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Validity of Force and Power Measures from an Integrated Rotary Encoder in a HandyGym Portable Flywheel Exercise Device

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Abstract: Introduction: This study aimed to evaluate the validity of the HandyGym portable flywheel device with an integrated rotary encoder in measuring force and power during iso-inertial exercises compared to a traditional reference system. Methods: In total, 10 trained volunteers (3 women, 7 men; age 25.2 ± 3.8 years) performed half-squats with five different load configurations using the HandyGym device. Concurrent measurements were obtained from HandyGym's rotary encoder and a criterion system (MuscleLab 6000 strain gauge and linear encoder). Five load configurations were tested, with 15 repetitions recorded per condition. The validity of the HandyGym measurements was assessed through mean bias, typical error of estimation (TEE), and Pearson correlation coefficients, with Bland–Altman plots used to analyze the agreement between the two systems. Results: The HandyGym showed high correlations with the reference system for both force (r = 0.76–0.90) and power (r = 0.60–0.94). However, systematic biases were observed, with the HandyGym consistently underestimating force and power at lower loads and overestimating power at higher loads. The TEE values indicated moderate to large errors, particularly in power measurements. Conclusion: The HandyGym provides valid force measurements with moderate bias, suitable for general monitoring. However, power measurements are less consistent, especially at higher loads, limiting the device's utility for precise assessments. Adjustments or corrections may be necessary for accurate application in professional contexts.

Keywords: isoinertial training; strength training; sports technology; training load; monitoring

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Citation: Illera-Domínguez, V.; Font-Aragonés, X.; Toro-Román, V.; Díaz-Alejandre, S.; Pérez-Chirinos, C.; Albesa-Albiol, L.; González-Millán, S.; Fernández-Valdés, B. Validity of Force and Power Measures from an Integrated Rotary Encoder in a HandyGym Portable Flywheel Exercise Device. *Appl. Sci.* **2024**, *14*, 9832. https://doi.org/10.3390/app14219832

Academic Editors: Sime Versic and Toni Modric

Received: 2 September 2024
Revised: 18 October 2024
Accepted: 21 October 2024
Published: 28 October 2024

1. Introduction

Monitoring training loads is essential for optimizing exercise dosage according to individual characteristics and goals while minimizing risks such as overtraining [1–3]. Evidence shows that monitoring training loads and receiving real-time feedback can significantly improve exercise performance and training outcomes [4,5]. Advances in sports technology have greatly enhanced training monitoring capabilities, offering deeper insights into training processes and facilitating the individualization of both preventive and rehabilitative programs [6–9]. Although an increasing number of exercise parameters can now be tracked and quantified through sensors, many health and sports performance technologies still lack independent validation [10]. Consequently, it is essential to evaluate the validity of these methods for specific applications, and consumers should prioritize evidence-based products with proven efficacy.

Isoinertial training systems, commonly known as flywheel systems, have gained increasing attention for their effectiveness in promoting adaptations in strength, power, and speed [11,12]. These systems utilize the inertia of a rotating flywheel and offer distinct advantages over traditional gravity-based methods, including the potential for eccentric overload, which may lead to superior specific adaptations compared to other training methods [13,14]. The benefits of isoinertial training are broad, impacting both high-performance athletes and the general population. Notable outcomes include rapid and substantial increases in muscle mass and strength [15,16]. Among older adults, isoinertial training has been linked to significant improvements in strength, muscle mass, and balance, contributing to the prevention of sarcopenia and dynapenia [17–19]. In athletes, isoinertial training programs have demonstrated improvements in explosive and reactive strength, sprint capacity, change in direction, and jump performance [20–22]. Additionally, high-intensity isoinertial sessions have been associated with enhanced post-activation performance enhancement (PAPE) [23]. Moreover, isoinertial training has been shown to improve eccentric strength and functional strength ratios, thereby reducing the risk of injuries, particularly to the hamstrings and anterior cruciate ligament [20].

Despite these benefits, accurately quantifying load during isoinertial exercises is more complex than in traditional weight training systems. In isoinertial exercises, determining a one-repetition maximum (1-RM) is not feasible because there is no maximal load to lift. Instead, the user accelerates the inertia (flywheel discs) during the concentric phase, which then returns stored energy during the eccentric phase [24]. The gold standard for monitoring these exercises typically combines kinetic systems (e.g., force platforms) and kinematic systems (e.g., linear encoders), with force and power measurements being the most commonly used control parameters [25–27]. Although these systems provide precise measurements, they are often impractical for daily training due to their high cost, complex setup, and lack of portability [28]. In contrast, rotary encoders, which estimate kinetic parameters based on flywheel velocity, offer a more practical and accessible solution for athletes and coaches [25]. However, these devices may introduce errors in force and power estimations, which must be rigorously validated before they can be reliably used in professional practice [27,29].

Isoinertial training systems are typically classified based on the type of shaft they use, which can be either cylindrical or conical [26]. Each type has distinct characteristics that make it more suitable for specific applications [21,27,30], with certain systems designed to target specific muscle groups [16,31]. Cylindrical shaft devices generally produce high resistance and are mainly used in lower-body exercises performed in vertical or diagonal-ascending directions [15]. Most of these devices are now marketed with integrated rotary encoders [32], and some manufacturers have introduced models equipped with integrated force platforms. In contrast, conical shaft devices offer less resistance during movement compared to cylindrical shaft systems [26,30,33]. Due to their conical shape, the instantaneous radius varies throughout the range of motion [30]. These systems are particularly suited for lateral displacements, changes in direction, and movements involving diverse force vectors [21,34]. Although conical systems are also monitored with rotary encoders, estimating power and force is more complex due to the variability in instantaneous radius, with most software using an average radius based on the selected configuration [35].

Although most strength and conditioning coaches and therapists recognize the advantages of isoinertial devices in professional practice, barriers such as high cost, space requirements, and limited time often restrict their use [28,36,37]. The HandyGym system represents a new generation of portable isoinertial training devices, featuring compact dimensions (10 × 12 × 20 cm) and a lightweight (0.9 kg) design, making it easily transportable in a backpack [38]. It is also more affordable compared to other commercially available systems and integrates a wireless rotary encoder. Additionally, its design allows for various strength exercises across multiple vectors, similar to conical axis isoinertial systems [21]. To the authors' knowledge, HandyGym is the first fully portable isoinertial training system available on the market, with no other manufacturers currently offering similar features. These characteristics make HandyGym a promising solution to address some of the limitations practitioners encounter when implementing this technology in professional practice.

To the best of our knowledge, no scientific publication in major databases has investigated the use of this training system for exercise interventions or assessed the validity of the measurements obtained through its integrated encoder. Therefore, this study aims to evaluate the validity of the HandyGym sensor for measuring force and power during isoinertial exercises. We hypothesize that the HandyGym sensor will provide valid measurements of force and power, albeit with some bias and estimation errors that may vary depending on load conditions. Furthermore, we expect these measurements to closely correlate with those from a reference system, thereby demonstrating the sensor's suitability for practical application.

