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Reliability and validity of a new accelerometer (Wimu®) system for measuring velocity during resistance exercises

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Abstract

This study had two main goals. The first was to determine the reliability of the Wimu® system (accelerometer) for mean velocity measurements during resistance exercises at 40% and 80% 1 repetition maximum. The second was to compare the results for the Wimu system to a linear encoder (gold standard) for mean velocity measurements when clipped to the bar during back squat exercises using the Smith machine. In all, 23 trained men aged 22.3 ± 3.2 years participated in this study. At maximum velocity in the concentric phase, they performed 10 repetitions with 40% 1 repetition maximum and eight repetitions with 80% 1 repetition maximum while using the Wimu system and T-Force linear encoder simultaneously to record data. Reliability was analysed using intraclass correlation, standard error of measurement and coefficient of variation. The validity was assessed using R^2, intraclass correlation and Bland-Altman plots. The differences in test–retest reliability of both systems and systematic biases were non-significant (p = 0.08–0.85) and very close to 0. The random errors averaged ±0.010 m/s. All the calculated coefficient of variations were less than 5% and all measurements had high intraclass correlations (mean: 0.936). Least-square linear regression and intraclass correlations for validity were very close to 1. Significant systematic biases were observed between the linear encoder and the Wimu system ($p < 0.001$), although the effect sizes were small (0.21–0.44) and standard error of the estimate in concentric and eccentric phases at both intensities was less than 0.030. In conclusion, the findings of this study suggest that the Wimu system is a reliable and valid tool for the assessment of mean velocity during the back squat exercise using the Smith machine. These findings could help coaches and sport researchers evaluate athletes performing resistance exercises similar to squats with a reliable, valid and portable tool.

Keywords

Linear encoder, T-Force, Smith machine, squat, Wimu system, velocity

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Introduction

Resistance training designed to increase underlying strength and power in elite athletes is commonly utilized to improve athletic performance.[1] In many sports, athletes are required to repeatedly perform specific movements at different velocities and intensities to improve their sport performance.[2,3] Currently, the importance of movement velocity as a measure to control resistance training intensity and indicator of the degree of muscle fatigue during resistance training is well documented.[4–6] One of the most commonly used devices for measuring lifting velocity during training has been the linear position transducer (linear encoder).[7,8] Several studies have demonstrated good reliability[9–13] and validity[9,10,14] of these devices. Linear encoders use a tethered cord, attached to a person or equipment, to extract time–displacement data. From these data, movement velocities and subsequent accelerations are

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calculated.[14] However, linear encoders are limited in their range of movement because these devices require two cables to measure the linear velocity and connect to the personal computer to download the data.

In recent years, accelerometers have been used to assess movement velocities during resistance training. Due to their small size, portability and ease of use, these devices can be attached to a wide range of equipment or even directly to a person during sporting and normal everyday activities without the need for cables, thereby offering greater versatility than linear encoders.[14] Several studies have combined the use of an accelerometer (Myotest SA, Sion, Switzerland) and a linear encoder (as the gold standard) to compare the data for similar measures of performance on the field, in sport centres or in the laboratory.[13–15] These studies have demonstrated good reliability[13] and validity for measuring velocity, force and power production during resistance training.[14–16]

Sport scientists and industry have continued to develop and refine accelerometers to make them more economical and portable. For example, a new system called the Wimu® system (RealTrack Systems, Almería, Spain) was recently commercialized for measuring the velocity during resistance exercises. This device is equipped with a 1000 Hz accelerometer that provides important information, such as displacement as well as concentric and eccentric velocity. Thus, the Wimu system could be used in place of a linear encoder. However, to the best of the author's knowledge, no studies have evaluated the reliability and validity of this new device for measuring lifting velocity during resistance exercises.

