Validation of an opto-electronic instrument for the measurement of execution velocity in squat

Abstract

The purpose of this study was to analyse the reliability and validity of an opto-electronic sensor system (Velowin) for assessment of the bar-velocity in the deep squat exercise. Mean velocity, mean propulsive velocity and peak velocity generated in the deep squat exercise performed in the Smith machine bar were analysed compared to a linear velocity transducer considered as the gold standard. The study was conducted with a sample of 26 men with experience in resistance training. Six measurements were analysed for squat exercise in concentric phase using the a progressive loading increase. Three consecutive repetitions were performed per load with a 3-4 minutes recovery between loads. Analysis of variance confirmed that there were no significant differences (p >0.05) for the velocity variables between Velowin and T-Force for each of the loads. The reliability analysis showed high values of the intraclass correlation coefficient (ICC = 0.94-0.99), an "almost perfect" Lin´s concordance coefficient (CCC = 0.99) and a low coefficient of variation (CV <3.4%) for each of the loads and velocities. These results confirm the reliability and validity of the Velowin device for measuring the execution velocity in deep squat exercise.

Word account: 190

Key words: strength; reliability; evaluation; performance; velocity-based training

Introduction

Velocity-based resistance training has implied a paradigm shift in the way programming, control and assessment of resistance training has been conceived lately (González-Badillo et al., 2017b). However, velocity control requires the use of sufficiently reliable measuring instruments.

Execution velocity monitoring of the most common exercises in strength training has generated scientific interest, showing as its main finding a close relationship between the relative magnitude of the load (%1RM) and the execution velocity with each percentage, being this velocity specific for each exercise (Conceição et al., 2016; González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2011; González-Badillo et al., 2014; González-Badillo et al., 2017a). In addition, some researchers maintain that this relationship is very stable regardless of the modifications of the 1RM and the training experience of the subjects (González-Badillo et al., 2017a; González-Badillo et al., 2017b). It is known that the fastest repetition velocity attained during a set in the presence of an absolute load can be used as a good estimator of the relative intensity that this resistance represents at each moment with each exercise (González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2011; Sánchez-Medina et al., 2017). More recently, it has been proven that the mean velocity loss during the set is a reliable and quantifiable indicator that reflects the induced neuromuscular fatigue degree (Sánchez-Medina & González-Badillo, 2011; Pareja-Blanco et al., 2016), and therefore can be used as a variable to monitor resistance training and adjust the set load (González-Badillo et al., 2017b).

The importance of accurate velocity measurement lies in the fact that both the neuromuscular requirements and the training effects are largely conditioned by the concentric velocity at which training loads move (González-Badillo et al., 2014). Fortunately, due to growing technological advance, it is now possible to monitor execution velocity and other kinematic parameters through different devices, such as linear velocity or position transducers, video-analysis, accelerometers, and smartphone apps (Sato et al., 2009; Sánchez-Medina & González-Badillo, 2011; Balsalobre-Fernández et al., 2016; Balsalobre-Fernández et al., 2017; Comstock et al., 2011). Among all these instruments, the linear velocity or position transducers are considered by different researchers as reference gold-standard devices for measuring the bar execution velocity in linear movements (González-Badillo & Sánchez-Medina, 2010; Cormie et al., 2007a). 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 the different velocity variables by derivation 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 overcome some limitations and drawbacks of other type of electronic instruments when measuring execution velocity, such as moderate relative reliability of accelerometer systems (Banyard et al., 2017), low sampling frequency, not discriminating mean propulsive velocity, and not measuring displacement or eccentric action variables (i.e.: smartphone apps and accelerometry-based devices). Specifically, this opto-electronic device has the advantage with respect to the linear velocity or position transducers of not having any extendable cable to fix to the bar or load to move, allowing to assess a wide range of exercises, including the possibility of measuring changes of position (velocity) of any body segment. Despite the possible advantages of this new device, its validation is a prerequisite in order to use this tool with confidence for velocity monitoring.

Therefore, the objective of this study was to analyse the reliability and validity of an opto-electronic sensor system (Velowin) for assessment of the bar-velocity in the deep squat exercise. For this purpose, execution velocity performed in the Smith machine bar was analysed compared to a linear velocity transducer (T-Force System) considered as the gold standard. In this regard, it was hypothesized that the Velowin opto-electric system is reliable and valid for recording kinematic variables (mean, mean propulsive 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 deep back-loaded squat exercise (SQ) to obtain mean velocity (MV), mean propulsive velocity (MPV) and maximal or peak velocity (PV) data 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 SQ exercise, taking as independent variable both devices, and as dependent variables the MV (average bar velocity during the entire concentric phase in m/s^2), the MPV (average bar velocity of the propulsive phase, defined as the portion of the concentric action during which acceleration (a) experienced by the moving load is greater than acceleration due to gravity, i.e., a ≥ -9.81 $m \cdot s^{-2}$) (Sánchez-Medina et al., 2010) and the PV (maximal instantaneous bar velocity reached at a particular instant during the concentric phase in m/s^2). 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.