2. Materials and Methods

2.1. Participants

Overall, 10 young volunteers (3 women and 7 men; mean ± SD: age 25.2 ± 3.8 years, height 1.72 ± 0.66 m, weight 71.0 ± 7.4 kg) were recruited from TecnoCampus-Mataró (Pompeu Fabra University) for this study. All participants were students enrolled in sports and exercise science programs, with at least two years of strength training experience and prior use of isoinertial training systems, including the system used in this study. The exclusion criteria were (i) no prior experience with isoinertial training systems; (ii) no strength training experience; (iii) no experience in performing squats; (iv) current injury or muscle soreness; (v) having trained the day before assessments; and (vi) not being a student at TecnoCampus-Mataró (Pompeu Fabra University). Participants were selected for their availability to perform the exercises and to enhance their experience with these devices as part of their training.

Detailed written information and verbal instructions were provided to all participants prior to the commencement of testing, and each participant signed an informed consent form. The study protocol was approved by the Ethics Committee of the TecnoCampus Mataró Foundation (CEI 5/2022).

2.2. Study Design

In a single session, participants performed half-squats on a custom-built platform designed to accommodate the HandyGym device and the measurement systems (Figure 1). Data were collected concurrently using two methods: (I) the integrated wireless rotary encoder of the HandyGym device (practical measure) and (II) a strain gauge combined with a linear encoder attached to the harness (criterion measure). Five different isoinertial load configurations, representing the full range of resistances offered by the device, were tested. Fifteen complete repetitions were recorded from each participant for each of the tested load configurations. The agreement between the force and power values recorded by both methods was then analyzed. A familiarization session, lasting approximately 15 min, was conducted prior to data collection to ensure proper execution technique and understanding of the measurement systems.

2.3. Equipment

The exercise was conducted using the HandyGym portable isoinertial resistance training device (HandyGym, Global Traktus, Pontevedra, Spain; dimensions: 10 × 12 × 20 cm; weight: 0.9 kg). Exercises were performed on a custom-built platform designed to support the HandyGym device and ensure stability during the half-squats, while also providing sufficient space for the sensors, allowing for an unobstructed range of motion. This setup ensured that participants could achieve the desired range of movement, from 90° of knee flexion to full extension of the hips and knees, without interference from the measurement equipment (Figure 1).

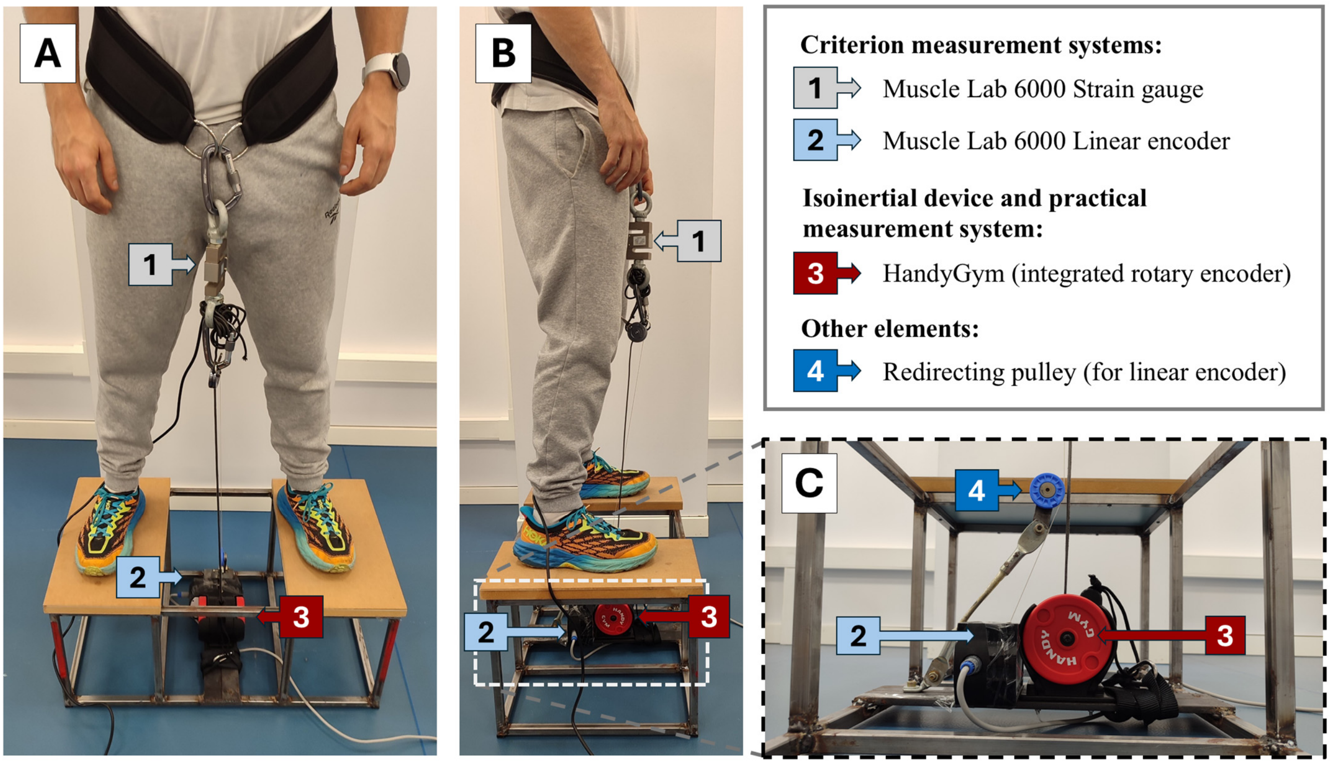


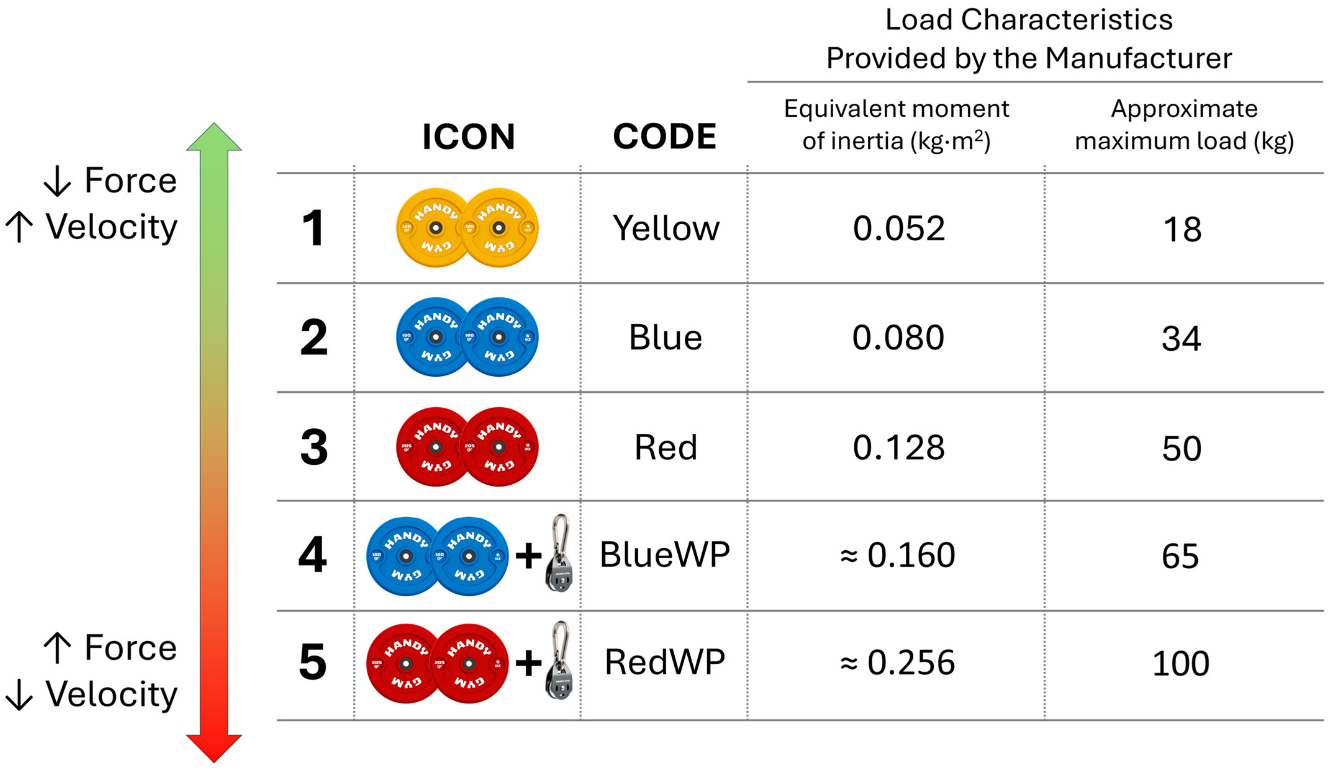
Figure 1. Setup of the training system and sensors used in the study. (**A**): Front view; (**B**): Side view; (**C**): Detailed view. The exercise was performed on a custom-built platform made of metal and wood to accommodate the space required by the sensors, which otherwise would have restricted the range of motion. This platform allowed for an adequate range of motion and ensured the comfortable execution of the exercise.