The Smith machine is often used to evaluate the velocity during resistance execises[9,15] because this machine eliminates the sagittal movement of the barbell during the test.[15] Therefore, the back squat in the machine Smith was used in this study, because although differences are well established between free weight and Smith machine resistance exercise modalities, instrument positioning and horizontal excursions from the vertical and bar rotational movements appear to be the major concerns for comparative accuracy between the different measurement systems.[17]

Therefore, this study determined the reliability of the Wimu (accelerometer) to measure the mean velocity during resistance exercises with two intensities, 40% and 80% 1 repetition maximum (RM), commonly used in resistance training. This study also evaluated the validity of the Wimu (accelerometer), compared to the linear encoder when the Wimu was clipped to the bar of a Smith machine to measure mean velocity during the back squat exercise in the concentric and eccentric phases.

Material and methods

Subjects

In all, 23 young men aged 22.3 ± 3.2 years, height 1.76 ± 0.06 m, body mass 76.3 ± 6.8 kg and body mass index 24.69 ± 1.87 volunteered to participate in this study. All participants had at least 2 years of experience in weight training for bodybuilding or recreation of 1 RM at 109.46 ± 18.14 kg and were healthy, without any musculoskeletal injuries. Each participant was informed of the study procedures and signed an informed consent agreement before the tests began. This study was approved by the institutional ethics committee of the University of Murcia (Murcia, Spain). The study was designed and conducted in accordance with the Ethical Standards in Sports and Exercise Science Research.[18]

Procedures

Familiarization and 1 RM assessment. During the first visit to the laboratory, the subjects were familiarized with the testing procedure and tested for 1 RM strength on the back squat exercise using the Smith machine bar. The estimated percentage 1 RM for calculating the accurate 1 RM was performed according to the participants' experience in resistance training. Maximum heart rate (HR) was predicted from the formula 206.9 − (0.67 × age).[19] Later, the 40% of heart rate reserve (%HRR) was calculated for each subject.

To begin the test, each participant performed a warm-up that consisted of 10 min running on a treadmill at 40% of maximal HRR, articular mobility and active lower limb stretching exercises.

Then, the subjects performed one set of 8–10 repetitions with approximately 40%–50% of their estimated 1 RM, followed by another set of 3–5 repetitions with approximately 85% of their estimated 1 RM. The Smith machine bar was then loaded with a weight similar to the subjects' estimated 1 RM and the participants performed one repetition. This repetition was considered successful if the subject was able to reach a depth of his thighs parallel to the ground, followed by raising the Smith machine bar completely to the start position.

The maximum weight lifted was recorded as 100% to calculate the 40% and 80% 1 RM loads. Both intensities were selected for this study because they are commonly used during resistance and hypertrophy training in bodybuilding.[20,21]

Experimental procedure for back squat testing. A minimum of 48 h after establishing the 1 RM and performing the familiarization, the subjects returned to the laboratory. The testing procedure involved the simultaneous assessment of back squat velocity using a linear encoder (T-Force Dynamic Measurement System; Ergotech, Murcia, Spain) and an accelerometer (Wimu system). Before the testing, subjects performed a warm-up identical to that used in the familiarization period, followed by one set of 15 repetitions of the back squat exercise with 10% of their estimated 1 RM. Then, the Smith machine bar was loaded with 40% 1 RM specific to each participant to perform 10 repetitions at maximum velocity. After resting for 5 min, the Smith machine bar was loaded with 80% 1 RM specific to each participant to perform eight repetitions at maximum velocity.

The back squats were performed using a standard technique according to previous studies.[22,23] Participants began in a standing position, feet shoulder-width apart, with the loaded bar placed on the shoulders and upper trapezius. Participants then descended to reach a depth of their thighs parallel to the ground, keeping the head up and back straight, before extending the bar upward to the start position. For each repetition of concentric and eccentric phases, the subjects were instructed to perform the back squat as rapidly as possible while always controlling the specific technique during the movement as directed by verbal feedback from a researcher.

To assess the reliability of these devices, all tests and protocols were repeated 7 days later, at the same time and under identical conditions. Before all attempts, both instruments were calibrated following the manufacturer's instructions. For the analysis, the mean velocity (m/s) of the 10 and 8 repetitions was calculated, differentiating between the concentric and eccentric phases.

