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Article *in* The Journal of Strength and Conditioning Research · January 2019

DOI: 10.1519/JSC.0000000000003118

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the Journal of Strength and Conditioning Research™

Reliability and Concurrent Validity of Seven Commercially Available Devices for the Assessment of Movement Velocity at Different Intensities During the Bench Press

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Abstract

Pérez-Castilla, A, Piepoli, A, Delgado-García, G, Garrido-Blanca, G, and García-Ramos, A. Reliability and concurrent validity of seven commercially available devices for the assessment of movement velocity at different intensities during the bench press. *J Strength Cond Res* XX(X): 000–000, 2019—The aim of this study was to compare the reliability and validity of 7 commercially available devices to measure movement velocity during the bench press exercise. Fourteen men completed 2 testing sessions. One-repetition maximum (1RM) in the bench press exercise was determined in the first session. The second testing session consisted of performing 3 repetitions against 5 loads (45, 55, 65, 75, and 85% of 1RM). The mean velocity was simultaneously measured using an optical motion sensing system (Trio-OptiTrack; "gold-standard") and 7 commercially available devices: 1 linear velocity transducer (T-Force), 2 linear position transducers (Chronojump and Speed4Lift), 1 camera-based optoelectronic system (Velowin), 1 smartphone application (PowerLift), and 2 inertial measurement units (IMUs) (PUSH band and Beast sensor). The devices were ranked from the most to the least reliable as follows: (a) Speed4Lift (coefficient of variation [CV] = 2.61%); (b) Velowin (CV = 3.99%), PowerLift (3.97%), Trio-OptiTrack (CV = 4.04%), T-Force (CV = 4.35%), and Chronojump (CV = 4.53%); (c) PUSH band (CV = 9.34%); and (d) Beast sensor (CV = 35.0%). A practically perfect association between the Trio-OptiTrack system and the different devices was observed (Pearson's product-moment correlation coefficient (r) range = 0.947–0.995; $p < 0.001$) with the only exception of the Beast sensor ($r = 0.765$; $p < 0.001$). These results suggest that linear velocity/position transducers, camera-based optoelectronic systems, and the smartphone application could be used to obtain accurate velocity measurements for restricted linear movements, whereas the IMUs used in this study were less reliable and valid.

Key Words: linear position transducer, linear velocity transducer, smartphone application, inertial measurement units, velocity-based training, testing

Introduction

Velocity-based resistance training has gained in popularity over recent years because of the proliferation of different commercially available devices (e.g., linear position transducers, inertial measurement units [IMUs], smartphone applications, etc.) that are supposed to accurately measure movement velocity (3,5). It has been proposed that the monitoring of barbell velocity could be an appropriate alternative to prescribe the training load as compared to the traditional approach that requires the determination of the 1 repetition maximum (1RM) (17,32). The use of movement velocity to prescribe the training load is justified by the strong and linear relationship that has been reported for multiple exercises between movement velocity and the %1RM (13,26,31). In this regard, instead of determining the 1RM through a single maximal lift or by a set of repetitions to failure, the load can be prescribed to match the desired velocity (17,34). Despite the encouraging applications of velocity-based resistance training (6), little research is available comparing the reliability and validity of different commercially available devices used in training and research to monitor movement velocity.

From a scientific standpoint, the three-dimensional (3D) motion capture has been recognized as the "gold-standard" instrument to measure movement velocity (22,36). However, because this technology is not practical or affordable for strength and conditioning professionals, other devices are typically used in practice when implementing the velocity-based resistance training approach. The linear position transducer has been the most used device in scientific research (2,5,10,14). The linear position transducer consists of an isoinertial dynamometer with a cable that is typically attached to the barbell, and it derives velocity from the recorded displacement-time data using the inverse dynamic approach (18). More recently, a linear velocity transducer named "T-Force" (T-Force system; Ergotech, Murcia, Spain) has been made commercially available, which directly provides velocity measurements through the recording of electrical signals that are proportional to the cable's extension velocity (33). It is reasonable to speculate that the linear velocity transducer could be more precise than linear position transducers because it is

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known that the successive manipulation of raw data increases measurement errors (25,30). However, it remains unexplored whether the reliability of velocity outputs significantly differs between linear position and linear velocity transducers, as well as their concurrent validity with respect to the "gold-standard" 3D motion capture.

It should be acknowledged that linear position/velocity transducers are not always practical or affordable. The need to attach the cable to the barbell restricts exercise selection to the ones predominantly performed in a vertical direction (5). Another common drawback of linear position/velocity transducers is their high price (≈2,000 US dollars), which may limit their use to laboratory-based or professional sport settings (7,23,24). However, it should be noted that a new linear position transducer AU1 named "Speed4Lift" (Speed4Lift; Madrid, Spain) has appeared on the market with a considerably lower price (340 US dollars), although there are no available data regarding its reliability and validity. As an alternative to linear position/velocity transducers, wearable technologies are increasingly gaining popularity in the field of strength training and conditioning (3,5,12,28).