Participants

The study sample included 26 men (age 29.8 ± 3.5 years, height 178 ± 6.5 cm, body mass 75.7 ± 7.6 kg) with experience in resistance training and familiar with the SQ 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 minimize 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 hours prior to the measurement day.

The present study met the ethical standards (Harriss et al., 2017) and was approved by the Research Ethics Commission 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 SQ exercise was performed on a Smith machine (Instruments and Sports Technology 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 extendable cable of the linear velocity transducer (T-Force System, v 2.35; Ergotech Consulting, Murcia, Spain) at the vertical projection of the bar. A complete description of the T-Force System linear velocity transducer is reported elsewhere (Sánchez-Medina & González-Badillo, 2011).

The opto-electronic system and the linear velocity transducer collected the MV, MPV 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, MPV and PV) are automatically made with the algorithms of each software (Velowin v.1.7.232 and T-Force System v. 2.35, respectively).

insert here Figure 1

Testing procedures

The participants of the investigation made all the SQ exercise measurements in a force-analysis laboratory (Murcia University, Spain). All tests were 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 standardized warm-up consisted of 5 minutes jogging, joint mobility exercises and dynamic stretching followed by three sets with a low number of repetitions of the SQ exercise in the Smith machine and a 20, 30 and 40 kg load, respectively. From there, the velocity data record for the SQ exercise was established by a progressive overload with the following dynamics for all participants (Table 1): initial load of the bar (20 kg), with an increase of 10 kg up to 70 kg, for each of the consecutive measurements. Three consecutive repetitions were made for each load. When the execution was considered incorrect (see criteria below), the set was discarded and another one was repeated with the same load after the established recovery interval. The recovery between each set with each load was 3-4 minutes.

An experienced evaluator supervised the subject correct starting position and the technical execution of the exercise. 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. A line drawn on the ground in the vertical projection of the Smith machine guide rods established the position of the feet metatarsus. Participants were instructed to hold the bar with a grip slightly greater than the width of the shoulders. The displacement of the eccentric phase had to overcome the horizontal plane with the upper part of the thighs, and the knees should be flexed at a tibio-femoral angle of less than 45º in the sagittal plane. The participants were instructed to perform the eccentric phase at a controlled velocity (0.45-0.75 m/s^2) with the real-time visual and acoustic feedback help provided by the linear velocity transducer software and, from that point, execute the concentric phase at the maximal possible velocity up to the initial position. Strong verbal encouragement was provided to perform the maximum effort (the instruction provided to the participants was "push as fast as you can"). It was required that the feet were in constant contact with the ground throughout the execution, although the heels were allowed to rise at the end of the concentric phase with lighter loads. It was not allowed to take off the bar resting on the shoulders during the braking phase of the concentric movement.

insert here Table 1

Statistical analyses

For analysis of the data, only the fastest repetition of each load of the evaluated velocity variables was selected. 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). Data are presented as means ± standard deviation. In addition, the confidence intervals (CI) were further calculated for all bar-velocity outcomes in each load. Analysis of variance (ANOVA) was performed to verify the existence of significant differences between both devices 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). Acceptable reliability was determined as an ICC > 0.75 and a CV < 10%. However, 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. For this reason, Lin (Lin, 1989) developed a proposal to evaluate the strength of concordance or agreement between continuous variables in a more demanding way through the concordance-correlation coefficient. This coefficient is defined as the product of precision -represented by the correlation coefficient- and accuracy -represented by the bias correction coefficient. Lin revealed that this method used to evaluate the reproducibility of measurements is superior to others (mentioned above) which are used for similar purposes. Values for CCC are classified as: "almost perfect" >0.99, "substantial" between 0.95 and 0.99, "moderate" between 0.90 and .95, and "poor" <0.90 (Cortés-Reyes et al., 2010). A significance level of $p < 0.05$ was accepted for all the analysis.

Results

Preliminary test of normality

Shapiro Wilk test was used to verify the normality of the MV, MPV and PV variables with each of the loads evaluated in both devices (Velowin and T-Force). The test confirmed that all the variables have a normal distribution of $p > 0.05$, except the mean velocity ($p = 0.17$ for velowin and $p = 0.02$ for T-Force) and the mean propulsive velocity ($p = 0.03$ for velowin and $p = 0.03$ for T-Force) in the first repetition (ST1) with the 20 kg load. Skewness and kurtosis values were between 0 and 2.

