

**Validity and Reliability of Flywheel Resistance Technology as an Assessment Method
and its Association with Sports Performance and Asymmetry: A Systematic Review**

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Abstract

Flywheel technology is commonly used in training but remains underutilized for monitoring and testing. Flywheel devices can provide valuable data from mechanical outputs during both concentric and eccentric movements. This systematic review assesses its validity and reliability for evaluating sports performance and limb asymmetry. Searches were conducted in PubMed, SPORT-Discus, Google Scholar, and Web of Science following PRISMA DTA guidelines, focusing on keywords related to flywheel testing. Results show that flywheel testing is reliable ($ICC=0.66-0.99$, $r=0.69-0.97$, $\alpha=0.85-0.98$) and valid for the athletic population when subjects undergo two familiarization sessions. The test can be conducted using rotary encoders, force plates, linear encoders, or inertial measurement units. Participants may perform 1-2 pre-repetitions followed by 5-10 recording repetitions with 1-4 sets and 2-3 minutes of rest between sets. Moment of inertia can be customized based on the athlete's experience and the type of flywheel device used. Key metrics for assessment encompass speed, force, and power, with peak power being the most commonly employed parameter. Few samples of evidence showed that increased asymmetry in concentric power may negatively affect change of direction performance, emphasizing the need for more high-quality studies. In conclusion, flywheel technology offers valuable insights across various movements, providing strength and power assessment while potentially improving athletic performance and injury prevention. Continued research is vital to explore its effectiveness in diverse athletic contexts.

Keywords: Flywheel; Iso-inertial; Testing; Asymmetry; Performance

Introduction

A flywheel device is defined as a machine that utilizes a rotating flywheel cone or disc to generate a resistance force (6). Specifically, the force provided throughout the concentric stage enables the linked cable or strap to unwind, allowing the flywheel to rotate and store energy; with kinetic energy developing as the flywheel spins faster(6). The cord rewinds when the concentric stage is finished, and the user needs to withstand the flywheel's pull during the braking eccentric stage (6,10). Flywheel resistance technology has been shown to enhance physical performance and can be easily integrated into various asymmetrical, sport-specific, or traditional training movements with metric or data monitoring, such versatility has led to its growing adoption in training programs aimed at injury prevention, rehabilitation, and athletic development across various sports and populations (1,4,6,17,20,47). However, despite the well-documented effectiveness of flywheel resistance training, the utilization of data or metrics generated by these devices for testing or monitoring is infrequently discussed and understood (41).

Reliability, a crucial aspect of measurement in medical and scientific contexts, refers to the consistency and stability of measurements obtained through a specific method or tool when no interventions are applied, and high reliability ensures that the collected data is both trustworthy and actionable (5,16,21,25). It can be represented using Pearson's r (r), the ICC, CV, or the limits of agreement (LOA) (16). Most currently used flywheel devices allow for quantifying mechanical parameters such as power, force, and speed (35,38). However, the reliability of these parameters depends on several factors including the user's effort, training experience, the chosen moment of inertia, and the mechanical characteristics of the equipment used, to name a few(6). At the moment, it is recommended to have the participants undergo 2–3 familiarization sessions with the flywheel device to ensure they understand the movements and can perform them effectively (7,22,35). Previous research has reported *high* relative reliability (intraclass correlation coefficients (ICC) = 0.94–0.95) and *acceptable* absolute reliability (coefficient of variation (CV) = 5.9–6.8%), for both concentric and eccentric power outputs during the flywheel squat test with amateur team sports athletes (8). Another study with physically active males also showed that mean concentric linear velocity (MCLV) is a highly reliable metric for quantifying exercise load during flywheel training, with an ICC of 0.9 for both MCLV and rating of perceived exertion (RPE) across multiple testing sessions; thus, indicating the consistency and reliability of these measurements (36). The evidence indicates that the flywheel test has the potential to achieve high reliability for future applications;

however, there is currently no summary regarding the various protocols, methods, or equipment involved.

Validity in performance testing is crucial for practitioners, as it ensures that assessments accurately reflect an athlete's capabilities and the demands of their sport (16). Valid tests can inform tailored training programs and monitor progress effectively, leading to improved performance outcomes through better decision-making (16). There will be three types of validity: (i) logical validity, (ii) criterion validity, and (iii) construct validity that evaluates performance testing protocols (16). Logical validity for a test is the degree to which the test measures what it is intended to measure, for instance, a flywheel squat test is intended to measure lower limbs' strength and power. There are two types of criterion validity: concurrent and predictive. Concurrent validity for a test is established by comparing such test with a previously validated measure, i.e., the correlation between flywheel outputs and measures from a gold standard, and predictive validity assesses how well a performance testing protocol can forecast future performance outcomes or behaviors. Currently, various monitoring methods, equipment, and testing approaches have been employed to observe performance or intensity during flywheel training (35,60). Multiple studies showed friction encoders in a flywheel device have a near-perfect correlation with linear encoders (26,34,60), and another study reported high R^2 values for average power (0.98), average force (0.97), and total work (0.94), indicating a strong correlation between the measured and predicted outcomes (12). Finally, construct validity includes both discriminant validity and convergent validity, therefore flywheel tests should demonstrate both a strong correlation with other measures of the same construct (convergent validity) and a lack of correlation with measures of different constructs (discriminant validity) (59). For example, the flywheel squat test is valid for assessing lower limb performance due to its *moderate* to *large* correlations with isokinetic assessments of knee extensor and flexor muscle peak forces (r range: 0.465–0.566) (8). In contrast, the flywheel squat test shows only a *small* correlation with the standing long jump (r range: 0.123 - 0.243) (8) and 5-m change of direction (r range: 0.130 – 0.225) (8). These examples demonstrate that the flywheel test offers unique and valuable insights into an athlete's performance capabilities.

