –0.99)	0.0024	
MV_33.5 kg	VW	1.87	0.98	(0.96 –0.99)	0.0022	0.96
	TF	1.71	0.99	(0.97 –0.99)	0.0022	
PV_33.5 kg	VW	1.60	0.99	(0.97 –0.99)	0.0018	0.99
	TF	1.61	0.99	(0.97 –0.99)	0.0018	
MV_43.5 kg	VW	2.03	0.99	(0.96 –0.99)	0.0040	0.98
	TF	1.88	0.99	(0.97 –0.99)	0.0038	
PV_43.5 kg	VW	1.57	0.99	(0.98 –0.99)	0.0027	0.99
	TF	1.53	0.99	(0.97 –0.99)	0.0029	

MV: Mean Velocity; PV: Peak Velocity; VW: Velowin device; TF: T-Force device; CV: Coefficient of variation; ICC: Intraclass correlation coefficient; CI: Confidence interval; SEM: Standard error of measurement; CCC: Lin concordance coefficient. $p < 0.05$.

Validity

Standard statistical mean and standard deviation for velowin and t-force in CMJ exercise

Mean values ± SD, skewness and kurtosis of the velocities for Velowin and T-Force devices are summarised (Table 3). The means values are similar in both devices for each of the velocities analysed in different loads.

Analysis of variance (ANOVA) for mean velocity and peak velocity variables for velowin and t-force in CMJ exercise

To analyse the existence of significant differences in the total scores of mean and peak velocity of CMJ for each of the recorded loads, an ANOVA was performed considering MV and PV as dependent variables and the 'Test' variable as a factor or independent variable with two levels (Test 1 = Velowin, Test 2 = T-Force). The variances are homogeneous (*Levene test*) $p > 0.05$ and no significant differences were found between the variances of the two devices (Test), indicating that they measure in a similar way (Figure 2).

Discussion and implications

According to the obtained results, the reliability and validity of the opto-electric device to measure execution velocity in CMJ exercise, compared to the linear T-Force System velocity transducer used as 'gold standard', confirms our hypothesis. To the best of our knowledge, this is the first scientific study that aims to validate the Velowin opto-electronic device by comparing it with a linear velocity transducer as a reference

Table 3. Standard statistical mean. standard deviation. skewness and kurtosis for Velowin and T-Force in CMJ exercise.

	N	*M*	*SD*	*S*	*K*
MV_3.5_VW	21	1.56	0.11	−0.47	−0.15
MV_3.5_TF	21	1.53	0.11	−0.62	−0.04
PV_3.5_VW	21	2.95	0.22	0.31	−0.72
PV_3.5_TF	21	2.96	0.24	0.49	−0.41
MV_13.5_VW	21	1.45	0.10	−0.14	−0.83
MV_13.5_TF	21	1.43	0.24	−0.07	−0.84
PV_13.5_VW	21	2.74	0.22	0.22	−0.46
PV_13.5_TF	21	2.74	0.24	0.40	−0.22
MV_23.5_VW	21	1.36	0.09	−0.17	−0.56
MV_23.5_TF	21	1.34	0.10	−0.06	−0.78
PV_23.5_VW	21	2.53	0.22	0.34	−0.19
PV_23.5_TF	21	2.53	0.25	0.52	−0.02
MV_33.5_VW	20	1.26	0.43	−0.22	−0.43
MV_33.5_TF	20	1.24	0.11	−0.03	−0.29
PV_33.5_VW	20	2.35	0.21	−0.23	−0.35
PV_33.5_TF	20	2.35	0.22	0.07	−0.48
MV_43.5_VW	10	1.22	0.11	−0.80	−0.36
MV_43.5_TF	10	1.20	0.11	−0.18	−0.79
PV_43.5_VW	10	2.23	0.14	−0.14	−0.67
PV_43.5_TF	10	2.24	0.07	−0.07	−0.81

MV: Mean Velocity; PV: Peak Velocity; VW: Velowin device; TF: T-Force device; N: sample; M: Media; SD: Standard Deviation; S: Skewness; K: Kurtosis.

instrument for the variables of mean velocity and peak velocity in the counter-movement jump.