The HandyGym device incorporates an integrated wireless rotary encoder that measures angular velocity. These data are transmitted via Bluetooth to an associated mobile application (HandyGym APP v. 1.1.0 for Android). Once the load parameters and exercise configuration are set in the app, the software calculates the mean force and power for each repetition, during both the concentric and eccentric phases of the movement.

For criterion measurements, a strain gauge combined with a linear encoder (Muscle Lab 6000, Ergotest Technology, Porsgrunn, Norway) was used. This method has previously been used as a reference measurement system in isoinertial training [39–41]. The strain gauge (accuracy: 63 g, sampling rate: 200 Hz) was attached between the flywheel strap and the vest, while the linear encoder (accuracy: 0.019 mm, sampling rate: 200 Hz) was secured to the structure using adhesive tape. The string from the linear encoder was redirected by a pulley to align parallel with the HandyGym rope and then attached to the vest (see detailed view in Figure 1) [39,40].

The HandyGym device utilizes two small-diameter inertia discs, with resistance amplified by an internal gear system. The load can be adjusted by using pairs of interchangeable discs with different masses (Yellow: 120 g each; Blue: 180 g each; Red: 205 g each). Additionally, the load can be increased by incorporating an intermediate pulley, which distributes the force applied by the user between a fixed anchor point on the structure and the cable that drives the system. This mechanism, commonly used in other isoinertial training systems, approximately doubles the load provided by the device [42].

Five different load configurations were tested in this study to cover the full range of resistances and the force-velocity spectrum available on the HandyGym device, from the lowest to the highest possible loads. Intermediate configurations represented varied resistances. This range is relevant for practical training scenarios, as configurations with higher loads and pulley multipliers provide increased resistance, making them suitable for hypertrophy and near-maximal strength training [43]. In contrast, lower loads without pulley configurations are typically used in rehabilitation, beginner training, or power development [19,43,44]. The configurations used, described in more detail in Figure 2, were as follows: Yellow/Yellow (Yellow), Blue/Blue (Blue), Red/Red (Red), Blue/Blue with a multiplier pulley (BlueWP), and Red/Red with a multiplier pulley (RedWP).



	ICON	CODE	Load Characteristics Provided by the Manufacturer: Equivalent moment of inertia (kg·m²)	Load Characteristics Provided by the Manufacturer: Approximate maximum load (kg)
1		Yellow	0.052	18
2		Blue	0.080	34
3		Red	0.128	50
4	+	BlueWP	≈ 0.160	65
5	+	RedWP	≈ 0.256	100

Figure 2. Load configurations tested in the study. The arrow on the left side of the figure indicates the progression of load from lower to higher resistance across the tested configurations.

2.4. Data Collection

Data collection was conducted in a single session for each volunteer, lasting approximately 45 min, at the Laboratory of Technological Innovation, Strength, and Functional Assessment (LabIT) at TecnoCampus. Climatic conditions in the laboratory were consistent (20–25 °C and 60–65% humidity). One or two participants were assessed per data collection session. Each session began with a standardized warm-up and familiarization period lasting 10–15 min, during which the protocol was explained in detail, informed consent was obtained, and the procedure was practiced. The warm-up included general joint mobility exercises, 5 min of cycling on a cycloergometer, and 15 repetitions of bodyweight squats.

The criterion measurement system was calibrated before each session. This was followed by the exercise protocol (lasting 30 min), in which participants performed the exercise with the tested load configurations (see Figure 2). The load order for each participant was randomized prior to the start of the experiment using a list of conditions (1–5, as shown in Figure 2), generated by the Randomizer mobile application [45]. The rope length was adjusted to match each participant's range of motion before each set, ensuring full extension while avoiding a phase without tension. For each load configuration, participants performed three initial half-squats to progressively accelerate the flywheel, followed by a set of 15 near-maximal half-squats. Participants were instructed to maintain a range of motion from 90° of knee flexion to full extension of the hips and knees, exerting maximal effort during each repetition while adhering to the specified range of motion. A 3-min recovery period was provided between sets. If a set did not meet the prescribed guidelines, it was discarded, followed by a 3-min recovery period, after which the set was repeated.

2.5. Data Analysis

Since data from the HandyGym mobile application could not be exported, the average force and power data for the concentric and eccentric phases of each repetition were manually recorded in an Excel matrix. As the app expresses force in equivalent kilograms, these values were converted to Newtons by multiplying by 9.80. To obtain comparable summary data from the criterion method, raw data (200 Hz) for time, position, force, and velocity from the Muscle Lab sensors were downloaded using MuscleLab Software v.10. The raw data were processed using a custom routine in the open-source R statistical software (v. 4.4.1; R Core Team 2024, Vienna, Austria) for Windows [46]. This routine sequentially calculated instantaneous power by multiplying velocity and force values at each time point automatically detected at the start and end of each phase (concentric–eccentric) based on extreme position data from the linear encoder and calculated the average force and power for each phase of every repetition. All data from both systems were consolidated into a single Excel matrix, including volunteer ID, load configuration, repetition number, phase, and the force and power values from both systems for subsequent statistical analysis.