Leveraging the unique properties of the flywheel devices, it is possible to say that flywheel resistance tests provide unique insights into athletes' performance in power, strength, speed, etc. (6). These devices can be used for testing or monitoring during training programs to assess the concentric and eccentric capabilities of various muscles, including intermuscular and

intramuscular coordination across different planes of movement (36). This includes specific actions such as side steps or crossover steps movements during changes of direction (23,30,31) as well as isolated single-joint exercises like the hamstring curl (18,45) or a normal traditional training movement like squat or deadlift (34,37). Moreover, flywheel tests can be used to assess muscle and limb asymmetries, which can have an impact on athletes' performance and the likelihood of injury (11,52). Therefore, Flywheel tests can provide valuable insights for practitioners researching training technologies that assess concentric and eccentric parameters and asymmetries. However, it's important to note that the current evidence on flywheel tests, mechanical outputs, and limb and muscle asymmetries is still limited (11).

The current literature has a notable lack of summary in reliability and validity regarding the use of flywheel technology for performance testing and monitoring. Therefore, further guidelines are needed to develop effective strategies for using flywheel technology in performance tests. With this in mind, the purpose of this systematic review is to provide an overview of the available data about the reliability and validity of flywheel-based tests, their association with sports performance and asymmetries, and suggest guidelines for using flywheel technology for testing purposes.

Methods

This systematic review followed the PRISMA 2020 guidelines(42) and took into consideration the recommendations for the diagnostic test accuracy studies checklist (PRISMA-DTA).

The systematic review was preliminarily submitted and published on the Open Science Framework. The protocol can be accessed via the web address osf.io/5a3re.

Eligibility criteria

Studies published in peer-reviewed journals, including those with the status of “in press” or “ahead-of-print”, were considered. No date limitations were set, and studies undertaken in all languages were considered. The eligibility criteria were established based on the PECOS (population, exposure, comparator, outcome, study design) approach:

- (i) Population: Any sporting populations, of any age, or gender, who were integrated into training routines (i.e., not injured or with any reported pathology or health problems). Excluded were disabled athletes or those competing in adapted sports.

- (ii) Exposure: Exposed to the analysis of flywheel resistance technology reliability and validity with sports performance and/or injuries on testing, whilst concurrently assessing interlimb asymmetries.
- (iii) Comparator: The study compared various exercises, equipment, protocols, and participant backgrounds, evaluating their influence on the reliability and validity of flywheel resistance technology and/or interlimb asymmetries.
- (iv) Outcome: Any metric investigating flywheel-related movement and/or their relationship with sports performance and/or interlimb asymmetry and/or injuries.
- (v) Study Design: Observational studies or interventions (both longitudinal and/or cross-sectional studies were considered).

Quality Assessment

The methodological quality of studies was assessed by the “quality assessment tool for observational cohort and cross-sectional studies” proposed by the National Heart, Lung, and Blood Institute (63) (NIH National Heart, Lung, and Blood Institute, website), grading articles on a scale of 14 points.

Information sources

The following databases were searched: PubMed, SPORT-Discus, Google Scholar, and Web of Science (core collection). After performing the protocol registration, the searches were conducted on 30/09/2024. In addition to the database searches, manual searches were performed on the references list of included studies to identify potentially relevant titles. The abstracts of these articles were checked for relevant inclusion criteria and, if necessary, the full text was referred to. Snowballing citation tracking was also consulted in all related journals. Finally, errata and article retractions were analyzed for any articles that were included in the review.

Search Strategy

In the search, the Boolean operators AND/OR were applied. No filters or limitations were used (e.g., date; language; study design) to maximize of identification of appropriate studies. The main search strategy was as follows:

[Title/Abstract] Flywheel OR Flywheel exercise OR flywheel inertia OR flywheel resistance OR Flywheel training OR flywheel resistance exercise OR variable inertial OR rotary inertial OR inertial training OR isoinertial training OR isoinertial exercise OR eccentric overload OR eccentric overload training

AND Testing OR Assessment

AND Asymmetry

AND performance OR athletic performance OR jump OR sprint OR change of direction OR agility OR aerobic

Selection process

Two authors (MM and MB) independently screened the retrieved records (namely titles and abstracts). The same author also independently screened the gathered full texts. Disagreements between the authors were discussed in a joint reanalysis. In the case of no consensus being reached, the third author (CB) made the final decision. Where and when required, all co-authors shared opinions regarding any doubts raised in the selection process, with a view to supporting the final decision. The Zotero 6.0.30 (Corporation for Digital Scholarship, Vienna, VA, US) was used for managing records, namely the removal of duplicates either automatically or manually.

