Validity and reliability of smartphone high-speed camera and Kinovea for velocity-based training measurement

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ABSTRACT

The aim of this study was to validate the combination of smartphone high-speed camera and motion analysis software Kinovea methodology (SHSC-Kinovea) to measure kinematic variables of velocity-based training during back squat exercises. Fifteen athletes were voluntarily recruited for the study (age 22.8 ± 2.9 years, height 182.9 ± 8.9 cm, body mass 79.5 ± 9.6 kg). High-speed video recordings with a smartphone at 240 fps were used against a criterion linear force transducer (LPT) for measuring displacement of the barbell (RB), mean velocity (MV), maximum velocity (Vmax) and concentric phase time (CPT). The intra-class correlations coefficient between LPT and SHSC-Kinovea showed almost perfect agreement for consistency (.992, .995, .997, .993) and absolute agreement (.975, .978, .980, .964) for RB, MV, Vmax and CPT, respectively. The mean differences between instruments were 1.11 mm for RB, 0.03 m/s for MV, 0.05 m/s for Vmax and 65.91 ms for CPT, all $p < .001$. Bland-Altman plots showed low systematic bias ± random error for RB: 1.11 ± 1.50 cm (r^2: .006), MV: 0.03 ± 0.33 m/s (r^2: .001) and Vmax: 65.91 ± 63.82 m/s (r^2: .11), whereas Vmax showed overestimation for the high range of measures: 0.55 ± 0.42 m/s (r^2: .31). Pearson's product moment correlation coefficient showed almost perfect association between all variables: (r = .985 - .990) ($p < .001$). The SHSC-Kinovea methodology resulted in similar kinematic values than criterion so it can be considered as a trustworthy instrument for measuring velocity-based training.

Keywords: Technology; Instrument; Video; Barbell; Half squat; Biomechanics.

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INTRODUCTION

Velocity-based training (VBT) is a method used by trainers and physical trainers for load control and monitoring during training (Mann, Ivey, & Sayers, 2015). Monitoring of the barbell during the execution of exercises states that execution velocities are low with high loads, whereas light loads are moved at high velocities (González-Badillo, Rodríguez-Rosell, Sánchez-Medina, Gorostiaga, & Pareja-Blanco, 2014). In addition, the mean propulsive velocity (MPV) of the first or fastest repetition is related to the percentage of the maximum dynamic force, so this velocity value is a good estimator of the one-repetition maximum (1RM), as the maximum weight that an athlete can move for one repetition (Sánchez-Medina, Pallarés, Pérez, Morán-Navarro, & González-Badillo, 2017; Sanchez Medina & Gonzalez-Badillo, 2011). Therefore, by controlling and monitoring the velocity of execution, it is possible to determine whether the load used conforms to the programmed effort (González-Badillo, Yañez-García, Mora-Custodio, & Rodríguez-Rosell, 2017).

As a consequence, VBT has become very popular, with commercial technological devices allowing monitoring and control of the barbell velocity (Pérez-Castilla, Piepoli, Garrido-Blanca, et al., 2019). These devices rely on the implementation of different technologies to track barbell position monitoring during the lifts: electromechanical; optoelectronic; force dynamometry; 3D technology; accelerometry and video-based analysis (Balsalobre-Fernández, Geiser, Krzyszkowski, & Kipp, 2020).

The electromechanical instruments known as linear position transducers (LPT) or encoders, use a cable attached to the barbell where the exercise is performed. This cable is connected to a transducer that records signals proportional to the linear velocity of the cable. The calculation of force, power and acceleration is obtained indirectly from time. The use of this type of instrumentation requires exercises where a linear movement is carried out to acquire proper data recording. In addition, ad hoc software allows sending data to tablets wirelessly to give immediate feedback on execution velocities. Currently, these instruments are accepted to make accurate and reliable measurements and thus be used in quality scientific studies, as several publications on the validation and reliability of this type of instrument demonstrate (Banyard et al., 2017; Bosquet, Porta-Benache, & Blais, 2010; Pérez-Castilla et al., 2017).