2.6. Statistical Analysis

Statistical analyses were performed entirely using the open-source R statistical software (v. 4.4.1; R Core Team 2024, Vienna, Austria) for Windows [46]. All data are presented as mean ± standard deviation (SD). First, a descriptive analysis of force and power outputs across all load configurations was conducted, including the calculation of the eccentric/concentric (E/C) ratio, a parameter commonly used to assess the presence of eccentric overload [26,33,47]. Agreement between the criterion measures (MuscleLab) and the practical measures (HandyGym) of force and power was evaluated using a dedicated R code based on Hopkins' work for the analysis of validity [48]. This analysis included the calculation of mean bias, typical error of the estimate (TEE), and Pearson correlation coefficient, all with 90% confidence limits. The mean bias and TEE were standardized using the SD. The standardized mean bias was classified as trivial ($\leq$0.19), small (0.2–0.59), moderate (0.6–1.19), or large (1.2–1.99) [48]. The standardized TEE was classified as trivial (<0.1), small (0.1–0.29), moderate (0.3–0.59), or large (>0.59) [48]. The magnitude of the correlation was rated as trivial (<0.1), small (0.1–0.29), moderate (0.3–0.49), large (0.5–0.69), very large (0.7–0.89), or nearly perfect (0.9–0.99) [48]. Additionally, Bland–Altman plots were used to graphically complement the analysis of differences between the two systems [49]. Finally, the statistical power for the Pearson correlation test was calculated using the G*Power program (version 3.1.9.7, Heinrich Heine University Düsseldorf, Düsseldorf, Germany). Post hoc statistical power for an alpha error of 0.05 was 0.977 for Pearson's correlation coefficients. Additional details on the interpretation of the statistical methods used in this study can be found in the following reference [50].

3. Results

Table 1 provides a comprehensive overview of performance across the load configurations used in this study, including the average force and power generated at each load, as well as the E/C ratio.

A comparative analysis of force measurements between the criterion method (MuscleLab) and the practical method (HandyGym) is presented in Table 2. Bias values range from "moderate" to "large" across different conditions, indicating a significant standardized difference between the criterion and practical measures. The TEE also ranges from "moderate" to "large," suggesting moderate accuracy in the practical measure's estimation. The Pearson correlation coefficient shows a strong relationship between the two measures, with values ranging from "very large" to "nearly perfect", confirming a robust association between the variables. All p-values associated with the correlations are highly significant ($p < 0.001$).

Table 1. Mean force and power outputs with eccentric/concentric (E/C) ratios for different loads tested in the study. The table presents both criterion measures (left) and practical measures (right), with data expressed as mean ± SD.

		MuscleLab (Criterion Measure)			**HandyGym (Practical Measure)**		
		Concentric Force	**Eccentric Force**	**E/C Force Ratio**	**Concentric Force**	**Eccentric Force**	**E/C Force Ratio**
Force measures (N)	(1) Yellow	462.0 ± 86.8	268.6 ± 64.3	0.6 ± 0.1	155.3 ± 27.9	96.9 ± 22.8	0.6 ± 0.2
	(2) Blue	588.2 ± 229.7	418.6 ± 176.4	0.7 ± 0.1	276.2 ± 217.3	159.4 ± 137.3	0.6 ± 0.1
	(3) Red	639.3 ± 111.7	451.1 ± 113.2	0.7 ± 0.1	346.7 ± 60.5	204.2 ± 38.6	0.6 ± 0.1
	(4) BlueWP	884.5 ± 161.2	563.8 ± 151.0	0.6 ± 0.1	597.2 ± 114.1	352.1 ± 71.2	0.6 ± 0.1
	(5) RedWP	951.5 ± 189.2	619.8 ± 160.6	0.6 ± 0.1	678.1 ± 151.9	429.8 ± 97.2	0.6 ± 0.1
	Pooled data	704.3 ± 230.1	464.2 ± 176.9	0.7 ± 0.1	409.8 ± 217.6	248.3 ± 137.5	0.6 ± 0.1
		MuscleLab (Criterion Measure)			**HandyGym (Practical Measure)**		
		Concentric Power	**Eccentric Power**	**E/C Power Ratio**	**Concentric Power**	**Eccentric Power**	**E/C Power Ratio**
Power measures (W)	(1) Yellow	347.5 ± 93.8	205.2 ± 71.1	0.6 ± 0.1	211.0 ± 49.3	78.6 ± 21.8	0.4 ± 0.1
	(2) Blue	449.3 ± 116.4	337.6 ± 103.1	0.7 ± 0.1	392.3 ± 347.5	133.5 ± 146.6	0.4 ± 0.1
	(3) Red	409.3 ± 95.7	274.1 ± 82.0	0.7 ± 0.1	416.0 ± 100.6	151.9 ± 35.5	0.4 ± 0.1
	(4) BlueWP	427.0 ± 118.8	241.9 ± 87.0	0.6 ± 0.1	898.3 ± 285.9	351.6 ± 106.3	0.4 ± 0.1
	(5) RedWP	414.3 ± 120.3	241.5 ± 83.1	0.6 ± 0.1	915.6 ± 298.7	392.7 ± 117.2	0.4 ± 0.1
	Pooled data	409.5 ± 117.2	260.1 ± 103.7	0.6 ± 0.1	565.3 ± 347.9	221.5 ± 146.7	0.4 ± 0.1

Table 2. Comparative analysis between criterion (MuscleLab) and practical (HandyGym) force measures (N).

		Criterion Measure (MuscleLab) (N)	**Practical Measure (HandyGym) (N)**	**Bias (Standardized)**	**TEE (Standardized)**	**Correlation**	**Correlation p Value**
Load	**(1) Yellow**	364.98 ± 123.26	125.98 ± 38.76	−1.94 [−2.01 to −1.86] (large)	0.85 [0.69 to 1.02] (large)	0.76 [0.7 to 0.82] (very large)	<0.001
	C	462.02 ± 86.79	155.25 ± 27.93	−3.53 [−3.66 to −3.41] (very large)	2.81 [1.91 to 4.73] (very large)	0.34 [0.21 to 0.46] (moderate)	<0.001
	E	268.59 ± 64.31	96.9 ± 22.84	−2.67 [−2.79 to −2.55] (very large)	1.49 [1.91 to 4.73] (very large)	0.56 [0.21 to 0.46] (large)	<0.001
	(2) Blue	503.4 ± 149.74	217.8 ± 76.41	−1.91 [−1.98 to −1.84] (large)	1 [0.69 to 1.02] (large)	0.71 [0.7 to 0.82] (very large)	<0.001
	C	588.19 ± 118.02	276.2 ± 57.33	−2.64 [−2.76 to −2.53] (very large)	1.62 [1.91 to 4.73] (very large)	0.53 [0.21 to 0.46] (large)	<0.001
	E	418.6 ± 128.79	159.41 ± 39.53	−2.01 [−2.13 to −1.89] (very large)	1.56 [1.91 to 4.73] (very large)	0.54 [0.21 to 0.46] (large)	<0.001
	(3) Red	545.19 ± 146.61	275.45 ± 87.49	−1.84 [−1.91 to −1.77] (large)	0.9 [0.69 to 1.02] (large)	0.74 [0.7 to 0.82] (very large)	<0.001
	C	639.32 ± 111.68	346.65 ± 60.53	−2.62 [−2.74 to −2.5] (very large)	1.98 [1.91 to 4.73] (very large)	0.45 [0.21 to 0.46] (moderate)	<0.001
	E	451.06 ± 113.24	204.24 ± 38.56	−2.18 [−2.29 to −2.07] (very large)	1.35 [1.91 to 4.73] (very large)	0.6 [0.21 to 0.46] (large)	<0.001
	(4) BlueWP	723.62 ± 223.82	474.21 ± 155.14	−1.11 [−1.16 to −1.07] (moderate)	0.48 [0.69 to 1.02] (moderate)	0.9 [0.7 to 0.82] (nearly perfect)	<0.001
	C	884.5 ± 161.22	597.19 ± 114.09	−1.78 [−1.87 to −1.69] (large)	0.87 [1.91 to 4.73] (large)	0.76 [0.21 to 0.46] (very large)	<0.001
	E	563.82 ± 150.95	352.06 ± 71.17	−1.4 [−1.49 to −1.32] (large)	0.55 [1.91 to 4.73] (moderate)	0.87 [0.21 to 0.46] (very large)	<0.001
	(5) RedWP	784.55 ± 241.37	553.12 ± 177.88	−0.96 [−1 to −0.91] (moderate)	0.51 [0.69 to 1.02] (moderate)	0.89 [0.7 to 0.82] (very large)	<0.001
	C	951.49 ± 189.23	678.13 ± 151.93	−1.44 [−1.53 to −1.36] (large)	0.81 [1.91 to 4.73] (large)	0.78 [0.21 to 0.46] (very large)	<0.001
	E	619.84 ± 160.64	429.77 ± 97.24	−1.18 [−1.26 to −1.1] (moderate)	0.68 [1.91 to 4.73] (large)	0.83 [0.21 to 0.46] (very large)	<0.001
Phase	**C**	704.29 ± 230.08	409.81 ± 217.64	−1.28 [−1.31 to −1.25] (large)	0.5 [0.42 to 0.57] (moderate)	0.9 [0.87 to 0.92] (very large)	<0.001
	E	464.25 ± 176.89	248.34 ± 137.54	−1.22 [−1.25 to −1.19] (large)	0.67 [0.42 to 0.57] (large)	0.83 [0.87 to 0.92] (very large)	<0.001
Pooled data		583.95 ± 237.63	328.86 ± 199.01	−1.07 [−1.09 to −1.05] (moderate)	0.51 [0.45 to 0.56] (moderate)	0.89 [0.87 to 0.91] (very large)	<0.001