Materials

The two devices employed in this study (the Wimu system and the T-Force linear encoder) were placed and secured, in accordance with specified manufacturers' instructions, onto the same lateral edge of the barbell of the Smith machine bar (Multipower; Technogym, Cesena, Italy). The Wimu system was secured with a fixing flange onto the Smith machine bar to avoid its movement. The Wimu system is a small, wireless device with more than 20 integrated sensors. Among the sensors, there is a 1000 Hz three-dimensional (3D) accelerometer, 1000 Hz 3D gyroscope with 2000°/s resolution, 3D magnetometer and barometer that works with an integration of sensors to improve the information. All data regarding the mean velocity (m/s) of each repetition for both concentric and eccentric phases were sent via Bluetooth to a personal computer in real time and were recorded using Qüiko® software (RealTrack Systems). A linear encoder (T-Force Dynamic Measurement System) was used as a reference system to determine the validity of the Wimu. The linear encoder has been widely used to evaluate kinetic and kinematic variables in resistance exercises[5,6,24,25] while also serving as a gold standard instrument in studies of reliability and validity.[9,13] This system consists of a linear velocity transducer extension cable that interfaces with a personal computer that obtains data with an analog-to-digital resolution of 14 bits. The specific software (T-Force System, version 2.35; Ergotech, Murcia, Spain) calculates the mean velocity (m/s) of each repetition in both the concentric and eccentric phases.

Statistical analyses

Data are shown as the mean(s) and standard deviation(s). Normality was analysed using the Shapiro–Wilk test. All variables followed normal distributions. Paired Student's *t*-tests were used to detect any systematic differences (bias) between test sessions (reliability) and tools (validity). Between-group effect sizes (Cohen's *d*) were calculated using a pooled standard deviation. Effect sizes were evaluated as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large ($\geqslant$0.80).[26] The intraclass correlation coefficients (ICCs) with 95% confidence intervals (CI) were used to examine the relative reliability of the Wimu system (mean velocity of the concentric and eccentric phases). According to Weir,[27] the ICC (model 2,1) is a two-way random factor model that uses both random and systematic errors in the denominator of the ICC equation and, therefore, can be generalized to other context (laboratories and tester). Additionally, absolute reliability, defined as the degree to which repeated measurements vary for individuals, was determined using the standard error of the measurement (SEM) and coefficients of variation (expressed as a CV%).[28]

The validity of the Wimu system was assessed by the following methods: least squares linear regression determining pairwise relationships between the Wimu and the linear encoder systems,[29] ICCs with a 95% CI, difference between the two systems (systematic bias) and Bland–Altman plots.[30,31] Additionally, a calculation was made of the standard error of the estimation used in regression analysis to assess measurement error for the validity of the Wimu compared to the linear encoder[32] and the coefficients of variation between both systems (expressed as a CV%).[28] Statistical power and effect sizes were calculated using equation (1)[32]

$$G * \mathrm{Power3.1} \tag{1}$$

Other analyses were performed using Statistical Package OS X (Version 22.0; Armonk, NY, USA). The level of significance was set at $p < 0.05$. The statistical power was greater than 0.85 for both intensities and contraction phases.

Results

The test–retest reliability of the linear encoder and the Wimu systems is given in Table 1. Systematic biases were non-significant ($p = 0.08$–0.85) and very close to 0. Effect sizes were trivial (0–0.15) for all variables except for the encoder at 80% 1 RM during the concentric phase for which the effect size was small ($d = 0.24$). The standard error of mean was $\pm$0.010 m/s. All the calculated CVs were less than 5% for all variables analysed. All measurements had high ICCs (mean: 0.936). The ICC and CV values from the Wimu system were similar to those calculated for the linear encoder.

Table 1. Test–retest reliability of linear encoder and Wimu systems for measuring mean velocity in both intensities 40% and 80% (1 RM) in back squat exercise in Smith machine.[a]