Data extraction process

The data extraction process was first performed by the author (MM) and was verified by two other authors (MB and CH) to confirm the accuracy and details of the data. A specially designed Microsoft® Excel datasheet was created and used to contain the data and the main information. The Excel datasheet can be observed in the supplementary material. In the case of relevant data being missing from the full text of a study, the author (MM) directly contacted the corresponding author of that study by email and/or ResearchGate to obtain the required information. The authors of the present systematic review sought to examine several aspects

related to flywheel assessment which can be divided into 3 sub-headings respectively with different table and reporting date items, the sub-headings included 1) Reliability of flywheel resistance technology assessment 2) Validity of flywheel resistance technology assessment (criterion-related validity and construct validity) 3) Asymmetries construct validity: correlation between flywheel testing asymmetries with performance testing

Reliability of Flywheel Resistance Technology Assessment

Under this sub-heading, this review will report the participants, country, exercise selection, testing design and procedures, Instrument used, the moment of inertia, outcome measure, absolute reliability measure, and relative reliability measure.

Validity of Flywheel Resistance Technology Assessment

Under this sub-heading, this review will report the participants, country, exercise selection, testing design and procedures, Instrument used, the moment of inertia, outcome measure, Type of Validity, and Validity measure.

Flywheel Resistance Technology Assessment with its Association with Sport Performance and Asymmetry

Under this sub-heading, this review will report the participants, country, exercise selection, testing exercise selection, asymmetry reported, and any Pearson's r or Spearman's ρ correlations between flywheel test metrics and independent measures of inter-limb asymmetry.

Methodological quality

Results

Study identification and selection

The initial search yielded a total of 310 articles (figure 1). The data were imported to the ZoteroTM reference manager software version 6.0.30 (Vienna, Virginia, USA). Duplicates (30 titles) were subsequently removed, either automatically or manually. The remaining 280 articles were screened for their relevance based on their titles and abstracts. Of those, 260 articles were removed, and the full texts of the remaining studies were then inspected. After the automatic search, 20 articles remained for data extraction and further analysis. Following the citation of the list of 20 articles, 7 more eligible titles were suggested, reviewed, and integrated. Consequently, a total of 27 articles were included in the final systematic review.

Insert Figure 1 here

Quality Assessment Results

A total of 27 studies were evaluated using the "Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies". Scores ranged from 3 to 6 out of a maximum of 14 points. Since this tool is not specifically designed for sports sciences, the quality scores may seem low. However, many criteria were not applicable due to the descriptive nature of the studies and the type of variables measured, such as exposures assessed only once or participant dropouts after baseline. Consequently, questions related to these variables (specifically questions 6, 7, 8, 10, and 13) were removed from the assessment scale, adjusting the highest possible score to 9. Additionally, details regarding subject eligibility and assessor blinding were not consistently reported, the result was reported in Table 1 (63). The highest score is 8 out of 9 (18), while the lowest score is 5 out of 9 (29), with an average score for the methodological quality of the included studies being 5.81 out of 9.

Insert Table 1 here

Insert Table 2 here

Study characteristics and context-related information

The characteristics and context-related information of the included studies can be observed in Table 2. All of them performed testing with flywheel devices with 22 out of 27 studies (81.5%) with reported reliability, and 11 out of 27 studies (40.7%) with reported validity. While 5 out of them (18.5% in 27 studies) used the flywheel test asymmetries result to compare with sports performance.

Figure 2 presents the distribution of the included studies per continent and age group. Of the 27 included articles, 88.9% were conducted in Europe, 7.4% in North America, and 3.7% in Middle America. 20 articles (74.1%) of the studies were conducted in populations with average ages greater than 18 years old, while 7 studies (25.9%) were undertaken in participants below 18 years old.

Insert Figure 2 here

Methodological characteristics and findings of the included studies

Reliability

A total of 18 different exercises have been selected to perform the flywheel test for assessing reliability (8,13,13,18,23,28,30–32,34,39,40,44–46,49–51,56–58,61,62). Specifically, 9 studies used flywheel squat, and 4 studies used crossover step and lateral squat, respectively. Meanwhile, a total of 18 flywheel metrics were measured in different studies. Peak concentric power and peak eccentric power were the most widely used, with 13 studies using each. The following will be average concentric power, average eccentric power, and eccentric overload ratio with 6 used. For the moment of inertia selection, there is a total of 24 different moments of inertia, and 47 separate tests were performed (figure 3). The measurement sensors of the flywheel test can be a Rotary Encoder Sensor, Linear Encoder Sensor, force plates, and Inertial Measurement System. The reliability range for these measurements is ($ICC = 0.66–0.99$, $r = 0.69–0.97$, $\alpha = 0.85–0.98$).

Insert Table 3 here

Insert Figure 3 here

In terms of the importance of familiarization, a total of 7 research groups (12,23,31,45,49,51,61) emphasized the need for familiarization sessions, and 4 studies showed improvement in reliability with no significant differences between sessions 3 and 4 after two familiarization sessions in flywheel squat and leg curl exercise (45,49,51,61).