The results are presented in three sections: the first section details the values corresponding to the five load configurations tested, including a sub-analysis for each specific phase of movement (C, concentric; E, eccentric); the second section provides a global analysis of the two phases; and the third section presents a pooled data analysis. Mean values and standard deviations for both measurement methods are reported, along with bias (the difference between an estimate and the true value), typical error of estimation (TEE, representing the magnitude of prediction errors), and Pearson correlation coefficients, all with 90% confidence intervals.

Figure 3 further illustrates these findings using scatter plots and Bland–Altman plots, comparing the force measured by HandyGym with the reference force from MuscleLab. High correlations (R^2 values ranging from 0.9316 to 0.9819) are evident across all resistance levels. However, the Bland–Altman plots reveal systematic biases that vary depending on the resistance level. With the exception of a few outliers, these biases are generally negative, indicating that HandyGym consistently underestimates force across conditions.

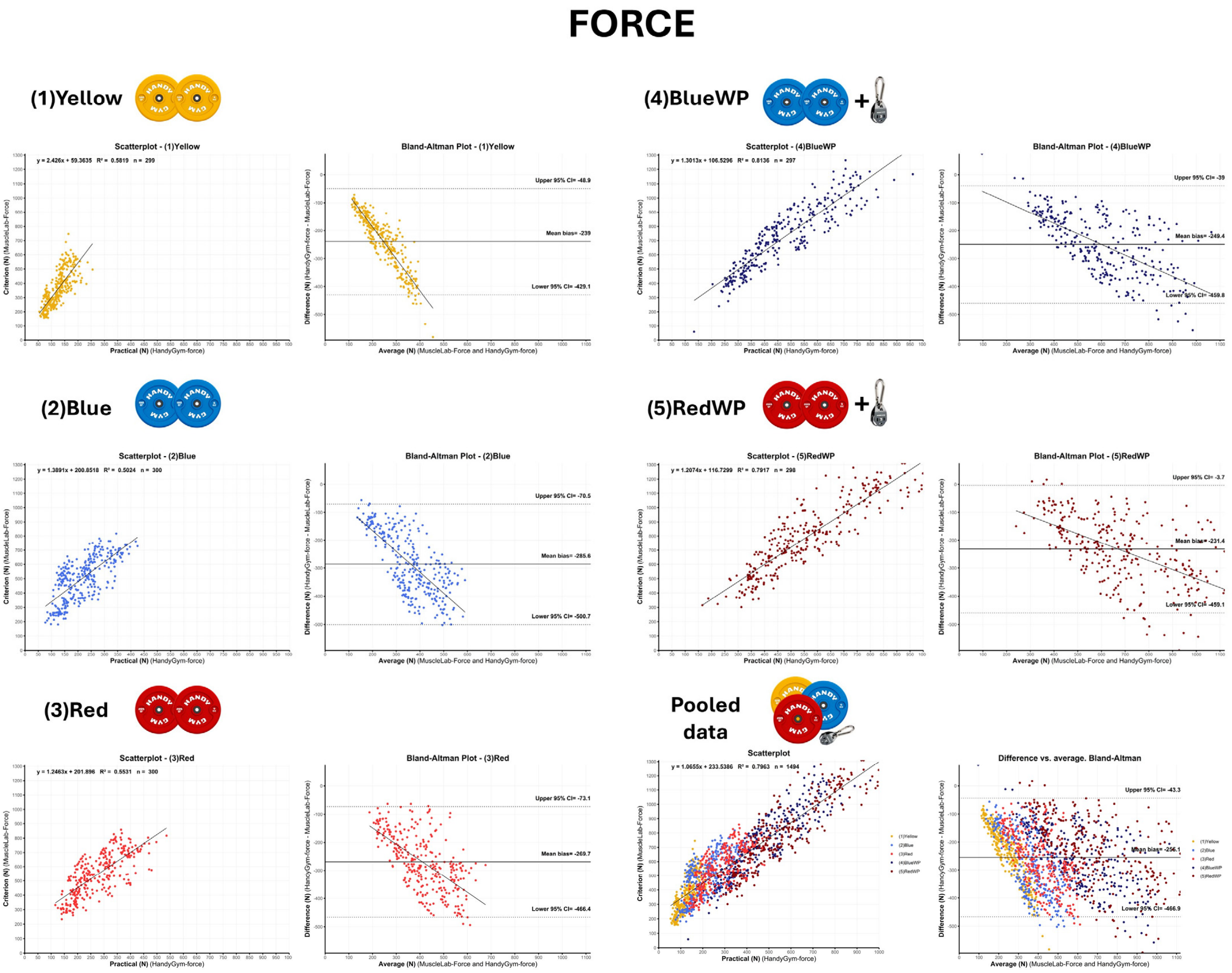


Figure 3. Scatterplots and Bland–Altman plots illustrating the agreement between the criterion and practical measures of force (N) across the five tested load configurations, as well as for the pooled data. The scales are consistent across all conditions. In the scatterplots, R^2 values and regression equations for estimating criterion measures from practical measures are provided. Regression lines are included to assess the homoscedasticity of errors. In the Bland–Altman plots, the difference between the two methods is plotted on the y-axis, with the average of the two methods on the x-axis. The solid horizontal line represents the mean bias, while the dashed horizontal lines indicate the upper and lower 95% limits of agreement.