The optical position transducers allow tracking of movements through an infrared camera that follows an active marker/reflection, computing parameters of interest such as force, acceleration and power in an indirect way by means of the marker position over time (Garcia Ramos, Perez-Castilla, & Martin, 2011).

The technology-based on force dynamometry is marketed through platforms that have pressure sensors (strain gauges or piezoelectric) connected to a recording and amplification system. Force dynamometric platforms allow recording of the ground reaction force in the x, y, and z axes. By using them, the reaction forces can be measured directly, as well as the pressure centre oscillation. Although they are considered a "*gold-standard*", their use for performance evaluation and their assembly for athlete evaluations is questionable due to the complexity of use and both financial and personal resources involved in their use (Dorrell, Moore, Smith, & Gee, 2018).

Both 3D photogrammetry technology as well as dynamometric force platforms are considered as gold-standard instruments and have been implemented in studies for velocity control in lower-limb force executions (Pueo, Lipinska, Jiménez-Olmedo, Zmijewski, & Hopkins, 2017) and for weight lifting (Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca, & García-Ramos, 2019).

Accelerometer-based devices have been very popular in recent years. They comprise triaxial accelerometers (measurement in x, y and z axis) and gyroscopes and incorporate wireless technology for data transfer to storage devices such as smartphones or tablets. The velocity of execution is obtained indirectly through the time integration of vertical acceleration. Their convenience, small size and ease of use make them perfect for everyday use, but despite studies on their validation and reliability (Balsalobre-Fernández, Kuzdub, Poveda-Ortiz, & Del Campo-Vecina, 2016), they still show troubles when tracking barbell at low velocities.

Finally, video technology has led to the rise of applications aimed at controlling velocity and execution in weightlifting exercises (Balsalobre-Fernández et al., 2017; Balsalobre-Fernández, Marchante, Muñoz-López, & Jiménez, 2018). Despite the ease of use of this type of analysis, an analysis of the video after the recording must be performed, which requires a correct observation protocol with experienced observers (Pueo, Jimenez-Olmedo, Penichet-Tomas, & Bernal-Soriano, 2018). For this reason, the use of high-speed video has led to the development of analytical methodologies that have been validated for the analysis of flight time in vertical jumps (Balsalobre-Fernández, Tejero-González, Campo-Vecino, & Bavaresco, 2014).

However, high-speed video recordings were only possible with expensive video cameras (Pueo, 2016) and through the necessary technical knowledge to use them properly. Nevertheless, thanks to the commercialization of smartphone models which allow recordings of up to 960 fps, it is now possible to carry out a kinematic analysis of the barbell velocity with video post-processing for free with open-source motion analysis software, such as Kinovea (Kinovea, Bordeaux, France). This methodology, based on the use of the smartphone high-speed camera (SHSC), allows to carry out complete low-cost analyses with ease of use.

Therefore, the aim of this study is to validate the combination of smartphone high-speed camera and motion analysis software Kinovea methodology (SHSC-Kinovea) to measure kinematic variables of velocity-based training during back squat exercises.

MATERIAL AND METHODS

Participants

Fifteen physically active sportsmen in various disciplines were voluntarily recruited for the study (age 22.8 ± 2.9 years, height 182.9 ± 8.9 cm, body mass 79.5 ± 9.6 kg). All participants were familiarized with the back squat exercise before the beginning of the study. Volunteers were instructed to avoid any exercise 48 h before each testing session. All tests were performed by each participant at the same time of the day to eliminate the effects of circadian rhythm. Participants included in the sample had no musculoskeletal injuries or diseases or were recovering from previous operations or injuries. All participants gave their written consent after project information, which was previously approved by the research ethics committee of the University of Alicante (IRB No. UA-2019-01-19). The study protocol conformed to the guidelines of ethical principles of the Declaration of Helsinki.