One of the wearable devices that have recently appeared on the market is named "Velowin" (Velowin; DeporTeC, Murcia, Spain). Velowin is a camera-based optoelectronic system designed to measure movement velocity by the tracking of an infrared reflective marker placed in the barbell. A high reliability and concurrent validity of the Velowin to measure movement velocity has been reported during the free-weight back squat exercise (12,21). The main advantage of Velowin as compared to linear position/velocity transducers is that it does not require to be attached to the barbell through a cable and, therefore, this would eliminate the risk of cable rupture (21). However, the Velowin cost (≈625 US dollars) and limited portability (e.g., a PC software is needed) could limit its use for many strength and conditioning professionals. Many practitioners can only afford more practical devices such as smartphone applications or IMUs (2,28).

A smartphone application named "PowerLift" has been designed to monitor movement velocity by the manual inspection of a slow motion video recording by the smartphone high-speed camera (4). The high reliability and validity of PowerLift to monitor mean velocity has been confirmed in exercises such as the bench press, full-squat, and hip-thrust (3,4). However, the main limitation of PowerLift is that it does not provide real-time velocity feedback because coaches are required to indicate manually the start and end of the concentric phase. The PUSH band (PUSH band, PUSH, Inc., Toronto, Canada) and Beast sensor (Beast sensor, Beast Technologies Srl., Brescia, Italy), which are composed by the combination of 3-axis accelerometers and 3-axis gyroscopes, are 2 of the IMUs most commonly used in research and practice (3,5). An advantage of IMUs is that they are able to account for the anteroposterior displacement that is frequent during free-weight exercises (28), whereas linear position/velocity transducer cannot distinguish the direction of the cable displacement. However, owing to the discrepancies found between the studies that have evaluated the validity of the PUSH band (3,5,36) and owing to the scarce number of studies that have examined the reliability and validity of the Beast sensor (3), more research is needed to explore the feasibility of both IMU devices.

To address the existing gaps in the literature, this study was designed to provide a comprehensive analysis of different devices (i.e., linear velocity transducer, linear position transducers, camera-based optoelectronic system, smartphone application, and IMUs) that are being used in practice for the measurement of movement velocity during resistance training. Specifically, the objective of this study was to compare the reliability and validity of 7 commercially available devices to measure movement velocity during the bench press exercise. We hypothesized that the devices would be ranked from the most to the least reliable and valid as follows: (a) linear velocity transducer; (b) linear position transducers; (c) camera-based optoelectronic device; (d) smartphone application; and (e) IMUs. The results of this study should provide practical information for strength and conditioning coaches regarding the reliability and concurrent validity of different devices that can be used in practice for the assessment of movement velocity.

Methods

Experimental Approach to the Problem AU2

This study was designed to explore the reliability and concurrent validity of 7 commercially available devices for the measurement of movement velocity. Subjects completed 2 testing sessions separated by 48–72 hours. The 1RM in the bench press exercise was determined in the first testing session. The second testing session consisted of performing 3 repetitions against 5 different loads (45, 55, 65, 75, and 85% of 1RM). The mean velocity of the barbell was measured using an optical motion sensing system (V120: Trio, OptiTrack; NaturalPoint, Inc., USA) that was considered AU3 the gold standard in this study (27,38). In addition, the mean velocity was also measured by 7 commercially available devices: 1 linear velocity transducer (T-Force system, Ergotech), 2 linear position transducers (Chronojump; Boscosystem, Barcelona, Spain; and Speed4Lift), 1 camera-based optoelectronic system (Velowin, DeporTeC), 1 smartphone application (PowerLift), and 2 IMUs (PUSH band; PUSH, Inc., and Beast sensor; Beast Technologies Srl.). The 2 repetitions with higher mean velocity recorded by the Trio-OptiTrack at each load were used for calculating intrasession reliability (3,21), whereas only the repetition with the highest mean velocity recorded at each load by the Trio-OptiTrack was used for validity analyses.

Subjects

Fourteen physically active men (age: 22.9 ± 1.6 years; body AU4 height: 1.76 ± 0.06 m; body mass: 76.9 ± 7.8 kg; bench press AU5 1RM: 86.1 ± 11.9 kg) volunteered to participate in this study. Subjects were recruited from a fitness center, and all of them were AU6 familiarized with the bench press exercise before the beginning of the study. None of them suffered from physical limitations, health problems, or musculoskeletal injuries that could compromise tested performance. Subjects were instructed to avoid any strenuous exercise 2 days before each testing session. They were informed of the study procedures and signed a written informed consent form before initiating the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board.

Testing Procedures. The first testing session was used for an- AU7 thropometric measures and to determine the 1RM during the concentric-only bench press exercise following an incremental loading test (11). The standardized warm-up consisted of jogging, self-selected dynamic stretching and joint mobilization exercises, and 1 set of 5 repetitions performed against external load of 17 kg (mass of the unloaded Smith machine barbell) during the bench press exercise. Thereafter, the external load was incremented from 10 to 1 kg until the 1RM load was reached. The average AU8 number of loads tested was 8.9 ± 1.3. The interset rest was set to 4 minutes, and 1–2 repetitions were performed with each load.