Insert Table 4 here

Insert Table 5 here

Validity

In addition, a total of 7 exercises have been selected to perform the flywheel test for assessing validity (8,13,27,34,37,44,53,55,57,58,60). Specifically, the Most used is flywheel squat, with 8 studies used. Regarding criterion-related validity (7 out of 11, 63.6%), 3 studies(26,57,60) used a rotary encoder for validation, and both studies recommend utilizing mean values for velocity, force, and power due to their very *large* or *nearly perfect* correlation (r range = 0.712 – 0.999) with criterion measures.

Meanwhile, three studies (34,37,44)utilized an inertial measurement device or system for validation and demonstrated that mean and peak velocity measurements are valid due to their nearly perfect correlation with criterion measures. However, various power parameters for the 45-degree hip extension (HE) and unilateral straight knee bridge (SKB) do not meet minimum validity requirements. Nonetheless, the device is valid for measuring force in both HE and SKB, as well as power in the bilateral stiff-leg deadlift (SDL). Lastly, using a force plate with a linear encoder is also considered valid equipment for force and velocity measurements (57,58). Regarding convergent validity, the correlation coefficients (r values) indicate a range from trivial to large positive correlations between flywheel output and isokinetic assessments ($r = 0.465\text{--}0.566$). There are also moderate correlations with eccentric force during countermovement jumps (CMJ) ($r = 0.22\text{--}0.335$), as well as negative correlations with 90° change of direction (CoD) time ($r = -0.14$ to -0.19) and 180° CoD time ($r = -0.190\text{--}0.262$). Additionally, the karate-specific CoD test shows a correlation of $R^2 = 0.138$.

*****Insert Table 6 here*****

Flywheel test asymmetry to sports performance. A total of 5 studies (23,30–32,46) used the asymmetry percentage in flywheel testing to predict sports performance. In total, 91 subjects (mean = 18, maximum = 26, minimum = 11) were studied. Of these, only 16 of the subjects are above 18 years, and all the rest is under. In addition, the asymmetry rate of the crossover step is the most common exercise to predict sports performance, which happened in 4 of 5 studies. The second will be Sidestep, which happened in 3 studies. Acceleration steps, deceleration steps, leg curls, leg extensions, and squats were conducted only once in each study accordingly. The significant correlation level will be from $r = 0.41$ to $r = 0.78$. The highest correlation will be Sidestep concentric power (CON) to change of direction deficit with 135 degrees in the high-performance leg, $r = 0.78$, with the lowest as crossover Steps-CON to CoD speeds in 180 degrees in the Non-Dominant Leg, $r = 0.41$.

Discussion

The purpose of this systematic review is to provide an overview of the available data about the reliability of flywheel-based tests, flywheel tests validity, and their association with sports performance and asymmetries, and suggest a suitable application for using flywheel technology for testing.

Reliability plays a key factor in testing because it is a critical parameter that defines the capacity of the test to detect performance differences (16). The review shows that if subjects are previously familiarized (23,31,32) or went through at least 2 flywheel training sessions (12,35,45,49,51,61), outcome measures are likely to exhibit *good* to *excellent* levels of reliability ($ICC = 0.66-0.99$, $r = 0.69-0.97$, $\alpha = 0.85-0.98$), except on the E: C ratio for studies (45,51) showed the lowest reliability scores as *poor* to *good* ($ICC = 0.2-0.75$, $\alpha = 0.24-0.7$). This is applied across all exercise selections, whether they are single-joint exercises, multi-joint movements, or sport-specific movements (e.g., crossover steps/lateral side steps). Therefore, experience with flywheel equipment plays an important role in obtaining reliable data results. Although most of the studies in this review suggested that 2 familiarization sessions are enough to obtain reliable output measures (because all subjects were from sporting populations), the actual familiarization period will depend on the individual and requires standardized warm-up and coaching cues and procedures (35). Additionally, the review indicates that various devices, such as rotary and linear encoders, force plates, and inertial measurement systems, can be effectively used to gather reliable data from flywheel testing. These tools have demonstrated strong reliability metrics, underscoring the versatility of flywheel technology in assessing different performance metrics, such as power, force, and velocity. The majority of the data (90.9%, or 20 out of 22 studies) was collected using 1 to 4 sets, with repetitions ranging from 5 to 10 per set. Only 2 studies utilized more than 5 sets, and both still maintained fewer than 10 repetitions. Additionally, only one study (51) analyzed intraset metric differences using the same setup and exercise with the flywheel squat. It found that concentric power started lower significantly at the 11th repetition with 0.025 kg/m², the 8th repetition with 0.050 kg/m², the 7th repetition with 0.075 kg/m², and the 11th repetition with 0.100 kg/m². For eccentric power, the 10th repetition with 0.025 kg/m², the 7th with 0.050 kg/m², the 9th with 0.075 kg/m², and the 13th with 0.100 kg/m² were also significantly lower than the best repetition in the set. It is important to note that, regardless of the inertial load, the optimal repetition is not the first one but falls between the third and fifth repetitions (51). In fact, with lighter inertial loads, the first repetition yields significantly lower values compared to the best repetition within the set (51), indicating the necessity for pre-reps. Since no other studies are comparing the influence of metrics under different repetitions within the same exercise, no definitive conclusions can be drawn. Based on the current evidence, it is recommended to perform 1 to 4 sets of 5 to 10 repetitions, with rest periods of approximately 2 to 3 minutes between sets, to ensure the collection of high-reliable data. Within this range, the test data seems to show a high level of reliability if we have a proper setup and

