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Test-Retest and Inter-Rater Reliability of a Rotary Axis Encoder-Flywheel System for the Assessment of Hip Rotation Exercises

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Abstract: Background: Flywheel devices have found extensive use as a resistance training method. Performance monitoring during functional exercises can be achieved through a coupled rotary axis encoder. However, the reliability of a rotary axis encoder-flywheel system remains underexplored for isolated movements. This study aims to assess test-retest and inter-rater reliability of a rotary axis encoder-flywheel system for assessing hip rotation movements. Methods: Twenty-nine physically active participants were included. The Conic Power Move® flywheel was used to perform hip internal and external rotation exercises. Mean and peak values for velocity, force, and power were collected using a Chronojump rotary axis encoder and the Chronojump software v.2.2.1. The intraclass correlation coefficient (ICC) and the coefficient of variation (CV) were calculated to assess relative and absolute reliability, respectively. Standard error of measurement and minimum detectable changes were also calculated. Results: Good to excellent ICCs (0.85–0.98) were achieved for test-retest and inter-rater reliability in all outcomes for both hip internal and external rotation exercises. There was acceptable test-retest absolute reliability (CV < 10%) for mean and peak velocity, and mean force of hip internal and external rotation (CV = 4.7–7%). Inter-rater absolute reliability was acceptable for mean and peak velocity, mean power, and mean force (CV = 4.7–9.8%). Conclusion: The rotational encoder-flywheel system demonstrated good to excellent relative reliability for assessing hip rotation exercises. Peak force and power values exhibit absolute reliability >10%, so the use of mean and peak velocity, mean force, and mean power seems more adequate for measurements with the rotary axis encoder-flywheel system.

Keywords: flywheel device; rotary axis encoder; reliability; rotation exercises; assessment

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1. Introduction

Muscle function is considered a basic physical quality necessary for the development of physical performance and the prevention of a wide variety of injuries [1,2]. Strength, velocity, and power data are the most evaluated characteristics of muscle function that provide information about the current status of the patients [3,4]. Depending on the instrument, the muscle function can be assessed isometrically or dynamically using different methods: (i) isometric dynamometers (hand-held dynamometers- HHDs); (ii) isokinetic dynamometers (IDs); and (iii) isoinertial devices. HHDs and IDs are considered the main tools for assessing strength and power [4–6].

HHDs are known as a cost-effective option for the assessment of isometric muscle strength and power, while IDs represent the gold standard for assessing lower limb dynamic strength, also providing data on velocity and endurance [3,4]. Isoinertial technology like flywheel devices is based on the implementation of non-gravitational movements by creating mechanical overload in the eccentric phase throughout the concentric phase [7].

They have become a useful option for resistance training, due to their immediate effect in post-activation potentiation (PAP), obtaining greater responses than power or conventional training [8]. Moreover, this type of training promotes neuromuscular adaptations, and also enhances muscle strength, power, and hypertrophy [2,7,9–11]. Notwithstanding, flywheel devices have not been used as assessment tools in clinical settings yet.

Flywheel devices can be used attached to linear and rotary axis encoders. Linear encoders allow the analysis of kinematics based on concentric and eccentric phases to be evaluated separately [10,12]. Rotary encoders are devices connected to the main axis of rotation, which are used to monitor kinematic data during the execution of flywheel exercises. They primarily provide pooled concentric-eccentric information related to angular velocity, supplying data of force and power [10,13]. Consequently, rotary axis encoders could identify intraindividual changes and compare performance development between subjects [14,15].

The encoder-flywheel system has shown adequate validity when compared to IDs [16,17]. Nevertheless, the reliability of these devices has only contrasted for functional movements like squats or quarter squats [7,10,18,19]. The reliability of physical performance tests depends not only on the joint and the executed movement, but also on the measurement protocol, including the assessment position and the fixation system, like with IDs [4].