The second testing session began with the same warm-up described for session 1. Afterward, subjects performed the concentric-only bench press exercise against 5 relative loads (45, 55, 65, 75, and 85% of 1RM) that were implemented in an incremental order. Lower loads (i.e., <45% of 1RM) were not tested because they are generally not used in training with the bench press exercise, whereas higher loads (i.e., >85% of 1RM) were excluded to avoid high fatigue that could compromise reliability analyses. Three repetitions were executed with each load. Interrepetition rest was set to 15 seconds, and interset rest was fixed to 4 minutes. The barbell was held by the safety stops of the Smith machine during the recovery periods. Subjects were encouraged to lift the barbell at the maximum possible velocity.

The standard 5-point body contact position technique (head, upper back, and buttocks firmly on the bench with both feet flat on the floor) was followed in the 2 testing sessions. Subjects self-selected the grip width, which was measured and kept constant on every lift. The barbell was held by the safety stops of the Smith machine 1–2 cm above the subjects' chest at the level of the sternum. From that position, subjects were instructed to perform a concentric-only movement as fast as possible until their elbows reached full extension. Two spotters were responsible for lowering the barbell after each repetition.

Measurement Equipment and Data Acquisition. The measurement devices were not synchronized, and they separately collected
[F1] the mean velocity of the same repetitions (Figure 1). The specific characteristics of each device are provided below:

Trio-OptiTrack. Trio-OptiTrack (V120:Trio; OptiTrack, NaturalPoint, Inc.) is an optical motion sensing system, which included 3 infrared and precalibrated cameras fixed on a rectangular frame that gives 3D position data of a reflective marker at a sampling rate of 120 Hz. Raw data of marker position in space were acquired using the software Motive v.1.5.0 (OptiTrack, NaturalPoint, Inc.) and then analyzed in Microsoft Excel (Microsoft, Seattle, WA, USA). Instantaneous velocity was calculated by the differentiation of the displacement data with respect to time. The reflective marker was placed on the left side of the barbell, and the Trio-OptiTrack was positioned at a distance of 2.5 m from the marker.

T-Force. T-Force (T-Force system, Ergotech) is an isoinertial dynamometer that consists of a cable-extension linear velocity transducer interfaced with a personal computer by means of a 14-bit resolution analog-to-digital data acquisition board. Instantaneous velocity was automatically calculated at a sampling rate of 1,000 Hz by the custom software v.2.28. The cable was vertically attached to the right side of the barbell using a Velcro strap.

Chronojump. Chronojump (Chronojump Boscosystem, Barcelona, Spain) is an isoinertial dynamometer that consists of a cable-extension linear position transducer attached to the barbell interfaced with a personal computer at a sampling rate of 1,000 Hz. Raw data were exported from the custom software v.1.6.2 and then analyzed in Microsoft Excel (Microsoft). Instantaneous velocity was calculated by the differentiation of the displacement data with respect to time. The cable was vertically attached to the right side of the barbell using a Velcro strap.

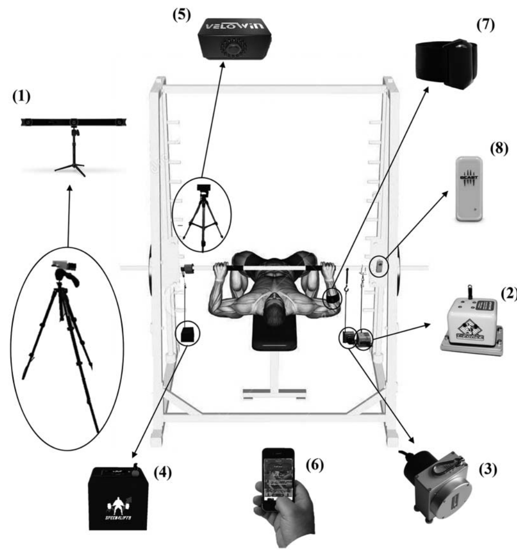

Figure 1. Distribution of the measurement devices during the testing protocol: (1) Trio-OptiTrack, (2) T-Force, (3) Chronojump, (4) Speed4Lift, (5) Velowin, (6) PowerLift, (7) PUSH band, and (8) Beast sensor.

Speed4Lift. Speed4Lift (Speed4Lift) is an isoinertial dynamometer that consists of a cable-extension linear position transducer attached to the barbell. Data were directly recorded by the differentiation of the displacement data with respect to time at a sampling rate of 1,000 Hz through Wi-Fi connection with an Android smartphone using Speed4Lift application v.4.1. The cable was vertically attached to the left side of the barbell using a Velcro strap.

Velowin. Velowin (Velowin; DeporTeC) is an optoelectronic system, which included an infrared camera interfaced with a personal computer that measured displacement of a reflector fixed to the barbell. Data were directly recorded from the custom software v.1.6.314 by the differentiation of the displacement data with respect to time at a sampling rate of 500 Hz. The Velowin was placed at a distance of 1.7 m from the infrared reflector, and it was calibrated according to the manufacturer's instructions.

