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Pino-Ortega, José; Hernández-Belmonte, Alejandro; Bastida-Castillo, Alejandro; Gómez-Carmona, Carlos D.; Rojas-Valverde, Daniel
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Accuracy and Reliability of Inertial Devices for Load Assessment During Flywheel Workout

Precisión y confiabilidad de los dispositivos inerciales para la evaluación de la carga durante entrenamiento con polea cónica

Precisão e confiabilidade dos dispositivos inerciais para avaliação da carga durante o treinamento com polia cônica

José Pino-Ortega
Universidad de Murcia, España
pepepinoortega@gmail.com
https://orcid.org/0000-0002-9091-0897

Alejandro Hernández-Belmonte
Universidad de Murcia, España
aleexhernz7@gmail.com
https://orcid.org/0000-0002-0638-5859

Alejandro Bastida-Castillo
Universidad de Murcia, Physical Activity and Sport Department, España
alejandrobastidacastillo@gmail.com
https://orcid.org/0000-0002-8293-4549

Carlos D. Gómez-Carmona
Universidad de Extremadura, Training Optimization and Sports Performance Research Group (GOERD), España
cdgomezcarmona@gmail.com
https://orcid.org/0000-0002-4084-8124

Daniel Rojas-Valverde
Universidad Nacional, Escuela Ciencias del Movimiento Humano y Calidad de Vida, Centro de investigación y Diagnóstico en Salud y Deporte (CIDISAD), Costa Rica
drojasv@hotmail.com
https://orcid.org/0000-0002-0717-8827

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Resumen:

Actualmente, hay un aumento en la utilización de la polea cónica en el entrenamiento de fuerza; por lo tanto, es necesario monitorearlo con un dispositivo preciso y confiable. El presente estudio probó: (1) la precisión de un dispositivo de medición inercial (IMU), para medir correctamente la velocidad angular y (2) su confiabilidad entre unidades para la medición de carga externa. El análisis se realizó utilizando la correlación de Pearson y el Coeficiente de Correlación Intra-clase (CCI). La precisión de la IMU se probó usando Bland-Altman y la confiabilidad con el Coeficiente de Variación (CV). Diez jugadores de fútbol de nivel élite realizaron 10 series de 5 repeticiones en un ejercicio de fila de pie con una mano (5 series con cada brazo). Se encontró una precisión casi perfecta (ICC = .999) y una muy buena confiabilidad entre dispositivos (Sesgo = -. 010; CV = .017%). IMU´s es un dispositivo confiable y válido para evaluar objetivamente la velocidad angular en el entrenamiento inercial de la polea cónica.

Palabras clave: tecnología, levantamiento de pesas, ejercicio, aptitud física, deportes.

Abstract:

There is currently an increase in inertial flywheel application in strength training; thus, it must be monitored by an accurate and reliable device. The present study tested: (1) the accuracy of an inertial measurement device (IMU) to correctly measure angular velocity and (2) its inter-unit reliability for the measurement of external load. The analysis was performed using Pearson Correlation and Intraclass Correlation Coefficient (ICC). The IMU accuracy was tested using Bland-Altman and the reliability with the coefficient of variation (CV). Ten elite-level football players performed ten series of 5 repetitions in a one-hand standing row exercise (5 series with each arm). A nearly perfect accuracy (ICC=.999) and a very good between-device reliability (Bias=-.010; CV=.017%) was found. IMU is a reliable and valid device to assess angular velocity in inertial flywheel workout objectively.

Keywords: technology, weightlifting, exercise, physical fitness, sports.

Resumo:

Atualmente, há um aumento na utilização da polia cônica no treinamento de força; portanto, é necessário monitorá-lo com um dispositivo preciso e confiável. O presente estudo testou: (1) a precisão de um dispositivo de medição inercial (IMU), para medir corretamente a velocidade angular e (2) sua confiabilidade interunidades para medição de carga externa. A análise foi realizada por meio da correlação de Pearson e do Coeficiente de Correlação Intraclasse (ICC). A precisão do IMU foi testada usando Bland-Altman e a confiabilidade com o Coeficiente de Variação (CV). Dez jogadores de futebol de elite realizaram 10 séries de 5 repetições em um exercício de linha em pé com uma mão (5 séries com cada braço). Foi encontrado uma precisão quase perfeita (ICC = 0,999) e confiabilidade entre dispositivos muito boa (Bias = - 0,010; CV = 0,017%). IMU's é um dispositivo confiável e válido para avaliar objetivamente a velocidade angular no treinamento inercial da polia cônica.