Reliability

ICC shows a mean value of 0.98 and values from 0.94 to 0.99 (95% CI) based on the MV, MPV or PV variable for Velowin and T-Force. The Pearson correlation coefficient showed values from $r \geq 0.70$ to $r = 0.96$. CV values for the analysed variables with each one of the loads were less than 3.4% (Table 2).

CCC values show an "almost perfect" agreement or concordance with all analysed loads and velocity variables (CCC = 0.99; CCC = 0.98 for MV with 20 kg). This corroborates the concordance (precision and accuracy) of the measurement in the Velowin device for MV, MPV and PV kinematic variables in SQ exercise.

insert here Table 2

Validity

Standard statistical mean and standard deviation for Velowin and T-Force in Squat exercise.

Mean values ± SD of the velocities for Velowin and T-Force devices are summarized (Table 3). Mean values are similar in both devices for each of the velocities analysed with the different loads.

insert here Table 3

Analysis of variance (ANOVA) for mean velocity, mean propulsive velocity and peak velocity variables for Velowin and T-Force in Squat exercise.

To analyse the existence of significant differences in the total scores of MV, MPV and PV an ANOVA was performed considering velocity outcomes as dependent variables and the "Test" variable as an 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.

Discussion and implications

According to the obtained results, the hypothesis of reliability and validity of the opto-electric device to measure execution velocity in squat exercise was confirmed. To the best of our knowledge, this is the first scientific study that aimed to validate the Velowin camera-based opto-electronic device by comparing it with a linear velocity transducer as a reference instrument for the variables of MV, MPV and PV in deep squat exercise conducted in a Smith machine.

Research has shown that monitoring repetition velocity is an objective, real time, and noninvasive indicator of relative intensity (from fastest repetition velocity attained during a set), the number or percentage of repetitions performed (using the magnitude of velocity loss attained in the set) and the muscle fatigue during resistance training (González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2011, González-Badillo et al., 2017a). Accordingly, the importance of accurately assessing bar-velocity for strength training prescription and load control purposes is essential. In this sense, some data sustain that differences of mean propulsive velocity as small as 0.07-0.09 m/s^2 against the same absolute load can represent variations of approximately 5% of the relative training intensity (González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2017b). For this reason, the validation of this novel device is important as it presents some advantages and could overcome some limitations of other type of electronic instruments for measuring execution velocity.

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 (Sato et al., 2009). 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 = 0.94-0.99) 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 (Thomas, 2005). Likewise, the values of the Coefficient of Variation for the same variables demonstrate a good absolute reliability (CV <3.4%) with different loads. Scientific literature suggests that the coefficient of variation should be lower than 10%, although these estimates have been a source of discrepancy (Atkinson & Nevill, 1998; Cronin et al., 2004). In the same way, the Lin´s concordance correlation coefficient shows an "almost perfect" agreement or concordance in all analysed loads and velocity variables (CCC = 0.99). According to Lin et al. (Lin, 1989) 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, MPV and PV). All these data together corroborate the measurement accuracy of the Velowin device for the kinematic variables of mean velocity, mean propulsive velocity and peak velocity in the SQ exercise. In addition, having used a Smith machine for velocity measurement could help reduce the measurement error both random and systematic. Since the free weight squat exercise does not follow a strictly linear trajectory (Rudner et al., 2003), the use of a Smith machine is recommended to restrict the displacement of the bar to the vertical direction in this validation study. 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., 2007a).

Validity is generally referred to as the ability of a measurement tool to reflect what it is designed to measure (Atkinson & Nevill, 1998). 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 recognized standards (Sato et al., 2009). 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, MPV and PV measurements for each of the recorded loads with the Velowin and the T-Force device in deep squat exercise, indicating that they measure in a similar way.

The linear velocity or position transducers are considered by different researchers to be the reference instruments for measuring the bar execution velocity in linear movements (González-Badillo & Sánchez-Medina, 2010; Cormie et al., 2007a). These devices are electromechanical measuring instruments, since the transducer output is usually an electric signal such as voltage or electric current intensity (González-Badillo et al., 2017b; Harris et al., 2010). All of them have an extendable cable that is attached to the moving external resistance. Depending on the linear velocity changes of cable displacement or the changes in position, as a function of time, the rest of the kinematic (acceleration) and dynamic variables (force, power) are derived (González-Badillo et al., 2017b). These devices require the trajectory of the bar movement to be linear so that the recording is as reliable and accurate as possible (Sánchez-Medina & González-Badillo, 2011; Harris et al., 2010). Specifically, the linear velocity transducer used for this study as a "gold-standard" (T-Force System) has been widely used to evaluate kinetic and kinematic variables in resistance exercises (González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2011; González-Badillo et al., 2014; González-Badillo et al., 2017; Sánchez-Medina and González-Badillo, 2011; Pareja-Blanco et al., 2016; Sánchez-Medina et al., 2017). The high reliability (ICC = 1.00, CV = 0.57%) and validity of this instrument have been previously described (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 linear position transducers in the estimation of velocity according to time (Harris et al., 2010). Likewise, the T-Force transducer has a high sampling frequency (1000 Hz), which is essential to correctly detect the starting and ending moment of each repetition performed, as well as to accurately obtain the peak values and derived variables (González-Badillo et al., 2017b).