PowerLift. PowerLift is a smartphone v.6.0.1 application that involves a frame-by-frame manual inspection of a slow motion video recording by the smartphone high-speed camera at a frequency of 240 frames per second and a quality of 720 pixels. The mean velocity was computed as the individual range of motion (i.e., vertical displacement of the barbell from the initial [≈1 cm above the subject's chest] to the final [elbows at full extension] position) divided by the lifting time (i.e., time between 2 frames selected by the user). The smartphone (iPhone; Apple, Inc., CA, USA) was held by a researcher in a portrait position and recorded each lift from the front of the subject at approximately 1.5 m.

PUSH Band. PUSH band (PUSH band, PUSH, Inc.) is a wearable wireless IMUs that consist of a 3-axis accelerometer and a gyroscope that provided 6 degrees of freedom in its coordinate system (2). Data were directly recorded by the integration of the acceleration data with respect to time at a sampling rate of 200 Hz through Bluetooth 4.0 LE connection with a smartphone (iPhone, Apple, Inc.) using PUSH application v.1.1.26. The PUSH band was worn on the subject's dominant forearm immediately inferior to the elbow crease with the main button located proximally (2,5).

Beast Sensor. Beast sensor (Beast sensor, Beast Technologies Srl.) is a wearable wireless IMUs that included a 3-axis accelerometer, gyroscope, and magnetometer. Data were directly recorded by the integration of the vertical acceleration with respect to time at a sampling rate of 50 Hz through Bluetooth 4.0 LE connection with a smartphone (iPhone, Apple, Inc.) using Beast application v.2.3.7. The Beast sensor was placed on the barbell using a built-in magnet (3).

Statistical Analyses

Descriptive data are presented as means and *SD*s, whereas the coefficient of variation (CV) of the 5 loads is presented through their median value. Reliability was assessed for each individual load by the CV and the intraclass correlation coefficient (ICC model 3,1). Acceptable reliability was determined as a CV <10% and an ICC >0.70 (8). The median CV value of the 5 loads was calculated to compare the reliability between the 8 devices examined in this study. To interpret the magnitude of differences observed between 2 CVs, a criterion for the smallest important ratio was established as higher than 1.15 (37). Bland-Altman plots were constructed to explore the concurrent validity of the 7 commercially available devices with respect to the Trio-OptiTrack system. Because we observed proportional bias in 6 of 7 comparisons ($r^2 > 0.1$) (1), the data were log transformed before calculating the Pearson's product-moment correlation coefficients (r) (19). The criteria to interpret the strength of the r coefficients were as follows: trivial (<0.1), small (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), or practically perfect (>0.9) (19). Statistical significance was accepted at the $p < 0.05$ level, and confidence limits were set at 95%. All reliability assessments were performed by means of a custom spreadsheet (20), whereas other statistical analyses were performed using the software package SPSS (IBM SPSS version 22.0, Chicago, IL, USA).

Results

Mean velocity values only reached an acceptable reliability at all loads for the Trio-OptiTrack system, the linear velocity/position transducers, and the smartphone application (CV < 6.24% and
[T1] ICC > 0.73) (Table 1). Based on the comparison of the median CVs of the 5 loads, the devices were ranked from the most to the least reliable as follows: (a) Speed4Lift (CV = 2.61%); (b) Velowin (CV = 3.99%), PowerLift (3.97%), Trio-OptiTrack (CV = 4.04%), T-Force (CV = 4.35%), and Chronojump (CV = 4.53%); (c) PUSH band (CV = 9.34%); and (d) Beast sensor (CV = 35.0%).

Bland-Altman plots revealed low systematic bias and random errors (≤0.05 m·s^{-1}) for the T-Force, Chronojump, Speed4Lift, Velowin, and PowerLift as compared to the Trio-OptiTrack
[F2] system (Figure 2). Both IMUs showed larger random errors (PUSH band = 0.06 m·s^{-1} and Beast sensor = 0.21 m·s^{-1}). Heteroscedasticity of the errors was observed for all devices with the only exception of the Speed4Lift ($r^2 = 0.007$). A practically perfect association between the Trio-OptiTrack system and the different devices was observed (r range = 0.947–0.995; $p <$ 0.001) with the only exception of the Beast sensor ($r = 0.765$; $p <$
[F3] 0.001) (Figure 3).

Table 1

Reliability of mean velocity values obtained from the Trio-OptiTrack method and 7 commercially available devices at different loads during the bench press exercise.*