familiarization period (table 3). However, given the variability in exercises and inertia used, the optimal set and repetition approach remains unclear, as this range is only suggested based on various studies demonstrating *good* to *excellent* reliability and correlations with other measures. Further investigation into different exercises is necessary to distinguish the effects of various set and repetition approaches on testing different abilities. This includes potentially assessing strength and speed with lower repetitions at higher inertia, or endurance with higher repetitions at lower inertia. However, it is important to note that while flywheel testing generally shows *high* relative reliability, certain parameters may exhibit variable reliability outcomes. For instance, the eccentric-to-concentric (E:C) ratio has been reported to display *lower* ICCs, all three studies (18,45,51) highlighted the low reliability of the E:C ratio stemming from the unfamiliarity with flywheel training. Only one study (51) indicated that the E:C ratio could return from *poor* (ICC=0.20-0.48) to *moderate to high* (ICC=0.60-0.75) levels after two familiarization sessions. They recommended that this metric either should not be used or requires proper familiarization at that exercise, as it is often problematic and easily misused. Meanwhile, the force symmetry value measured on the force plate during heavy-load flywheel squats (61), suggests that both measures may require further investigation regarding reliability changes influenced by experience and improvements in coaching cues, feedback, or setup during testing protocols.

Validity is also crucial in testing, as the proper testing approach methods can ensure that assessment output can closely reflect actual performance levels (16). For construct validity, the reported correlation coefficients (r values) for flywheel outputs about various assessments indicate a range of relationships, from *trivial* to *moderate*. For isokinetic assessments, the values are within the range of 0.465 to 0.566 (8), suggesting a *moderate* positive correlation. This indicates that flywheel outputs are reasonably well aligned with isokinetic measures, reflecting a meaningful relationship relevant to strength and power assessments in the lower body. In contrast, the r for eccentric force in the CMJ range from 0.220 to 0.335 (54), representing a *low* to *moderate* positive correlation. While there is a relationship, it is not particularly strong, suggesting that flywheel testing may not fully capture eccentric load during the countermovement on a jump. When examining the CoD ability, the results present a different picture. For the CoD 90° time, the correlation coefficient is between -0.14 and -0.19 (54), indicating a *trivial* negative correlation. This suggests that as flywheel outputs increase, there is little meaningful relationship with performance time for the CoD test. Similarly, the CoD 180° time shows a negative correlation ranging from -0.190 to -0.262, which also reflects

trivial to *low* negative correlations, implying minimal practical significance in the relationship between flywheel performance and the ability to change direction (54). Additionally, the karate-specific CoD test yields an R^2 value of 0.138 (55), indicating a *low* level of construct validity when comparing flywheel outputs to performance measures in this context. Overall, these r values illustrate a spectrum of relationships, with *moderate* correlations primarily observed with isokinetic assessments, while correlations with COD and specific sports performance metrics are generally *weak* or *trivial*. This variability underscores the need for careful consideration when interpreting the validity of flywheel testing across different performance contexts. More different and robust correlations with higher R/R^2 value are needed to establish construct validity, particularly for dynamic movements like CoD, jumping, speed, etc. However, all current studies analyze absolute results without considering relative power concerning body weight. This oversight may contribute to and explain why the correlations are generally weak or trivial, as body weight is also an important factor during dynamic movements (33).

By extension of the finding, it is also important to conduct more different exercises via using flywheel technology that closely replicates movements found in traditional assessments, such as leg curls or hip extensions, to help evaluate the concentric and eccentric capacity of specific muscle groups more time and cost-effectively at an invisible monitoring setting(48). For instance, comparing flywheel leg curl exercise testing with the isokinetic strength of the quadriceps and/or hamstrings, Nordic hamstring strength tests, isometric hamstring strength tests, etc., can provide valuable insights into how effectively flywheel technology replicates and predicts performance in specific muscle groups during training without spending extra time for testing(48). This type of assessment is very common in professional settings for evaluating strength and power, offering critical information for training and performance optimization (2,3,9). This comparison can shed light on the effectiveness of flywheel technology in targeting eccentric strength and injury prevention, particularly for the hamstrings, which are pivotal in athletic performance (15). Additionally, incorporating exercises like side steps and change of direction drills could enhance our understanding of how flywheel training relates to dynamic movements essential in sports. By examining the correlation between flywheel outputs and performance metrics in side steps, we can better assess how well these tests predict agility and directional change abilities. This approach will enhance the understanding around the construct validity of flywheel tests and will improve the practical application of this technology in athletic development and injury prevention strategies.