Instruments

A multipower machine (ProStrength Multipower Professional, Pro-Gym, Barcelona, Spain) was used for all measurements test and warming exercises. This machine allows only the vertical displacement of the load thanks to rails to which the bar is attached. The machine was correctly aligned so as not to have any deviations that would affect the performance of the exercises. It was also anchored and fixed to avoid displacement during the movement of the loads by the athletes. The rails were greased to facilitate the movement of the bar and minimize friction. A set of discs (ProWod, Pro-Gym, Barcelona, Spain) were also used at the ends of the bar to add precise extra load. A linear force transducer (LPT) (Chronojump, Barcelona, Spain) was used as a criterion instrument (Courel-Ibáñez et al., 2019) in the data collection. Data was collected with the Chronojump software (v.18.1, Chronojump, Barcelona, Spain) at a frequency of 1000 Hz and exported to spreadsheet software (Microsoft Excel v.14, Microsoft, Redmond, USA). High-speed video recordings were made with a smartphone (Redmi Note 8, Xiaomi, Beijing, China) featuring a Snapdragon 886 processor at 2.0 GHz and 48+8+2 Megapixel quad-cameras. Videos were recorded in the slow-motion option at 240 fps in automatic mode, with the camera app provided by the Android 9.0 operating system. Then, videos were exported to the computer without any image post-processing or video re-encoding to simulate the typical operations any user would carry out in the procedure.

The kinematic analysis of the study variables was performed with the open-source motion analysis software Kinovea (v.0.9.1, Kinovea, Bordeaux, France) (Balsalobre-Fernández et al., 2014). The time and distance variables were taken at a frequency of 240 Hz.

Procedure

Configuration setup

The linear force transducer was placed inside the multi-power unit next to the rod guides. To avoid displacement of the device, it was placed on a magnetic metal surface, which was fixed to the floor. The cable was attached to the barbell using a carabiner with a strap. Subsequently, the verticality of the cable was checked with a level during unwinding. The multipower machine was calibrated for the video recordings using a calibrated adhesive tape attached to the structure's vertical fasteners in the same plane as the displacement of the barbell. The position of the barbell was tracked following a marker of a contrasting colour with respect to the background colour. The smartphone was attached to a tripod performing a pressure clip that prevented it from moving during the recordings at 150 cm from the focal plane to the plane of movement of the marker placed on the bar. The main lens of the camera was then placed at a 75 cm height. It was verified that the marker placed on the barbell during the range of lift executions remained within the recording plane.

Test procedure and data analysis

All participants performed a joint mobility standard warm-up of 5 min followed by general activation of the upper and lower body for 8 min with 5-kg elastic bands. Finally, they performed 5 series of 6 repetitions of half-squat exercise with the weight of the barbell only (20 kg) and 1-min rest time between series. After a 5-min break, participants performed 2 repetitions at different velocities with a standard weight of 50 kg. LPT data and video recordings were not synchronized during data collection. Video recordings of the half squat exercises were opened directly with the Kinovea software with no previous processing. The 2D recording plane was spatially calibrated using the coloured tape located in the multipower machine and temporally calibrated at 240-fps video frame rate for the correct computation of barbell velocities by the motion analysis software. The markers in the barbell were tracked and further analysed with the linear kinematic option by which bar range and velocity values were calculated. All lifts were analysed continuously and the data obtained from the marker placed on the barbell was exported in comma-separated value (csv) format for further analysis.

Data collected from LPT and Kinovea was debugged to select only the time slots in which the movement was being executed (Pérez-Castilla, Rojas, & García-Ramos, 2019). To calculate the total range of displacement of the barbell (RB), the instant before the beginning of the descent of the barbell was taken as the baseline point of displacement so the movement lasts until returning to baseline. For the calculation mean velocity (MV) of the concentric phase, the time interval between the barbell was at its position furthest from baseline until the bar returned to baseline was used. The MV were computed using the aforementioned ranges of motion. The maximum velocity value (Vmax) and the concentric phase time of the exercise (CPT) were also calculated.