We are not aware of any validation study that has used a position opto-electronic device to measure execution velocity in exercises with linear trajectories such as the squat conducted in a Smith machine. A validation study of a linear position transducer, which used the bench press and squat exercises, was able to verify the high reliability (ICC = .85-.98) and the low to moderate systematic and random error of peak velocity, mean velocity, and mean power variables with respect to the same linear velocity transducer used in our study as reference (Garnacho-Castaño et al., 2015), but could not compare mean propulsive velocity data since the linear position transducer analysed does not have this data. Other validation studies of linear position transducers have used force platforms (Cormie et al., 2007b; Crewther et al., 2011) or video-analysis (Drinkwater et al. 2007) as a criterion to study force and power values in different jumps and other resistance exercises, but none of them analysed velocity variables with which to compare the results of our study.

On the other hand, in recent years different studies have been published on the reliability and concurrent validity of accelerometry-based devices and smartphone apps (Sato et al., 2009; Balsalobre-Fernández et al., 2016; Balsalobre-Fernández et al., 2017; Comstock et al., 2011) for measuring execution velocity. Although these studies generally show a high correlation of mean and peak velocity with those recorded by the linear position transducer used as a reference (r = 0.86; r = 0.98, respectively) (Balsalobre-Fernández et al., 2016), the peak and mean velocity values are slightly lower (-0.07 ± 0.1

m/s^2) and higher (0.11 ± 0.1 m/s^2), respectively, than the transducer used for each study in the analysed exercises, both for accelerometers (Balsalobre-Fernández et al., 2016) as for the video-analysis through app (Balsalobre-Fernández et al., 2017). A recent validation study that compared an accelerometer system and a linear position transducer with a force platform and other linear transducers during the free weight squat exercise concluded that only the linear position transducer was reliable enough for velocity measurements (Banyard et al, 2017). It has been described that accelerometry-based devices provide velocity values with great error, especially when working with low or very high loads (González-Badillo et al., 2017b), which discourages their use when it is intended to collect data accurately and correctly interpret the effects of training. Therefore, since velocity outcomes recorded by the accelerometry-based devices are not "real" in absolute terms, compared to those recorded by linear position transducers, they are not interchangeable instruments (Balsalobre-Fernández et al., 2016; Balsalobre-Fernández et al., 2017). It is also important to note that none of the validation studies of the aforementioned devices has been based on Lin's correlation-concordance coefficient as a statistical indicator to analyse reliability.

Another remarkable issue is the fact that the Velowin opto-electronic device used for this study is capable of measuring MPV, that is, the portion of the movement during which the applied force is positive (>0) (González-Badillo et al., 2017b). By contrast, no current wearable device (accelerometers and apps) allows discriminating mean velocity of the *propulsive* phase, that is, mean values of the "propulsive" phase of the concentric action. According to some authors, this velocity variable is probably the most relevant in the analysis of load programming and assessment of the training effect on performance, since it better discriminates the potential or neuromuscular ability of subjects at low and medium loads (González-Badillo et al., 2017b; Sánchez-Medina et al., 2010). Furthermore, for the precise calculation of the propulsive phase duration of each repetition - and, therefore, of the mean propulsive velocity - it is necessary to have devices with a sampling frequency of at least 500 Hz, since, without a high sampling frequency and a very accurate acceleration value, the propulsive phase cannot be adequately determined (González-Badillo et al., 2017b). Lastly, this opto-electronic device has the advantage with respect to the gold standard of not having any extendable cable to fix to the load to move, allowing to assess a wide range of exercises (i.e. vertical jumps, machine exercises), including the possibility of measuring changes of velocity (position) of any body segment. Nevertheless, we consider that this novel device should improve other aspects to facilitate its usability: a simpler calibration procedure and an electric self-feeding system.

Conclusions

The main finding of this study was the high reliability and concurrent validation of the Velowin opto-electronic system for measuring the execution velocity. In this regard, this tool could be useful for training, monitoring and assessing the performance of resistance exercises with linear trajectories such as squat. This study shows that it is possible to control and assess neuromuscular performance, using execution velocity in linear resistance training exercises such as squat, in an accessible and effective way by using this measurement system instead of a 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 resistance training exercises through execution velocity.

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