In relation to the hip, the reliability during dynamic tasks involving flexion, extension, abduction, and adduction movements has been analyzed through IDs. However, hip rotatory movements appear to be scarcely analyzed across reliability studies [4,20]. This limitation must be overcome due to their important role both for joint assessment and as a part of prevention protocols and therapeutic exercises in patients with diverse pathologies of lumbopelvic complex [21,22]. In this sense, weakness and imbalance of internal/external rotator muscles can give rise to: (i) low back pain [23]; (ii) pelvic, hip, and knee instability during stance [21,24,25]; (iii) hip pain and hip related groin pain; (iv) anterior cruciate ligament injury; and patellofemoral dysfunction [21,25]. Therefore, active hip mobility assessment appears to be an important key aspect to detect muscle function abnormalities.

Flywheel devices can be incorporated as part of their examination. Nevertheless, the use of the rotary axis encoder-pulley system has not been investigated as a measurement method for hip internal and external rotation exercises.

Considering the lack of scientific literature on the establishment of a reliable protocol to evaluate internal and external rotation exercises using IDs, flywheel technology appears to be a suitable alternative to measure these movements. Until now, this system has been primarily used for training purposes, and there is a lack of reliable protocols for measuring kinematic data of isolated rotatory movements. Therefore, the aim of this study was to analyze the test-retest and inter-rater reliability of a rotary axis encoder-flywheel system for assessing velocity, power, and strength during hip internal and external rotation exercises in healthy young adults.

2. Materials and Methods

2.1. Study Design

A reliability study was designed in accordance with the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) [26]. This study received approval from the Research Ethics Committee of Valladolid Este (code: PI 23-3010). All procedures followed the ethical principles of the Helsinki Declaration for research involving human subjects.

The inclusion criteria were: (1) asymptomatic participants between 18 and 30 years, (2) without any pain or pathology, (3) and engaged in regular sports practice (a minimum of three training sessions per week, each lasting at least 30 min). Individuals with a history of hip or knee surgery, the use of analgesics or muscle relaxants, or prior physiotherapy treatment within the last month were excluded.

2.2. Sample Size

The sample size calculation was conducted using the web-based Sample Size Calculator developed by Arifin for reliability studies [27]. A total of 29 participants were estimated to be necessary to achieve statistical significance of 0.05, a power (1–β) of 80%, and an expected dropout rate of 10%. The number of examiners/repetitions per patient (k) was set to 2, with a minimally acceptable intraclass correlation coefficient (ICC) of 0.75 and an expected ICC of 0.9.

2.3. Outcome Measurement

Data were recorded with the Chronojump rotary axis encoder and analyzed using Chronojump software v.2.2.1 (Chronojump Boscosystem, Barcelona, Spain). The software was configured to record the average of the three best attempts for each set. Mean and peak values of an entire repetition (combining concentric and eccentric phases) were collected for velocity, force, and power.

2.4. Inertial Flywheel Measurement Protocol

The Conic Power Move® flywheel (TMR World, Barcelona, Spain) was used to perform the hip rotation exercises. The flywheel (mean diameter: 7.5 cm) was arranged horizontally fixed to the wall 7 cm above the floor with an attached load (weight: 460 g; axis distance: 15 cm). The sliding frame of the device was fixed in the upper middle position.

Participants were seated on a hydraulic table, elevated to 75 cm from the floor, with their knees and hips flexed at 90°. They were instructed not to touch the ground with their feet, to cross their hands on their shoulders, and to maintain the pelvis in a neutral position. An ankle brace was applied to the assessed leg and coupled to the flywheel cable with a carabiner. The examiner adjusted the cable length to the amplitude of maximum active range hip rotation. Three belts were used to fix the participants: one belt secured the distal region of the femur of the assessed leg to avoid undesired hip movements, while two belts fixed the anterior superior iliac spines to prevent associated spine movements (Figure 1).

Figure 1. Patient position for the hip rotation measurement.