Device	Load (%1RM)	Mean velocity (m·s^{-1})	CV (95% CI)	ICC (95% CI)
Trio-OptiTrack	45	0.84 ± 0.05	3.47 (2.52–5.59)	0.73 (0.35–0.90)
	55	0.71 ± 0.05	2.22 (1.57–3.76)	0.93 (0.79–0.98)
	65	0.58 ± 0.05	4.04 (2.93–6.50)	0.84 (0.57–0.95)
	75	0.46 ± 0.05	4.15 (2.98–6.85)	0.83 (0.54–0.95)
	85	0.35 ± 0.05	4.64 (3.37–7.48)	0.88 (0.67–0.96)
T-Force	45	0.83 ± 0.06	2.48 (1.78–4.09)	0.90 (0.70–0.97)
	55	0.70 ± 0.05	1.82 (1.32–2.93)	0.95 (0.84–0.98)
	65	0.59 ± 0.05	4.35 (3.15–7.01)	0.78 (0.45–0.93)
	75	0.49 ± 0.05	4.78 (3.43–7.89)	0.77 (0.40–0.92)
	85	0.37 ± 0.05	4.90 (3.55–7.90)	0.87 (0.64–0.96)
Chronojump	45	0.90 ± 0.05	2.31 (1.67–3.72)	0.87 (0.64–0.96)
	55	0.76 ± 0.05	2.09 (1.51–3.36)	0.90 (0.71–0.97)
	65	0.60 ± 0.07	6.24 (4.47–10.3)	0.72 (0.31–0.90)
	75	0.47 ± 0.06	4.53 (3.25–7.48)	0.85 (0.58–0.95)
	85	0.34 ± 0.05	5.65 (4.05–9.32)	0.86 (0.60–0.95)
Speed4Lift	45	0.88 ± 0.06	2.61 (1.80–4.77)	0.87 (0.55–0.96)
	55	0.75 ± 0.04	2.39 (1.73–3.85)	0.84 (0.57–0.94)
	65	0.63 ± 0.05	2.42 (1.69–4.25)	0.93 (0.78–0.98)
	75	0.51 ± 0.05	3.92 (2.81–6.47)	0.81 (0.49–0.94)
	85	0.38 ± 0.05	3.41 (2.38–5.98)	0.94 (0.78–0.98)
PowerLift	45	0.79 ± 0.04	2.85 (2.02–4.83)	0.84 (0.55–0.95)
	55	0.70 ± 0.06	3.97 (2.81.6.74)	0.85 (0.57–0.96)
	65	0.58 ± 0.05	4.91 (3.48–8.33)	0.74 (0.32–0.92)
	75	0.51 ± 0.05	3.69 (2.58–6.48)	0.87 (0.58–0.96)
	85	0.40 ± 0.04	4.97 (3.47–8.71)	0.85 (0.54–0.96)
Velowin	45	0.91 ± 0.06	2.89 (2.09–4.65)	0.83 (0.56–0.94)
	55	0.77 ± 0.05	3.27 (2.35–5.40)	0.79 (0.45–0.93)
	65	0.64 ± 0.06	3.99 (2.86–6.59)	0.83 (0.53–0.94)
	75	0.51 ± 0.05	6.01 (4.36–9.69)	0.68 (0.26–0.89)
	85	0.38 ± 0.06	7.64 (5.54–12.3)	0.69 (0.27–0.89)
PUSH band	45	0.79 ± 0.07	5.02 (3.56–8.52)	0.69 (0.22–0.89)
	55	0.63 ± 0.07	7.84 (5.39–14.3)	0.46 (−0.27–0.81)
	65	0.46 ± 0.08	9.34 (6.77–15.0)	0.78 (0.45–0.92)
	75	0.31 ± 0.06	14.6 (10.0–26.6)	0.50 (−0.21–0.82)
	85	0.24 ± 0.06	19.1 (13.7–31.5)	0.47 (−0.09–0.80)
Beast sensor	45	0.82 ± 0.32	33.4 (23.5–58.9)	0.29 (−0.42–0.72)
	55	0.70 ± 0.27	24.2 (15.6–53.2)	0.64 (−0.28–0.89)
	65	0.51 ± 0.21	35.0 (22.6–77.1)	0.30 (−0.91–0.77)
	75	0.34 ± 0.16	40.2 (28.1–70.5)	0.31 (−0.40–0.73)
	85	0.23 ± 0.15	54.9 (38.9–93.2)	0.27 (−0.38–0.70)

*1RM = 1 repetition maximum; CV = coefficient of variation; 95% CI = 95% confidence interval; ICC = intraclass correlation coefficient.

Discussion

This study compared the reliability and concurrent validity of 7 commercially available devices for the measurement of movement velocity during the bench press exercise performed in a Smith machine. The different devices were ranked from the most to the least reliable as follows: (a) Speed4Lift; (b) Velowin, PowerLift, T-Force, and Chronojump; (c) PUSH band; and (d) Beast sensor. The concurrent validity of the T-Force, Chronojump, Speed4Lift, Velowin, and PowerLift with respect to the Trio-OptiTrack system was practically perfect. The 2 IMUs, especially the Beast sensor, showed the lowest concurrent validity (i.e., lower r coefficients and larger random errors) as compared to the Trio-OptiTrack system. The Speed4Lift was the only device that did not report heteroscedasticity of errors. The results of this study speak in favor of the Speed4Lift as the most reliable and valid device for the measurement of movement velocity during the