Palavras-chave: tecnologia, levantamento de pesos, exercício, aptidão física, esportes.

Introduction

Muscle strength is defined as the ability to develop a force to an external object or resistance; it is considered the main component of physical fitness as related to the quality of life (Geirsdottir et al., 2012). This basic physical ability has an effect from the realization of daily tasks for older adults (Burton et al., 2013) to sports performance (Suchomel et al., 2016) and injury prevention (Lauersen et al., 2014). When a strength training program is started, it is important to evaluate the athlete's initial level (Gómez-Carmona et al., 2020) with the purpose of elaborating an individual protocol, and to verify the improvements of the applied training program (González-Badillo & Sánchez-Medina, 2010). Researchers have currently made significant advances in evaluating strength, with the execution velocity measurement (Morán-Navarro et al., 2019). Velocity in strength training can be evaluated by different systems, such as dynamometric force platforms, telephone applications, accelerometers, or linear velocity transducers (LT) (García-Orea et al., 2017). LT has been the most used instrument thanks to the great results in validity and reliability exhibited in different publications (García-Ramos et al., 2016; Garnacho-Castaño et al., 2015; Pérez-Castilla et al., 2017). The use of LTs is limited to vertical movements only. Therefore, most researchers use the Smith machine to ensure movements' verticality (García-Ramos et al., 2017; Sánchez-Medina et al., 2014). When deviations occur in the horizontal plane of the execution, the LT overestimates the measurement (Cormie, Deane, et al., 2007; Cormie, McBride, et al., 2007; Crewther et al., 2011; Hori et al., 2007).

However, most exercises available in the strength training area, whose movement is performed on the transverse or anteroposterior axis, require accurate and reliable instruments for velocity and power measurement. Recently, new machines have been developed, known as inertial flywheels because of their conical shape. This instrument is characterized by using a mechanism to produce resistance during movement (Maroto-Izquierdo et al., 2017). The actual increase of inertial flywheel use is for its effectiveness in terms of injury prevention (Goode et al., 2015; Hibbert et al., 2008), muscle hypertrophy (Hedayatpour & Falla, 2015; Roig et al., 2009), and improving sports performance (de Hoyo et al., 2016).

Unlike the linear velocity generated by the Smith Machine, which is used for vertical movement, the inertial flywheel generates a circular movement due to its turning wheel; this circular movement can be measured using angular velocity. This velocity is characterized by the rotation of an object around a turning center. This magnitude can be measured in different units, such as revolutions per minute (rpm) (Mollinedo-

Ponce-de-León et al., 2012), radians per second (rad/s), or grades per second (deg/s) (Arai et al., 2017; Śliwowski et al., 2017a). However, the measurement of angular velocity in strength training is limited to non-linear or rotational velocity transducers implementing few inertial flywheels.

Recently, technological development has allowed for the integration of different sensors in the same unit, such as accelerometers, gyroscopes, or magnetometers. These units are known as inertial devices (Fong & Chan, 2010). The gyroscopes containing these units have offered a new possibility for angular velocity measurement, especially for the evaluation of swimming performance (Mooney et al., 2016), gait biomechanics (Glowinski et al., 2017), or the joints movement (Edwan et al., 2012). For this reason, to monitor strength training through velocity measurement and obtain angular velocity data for rotational exercises, there is a need to implement these new devices within a gyroscope. Therefore, the aims of this research are (1) to examine the accuracy of an inertial device WIMU PROTM to angular velocity measurement and (2) to verify inter-unit reliability to measure this variable.