Criterion-related validation requires to know the correlation between a criterion and an instrument working simultaneously, and which allows the replacement of the more complex criterion for another (instrument) that is simpler or more accessible. For this purpose, the choice of criterion is critical (Thomas, Nelson, & Silverman, 2005). When the degree of measure agreement between two instruments is known, it can be established whether or not they can be validated, and therefore if they can be interchanged for the measurement of certain variables. In this line, the analysis of relative reliability measures shows very high values in the Intraclass Correlation Coefficient (ICC = 0.95-.99) for both devices with different loads for velocity variables. Although there are no pre-established standards for reliability measures of concurrent validation studies, it has been suggested that ICC values above 0.75 can be considered reliable, and that this index should be at least 0.90 for most clinical applications (Thompson & Bemben, 1999). Likewise, the values of the Coefficient of Variation for the same variables show a good absolute reliability (CV <3%) with different loads. Scientific literature suggests that coefficient of variation should be lower than 10%, although these estimates have been a source of discrepancy (Atkinson, Davison, & Nevill, 2005; Atkinson & Nevill, 1998). In the same way, the Concordance Correlation Coefficient shows a moderate and substantial agreement (CCC ≥0.96) for mean velocity, and even ‘almost perfect’ (CCC = 0.99) for peak velocity with each of the analysed loads. According to Lin et al. (Lin, 1989) the CCC is the most relevant and adequate statistical correlation test used in validation studies to confirm the accuracy and precision of an instrument for continuous numerical variables (in this case, MV and PV). All these data jointly corroborate the accuracy of the measurement with the Velowin device for the kinematic variables of mean velocity and peak velocity in CMJ exercise. In addition, having used a Smith machine for the velocity