The assessed hip (left or right) and the order of hip rotation (internal or external) were randomized using a coin toss. Prior to the assessment, participants performed two sets of 10 warm-up flywheel exercises for each hip rotation, gradually increasing the intensity. In the assessment period, the participants performed 3 repetitions at progressive intensity, followed by 7 high-intensity repetitions recorded by the encoder. They were instructed to perform the concentric phase as fast as possible, while in the eccentric phase, they had to counteract the inertia generated by the flywheel. The procedure was repeated for the other hip rotation, with a 5-min rest period provided between sets to ensure full recovery [2,7]. The examiner instructed the participants on the hip rotation movement under the flywheel mechanism and encouraged them to perform the repetitions recorded by the encoder at maximal intensity. The repetition rate was determined by each participant's ability to perform the exercise.

2.5. Procedure

Participants attended two sessions within a week: a first session to familiarize with the flywheel exercise and a second session to perform the measurement. Prior to the first session, participants signed an informed consent form, and socio-demographic data, including sex, height, weight, and body mass index were recorded. In the familiarization session, participants performed the warm-up followed by the flywheel hip rotation exercises, similar to the measurement session.

The measurement session involved two examiners assessing the participants. After the warm-up, each participant was assessed by Examiner 1. Then, Examiner 2 performed an independent assessment to determine inter-rater reliability. Both examiners were blinded to the assessment of each other.

To assess test-retest reliability, Examiner 1 conducted a second measurement. A 30-min period between measurements of Examiner 1 was ensured to minimize memory bias or recall of previous measurements [28,29]. The measurement protocol (patient position, belt adjustment) was restarted after each attempt.

2.6. Statistical Analysis

The Statistical Package for the Social Sciences (IBM, Chicago, IL, USA) software v.26.0 for Windows was utilized for data analysis. Means (M) and standard deviations (SDs) were calculated for the quantitative analysis. ICCs with a 95% confidence interval (CI) were used to analyze relative test-retest and inter-rater reliability. The interpretation of ICC values followed the criteria established by Koo and Li [30]: ICC > 0.9 indicated excellent reliability, 0.75–0.9 indicated good reliability, 0.75–0.50 indicated moderate reliability, and ICC < 0.5 indicated low reliability. The absolute reliability was assessed using the coefficient of variation (CV), which was calculated by dividing the standard deviation (SD) by the mean (M) of the repeated measures, and then multiplying by 100. Acceptable absolute reliability was defined as a CV < 10%. The standard error of measurement (SEM) was obtained using the formula: $SEM = SD \times \sqrt{(1 - ICC)}$. The relative SEM (SEM%= SEM/computed M × 100) was also calculated. The minimum detectable change (MDC) was determined by the formula: $MDC = 1.96 \times \sqrt{2} \times SEM$.

3. Results

All participants completed the measurement protocol. The included participants (13 men, 16 women) presented a mean age of 21.62 ± 2.02 years, a mean height of 169.21 ± 9.57 cm, a mean weight of 65.07 ± 12.96 kg, and a mean body mass index of 22.53 ± 2.84 kg/m^2. Fifteen right hips and fourteen left hips were analyzed. A total of 1.218 repetitions were registered in the Chronojump software, out of which 522 were analyzed.

3.1. Test-Retest Reliability

The test-retest reliability for hip external rotation demonstrated ICC values ranging from 0.95 to 0.98 for all outcome variables, which indicates excellent test-retest reliability. For hip internal rotation, there was excellent test-retest reliability in mean and peak velocity (ICC = 0.93, 95%CI = 0.85–0.97), and mean power and mean force (ICC = 0.96, 95%CI = 0.92–0.98). There was good reliability for peak power (ICC = 0.89, 95%CI = 0.75–0.94) and peak force (ICC = 0.86, 95%CI = 0.69–0.94). Test-retest absolute reliability was acceptable for mean and peak velocity, and mean force of hip internal and external rotation (CV = 4.7–7%), but was unacceptable for mean and peak power, and peak force of both external and internal rotation (CV = 10.6–18.6%). ICC, SEM, MCD, and CV values of test-retest reliability are detailed in Table 1.