443

444 The criterion-related validity of flywheel resistance technology is supported by various studies
445 that compare flywheel outputs to established measures, showing generally strong correlations
446 and agreements across different exercises and instruments, the study concluded that using a
447 rotary encoder, force plate, inertial measurement unit, or linear encoder are a valid tool for real-
448 time performance monitoring in flywheel training(8,12,26,34,37,44,54,55,57,58,60). However,
449 in terms of practical application, the rotary encoder may prove to be the most advantageous
450 option(6). Its ability to seamlessly integrate into the existing setup not only enhances the
451 efficiency of the data collection but also minimizes the need for extensive modifications or
452 additional equipment. By utilizing a rotary encoder, we can streamline our processes, ensuring
453 that we capture performance metrics within every plane of motion in almost every exercise
454 method(19). This will ultimately save time and resources during our training sessions with
455 monitoring, allowing us to focus more on optimizing performance rather than managing
456 cumbersome setups(14). Thus, adopting the rotary encoder in flywheel technology for training
457 or testing can be a valuable option for practitioners.

458

459 Regarding flywheel test asymmetry and sports performance, this technology can be used to
460 assess both bilateral and unilateral exercises(11); it can be a potential tool to assess asymmetry
461 during the return to play process or monitor performance during training(43). As there are some
462 links between asymmetry and sports performance(24), the link between flywheel testing and
463 performance is still under discovery. Under the outcome of this review, most of the asymmetry
464 from flywheel devices can be calculated from a single joint movement (32), multi-joint
465 movement (46), or a sport-specific movement (23,31,31,32). These studies suggest a potential
466 relationship between flywheel outcome measures asymmetry and sports performance,
467 particularly regarding sport-specific movements such as side-steps and cross-over steps.
468 Notably, an increase in asymmetry in concentric power during these movements seems to
469 negatively affect change of direction performance, as evidenced by a significant R^2 value
470 ranging from 0.44 to 0.81 (details can be referred to in table 5). Meanwhile, with an increased
471 asymmetry of eccentric power in the cross-over step, it also decreased the performance of leg
472 extension with the flywheel in both legs at both phrases, $R^2 = -0.51$ to -0.58 (32). However,
473 there are not enough studies investigating single-joint movement and multi-joint movement
474 with the flywheel to sports performance, only one for each. It cannot be concluded if any of
475 those have any association with any sports performance, therefore the relationship is still
476 unclear. However, multiple studies (23,30,32) have shown a decreased change of direction

performance from an increased asymmetry on concentric power in the cross-over step and side-step. Practitioners can use this information to perform a flywheel test or monitor the output during training sessions for tracing the changes in sports performance.

Limitations and Future Directions

Based on our findings, it is difficult to specify exact protocols, but we can suggest a range of approaches, as most show similar reliability. More extensive studies are needed to establish normative data and validate the effectiveness of flywheel testing across different exercises, particularly in comparing asymmetry with other measurement methods. Additionally, exploring flywheel testing in diverse populations is crucial to assess its versatility and effectiveness beyond athletic contexts.

Practical Applications

Subjects with sports backgrounds who completed at least two familiarization sessions or prior flywheel training demonstrated a good level of reliability and validity during flywheel testing. However, the optimal protocol and equipment remain unclear. To obtain high reliability under current evidence, testing will need to be performed in between 1-4 sets with 1-2 pre-test repetitions to gain momentum and 5 to 10 recording repetitions with 2-3 minutes resting in between sets to prevent fatigue effect. The moment of inertia can be selected based on the athletes' level, their experience, and the type of flywheel used. All metrics like speed, force, and power (peak or mean) can be used for assessing athletes but peak power is the most commonly used parameter. The body of evidence around the correlation between flywheel test outputs and performance is not large enough, so further research is needed on this topic (validation studies). About asymmetries, there is little evidence to suggest that an increased asymmetry in concentric power in sport-specific movements (i.e., crossover step/side step) reduces CoD performance, the relationship is still unclear between asymmetry in flywheel test to other performance. However, more high-quality studies with larger sample sizes and using different exercise selections are needed to understand the effect of asymmetry assessed using flywheel devices on athletic performance. In conclusion, the unique properties of the flywheel allow for testing in all planes of motion, both bilaterally and unilaterally, through single-joint exercises, multi-joint movements, and sport-specific actions. As a result, flywheel testing demonstrates significant potential for assessing strength and power levels in specific muscle groups.