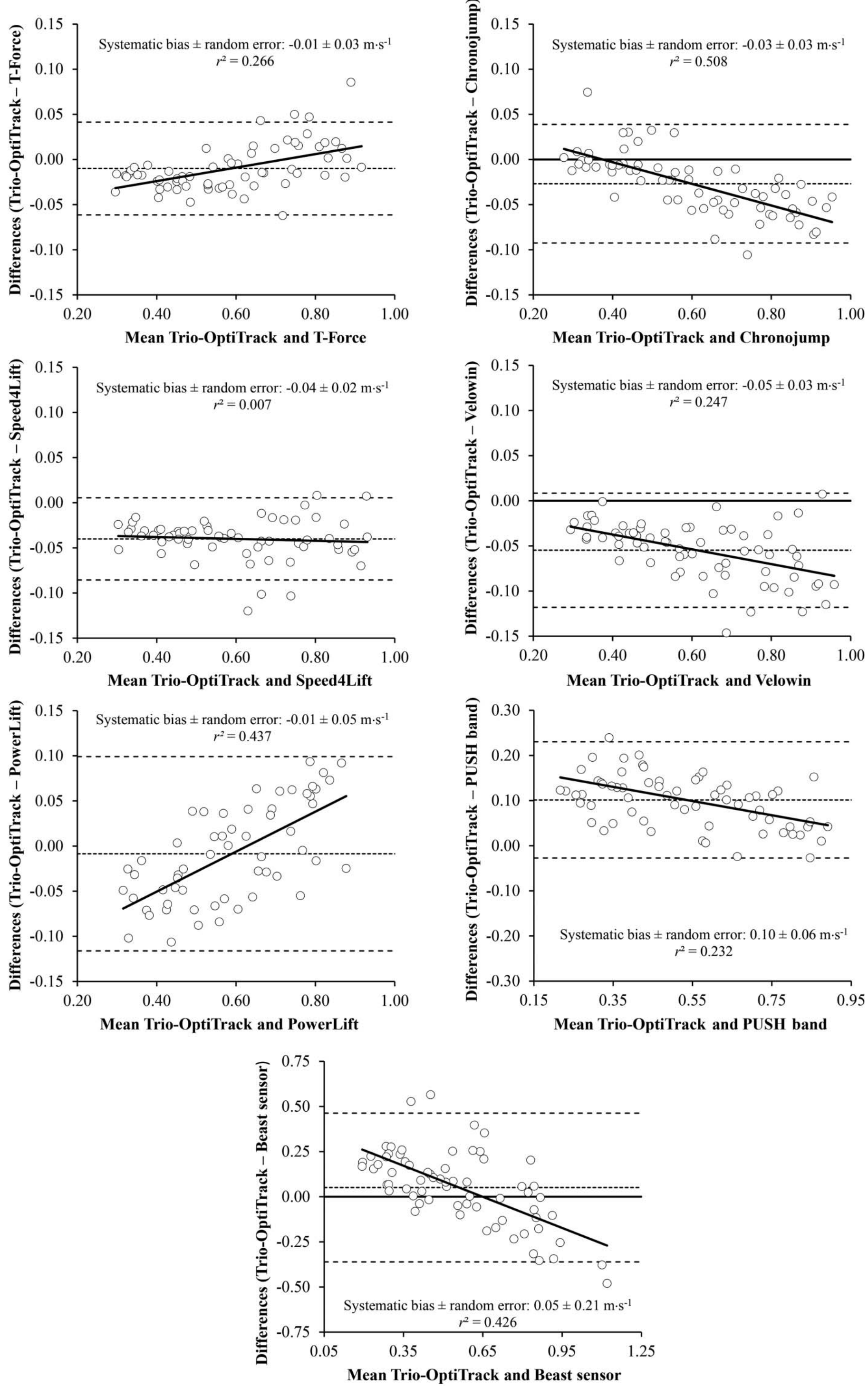

Figure 2. Bland-Altman plots for the measurement of mean velocity between the Trio-OptiTrack system and the 7 commercially available devices: T-Force (upper-left panel), Chronojump (upper-right panel), Speed4Lift (upper middle-left panel), Velowin (upper middle-right panel), PowerLift (lower middle-left panel), PUSH band (lower middle-right panel), and Beast sensor (lower panel). Each plot depicts the averaged difference and 95% limits of agreement (dashed lines), along with the regression line (solid line).

bench press exercise performed in a Smith machine. Collectively, the results of this study suggest that all devices, with the exception of the IMUs (especially the Beast sensor), could be used to obtain accurate velocity measurements for restricted linear movements. However, strength and conditioning professionals should be aware of the presence of heteroscedasticity between these devices, which could limit the interchangeable use of different devices.

Linear position/velocity transducers have been routinely used for training and testing purposes (5,16,29). These devices have been considered the "gold-standard" to measure barbell velocity