Table 1. Test-retest reliability of the flywheel-encoder system for hip external and internal rotation.

	Variables	Test 1 (M ± SD)	Test 2 (M ± SD)	ICC (95% CI)	SEM	SEM%	MDC	CV (%)
ER	V (m/s)	0.55 (0.08)	0.56 (0.08)	0.95 (0.89–0.98)	0.02	3.58	0.06	6.9
	Vmax (m/s)	0.71 (0.12)	0.72 (0.11)	0.97 (0.93–0.99)	0.02	2.80	0.06	5.6
	P (W)	47.93 (20.92)	48.13 (21.33)	0.98 (0.96–0.99)	2.95	6.14	8.18	12.0
	Pmax (W)	143.95 (66.93)	151.39 (66.68)	0.97 (0.93–0.99)	11.47	7.78	31.79	18.6
	F (N)	130.62 (34.16)	130.90 (34.90)	0.98 (0.96–0.99)	4.84	3.70	13.42	7.0
	Fmax (N)	480.72 (128.97)	503.45 (118.15)	0.95 (0.89–0.98)	27.50	5.59	76.23	12.0
IR	V (m/s)	0.64 (0.06)	0.65 (0.06)	0.93 (0.85–0.97)	0.02	3.08	0.05	4.7
	Vmax (m/s)	0.86 (0.08)	0.85 (0.08)	0.93 (0.85–0.97)	0.02	2.35	0.06	4.9
	P (W)	72.98 (20.82)	71.95 (22.31)	0.96 (0.92–0.98)	4.01	5.50	11.12	10.6
	Pmax (W)	190.39 (63.94)	213.91 (66.96)	0.89 (0.75–0.94)	21.86	10.81	60.59	18.2
	F (N)	169.55 (32.30)	169.61 (30.66)	0.96 (0.92–0.98)	6.24	3.68	19.18	6.9
	Fmax (N)	550.93 (126.38)	590.60 (120.28)	0.86 (0.69–0.94)	46.33	8.12	128.42	15.6

ER: external rotation; IR: internal rotation; M: mean; SD: standard deviation; ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement; SEM%: relative standard error of measurement; MDC: minimal detectable change; CV: coefficient of variation; V: velocity; Vmax: peak velocity; P: power; Pmax: peak power; F: force; Fmax: peak force.

3.2. Inter-Rater Reliability

The inter-rater reliability for hip external rotation was excellent (ICC = 0.95–0.98) for all the outcome variables. The inter-rater reliability was excellent in all the outcomes for hip internal rotation (ICC = 0.91–0.97), except for peak power (ICC = 0.85, 95%CI = 0.66–0.93), which showed good reliability. The absolute reliability was acceptable for all variables (CV = 4.7–9.8%) except for peak power and peak force of external and internal rotation (CV = 11–16.9%). Inter-rater ICC, SEM, MCD, and CV values are detailed in Table 2.

Table 2. Inter-rater reliability of the flywheel-encoder system for hip external and internal rotation.