Statistical analyses

All data were reported with descriptive statistics (mean ± SD). The reliability of the SHSC-Kinovea in comparison with the LPT is carried out using a 2-way random single measurements (consistency and absolute agreement) intra-class correlation coefficient (ICC) (2,1) and Cronbach's α (Hopkins, Marshall, Batterham, & Hanin, 2009). ICC values were interpreted as poor (< 0.5), moderate (0.5-0.75), good (0.75-0.9) and excellent (> 0.9) reliability (Koo & Li, 2016). Besides, the outcome differences between the LPT system and the HSCS-Kinovea paired samples t-tests and mean differences with 95% confidence interval were calculated. The agreement between instruments was also explored using Bland-Altman plots (Bland & Altman, 1986), which show mean outcomes pairs against their difference between values to identify any random error and proportional bias between instruments. To that end, bivariate Pearson's product-moment correlation coefficient was set at $r^2 > .1$ (Atkinson & Nevill, 1998). Finally, the bivariate Pearson's product-moment correlation coefficient (r) with 95% confidence intervals (CI) was used between instruments to study the validity of the variables RB, MV, Vmax and CPT, through the following thresholds: trivial (< 0.1), small (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), very high (0.7-0.9) and practically perfect (> 0.9) (Will G Hopkins, 2018). All data were categorized according to the velocity percentage of 1RM as high (< 40% RM), moderate (40%-70% RM) and low (> 70% RM) to account for different ranges of load (Martínez-Cava, Morán-Navarro, Sánchez-Medina, González-Badillo, & Pallarés, 2019). Statistical analyses were computed with IBM SPSS v. 22 (IBM Corp, Armonk, NY, USA).

RESULTS

Thirty jumps collected from 15 participants were concurrently compared to analyse the agreement between the LPT as a criterion instrument with the results obtained from the SHSC-Kinovea analysis. The descriptive analysis showed the following mean values of barbell displacement (mean ± SD): 50.04 ± 5.92 cm for SHSC-Kinovea and 51.15 ± 6.11 cm for LPT. Regarding MV, the SHSC-Kinovea and LPT system showed values of 0.62 ± 0.17 m/s and 0.66 ± 0.17 m/s, respectively. Also, the SHSC-Kinovea system resulted in maximum barbell velocity (Vmax) mean values of 0.91 ± 0.28 m/s and the LPT system showed values of 0.95 ± 0.30 m/s. Finally, the CPT during the back squat exercise was 837.22 ± 263.98 ms for the SHCS-Kinovea system and 903.13 ± 274 ms for the LPT system.

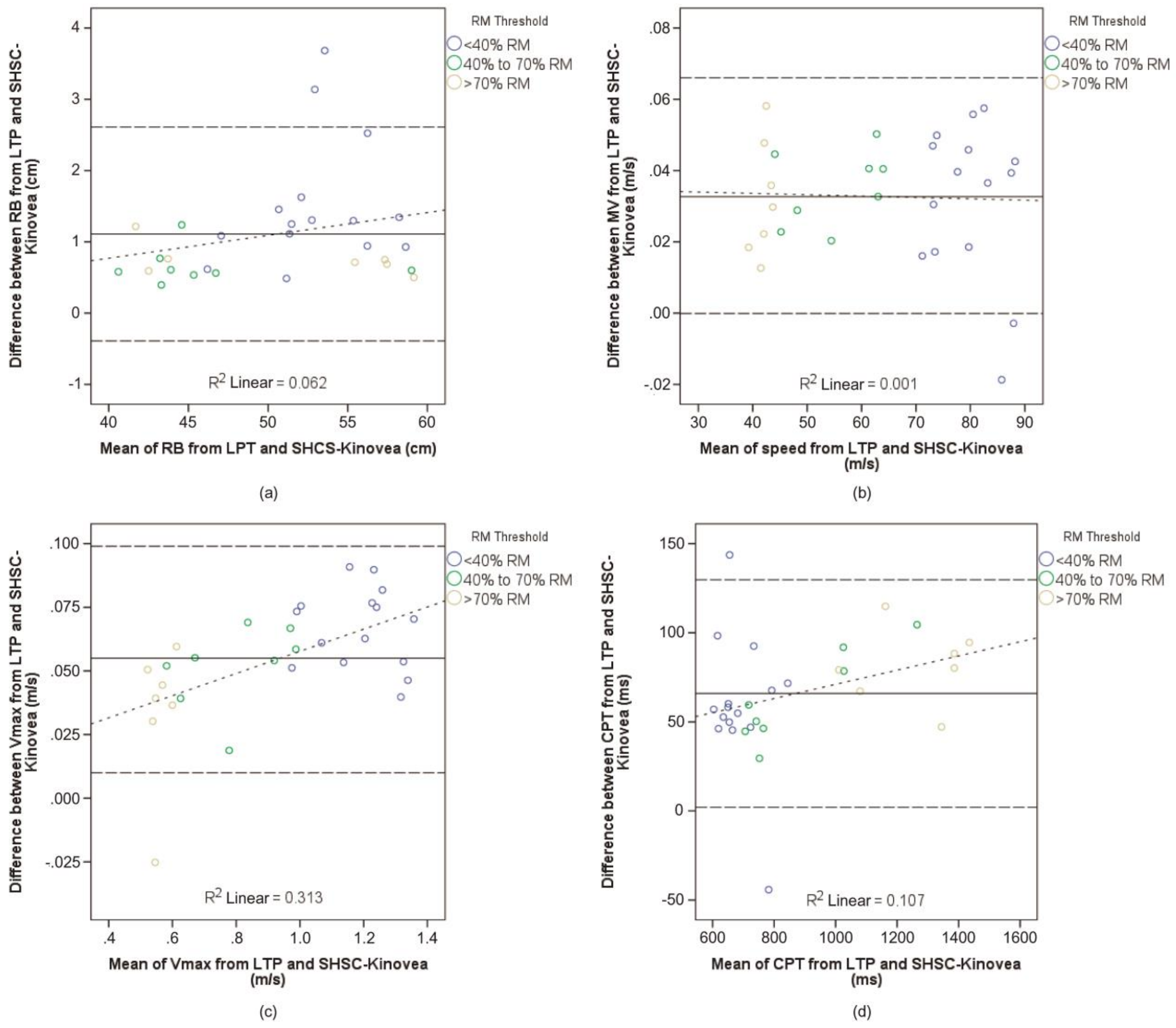
Table 1. Pairwise reliability of LPT and SHSC-Kinovea.