Participants

Ten elite-level Spanish male football players (age: 23.2±3.62 years; height: 180.81±5.81 cm, and weight: 76.16±6.32 kg) participated voluntarily in this research. All the participants met the following requirements: (i) more than two years of strength training experience, and (ii) no musculoskeletal injuries. The study, which was conducted according to the Declaration of Helsinki, was approved by the Bioethics Commission of the University of Murcia (R 2061/2018). Participants were informed of the risks and discomforts associated with testing and provided written informed consent.

Instruments

Height was measured using a wall-mounted stadiometer (SECA, Hamburg, Germany). Body weight was determined using an 8-contact electrode segmental body composition analyzer (TANITA BC-601, Tokyo, Japan).

An Eccotek Training Force® inertial flywheel (Byomedic System, Barcelona, Spain) was used for all testing. Since this machine uses a rotational inertia cone, it offers a free gravity resistance system that stores an athlete's energy in the concentric phase and releases it back in the eccentric phase.

WIMU PROTM (RealTrack Systems, Almeria, Spain): This is an inertial device composed of different sensors (accelerometers, gyroscopes, magnetometers, GPS, UWB, etc.). In this research, the 3-D gyroscopes (recording sampling rate of 1000Hz) that compose this inertial device were used. The average data point accumulation (signal redundancy) in the 3-D gyroscope’s three axes, with a full-scale output range of 2000 grades per second, was registered

Smart Coach Versapulley Sensor® (SmartCoach Europe, Estocolm, Sweden): This is an optical receiver that measures the revolutions per minute of the inertial flywheel movement to which it is attached. From the angular velocity, the power generated by the participant in the concentric and eccentric phases was registered at a sampling frequency of 1000 Hz.

Procedures

All participants attended the laboratory twice for about an hour. The study was conducted for two weeks. In the first week, the familiarization session was carried out to acquaint athletes with experimental equipment, procedures, and the anthropometric and physiological assessment. In the second week, the testing protocol comprised ten series of five repetitions in a one-hand standing row exercise (five series with each arm) using an inertial flywheel.

To start, participants must be standing in front of the machine. The pulling arm must be attached to the rope by gripping the handle. The opposite arm should be parallel to the trunk. It was determined that the grip should reach the chest in the last phase of the pull to standardize the course. Both legs should be placed in a semi-flexed position. A rigid base was placed to support the participant's front foot to avoid any imbalances during the execution. The participants selected the leg that was placed on the base to make the movement comfortable. The participant will then voluntarily pull the cable attached to the inertial flywheel at maximum velocity for each repetition. Between series, an active rest of 20 seconds was taken (Bastida-Castillo et al., 2016).

Before beginning the protocols, athletes performed a standardized warm-up of 5 minutes of indoor rowing at aerobic intensity (RPE 4-5/10) and a further ten minutes of specific warm-up composed of joint mobility, dynamic stretching, and four series of eight repetitions of standing rowing at submaximal intensity. The warm-up period was monitored in real-time with S PROTM software to verify the devices' perfect functioning. When athletes had finished the testing, they performed five minutes of indoor rowing at recovery intensity (RPE 2-3/10).

The main variable analyzed was the number of rotations that the inertial flywheel realized per second in the concentric and eccentric phase of each execution, expressed in revolutions per second (rps). This variable was obtained through the angular velocity measured by the WIMU PROTM inertial device in grades per second, dividing the value by 360°. To analyze the accuracy of the revolutions per second that the inertial device measured, a SmartCoach Versapulley Sensorâ was employed as a criterion measure. The revolutions per second were calculated using the following formula (Figure 1):

$$\text{rps} = \frac{Angular\ Velocity\ /\ 360^{\text{o}}}{Execution\ time\ (Seconds)}$$

FIGURE 1
Formula to calculate revolutions per second, measured by the inertial device.

Data analysis of the WIMU PROTM inertial device was performed using S PROTM software (RealTrack Systems, Almeria, Spain). Raw files were exported into the S PROTM software (see figure 2) to synchronize the Smart Coach Versapulley Sensorâ and inertial device's data.