	Variables	Test 1 (M ± SD)	Test 2 (M ± SD)	ICC (95% CI)	SEM	%SEM	MDC	CV (%)
ER	V (m/s)	0.55 (0.08)	0.55 (0.08)	0.95 (0.89–0.98)	0.02	3.63	0.06	6.2
	Vmax (m/s)	0.71 (0.12)	0.70 (0.10)	0.97 (0.94–0.99)	0.02	2.83	0.06	4.8
	P (W)	47.93 (20.92)	46.02 (18.65)	0.98 (0.96–0.99)	2.78	5.92	7.71	9.8
	Pmax (W)	143.95 (66.93)	142.53 (54.58)	0.95 (0.89–0.98)	13.52	9.46	37.47	15.5
	F (N)	130.62 (34.16)	128.03 (32.07)	0.98 (0.96–0.99)	4.64	3.59	12.86	6.1
	Fmax (N)	480.72 (128.97)	480.72 (128.96)	0.95 (0.90–0.98)	27.35	5.72	75.81	11.0
IR	V (m/s)	0.64 (0.06)	0.64 (0.07)	0.91 (0.81–0.96)	0.02	3.12	0.06	5.5
	Vmax (m/s)	0.86 (0.08)	0.84 (0.09)	0.94 (0.88–0.97)	0.02	2.35	0.06	4.7
	P (W)	72.98 (20.82)	71.95 (22.31)	0.97 (0.94–0.99)	3.70	5.11	10.26	9.0
	Pmax (W)	190.39 (63.94)	191.26 (70.64)	0.85 (0.66–0.93)	25.85	13.55	71.65	16.9
	F (N)	169.55 (32.30)	167.97 (35.61)	0.98 (0.95–0.99)	4.36	2.58	12.09	6.0
	Fmax (N)	550.93 (126.38)	553.76 (141.26)	0.91 (0.80–0.96)	39.83	7.21	110.40	11.9

ER: external rotation; IR: internal rotation; M: mean; SD: standard deviation; ICC: intraclass correlation coefficient; CI: confidence interval; SMD: standard error of measurement; SEM%: relative standard error of measurement; MDC: minimal detectable change; CV: coefficient of variation; V: velocity; Vmax: peak velocity; P: power; Pmax: peak power; F: force; Fmax: peak force.

4. Discussion

This study aimed to assess the test-retest and inter-rater reliability of a rotary axis encoder-flywheel system for assessing hip rotation exercises. These results demonstrate good to excellent relative reliability for hip external and internal rotation in mean and peak velocity, power, and force.

Previously examined linear encoders have reported acceptable reliability for power, force, and velocity during free-weight exercises such as jumps [31], squats [32–34], and bench press [33]. Additionally, some studies have focused on the reliability of the encoder-flywheel system. Maroto-Izquierdo et al. [10] and Martín-Rivera et al. [12] achieved an ICC exceeding 0.88 when assessing velocity with a flywheel-squat exercise using a linear encoder. On the other hand, some studies investigated the reliability of a rotary axis encoder-flywheel system in both multi-joint exercises (squat, half squat, lunge) [7,35] or single-joint exercises (leg curl) [2]. In both cases, the measurement system demonstrated good to excellent relative reliability. These findings support that both linear and rotary encoders are generally reliable systems for measuring strength, power, and velocity across a range of exercises in asymptomatic individuals. Nevertheless, our study is the first to demonstrate an excellent relative reliability of a protocol for measuring a hip rotation exercise using a rotary axis encoder-flywheel system.

Focusing on the rotary axis encoder-flywheel system, previous studies have established the primary emphasis on the test-retest reliability of power and peak power as the main outcomes of interest [2,7,35]. The analysis of inter-rater reliability and the inclusion of the mean and peak values of velocity and force were novel aspects of this study. It could be noted that both force and velocity are widely used outcomes for monitoring performance, even in flywheel exercises [36,37]. In addition, the exercise performance may be conditioned by the patient's positioning relative to the flywheel and the instructions provided by the examiners. Proper adjustment of the belts may be particularly relevant to isolate the activation of the hip rotator muscles and prevent the activation of other muscle groups that could potentially influence the output during the assessment.