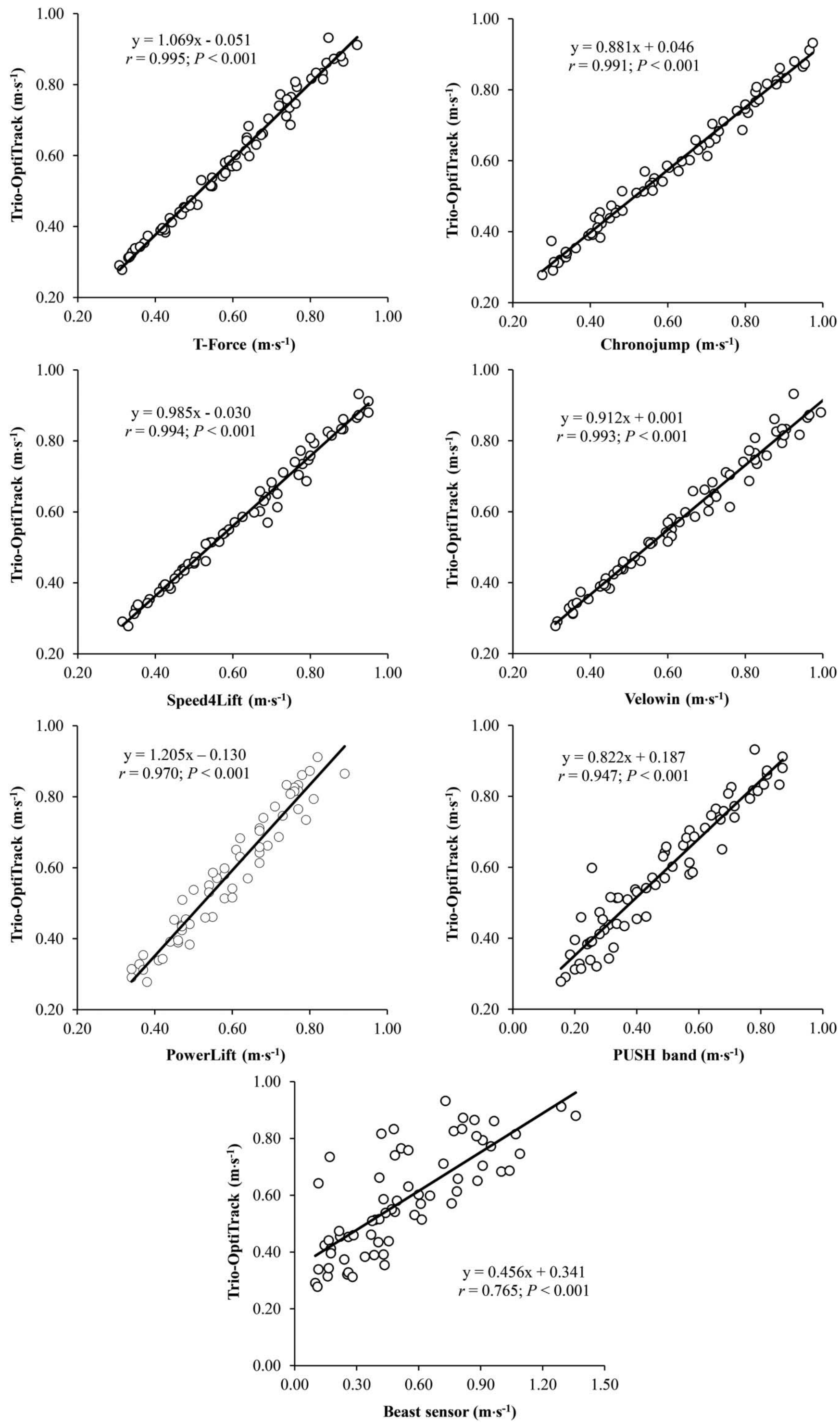

Figure 3. Relationship of mean velocity values between the Trio-OptiTrack system and the 7 commercially available devices: T-Force (upper-left panel), Chronojump (upper-right panel), Speed4Lift (upper middle-left panel), Velowin (upper middle-right panel), PowerLift (lower middle-left panel), PUSH band (lower middle-right panel), and Beast sensor (lower panel). The Pearson's correlation coefficient (r) was calculated using the log transformation because the assumption of homoscedasticity was violated.

in many studies (2,3,5). Specifically, the linear velocity transducer used in this study (T-Force) has been frequently used to validate other devices that were designed to measure movement velocity (2,14,15). The preferential use of linear velocity transducers as compared to linear position transducers could be justified because the direct measurement of movement velocity is expected to provide more accurate velocity outputs (30). However, there is scarce information regarding the comparison of the reliability of velocity outputs between linear velocity and linear position transducers. Contrary to our hypothesis, the linear velocity transducer (i.e., T-Force) was not more reliable than the 2 linear position transducers used in this study (i.e., Chronojump and Speed4Lift). In addition, to the best of our knowledge, this is the first scientific article that has provided data regarding the validity of the Chronojump and Speed4Lift. It should be noted that the Speed4Lift was the most reliable device and the only device that did not report heteroscedasticity of errors with respect to the Trio-OptiTrack system. These results together with its lower price (≈340 US dollars) and excellent portability (the software is installed in a smartphone app that is wirelessly connected with the hardware) place the Speed4Lift as an accurate, cost-effective, and practical device for the measurement of movement velocity. It is worth noting that the heteroscedasticity of errors observed for the other devices compromises their interchangeability. The T-Force and PowerLift showed progressively larger values than the Trio-OptiTrack with increasing velocities, whereas opposite results were observed for the Chronojump, Velowin, PUSH band, and Beast sensor.