References

1. Allen, WJC, De Keijzer, KL, Raya-González, J, et al. Chronic effects of flywheel training on physical capacities in soccer players: a systematic review. *Res Sports Med* 31: 228–248, 2023.
2. Asimakidis, ND, Bishop, CJ, Beato, M, et al. A survey into the current fitness testing practices of elite male soccer practitioners: from assessment to communicating results. *Front Physiol* 15: 1376047, 2024.
3. Asimakidis, ND, Mukandi, IN, Beato, M, Bishop, C, and Turner, AN. Assessment of Strength and Power Capacities in Elite Male Soccer: A Systematic Review of Test Protocols Used in Practice and Research. *Sports Med* 54: 2607–2644, 2024.
4. Askling, C, Karlsson, J, and Thorstensson, A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci SPORTS* 244–250, 2003.
5. Bartlett, JW and Frost, C. Reliability, repeatability and reproducibility: analysis of measurement errors in continuous variables. *Ultrasound Obstet Gynecol* 31: 466–475, 2008.
6. Beato, M, De Keijzer, KL, Muñoz-Lopez, A, et al. Current Guidelines for the Implementation of Flywheel Resistance Training Technology in Sports: A Consensus Statement. *Sports Med* , 2024. Available from: <https://link.springer.com/10.1007/s40279-023-01979-x>
7. Beato, M and Dello Iacono, A. Implementing Flywheel (Isoinertial) Exercise in Strength Training: Current Evidence, Practical Recommendations, and Future Directions. *Front Physiol* 11: 569, 2020.
8. Beato, M, Fleming, A, Coates, A, and Dello Iacono, A. Validity and reliability of a flywheel squat test in sport. *J Sports Sci* 39: 482–488, 2021.
9. Beato, M, Madsen, EE, Clubb, J, Emmonds, S, and Krstrup, P. Monitoring Readiness to Train and Perform in Female Football: Current Evidence and Recommendations for Practitioners. *Int J Sports Physiol Perform* 19: 223–231, 2024.
10. Beato, M, Raya-González, J, Hernandez-Davo, JL, and Maroto-Izquierdo, S. Editorial: The science of flywheel training: exercise physiology and practical applications. *Front Physiol* 14: 1241529, 2023.
11. Bishop, C, De Keijzer, KL, Turner, AN, and Beato, M. Measuring Interlimb Asymmetry for Strength and Power: A Brief Review of Assessment Methods, Data Analysis, Current Evidence, and Practical Recommendations. *J Strength Cond Res* 37: 745–750, 2023.
12. Bollinger, LM, Brantley, JT, Tarlton, JK, et al. Construct Validity, Test-Retest Reliability, and Repeatability of Performance Variables Using a Flywheel Resistance Training Device. *J Strength Cond Res* 34: 3149–3156, 2020.

13. Bollinger, LM, Brantley, JT, Tarlton, JK, et al. Construct Validity, Test-Retest Reliability, and Repeatability of Performance Variables Using a Flywheel Resistance Training Device. *J Strength Cond Res* 34: 3149–3156, 2020.
14. Carling, C, Lacome, M, McCall, A, et al. Monitoring of Post-match Fatigue in Professional Soccer: Welcome to the Real World. *Sports Med* 48: 2695–2702, 2018.
15. Claudino, JG, Cardoso Filho, CA, Bittencourt, NFN, et al. Eccentric Strength Assessment of Hamstring Muscles with New Technologies: a Systematic Review of Current Methods and Clinical Implications. *Sports Med - Open* 7: 10, 2021.
16. Currell, K and Jeukendrup, AE. Validity, reliability and sensitivity of measures of sporting performance. *Sports Med* 38: 297–317, 2008.
17. De Hoyo, M, Pozzo, M, Sañudo, B, et al. Effects of a 10-Week In-Season Eccentric-Overload Training Program on Muscle-Injury Prevention and Performance in Junior Elite Soccer Players. *Int J Sports Physiol Perform* 10: 46–52, 2015.
18. De Keijzer, KL, McErlain-Naylor, SA, and Beato, M. The Effect of Flywheel Inertia on Peak Power and Its Inter-session Reliability During Two Unilateral Hamstring Exercises: Leg Curl and Hip Extension. *Front Sports Act Living* 4: 898649, 2022.
19. De Keijzer, KL, McErlain-Naylor, SA, and Beato, M. Six Weeks of Unilateral Flywheel Hip-Extension and Leg-Curl Training Improves Flywheel Eccentric Peak Power but Does Not Enhance Hamstring Isokinetic or Isometric Strength. *Int J Sports Physiol Perform* 19: 34–43, 2024.
20. De Keijzer, KL, Raya-González, J, López Samanés, Á, Moreno Perez, V, and Beato, M. Perception and use of flywheel resistance training amongst therapists in sport. *Front Sports Act Living* 5: 1141431, 2023.
21. De Vet, HCW, Terwee, CB, Knol, DL, and Bouter, LM. When to use agreement versus reliability measures. *J Clin Epidemiol* 59: 1033–1039, 2006.
22. Dufner, TJ, Iacono, AD, Wheeler, JR, et al. The reliability of functional and systemic markers of muscle damage in response to a flywheel squat protocol. *Eur J Appl Physiol* , 2024. Available from: <https://link.springer.com/10.1007/s00421-024-05656-3>
23. Fort-Vanmeerhaeghe, A, Benet-Vigo, A, Montalvo, A, et al. Relationship between Performance and Inter-Limb Asymmetries Using Flywheel Resistance Device in Elite Youth Female Basketball Players. *Biology* 11: 812, 2022.
24. Fox, KT, Pearson, LT, and Hicks, KM. The effect of lower inter-limb asymmetries on athletic performance: A systematic review and meta-analysis. *PLOS ONE* 18: e0286942, 2023.
25. Hopkins, WG. Measures of Reliability in Sports Medicine and Science. *Sports Med* , 2000.