	Encoder 40% concentric Phase	Encoder 40% eccentric phase	Wimu 40% concentric phase	Wimu 40% eccentric phase	Encoder 80% concentric phase	Encoder 80% eccentric phase	Wimu 80% concentric phase	Wimu 80% eccentric phase
Session 1 (95% CI; m/s)	0.77 ± 0.12	−0.69 ± 0.13	0.74 ± 0.12	−0.67 ± 0.14	0.68 ± 0.09	−0.63 ± 0.10	0.65 ± 0.09	−0.60 ± 0.09
	(0.56 to 0.97)	(−0.95 to −0.52)	(0.54 to 0.97)	(−0.96 to −0.49)	(0.47 to 0.84)	(−0.83 to −0.44)	(0.46 to 0.84)	(−0.79 to −0.44)
Session 2 (95% CI; m/s)	0.78 ± 0.11	−0.71 ± 0.13	0.74 ± 0.12	−0.66 ± 0.15	0.66 ± 0.07	−0.62 ± 0.10	0.65 ± 0.08	−0.59 ± 0.08
	(0.64 to 0.97)	(−0.96 to −0.52)	(0.58 to 0.97)	(−0.95 to −0.24)	(0.55 to 0.82)	(−0.84 to −0.46)	(0.54 to 0.84)	(−0.78 to −0.45)
Systematic bias (m/s)	−0.012	0.012	−0.007	−0.002	0.018	−0.012	0.004	−0.010
Effect size *d*	0.08	0.15	0.00	0.06	0.24	0.10	0.00	0.11
SEM (m/s)	0.007	0.009	0.007	0.013	0.013	0.011	0.011	0.010
CV (%)	2.00	3.65	2.60	3.79	4.28	4.55	3.53	4.51
ICC (95% CI)	0.979	0.970	0.976	0.955	0.855	0.924	0.905	0.924
	(0.950–0.991)	(0.929–0.987)	(0.994–0.990)	(0.893–0.981)	(0.647–0.941)	(0.820–0.968)	(0.774–0.960)	(0.829–0.968)

CI: confidence interval; SEM: standard error of the measurement; CV (%): percentage coefficient of variation; ICC: intraclass correlation coefficient; 1 RM: one repetition maximum.
[a]Mean values ± standard deviation (s).

Table 2 presents the results for both systems to evaluate the validity of the Wimu. Although the least square linear regression and ICCs for validity were very close to 1 at 0.92–0.96 with $p = 0.000$ and 0.953–0.976, respectively, a significant systematic bias was observed between the linear encoder and the Wimu system results ($p < 0.001$). However, the effect sizes determined for all variables for both devices were small, between 0.21 and 0.44. Moreover, standard error of the estimate in concentric and eccentric phases for both intensities was less than 0.028.

The differences between the two devices (bias) and the 95% limits of agreement were calculated to illustrate the degree of agreement between the two methods as shown in Figure 1.

Discussion

Currently, technology is increasingly used to objectively quantify and monitor the training load undertaken by athletes to maximize sport performance and prevent possible injuries. One aim of this study was to be the first published research focused on evaluating the reliability and validity of the Wimu (accelerometer) system when clipped to the bar of a Smith machine to measure mean velocity during the back squat exercise. The main finding was that the Wimu system demonstrated an excellent test–retest reliability and strong concurrent validity for the evaluation of velocity during the resistance exercise.

The test–retest reliability (i.e. consistency or stability of measurements) of resistance exercises is very important to ensure that observed differences in these exercises between testing sessions are not due to systematic bias, such as learning effect or fatigue, or standard error due to possible biological or mechanical variations.[28] Although procedures such as the Pearson *r* and the coefficient of variation are frequently used, Weir[27] reported that the ICC is a more appropriate reliability statistic.

Nowadays, there are no standards for acceptable reliability measures.[33] However, ICC values above 0.75 have been suggested to be considered reliable, and this index should be at least 0.90 for most clinical applications.[34] In this study, the Wimu system presented very good results according to the reliability test. All ICC values for the Wimu system were greater than 0.90 (0.905–0.976). Moreover, this system demonstrated a slightly lower systematic bias than the linear encoder system in both intensities (40% and 80% 1 RM) and phases (concentric and eccentric). However, the linear encoder has been used in numerous studies and is considered the best system (gold standard) for assessing velocity during resistance exercises.[2,9,11–13]

An analytical goal of CV $\leqslant$ 10% might be considered an indicator of acceptable agreement.[28] In this study, the CVs were less than 5% for all the variables measured from the Wimu system. Similar CVs were observed with the linear encoder. The high ICCs; the