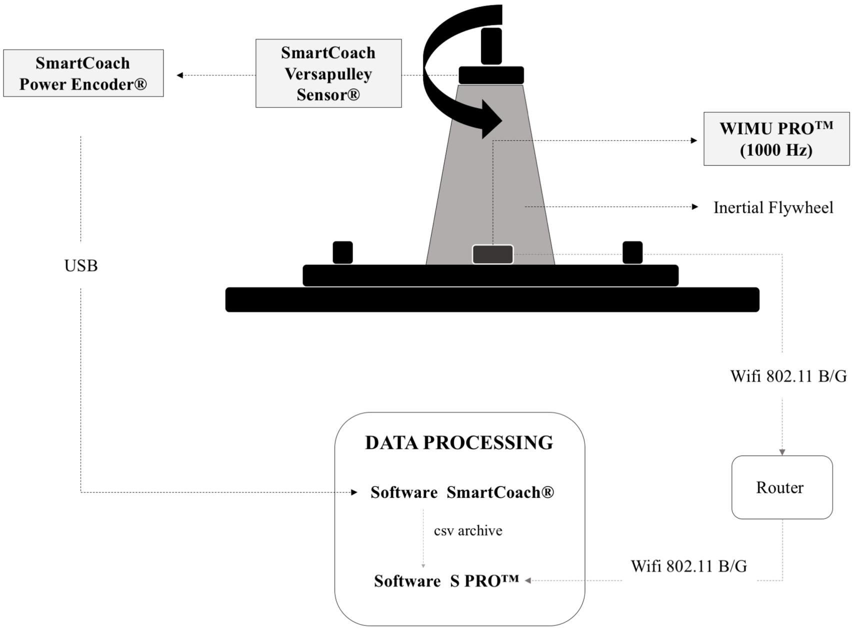

FIGURE 2
Devices placement and data processing to measure angular velocity in this research.

Statistical Analysis

Data obtained were shown as mean ± standard deviation. A Pearson correlation coefficient and intraclass correlation coefficient (ICC) were used to analyze the accuracy of the angular velocity between the SmartCoach Versapulley Sensorâ and the WIMU PROTM, with 95% confidence intervals. ICC values were interpreted following Vincent and Weir (2012) (Vincent & Weir, 2012): >0.90 high, 0.80-0.89 moderate, and <0.80 questionable. Pearson's r was interpreted according to Hopkins et al. (2009) (Hopkins et al., 2009) as follows: trivial (r2<0.1), small (0.10.9), and perfect (r2=1). For the reliability analysis, a Bland-Altman calculation was performed, showing a bias with 95% limits of agreement (LOA), and the magnitude of differences was shown through the coefficient of variation (CV).

Results

Table 1 shows the accuracy analysis of the revolutions per second variable for a one-hand standing row in an inertial flywheel between the WIMU PROTM inertial device and the SmartCoach Versapulley Sensorâ. In a global analysis, a nearly perfect correlation was found between the two systems (ICC=.999; r=.999).

TABLE 1

Validity analysis of the WIMU PROTM inertial device compared to the SmartCoach Versapulley Sensorâ as a criterion measure through ICC with 95% interval confidence and Pearson's coefficient

Velocity	SmartCoach® (Mean ± SD)	WIMU PRO™ (Mean ± SD)	ICC	CI 95 %		r
				L	U	
Low	1.21 ± 0.47	1.23 ± 0.49	.995	.995	.995	.995
Medium	2.78 ± 0.34	2.79 ± 0.35	.998	.998	.998	.998
High	3.75 ± 0.28	3.75 ± 0.28	.999	.999	.999	.999
Total	2.58 ± 1.11	2.59 ± 1.11	.999	.999	.999	.999

Note. SD: Standard deviation; ICC: Intraclass correlation coefficient; CI: Confidence interval (values L: Low y U: Upper).

Table 2 shows the WIMU PROTM unit's reliability analysis for a one-hand standing row exercise in an inertial flywheel. Great between-device reliability was found (Bias=.012; CV=.840%).