Table 3 compares power measurements obtained using the MuscleLab system (criterion measure) and HandyGym (practical measure). The standardized bias in power ranges from “small” to “very large”, with significant positive biases in the BlueWP and RedWP conditions, where HandyGym tends to overestimate power compared to the criterion measure. TEE values range from “moderate” to “very large”, reflecting variability in the accuracy of the practical measure. Correlation coefficients indicate a strong relationship in most conditions, except during the eccentric phase, where the correlation is “small”. All correlations are statistically significant ($p < 0.001$).

Table 3. Comparative analysis between criterion (MuscleLab) and practical (HandyGym) power measures (W).

		Criterion Measure (MuscleLab) (W)	Practical Measure (HandyGym) (W)	Bias (Standardized)	TEE (Standardized)	Correlation	Correlation *p* Value
Load	**(1) Yellow**	276.1 ± 109.46	144.55 ± 76.44	−1.2 [−1.26 to −1.14] (large)	0.8 [0.65 to 0.97] (large)	0.78 [0.72 to 0.84] (very large)	<0.001
	C	347.52 ± 93.79	210.98 ± 49.34	−1.46 [−1.57 to −1.34] (large)	1.44 [1.07 to 1.93] (very large)	0.57 [0.46 to 0.68] (large)	<0.001
	E	205.16 ± 71.11	78.56 ± 21.75	−1.78 [−1.89 to −1.67] (large)	1.27 [1.07 to 1.93] (very large)	0.62 [0.46 to 0.68] (large)	<0.001
	(2) Blue	393.46 ± 142.51	262.87 ± 155.56	−0.92 [−1 to −0.84] (moderate)	1.08 [0.65 to 0.97] (large)	0.68 [0.72 to 0.84] (large)	<0.001
	C	449.3 ± 129.15	392.26 ± 114.54	−0.44 [−0.53 to −0.35] (small)	0.83 [1.07 to 1.93] (large)	0.77 [0.46 to 0.68] (very large)	<0.001
	E	337.62 ± 133.4	133.48 ± 41.61	−1.53 [−1.64 to −1.42] (large)	0.81 [1.07 to 1.93] (large)	0.78 [0.46 to 0.68] (very large)	<0.001
	(3) Red	341.68 ± 111.82	283.95 ± 152.19	−0.52 [−0.59 to −0.44] (small)	0.74 [0.65 to 0.97] (large)	0.8 [0.72 to 0.84] (very large)	<0.001
	C	409.27 ± 95.74	415.99 ± 100.58	0.07 [−0.03 to 0.17] (trivial)	0.87 [1.07 to 1.93] (large)	0.75 [0.46 to 0.68] (very large)	<0.001
	E	274.09 ± 82.01	151.9 ± 35.49	−1.49 [−1.59 to −1.39] (large)	0.81 [1.07 to 1.93] (large)	0.78 [0.46 to 0.68] (very large)	<0.001
	(4) BlueWP	334.12 ± 139.25	624.05 ± 348.17	2.08 [1.93 to 2.24] (very large)	0.38 [0.65 to 0.97] (moderate)	0.94 [0.72 to 0.84] (nearly perfect)	<0.001
	C	427.02 ± 118.79	898.31 ± 285.94	3.97 [3.76 to 4.18] (very large)	0.4 [1.07 to 1.93] (moderate)	0.93 [0.46 to 0.68] (nearly perfect)	<0.001
	E	241.85 ± 86.96	351.63 ± 106.31	1.26 [1.2 to 1.33] (large)	0.39 [1.07 to 1.93] (moderate)	0.93 [0.46 to 0.68] (nearly perfect)	<0.001
	(5) RedWP	327.32 ± 134.59	652.37 ± 345.89	2.42 [2.26 to 2.57] (very large)	0.35 [0.65 to 0.97] (moderate)	0.94 [0.72 to 0.84] (nearly perfect)	<0.001
	C	414.28 ± 120.28	915.58 ± 298.73	4.17 [3.95 to 4.38] (very large)	0.35 [1.07 to 1.93] (moderate)	0.94 [0.46 to 0.68] (nearly perfect)	<0.001
	E	241.53 ± 83.15	392.68 ± 117.18	1.82 [1.73 to 1.9] (large)	0.44 [1.07 to 1.93] (moderate)	0.92 [0.46 to 0.68] (nearly perfect)	<0.001
Phase	**C**	409.5 ± 117.16	565.27 ± 347.94	1.33 [1.17 to 1.49] (large)	1.59 [1.39 to 1.82] (very large)	0.53 [0.48 to 0.58] (large)	<0.001
	E	260.07 ± 103.68	221.48 ± 146.74	−0.37 [−0.46 to −0.28] (small)	3.79 [1.39 to 1.82] (very large)	0.26 [0.48 to 0.58] (small)	<0.001
Pooled data		334.59 ± 133.46	392.92 ± 317.31	0.44 [0.35 to 0.52] (small)	1.32 [1.21 to 1.44] (very large)	0.6 [0.57 to 0.64] (large)	<0.001

The results are presented in three sections: the first section details the values corresponding to the five load configurations tested, including a sub-analysis for each specific phase of the movement (C, concentric; E, eccentric); the second section provides a global analysis of the two phases; and the third section presents a pooled data analysis. Mean values and standard deviations for both measurement methods are reported, along with bias (the difference between an estimate and the true value), typical error of estimation (TEE, representing the magnitude of prediction errors), and Pearson correlation coefficients, all with 90% confidence intervals.

Figure 4 visually supports these results, showing that while high correlations are maintained (R^2 values ranging from 0.8976 to 0.9871), Bland–Altman plots reveal biases that vary by resistance level. Lower load conditions (Yellow, Blue, Red) show negative biases, indicating power underestimation, whereas higher load conditions (BlueWP, RedWP) exhibit positive biases, with overestimations increasing alongside the magnitude of power.