Table 2. Concurrent validity of linear encoder and Wimu systems for measuring mean velocity in squat exercise in Smith machine.[a]

	40% Concentric phase	40% Eccentric phase	80% Concentric phase	80% Eccentric phase
Linear encoder (95% CI; m/s)	0.78 ± 0.11 (0.63 to 0.96)	−0.70 ± 0.13 (−0.95 to −0.53)	0.67 ± 0.08 (0.55 to 0.83)	−0.63 ± 0.10 (−0.84 to − 0.50)
Wimu system (95% CI; m/s)	0.74 ± 0.12 (0.60 to 0.97)	−0.67 ± 0.15 (−0.96 to −0.37)	0.65 ± 0.08 (0.54 to 0.84)	−0.59 ± 0.08 (−0.78 to −0.48)
Systematic bias (m/s)	0.037†	−0.033†	0.020†	−0.030†
Effect size *d*	0.34	0.21	0.25	0.44
SEM (m/s)	0.003	0.007	0.003	0.005
R^2 correlations	0.978†	0.954†	0.963†	0.930†
SEE	0.017	0.028	0.015	0.026
ICC (95% CI)	0.970 (0.931 to 0.987)	0.971 (0.931 to 0.988)	0.976 (0.942 to 0.990)	0.953 (0.888 to 0.980)

SEM: standard error of the measurement; R^2: least squares linear regression; SEE: standard error of the estimate; CI: confidence interval; ICC: intraclass correlation coefficient.
aMean values ± standard deviation (s).
†$p = 0.000$.

low systematic bias, random error and CVs; and the absence of any significant differences between trials and similar values noted with the linear encoder indicated that the Wimu system data were reliable.

This study also determined the validity of the Wimu system to measure velocity during the resistance squat exercise using the Smith machine by comparing its mean velocity with data obtained simultaneously with a linear encoder. The observed difference between both systems (approximately 0.03 m/s, $p < 0.001$) could be attributed to several factors that are all inherent to the devices. For example, the difference could be attributed to the methodology used in both systems to measure the velocity during the resistance exercise. Linear transducers use a tethered cord (attached to a person or equipment) to extract time–displacement data. From these data, movement velocity and subsequent accelerations are calculated.[14] However, the Wimu system is equipped with tri-axial accelerometers for assessing the movement in three different planes, allowing the accelerometer data to be mathematically integrated to obtain the vertical velocity from the Wimu. In this study, the random error was observed to be very low (mean: 0.004 m/s). The effect sizes between the differences found in both systems at 40% and 80% 1 RM (concentric and eccentric phases) were small (0.21–0.44). Moreover, the ICC values of both systems were greater than 0.95, with a very low standard error of the estimation (<0.029). Thus, this study presents data indicating good agreement between the two devices which could allow them to be interchangeable depending on test conditions and comfort level of the end user.

Based on the author's literature search, this report is the first study to evaluate the Wimu system, which has reported an adequate reliability and validity. Because peak power occurs between 30% and 50% 1 RM[35] and because 40% and 80% 1 RM are commonly used during resistance training[21] and hypertrophy,[20] respectively, these intensities were chosen in this study. However, this study has some limitations. For example, future studies will evaluate a wide range of relative intensities to understand the reliability and validity in intermediate intensities. Another limitation is that this study did not evaluate the peak power and velocity. For this reason, the authors cannot compare these findings with results obtained from accelerometer studies such as the Myotest system[13–16] that evaluated these variables. Future studies will measure both variables (peak power and velocity) and compare the results with other accelerometers. Additionally, more research is needed to evaluate velocity measurements of the Wimu system and a linear encoder for other intensities, imposing a pause between the eccentric and concentric phases.[36] Future work should also focus on other resistance exercises, such as the bench press or free-weight exercises, to establish a more complete understanding of the Wimu system as a tool to measure the movement velocities performed during other resistance training exercises.