	LPT vs SHSC-Kinovea			
	RB	MV	Vmax	CPT
ICC (2,1)#	0.992	0.995	0.997	0.993
(95% CI)	(0.983 − 0.996)	(0.989 − 0.998)	(0.994 − 0.999)	(0.985 − 0.996)
ICC (2,1)§	0.975	0.978	0.980	0.964
(95% CI)	(0.524 − 0.994)	(0.315 − 0.995)	(0.173 − 0.996)	(0.143 − 0.992)
Cronbach's α	0.996	0.997	0.998	0.996
Mean difference	1.11	0.03	0.05	65.91
(95% CI)	(0.82 − 1.40)	(0.03 − 0.04)	(0.05 − 0.06)	(53.69 − 78.13)

*Note: Intra-class correlation coefficient (ICC) showing consistency (#) and absolute agreement (§) for the comparison between systems, 95% CI = 95% confidence interval; *p < .01.*

The intra-class correlations coefficient between LPT and SHSC-Kinovea showed almost perfect agreement. The consistency test resulted in values between 0.992 and 0.997 for all analyses of variables. In addition, ICC testing absolute agreement showed values of 0.975 to 0.980 as shown in Table 1. Cronbach's α show excellent reliability in all variables.

In the comparison of LPT versus SHSC-Kinovea, there was a difference between instruments for the RB of 1.11 mm ($p < .001$). For the MV, the difference in measurement was 0.03 m/s ($p < .001$) and for the Vmax it was 0.05 m/s ($p < .001$). Finally, the time difference calculated between the two instruments for the CPT of each repetition was 65.91 ms ($p < .001$). In all variables, SCHS-Kinovea slightly underestimated the results compared to the LPT.