The Velowin has been recently developed as a more affordable and practical device to measure movement velocity during resistance training exercises. However, to date, only 2 studies have examined its reliability and concurrent validity to measure movement velocity. García-Ramos et al. (12) found a comparable reliability (CV = 4.29–4.60%) and high validity (r = 0.97–0.98) between the T-Force and Velowin systems during the free-weight back-squat exercise. Laza-Cagigas et al (21). also observed a high validity (concordant correlation coefficient = 0.96) and reliability (CV = 7.3% and ICC = 0.97) of the Velowin system to measure mean velocity during the free-weight back-squat exercise with respect to a 3D system. In line with these findings, our results showed a high and comparable reliability and validity of the Velowin system as compared to the data provided by linear position/velocity transducers during the bench press exercise performed in a Smith machine. More recently, an affordable (≈11 US dollars) smartphone application named PowerLift has been made commercially available to measure movement velocity. The results of this study corroborate the findings of Balsalobre-Fernández et al. who showed a comparable reliability (ICC = 0.93–0.99) and high validity (r = 0.94–0.98) of PowerLift with respect to the data provided by a linear position transducer (SmartCoach Europe, Stockholm, Sweden) during free-weight exercises (3,4). Although it should be acknowledged that it is possible to obtain accurate measurements of mean velocity with PowerLift, the necessity of individually selecting the start and end points of each repetition may be unpractical when many athletes need to be assessed. In addition, the no provision of real-time velocity feedback should also be considered a limitation compared with the other devices analyzed in this study (39).

Wearable technologies such as the PUSH band and Beast sensor are being increasingly used in the strength and conditioning field. These 2 IMUs have been recently validated to measure movement velocity during a variety of resistance training exercises (2,3,5,36). In line with our results, the PUSH band provided highly valid measurements of mean velocity when the data of several loads were combined for the analysis during the bench press performed in a Smith machine and during the free-weight shoulder press and biceps/arm curl exercises ($r > 0.86$) (2,36). However, the validity of the PUSH band seems to be compromised when the data of individual loads are analyzed separately (specially for loads ≥80% of 1RM) (5). The PUSH band device should be therefore considered with some caution given the controversial results and the lower reliability reported in this study. Regarding the Beast sensor, to the best of our knowledge, only 1 study has investigated the reliability and validity of this device with respect to the data provided by a linear position transducer (SmartCoach Europe), reporting both a very high reliability (ICC > 0.95) and validity ($r > 0.98$) during the bench press, full-squat, and hip-thrust exercises (3). On the contrary, our results suggest that the Beast sensor is the least reliable and valid device among all the commercially available devices analyzed in this study. It is plausible that the lower sampling frequencies of the IMUs or the need to integrate acceleration-time data to obtain velocity values could have caused their lower reliability (5,28). Therefore, more evidence about the feasibility of wearable technology in the field of velocity-based resistance training is needed.

Several limitations and directions for future research should be considered. First, it should be noted that the mean velocity is not the only velocity variable used in practice. The mean propulsive velocity (i.e., average velocity from the start of the concentric phase until the acceleration of the bar is lower than gravity) and maximum velocity (i.e., maximum instantaneous velocity value reached during the concentric phase) have been commonly recommended for training and testing (9,35). Therefore, future studies should consider expanding the analysis of the reliability and validity of different devices to these variables. It should be noted that the mean velocity was the only variable analyzed in this study because it was the only common variable for the 8 devices analyzed. Second, the PUSH band was placed on the subject's forearm, whereas the other devices were attached to the barbell. Therefore, although the measurement of the PUSH could be affected by anteroposterior movements, the displacement of the other devices was restricted to the vertical direction. Another factor that could have promoted the lower reliability and validity of the IMUs is their lower sampling frequency. In this regard, it is plausible that the reliability and validity of the PUSH could be improved with the current 2.0 version, which has a higher sampling frequency (1,000 Hz), and it can be directly attached to the barbell. Future studies should examine whether our findings could be applicable to free-weight exercises in which the displacement of the barbell is not restricted to the vertical direction. Finally, because one of the main applications of the use of velocity during resistance training is the prediction of the 1RM (13,26,31), future studies should examine the precision of different commercially available devices for predicting the 1RM during basic resistance training exercises.

Practical Applications

The devices were ranked from the most to the least reliable as follows: (a) Speed4Lift; (b) Velowin, PowerLift, T-Force, and Chronojump; (c) PUSH band; and (d) Beast sensor. All devices presented a high concurrent validity with respect to the Trio-OptiTrack system with the only exception of the Beast sensor, whereas the Speed4Lift was the only device that did not report heteroscedasticity of errors. Taken together, these results suggest that the Speed4Lift is the most appropriate device for the measurement of movement velocity during the bench press exercise performed in a Smith machine. Note that linear velocity transducers, linear position transducers, camera-based optoelectronic systems, and smartphone application could all be used to obtain accurate measurements of mean velocity during the bench press exercise performed in a Smith machine, although the presence of heteroscedasticity of errors should be in mind. The 2 IMUs present a lower reliability and validity and, consequently, more caution should be taken when using PUSH band and Beast sensor devices for implementing velocity-based resistance training programs.

Acknowledgments

The authors thank all the participants who selflessly participated in the study. This study was supported by the Spanish Ministry of Education, Culture and Sport under a predoctoral grant (FPU15/03649) awarded to A.P.C. and by the University of Granada under a postdoctoral grant (perfeccionamiento de doctores) awarded to A.G.R.

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