TABLE 2

Between-unit's reliability analysis. Bland-Altman bias, 95% limits of agreement and coefficient of variation (%)

Velocity	WIMU PRO™ 1 (Mean ± SD)	WIMU PRO™ 2 (Mean ± SD)	Bias	95% LOA		CV (%)
				L	U	
Low	1.24 ± 0.47	1.23 ± 0.50	.065	-.659	.791	.572
Medium	2.79 ± 0.35	2.78 ± 0.34	.002	-.924	.929	.253
High	3.72 ± 0.29	3.70 ± 0.26	.061	-.137	1.36	.381
Total	2.54 ± 1.10	2.51 ± 1.07	.012	-.245	.876	.840

Note. SD: Standard deviation; Bias: Mean difference between units of measurement; LOA: Limits of agreement; CV: Coefficient of variation.

Discussion

The objectives of the present research were the following: (1) to examine the accuracy of WIMU PROTM as an inertial device for the measurement of angular velocity and (2) verify the inter-device reliability to measure this variable. As for the first objective, the results obtained show the nearly perfect accuracy of the WIMU PROTM inertial device for angular velocity measurement in resistance training with an inertial flywheel (r=.999). In the analysis by velocities, a greater accuracy at high velocity was shown (r=.999) compared to the low-velocity repetitions group (r=.995). In the reliability analysis, great results between the WIMU PROTM inertial devices were found (CV=.840), with a value less than 1%. A slight decrease in reliability was found at low velocity (CV=.572).

Regarding the comparison of two different systems, such as the integrated gyroscope in an inertial device and a rotatory encoder, no research could be found that compares both devices to analyze the angular velocity parameter. Therefore, the present investigation can be considered as a pioneering analysis in this subject. Alternatively, as far as angular velocity measurement is concerned, several authors have examined the gyroscope's validity and reliability when integrated into inertial devices. Walker et al. (2017) examined the validity of an inertial device compared with a 3D optical system (Cortex 3.3 Motion analysis Corporation, USA) for trampoline jump analysis. These authors used a drilling machine to compare inertial devices, obtaining excellent results (r=1.000). Ex-Lubeskie (2013) evaluated the reliability of angular velocity measurements by an inertial device versus a video#analysis system, concluding that there was great data stability in the inertial device to gait biomechanics analysis. This result could be caused by the fact that a video-analysis system obtains the angular velocity indirectly through displacement and time, while an inertial device registers the angular velocity using a gyroscope, which is directly incorporated. Misu et al. (2017) (Misu et al., 2017) also analyzed the validity of an inertial device (located in the foot heel) for angular velocity measurement in comparison to a force sensor, obtaining great values on both devices (ICC=0.80-1.00). Moreover, research to evaluate angular velocity in strength training by an inertial device has not been identified.

The participants' strength is evaluated in most investigations using an isokinetic machine (Andrade et al., 2012; Igari et al., 2014; Śliwowski et al., 2017b). However, these devices present drawbacks such as their high economic cost, the complexity of their use, and the lack of specificity in the test. All these disadvantages create the need to develop and implement other possibilities to measure angular velocity in strength training. In conclusion, the inertial device WIMU PROTM, analyzed in the present study, is both a valid and reliable tool for measuring angular velocity in strength training with an inertial flywheel.

Some limitations of the present study should be considered when interpreting the findings. Participants were elite-level male football players, well-trained in strength and conditioning. It is unclear whether these findings can be extrapolated to other populations. Finally, only two WIMU PROTM inertial devices and one SmartCoach Versapulley Sensorâ optical receiver at a specific sampling rate were tested. Both the sensor components within the IMU, the sensors' calibration, and the sampling rate could influence the results. All processes were realized following the manufacturer's recommendations. Future studies aiming to explore the accuracy and reliability of inertial devices to measure load during flywheel exercises must include a greater sample size to confirm these results.

Considering the possibility of having instruments that objectively measure the load of the flywheel instruments, it is deemed necessary to carry out future studies on the effectiveness of these methods compared with other traditional methods for training physical qualities such as power.

Conclusion

The inertial measurement devices (WIMU PROTM) are valid and reliable tools for measuring angular velocity in strength training with an inertial flywheel. Due to the lack of objective methods to measure these kinds of resistance exercises, the present findings indicate that an inertial device could be used for monitoring movement velocity during strength training, both in linear and angular movements (with a center of rotation). These results expand the measurement possibilities using inertial devices in individual and team sports, whereas these instruments are already available in professional sport clubs.

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