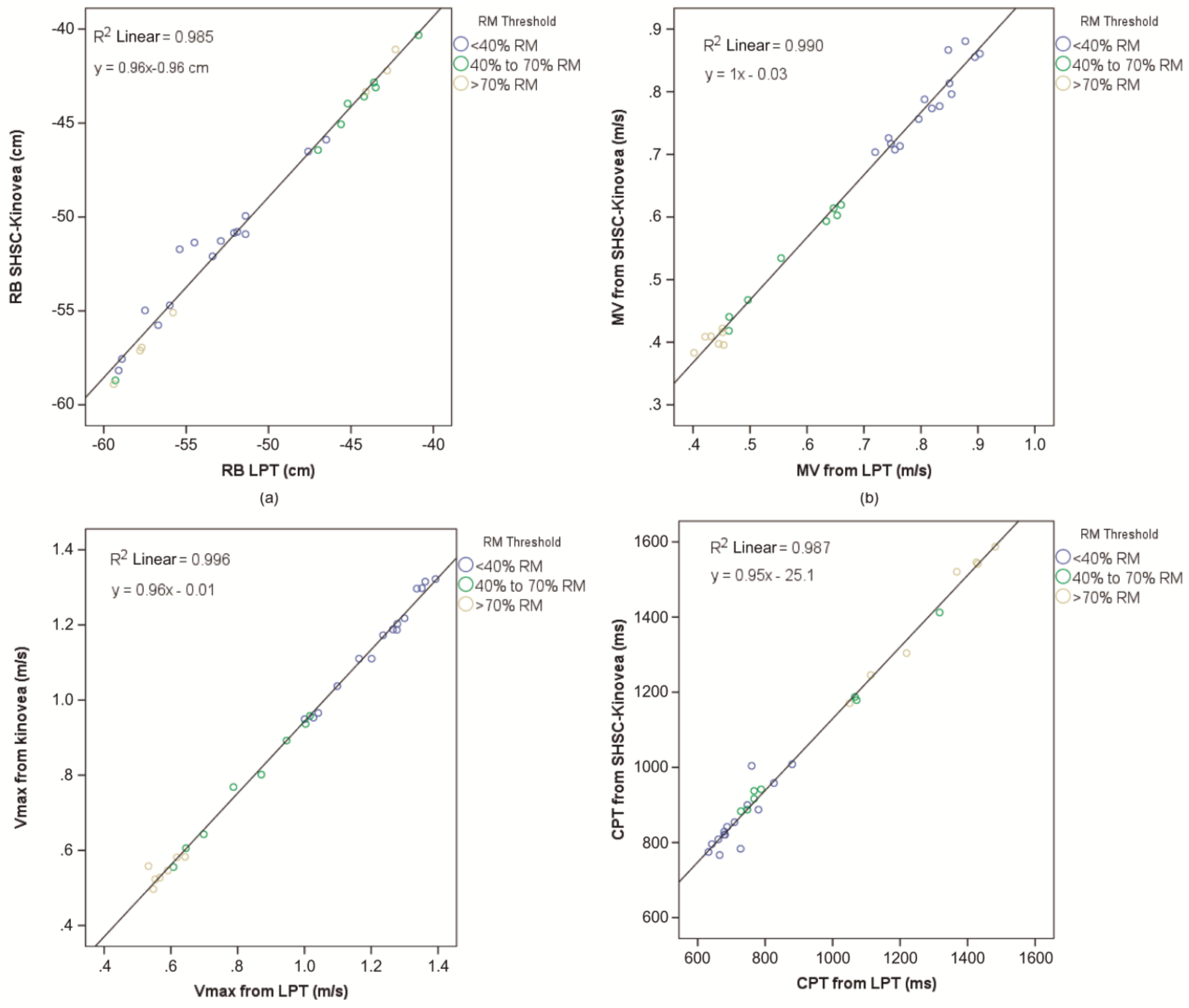
(a) (b)

(c) (d)

Figure 1. The solid central line in Bland-Altman plots shows mean between instruments (systematic bias); upper and lower dashed lines show a mean ± 1.96 SD (random error). Dotted line shows regression (proportional bias). (a) RB: regression $y = 0.03x + 0.51$ cm; (b) MV: regression $y = 0.003x + 0.4$m/s2 mm; (c) Vmax: regression $y = 0.04x + 0.01$ m/s; (d) CPT: regression $y = 0.04x + 31.3$ m/s.