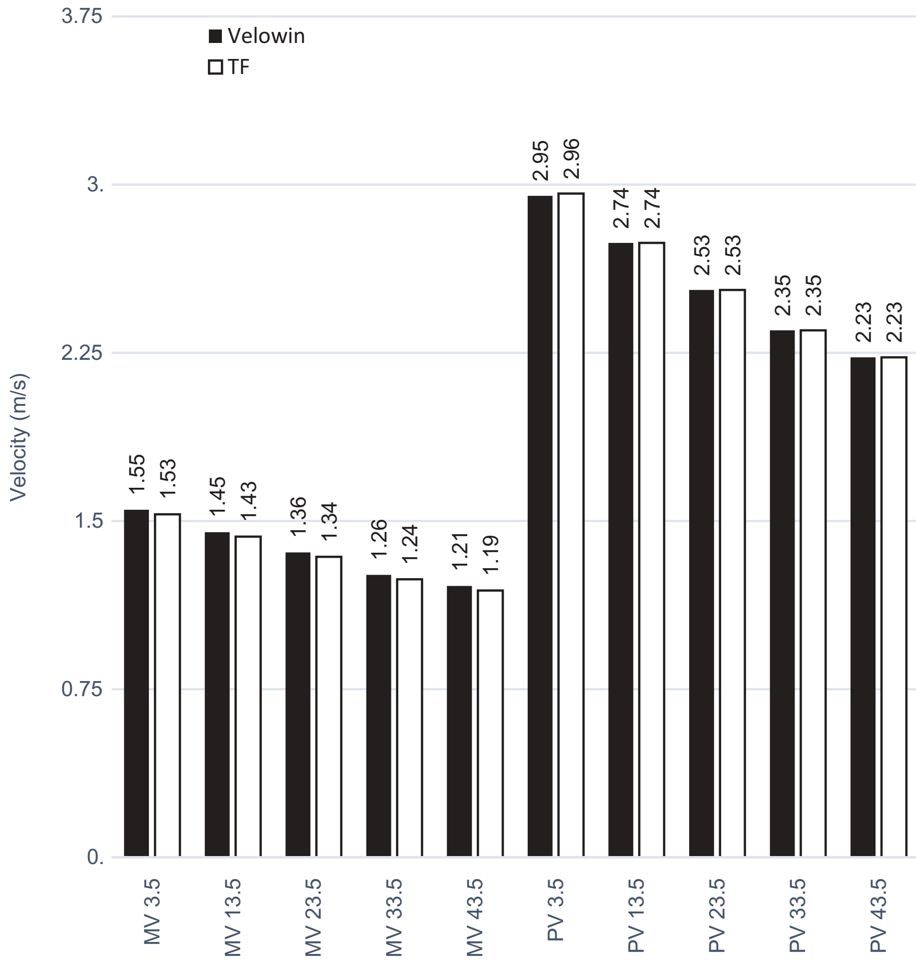

Figure 2. Variables values of mean velocity (MV) and peak velocity (PV) for each load recorded with Velowin (VW) and T-Force (TF) in CMJ exercise.

measurement could help to reduce the measurement error both random and systematic, as the use of a Smith machine restricts the displacement of the bar in the vertical direction. In fact, data derived from horizontal oscillations of the bar outside the vertical vector can modify the data and can alter the accuracy of the vertical velocity evaluation (Cormie et al., 2007).

Validity is generally referred to as the ability of a measurement tool to reflect what it is designed to measure (Atkinson & Nevill, 1998). Although there are different types of validity (logic, content, criterion and construct), in the presence of a standard measure it is particularly useful to establish criterion validity, which evaluates the degree to which the scores of a test are in relation to some recognised standards (Thomas et al., 2005). In this sense, an adequate criterion validity of the Velowin device is confirmed with respect to the 'gold standard' (linear velocity transducer). The analysis of variance (one-way ANOVA) showed that there were no significant differences ($p > 0.05$) in MV and PV measurements for each of the recorded loads with the Velowin device and the T-Force in CMJ exercise.

Force dynamometric platforms are commonly considered as the reference system or criterion with which to compare and validate other vertical jump measuring instruments (Linthorne, 2001). Force platforms determine the height of the vertical jump starting from the maximal velocity of the centre of mass just before takeoff according to the Impulse-momentum theorem, or by flight time determined by the time interval during which the force applied against the platform stops (Linthorne, 2001). However, the economic cost, transportation and assembly of these devices makes it the least used method to measure vertical jump outside the laboratory. On the other hand, the linear velocity and position transducers are considered by different researchers to be the reference instruments for measuring the bar execution velocity in linear movements (Cormie et al., 2007; González-Badillo & Sánchez-Medina, 2010; Jidovtseff et al., 2011). Specifically, the linear velocity transducer used for this study as 'gold-standard' (T-Force System) has been widely used to evaluate kinetic and kinematic variables in resistance exercises (González-Badillo & Sánchez-Medina, 2010; Jiménez-Reyes et al., 2016; Sánchez-Medina & González-Badillo, 2011). The reliability and validity of this instrument (ICC = 1.00, CV = 0.57%) has been described in another scientific document (Sánchez-Medina & González-Badillo, 2011). In addition, having used a linear transducer for direct measurement of velocity as a criterion for this study reduces the possible error generated by the mathematical derivation made by the linear position transducer in the estimation of velocity according to time (Harris, Cronin, Taylor, Jidovtseff, & Sheppard, 2010). However, a drawback in this type of devices is that they usually do not provide jump height measurements and need to have a extendable cable to fix to the load to move.

Also, in recent years, different studies have been published on the reliability and concurrent validity of accelerometry-based devices (Casartelli, Müller, & Maffiuletti, 2010; Castagna et al., 2013; Choukou, Laffaye, & Taiar, 2014; Lesinski, Muehlbauer, & Granacher, 2016; Mauch, Praxisklinik-Rennbahn, Hans-Joachim, & Xaver, 2014; Monnet et al., 2014; Nuzzo et al., 2011; Picerno, Camomilla, & Capranica, 2011; Requena et al., 2012) and video-analysis (Balsalobre-Fernández, Glaister, & Lockey, 2015; Carlos-Vivas, Martín-Martinez, Hernández-Mocholi, & Pérez-Gómez, 2016) to determine the height of the vertical jump starting from flight time. As a whole, these instruments show an acceptable reproducibility and reliability of the vertical jump measurement without load (CV 'low': <6%; CCI 'medium-high': ≥0.8; SEM: 1–5 cm).