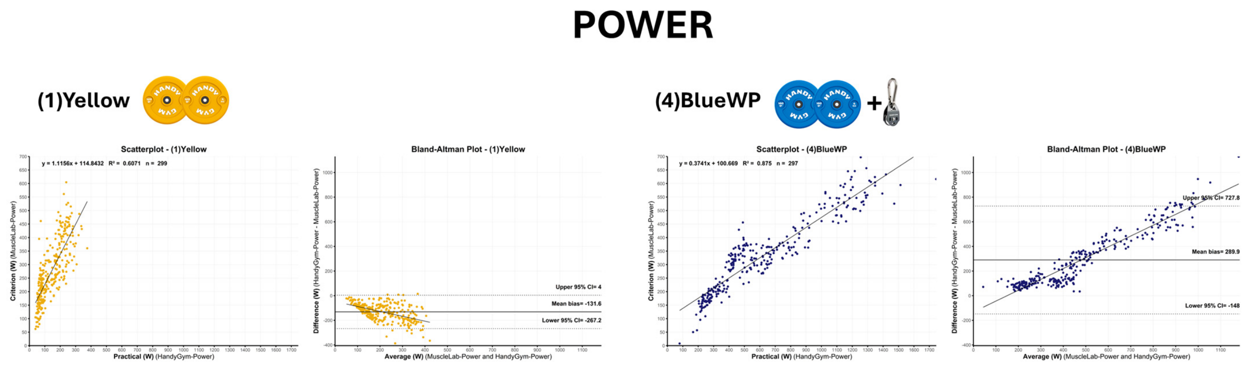


Figure 4. *Cont.*

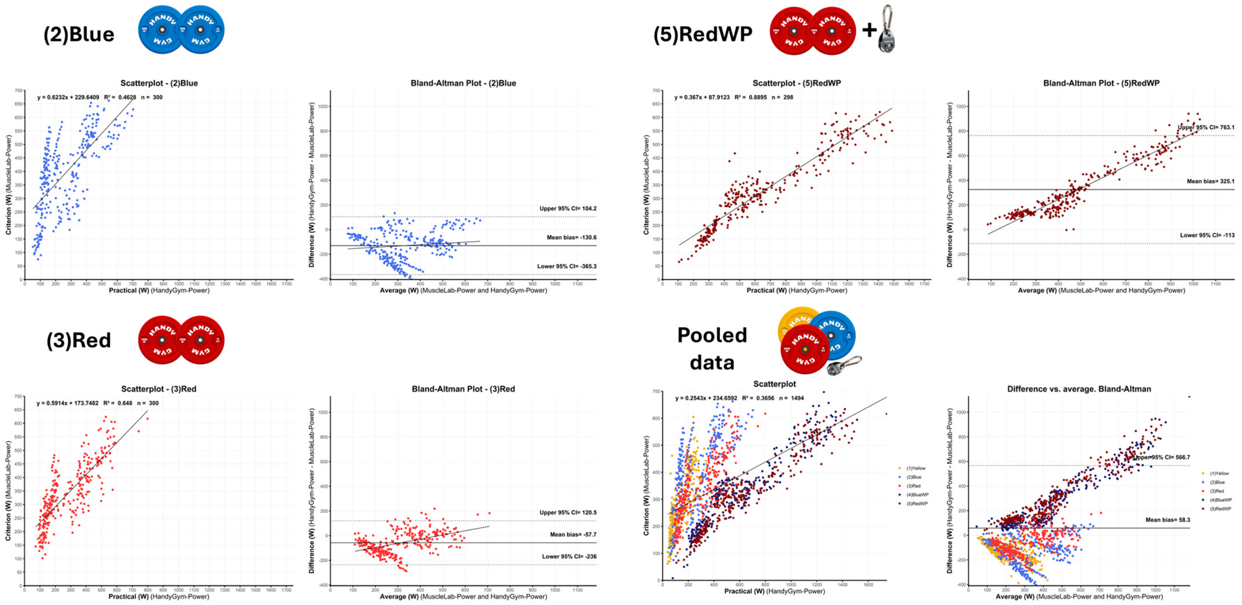


Figure 4. Scatterplots and Bland–Altman plots illustrating the agreement between the criterion and practical measures of power (W) across the five tested load configurations, as well as for the pooled data. The scales are consistent across all conditions. In the scatterplots, R^2 values and regression equations for estimating criterion measures from practical measures are provided. Regression lines are included to assess the homoscedasticity of errors. In the Bland–Altman plots, the difference between the two methods is plotted on the y-axis, with the average of the two methods on the x-axis. The solid horizontal line represents the mean bias, while the dashed horizontal lines indicate the upper and lower 95% limits of agreement.

4. Discussion

The main findings of this study indicate that while correlations between the two systems are consistently high, significant systematic and random biases are present, varying according to the parameter assessed, the resistance configuration, and the phase of the movement [48]. A certain level of bias and TEE is inherent in systems that evaluate mechanical parameters in isoinertial exercises based on rotational speed, as this speed does not perfectly correlate with the mechanical parameters being assessed [25,27,33].

In the present study, the highest (RedWP) and lowest (Yellow) resistance levels offered by the system were used, along with three intermediate loads, to cover the full force-velocity spectrum provided by HandyGym [43]. Despite its compact size compared to other isoinertial systems, the average force levels produced during exercise (Table 1) were substantial, though lower than those reported in studies involving squat and half-squat exercises with other isoinertial systems [15,33,44,50–53]. It is important to note that participants were not instructed to attempt eccentric overload (i.e., by delaying the braking action) [14]. As a result, the E/C ratio was 0.7 for average force and 0.6 for average power, indicating no eccentric overload [26]. These values are expected for this type of system, as the measured values represent averages of force and power, and ratios tend to be higher when peak values are assessed [33].

In terms of force measurements, correlations between HandyGym and MuscleLab were predominantly "very large" to "almost perfect" across different loading conditions and in the pooled data, suggesting that the device is capable of tracking general trends in force measurements (Table 2). This is consistent with findings for other previously validated rotary encoders [29,32,39,40]. However, Bland–Altman plots reveal a negative bias across all tested loading configurations, indicating that HandyGym systematically underestimates force compared to the reference system (Figure 3). This bias is particularly pronounced in the lower load configurations (Yellow, Blue, and Red; large bias) and diminishes in configurations with load-multiplying pulleys (BlueWP and RedWP; moderate bias). Additionally, random error, as assessed by TEE, was generally moderate but tended to be higher in the lower load configurations (Yellow, Blue, and Red; large TEE). These findings are significant as they suggest that the device may be more accurate when higher resistances are used but less reliable with lower loads. This discrepancy may be due to the fact that lower inertias require quicker transitions from the concentric to the eccentric phase, resulting in less precise control over transition timing and increased variability [29]. When analyzing the exercise phases, bias and TEE were similar between the concentric and eccentric phases, indicating no greater accuracy in estimating one phase over the other. Overall, based on the pooled data in Table 1, the bias and TEE for force measurements can be considered moderate.

Regarding power measurements, the results show high correlations between HandyGym and MuscleLab but with a different bias pattern. In low-load configurations (Yellow, Blue, and Red), HandyGym tends to underestimate generated power, while in high-load configurations (BlueWP and RedWP), the device significantly overestimates power (Table 3). This pattern highlights a limitation in HandyGym's ability to provide accurate power measurements across the load spectrum, especially in high-resistance conditions, where overestimations could lead to misinterpretations of user performance. This is crucial in professional practice, where incremental load protocols are often used to determine the load that elicits peak concentric power [23,54]. If relying solely on the integrated encoder, one might mistakenly conclude that the load eliciting the highest concentric power was the highest moment of inertia (RedWP), whereas the reference system shows it was a low-intermediate load (Blue). The power results from the reference system align more closely with previous studies using similar moments of inertia in flywheel squats with trained subjects [43,44].

In some loading conditions, power bias is negative, while in others, it is positive, resulting in a small average bias in the pooled data. However, the correlation for power measurements is lower than for force (0.6), and the TEE is very large (1.32). The high random error, combined with varying bias dynamics across load conditions, makes it challenging to compare data from different loading configurations, especially between those using a load-multiplying pulley and those without. Notably, the Red condition presents the lowest bias, although TEE values remain large. Conversely, despite a very large positive bias in high-load conditions (BlueWP and RedWP), the random error (TEE) was moderate and lower than in other load conditions. Therefore, while power values differ significantly from the reference system, evaluating the trend of exercise series in load-multiplying pulley conditions (BlueWP and RedWP) is more accurate than in non-pulley conditions, provided corrections are applied using a regression equation (Figure 4) [48].