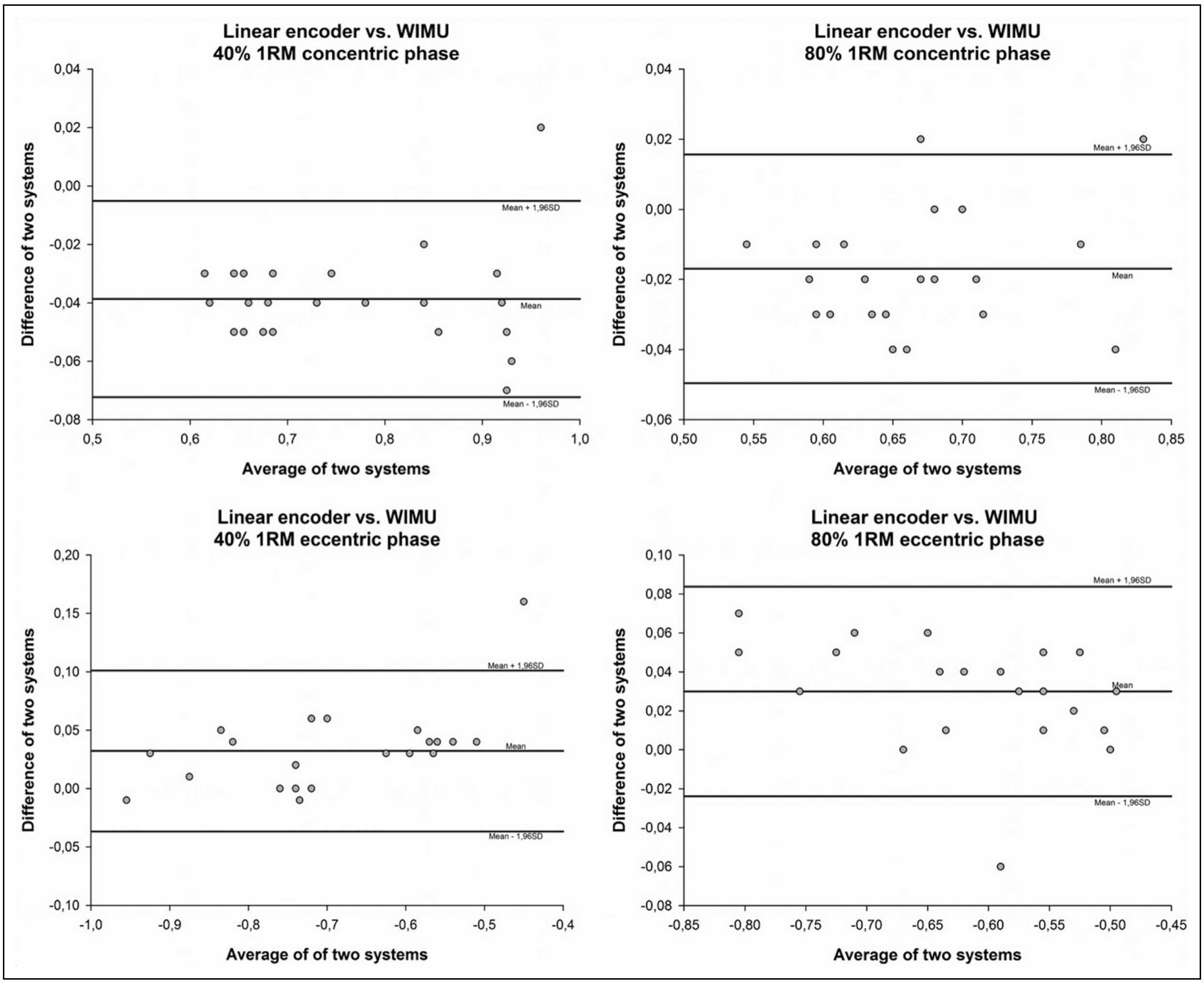

Figure 1. Bland–Altman plots for the differences of the Wimu® system and the linear encoder for both intensities (40% and 80% 1 RM) and phases (concentric and eccentric). The mean values and upper and lower 95% limits of agreement are presented.

In conclusion, the present findings suggest that the Wimu system is a reliable and valid tool for the assessment of mean velocity during the back squat exercise using the Smith machine. This cableless device is easy to handle and suitable for portable applications on the field and in sport centres, making it a more viable alternative to the linear encoder requiring multiple cables during measurement.

Declaration of conflicting interests

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