However, we are not aware of any validation studies that have used an opto-electronic device to determine the vertical jump performance starting from execution velocity; possibly because the traditional measurement procedures have been based on other types of methodologies and instruments (force platforms, contact platforms, accelerometry, linear position transducers). Cronin, Hing, and McNair (2004) conducted a study to determine the reliability and validity of a linear cable position transducer for measuring vertical jump performance with respect to a force platform based on force values. The inter-test reliability of the jumps measured by the linear cable position transducer gave an intraclass correlation coefficient of 0.92-.97 for mean force, 0.97–0.98 for peak force and 0.72–0.96 for the time until reaching the peak force, and coefficients of variation of 2.1–4.5%, 2.5–8.4%, and 4.1–11.8%, respectively. Another study proposed the use of maximal bar velocity to predict the vertical jump height in the Smith machine starting from different equations (García-Ramos et al., 2015) and having used the same linear velocity transducer used in this study (T-Force System).

On the other hand, a study conducted with an infrared optical barrier placed at ground level could determine an excellent relative and absolute reliability of the instrument (ICC: 0.98–0.99; CV: 1.76–6.47%). However, it presented a systematic error which underestimated between 11 and 14 cm the height of different types of vertical jumps with respect to a force platform as reference (−27–31%) (Attia et al., 2017). The flight time obtained by means of a contact platform or an optical barrier (infrared) placed on the ground refers to the flight time of the jumper's shoe tip, which is undoubtedly different from the flight time of the centre of mass or of any other part of the body. Even using jump platforms of different types (contact versus infrared) we can expect different jump heights estimated by flight time of 2.0 ± 0.8 cm (García-López et al., 2013). Therefore, although the estimation of the height reached in the vertical jump as an indicator or performance criterion starting from 'flight time' has been traditionally and greatly used, the main source of error of measurement can be found in its determination (Aragón-Vargas, 2000; Monnet et al., 2014; Musayev, 2006). The detection of the right moment of takeoff and landing is a key aspect to validate these instruments with respect to jump height, flight time and vertical take-off velocity (Monnet et al., 2014).

We think that many of the disadvantages derived from the use of this type of instruments (force platforms, velocity transducers, contact platforms, optical barriers, accelerometers, etc.) for the measurement of height or execution velocity of vertical jump could be solved by the opto-electronic technology used in this study. However, we consider that this novel device should improve other aspects to facilitate its usability (a simpler calibration procedure and an electric self-feeding system).

About these issues, some researchers consider the maximal velocity reached as the most reliable and sensitive variable and indicator and which best expresses and explains vertical jump performance (González-Badillo & Marques, 2010; González-Badillo et al., 2017; Jiménez-Reyes et al., 2016), that is, the velocity reached just at the end of the concentric phase. This means that a higher peak velocity in the jump necessarily implies an improvement in performance, since, in all cases, the height reached will depend directly on the takeoff velocity, which in turn has an almost perfect relationship with the maximal velocity reached moments before taking off from the ground, and it is also much easier to determine and measure in an accurate way (González-Badillo & Marques, 2010). In turn, using peak velocity as a criterion or performance indicator of vertical jump—and not flight time and derived jump height—has the advantage of not being able to be distorted by alterations in the execution technique (González-Badillo & Marques, 2010; Jiménez-Reyes et al., 2016). This reasoning would justify using the Velowin device to determine the performance of any type of vertical jump by means of the peak velocity, also allowing to find the reached height without having to pay attention to flight time (Linthorne, 2001): height = $(v_{peak})^2/2g$ ($g = 9.81\ m/s^2$).

Conclusions

The main finding of this study is the high reliability and concurrent validation of the Velowin opto-electronic system for measuring the execution velocity in loaded CMJ exercise. In this regard, this tool could be useful for training, monitoring and assessing vertical jump performance.

This study shows that it is possible to control and assess vertical jump performance in an accessible and effective way by using this measurement system instead of a force plate or linear transducer. Opto-electronic technology could become an accessible resource for exercise science professionals working in different contexts who need to accurately assess performance changes in vertical jump through execution velocity.

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No potential conflict of interest was reported by the authors.

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