Bland-Altman plots displaying 95% limits of agreement for RB, MV, Vmax and CPT shows high level of agreement since almost all paired measurement lie within ± 1.96*SD of the differences (dashed lied in Figure 1). For the RB, MV and CPT, results showed a low systematic bias ± random error, being 1.11 ± 1.50 cm (r^2: .006), 0.03 ± 0.33 m/s (r^2: .001) and 65.91 ± 63.82 ms (r^2: .11), respectively. These values indicate no association between the magnitude of error and the mean value (Bartlett & Frost, 2008). However, the Vmax variable resulted in values of 0.55 ± 0.42 m/s (r^2: .31), which shows that the maximum velocity is accurate but biased towards the high range of measurement.

Pearson's product moment correlation coefficient showed almost perfect association between different variables (r^2 = .985 - .990) (p < .001) (Figure 2).



(a) (b)

(c) (d)

Figure 2. Relationship between measurements from LPT and SHSC-Kinovea. (a) RG; (b) MV; (c) Vmax; (d) CPT.

DISCUSSION

This study aimed to check the reliability and validity of the use of the SHSC-Kinovea methodology as a valid instrument to control the MV of execution during the half squat exercise. This methodology aims to facilitate access to kinematic analysis related to force through an open code software (Kinovea) and a technological element available to most people, a smartphone.

Traditionally, the control of the velocity of execution in training or strength assessment has been carried out with LPT devices (Loturco et al., 2016; Martínez-Cava et al., 2019), which also has been used as a criterion for the validation of other instruments (Góme-Piriz, Trigo, Cabello, & Puga, 2012). Alternative commercial solutions have appeared related to the development of LPT (Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007), which have been validated to be used as valid and reliable measurement instruments for VBT (Crewther et al., 2011).

In addition to LPT systems, new technological solutions have appeared based on different technologies such as accelerometry (Balsalobre-Fernández et al., 2016), optoelectronic tracking (Garcia Ramos et al., 2011) or 3D technology (Pueo & Jimenez-Olmedo, 2017).

However, all these systems require an economic investment that ranges from low-cost to very expensive systems. For this reason, the use of video and the development of smartphones has allowed, facilitated and given access to low cost analysis. The performance of video cameras and processing capability of a modern smartphone has allowed the development of applications for the evaluation of force performance that have been validated (Balsalobre-Fernández et al., 2020; Balsalobre-Fernández et al., 2018). This type of application computes kinematic parameters based on time through high-speed video temporal resolution (Pueo, 2016). These applications have shown a very low systematic bias and random error when compared to criterion instruments (Pérez-Castilla, Piepoli, Delgado-García, et al., 2019). Before the launch of this type of applications, the use of high-speed video with Kinovea has been studied for the evaluation of the flight time in jump test. The study concluded that the combined use of commercial high-speed cameras together with Kinovea can be considered a valid and reliable option for analysis (Balsalobre-Fernández et al., 2014).

Therefore, the combination of high-speed cameras and open-source software with a proper analysis methodology, HSC-Kinovea (Balsalobre-Fernández et al., 2014) or SHSC-Kinovea in the present study, allows for the analysis and control the VBT.

In addition, the use of this methodology allows to perform analysis of other time-related parameters as Vmax, RB or time spans used in each of the phases of exercise (Pérez-Castilla, Rojas, et al., 2019), obtaining accurate data to help assess and control the development of the athlete's training.

CONCLUSIONS

In conclusion, the use of high-speed video recording capability of a current smartphone and the analysis with the open-source motion analysis software Kinovea through the SHSC-Kinovea methodology can be considered a low-cost option that allows valid and reliable analysis in half-squat exercise.

AUTHOR CONTRIBUTIONS

Conceptualization, J.M.J., B.P. and A.P.; Data curation, B.P. and L.V.; Formal analysis, J.M.J., L.V. and A.P.; Investigation, J.M.J. and L.V.; Methodology, B.P., L.V. and A.P.; Project administration, J.M.J.; Resources, B.P. and A.P.; Software, J.M.J. and A.P.; Supervision, J.M.J.; Validation, J.M.J. and A.P.; Visualization, L.V.; Writing – original draft, B.P.; Writing – review & editing, J.M.J., B.P., L.V. and A.P.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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