Various data collection methods have been employed with the encoder-flywheel system, ranging from separate phase analysis [2,7,10] to the calculation of the eccentric:concentric ratio [2,38]. In the present study, pooled output from both concentric and eccentric phases was recorded. This approach has the potential to streamline data output per repetition, ultimately facilitating the development of a protocol with greater practical applicability. It has been suggested that a minimum of three familiarization sessions is required to achieve measurement value stabilization when both phases are computerized, particularly for multi-joint exercises that involve greater movement variability and muscular engagement [38]. However, our results demonstrated good to excellent relative reliability with just a single familiarization session, likely attributed to the analysis of a single-joint exercise. Conversely, Piqueras-Sanchiz et al. [2] focused on a leg-curl flywheel exercise and reported lower relative reliability in power when recording the pooled phase (eccentric:concentric ratio) than when compared to the independent phase analysis. These differences may depend on the specific exercise analyzed, the collecting data method, and the measurement protocol. Remarkably, the present study reveals absolute reliability values >10% for peak power and force of absolute reliability. These values are not directly comparable to the study by Piqueras-Sanchiz et al. [2] because they did not provide coefficients of variation. In contrast, Beato et al. [7] achieved acceptable coefficients of variation (CV = 5.9–6.8%) in squat power. An independent phase data collection and a larger sample of repetitions assessed were the main differences from this study. Beato et al. [7] employed an average of twelve repetitions divided into two sets, while we used an average of three repetitions within a single set. Thus, the data collection method could have significantly influenced the absolute reliability of power outcomes. While the use of an independent phase data collection and a larger sample of repetitions can generate more stable values, it requires more time and may appear less practical in a clinical or sports training context.

Regarding the provided cutoffs points for relative SEM [39], there was moderate to high variability in peak power (%SEM = 7.78–13.55%), low to moderate variability in peak force (%SEM = 5.59–8.12%), and low variability in mean and peak velocity, mean power, and mean force (%SEM < 7%). Even though the relative SEM suggests minimal variability in mean power, it is important to note that the absolute test-retest reliability reveals CV values exceeding 10%. Nevertheless, the absolute reliability of mean power (CV = 10.6–12%) seems to be higher than that of peak power (CV = 18.2–18.6%). Thus, peak power and force outcomes displayed the greatest variability and unsatisfactory absolute reliability. This is likely attributed to the smaller sample size of data considered at a specific moment within a repetition, compared to the mean data derived from the entire repetition. One possible contributing factor could have been the compensatory activation of other muscle groups and the difficulty in maintaining pelvic stability during the exercises. Consequently, the use of mean power and force values seems more suitable, as they have shown an acceptable intra-rater reliability and low variability (%SEM = 2.58–6.14%).

Therefore, the primary implication of this study is the development of a reliable measurement protocol using the rotary axis encoder-flywheel system to assess velocity, power, and force in hip internal and external rotation exercises. This measurement system seems to be appropriate for its use in research and training monitoring. It enables the assessment of individual performance status through inertial training and holds potential applicability for velocity and power-based training regimens. Nonetheless, the results suggest advising against the use of peak force and power outcomes.

This study is not without limitations. Firstly, the sample consisted of asymptomatic participants engaged in recreational physical activity. Consequently, the results may not be extrapolated to elite athletes, sedentary or unconditioned individuals, older adults, or populations with medical conditions. Secondly, the study only incorporated a single familiarization session, whereas some research suggests a minimum of two such sessions to ensure participants' adequate familiarity with the procedures [38]. Thirdly, the frequency-amplitude of hip rotation movements was not standardized, allowing participants to perform them according to their ability. This aspect could have contributed to performance variability between participants, influencing the results. Fourthly, all measurements for test-retest and inter-examiner reliability were carried out in the same session. While the recommended physical recovery periods between each set were ensured, psychological fatigue might have influenced these results. Finally, only hip rotation exercises were analyzed. Future studies should assess the reliability in different flywheel exercises and aim to establish the optimal data collection procedure with the rotary axis encoder-flywheel system. Subsequent research should also evaluate both the reliability and tolerance of this system among individuals with specific pathologies for its integration and application within the healthcare domain. Additionally, future studies should focus on developing theoretical models to explore relationships among the studied outcome measures.

5. Conclusions

The rotary axis encoder-flywheel system demonstrates good to excellent relative test-retest and inter-rater reliability when assessing hip internal and external rotation exercises in an asymptomatic population. Peak force and power values exhibit absolute reliability values >10%. Therefore, the use of mean and peak velocity, mean force, and mean power seems more adequate for measurements with the rotary axis encoder-flywheel system.

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