We did not observe a clear pattern in measurement validity between phases. However, in the eccentric phase (Table 3), a very large TEE and small correlation were observed, indicating low measurement accuracy. This may not be evident when analyzing each load condition separately but could be due to an E/C ratio of less than 1 (Table 1), as different submaximal braking techniques during the eccentric phase, with varying peak joint angular velocities of the knee, trunk, and hip, may affect the mechanical impulse required to stop the flywheel within the range of motion, increasing technique variability (i.e., progressive or delayed braking) [27,44]. Additionally, during the concentric phase, the rope tension is generally constant, while during braking, slack in the rope can cause execution velocity (a key parameter for calculating power) to decouple from the rotational speed of the axis, where the rotary encoder is located [25]. Moreover, a tight initial rope setting may facilitate smoother transitions between eccentric and concentric phases at higher inertia, but it can hinder fluid transitions at lower inertia and higher velocities [29].

The presence of significant bias in both force and power measurements, whether negative or positive, raises questions about HandyGym's applicability in contexts where measurement accuracy is critical, such as elite athlete performance monitoring, rehabilitation protocols, scientific research, or power testing with progressive loads [27]. Although the device generally shows a strong correlation with a well-established reference system, the observed underestimations and overestimations may limit its practical utility. HandyGym consistently provides lower force values than the reference system across various loading conditions, with a very large correlation in the pooled data. Therefore, in contexts where precision is less critical, force values can be used as real-time feedback to enhance athlete engagement and to estimate applied force across different loading conditions or throughout the exercise series [4,5]. However, practitioners should take into account the moderate negative bias and TEE when interpreting these results. In contrast, the power values obtained from HandyGym's encoder do not demonstrate sufficient consistency for comparing performance across different loads due to varying bias dynamics. Power tends to be overestimated in load-multiplying pulley conditions (BlueWP and RedWP) and underestimated in the remaining load configurations.

This study has several limitations that may have influenced the validity of the measurements but were not specifically investigated. First, the sample size was limited to 10 participants. Future studies with larger samples from various sporting environments could improve the generalizability of the results. In terms of execution technique, although all participants received identical instructions, slight variations in braking techniques may have occurred due to individual differences. To the authors' knowledge, no studies have specifically examined the validity of performance measurements in isoinertial exercises based on execution techniques, such as delayed braking for eccentric overload versus maintaining constant tension, though this may be a contributing factor [14]. Additionally, due to the system's characteristics, which multiply the load via an internal gear system, greater friction between components may occur compared to other isoinertial systems. Factors such as internal device lubrication could increase variability in resistance between devices, potentially affecting the validity of force and power measurements. A limitation of this study is that only one HandyGym unit was evaluated. A more detailed discussion of the mechanical characteristics of the system, such as friction and gear ratios, would enhance the understanding of the observed biases. However, the system does not provide sufficient technical specifications to allow for in-depth analysis of these factors. Lastly, mechanical factors such as the vertical angle of the rope pull, harness compliance, and rope tension at the starting position of the squat may have contributed to discrepancies in the measured parameters [29]. Nonetheless, as outlined in Section 2, efforts were made to ensure protocol consistency and provide the best possible conditions for accurate measurements.

5. Conclusions

In conclusion, while HandyGym provides a highly practical and accessible system for isoinertial training, its force and power measurements should be interpreted with caution. Unlike other devices [32], we recommend monitoring force rather than power values with this device, as force measurements have demonstrated greater validity and consistency across different load conditions. HandyGym consistently reports lower force values than the reference system and exhibits a moderate typical error of estimation. Therefore, we do not recommend using the integrated encoder with the current software version when high precision is required. However, HandyGym can be a valuable tool for real-time monitoring if the goal is to enhance athlete engagement during training sessions [5], provided that the reported bias and TEE are considered. To improve the applicability of HandyGym, applying correction equations or adjustments based on the specific characteristics of each load configuration would enable more valid and reliable assessments.

Practical applications: HandyGym is a promising tool for isoinertial training due to its versatility, portability, and accessibility. While its resistance levels are lower than those of other isoinertial systems, they are substantial given the system's reduced mass and volume. The integrated encoder can be useful in training contexts where absolute measurement precision is not critical. In scenarios where the primary goal is to provide real-time feedback and boost athlete motivation, the force measurements provided by the system are suitable. It is recommended to rely on the force measurements for this feedback, as they have shown greater validity than power values. However, in situations where improving measurement validity and reducing systematic error is essential—such as regular testing in training environments—adjusting the obtained measurements is advised. Applying corrections based on regression equations from research is recommended, as the values obtained by HandyGym tend to underestimate the actual applied force. The regression equations provided in Figure 3 scatterplots can be applied to estimate the criterion force measurements and reduce bias. To do this, use the regression equation corresponding to the specific load configuration, where x represents the practical measure obtained from HandyGym and y represents the corrected criterion value. For more precise applications, such as research or force-velocity profiling with progressive loads, it is recommended to use other measurement tools with less bias and TEE.

To improve the validity of HandyGym's force and power measurements across different load conditions, potential optimization lies in enhancing the data processing algorithms used to calculate performance metrics. By developing and integrating more sophisticated algorithms, it may be possible to account for the systematic biases and random errors currently observed, particularly in power measurements, where deviations from the reference system are most pronounced. For example, machine learning algorithms could be employed to model and predict patterns in the data, adjusting for inconsistencies introduced by the device's physical limitations or variability in user technique. Future research could therefore focus on enhancing the validity of the encoder to address these biases and errors, making the device more suitable for professional and testing environments.

Supplementary Materials: The complete dataset of this study can be downloaded as an Excel file in the supporting information at: https://www.mdpi.com/article/10.3390/app14219832/s1.

Author Contributions: Conceptualization and methodology, V.I.-D. and B.F.-V.; formal analysis, V.I.-D., X.F.-A., V.T.-R., S.D.-A. and B.F.-V.; investigation, V.I.-D., X.F.-A., V.T.-R., S.D.-A., C.P.-C.; L.A.-A., S.G.-M. and B.F.-V.; data curation, V.I.-D., X.F.-A., V.T.-R., S.D.-A., C.P.-C.; L.A.-A., S.G.-M. and B.F.-V.; writing—original draft preparation, V.I.-D.; writing—review and editing, V.I.-D., X.F.-A., V.T.-R., S.D.-A., C.P.-C.; L.A.-A., S.G.-M. and B.F.-V.; visualization, V.I.-D., X.F.-A. and B.F.-V.; supervision, V.I.-D. and B.F.-V. All authors have read and agreed to the published version of the manuscript.

Funding: V.T.-R. is the recipient of a postdoctoral grant from the "Pla de recuperació, transformació i resiliència-Next Generation EU (200015ID3)".

Institutional Review Board Statement: This study was reviewed and approved by the Ethics Committee of the TecnoCampus Mataró Foundation (Approval code: CEI 5/2022, Date of approval: 10/11/2023). The study was conducted in accordance with the ethical standards outlined in the Declaration of Helsinki. All participants provided their written informed consent to participate in this study.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is contained within the article or Supplementary Materials.

Acknowledgments: We thank the participants of the study for their collaboration.

Conflicts of Interest: The authors declare no conflicts of interest.

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