26. Illera-Domínguez, V, Fernández-Valdés, B, Gisbert-Orozco, J, et al. Validity of a low-cost friction encoder for measuring velocity, force and power in flywheel exercise devices. *Biol Sport* 40: 805–811, 2023.
27. Illera-Domínguez, V, Fernández-Valdés, B, Gisbert-Orozco, J, et al. Validity of a low-cost friction encoder for measuring velocity, force and power in flywheel exercise devices. *Biol Sport* 40: 805–811, 2023.
28. Lahuerta-Martín, S, Esteban-Lozano, E, Jiménez-del-Barrio, S, et al. Test-Retest and Inter-Rater Reliability of a Rotary Axis Encoder-Flywheel System for the Assessment of Hip Rotation Exercises. *Appl Sci* 14: 372, 2023.
29. Lahuerta-Martín, S, Esteban-Lozano, E, Jiménez-del-Barrio, S, et al. Test-Retest and Inter-Rater Reliability of a Rotary Axis Encoder-Flywheel System for the Assessment of Hip Rotation Exercises. *Appl Sci* 14: 372, 2023.
30. Madruga-Parera, M, Bishop, C, Beato, M, et al. Relationship Between Interlimb Asymmetries and Speed and Change of Direction Speed in Youth Handball Players. *J Strength Cond Res* 35: 3482–3490, 2021.
31. Madruga-Parera, M, Bishop, C, Fort-Vanmeerhaeghe, A, et al. Interlimb Asymmetries in Youth Tennis Players: Relationships With Performance. *J Strength Cond Res* 34: 2815–2823, 2020.
32. Madruga-Parera, M, Dos'Santos, T, Bishop, C, et al. Assessing Inter-Limb Asymmetries in Soccer Players: Magnitude, Direction and Association with Performance. *J Hum Kinet* 79: 41–53, 2021.
33. Markström, JL and Olsson, C-J. Countermovement Jump Peak Force Relative to Body Weight and Jump Height as Predictors for Sprint Running Performances: (In)homogeneity of Track and Field Athletes? *J Strength Cond Res* 27: 944, 2013.
34. Maroto-Izquierdo, S, Nosaka, K, Alarcón-Gómez, J, and Martín-Rivera, F. Validity and Reliability of Inertial Measurement System for Linear Movement Velocity in Flywheel Squat Exercise. *Sensors* 23: 2193, 2023.
35. Maroto-Izquierdo, S, Raya-González, J, Hernández-Davó, JL, and Beato, M. Load Quantification and Testing Using Flywheel Devices in Sports. *Front Physiol* 12: 739399, 2021.
36. Martín-Rivera, F, Beato, M, Alepuz-Moner, V, and Maroto-Izquierdo, S. Use of concentric linear velocity to monitor flywheel exercise load. *Front Physiol* 13: 961572, 2022.
37. Martín-San Agustín, R, Sánchez-Barbadora, M, and García-Vidal, JA. Validity of an inertial system for measuring velocity, force, and power during hamstring exercises performed on a flywheel resistance training device. *PeerJ* 8: e10169, 2020.
38. McErlain-Naylor, SA and Beato, M. Concentric and eccentric inertia–velocity and inertia–power relationships in the flywheel squat. *J Sports Sci* 39: 1136–1143, 2021.

39. Moreno-Azze, A, Arjol-Serrano, JL, Falcón-Miguel, D, Bishop, C, and Gonzalo-Skok, O. Comparison of Three Eccentric Overload Training Strategies on Power Output and Interlimb Asymmetry in Youth Soccer Players. *Int J Environ Res Public Health* 18: 8270, 2021.
40. Moreno-Azze, A, Arjol-Serrano, JL, Falcón-Miguel, D, Bishop, C, and Gonzalo-Skok, O. Effects of Three Different Combined Training Interventions on Jump, Change of Direction, Power Performance, and Inter-Limb Asymmetry in Male Youth Soccer Players. *Sports* 9: 158, 2021.
41. Muñoz-López, A, Nakamura, FY, and Beato, M. Eccentric overload differences between loads and training variables on flywheel training. *Biol Sport* 40: 1151–1158, 2023.
42. Page, MJ, McKenzie, JE, Bossuyt, PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* n71, 2021.
43. Perna, P, De Keijzer, KL, and Beato, M. Flywheel resistance training in football: a useful rehabilitation tool for practitioners. *Front Sports Act Living* 6: 1434995, 2024.
44. Pino-Ortega, J, Hernández-Belmonte, A, Bastida-Castillo, A, Gómez-Carmona, C, and Rojas-Valverde, D. Accuracy and Reliability of Inertial Devices for Load Assessment During Flywheel Workout. *MHSalud Rev En Cienc Mov Hum Salud* 19: 1–11, 2021.
45. Piqueras-Sanchiz, F, Sabido, R, Raya-González, J, et al. Effects of Different Inertial Load Settings on Power Output Using a Flywheel Leg Curl Exercise and its Inter-Session Reliability. *J Hum Kinet* 74: 215–226, 2020.
46. Raya-González, J, Bishop, C, Gómez-Piqueras, P, et al. Strength, Jumping, and Change of Direction Speed Asymmetries Are Not Associated With Athletic Performance in Elite Academy Soccer Players. *Front Psychol* 11: 175, 2020.
47. Raya-González, J, Prat-Luri, A, López-Valenciano, A, Sabido, R, and Hernández-Davó, J. Effects of Flywheel Resistance Training on Sport Actions. A Systematic Review and Meta-Analysis. *J Hum Kinet* 77: 191–204, 2021.
48. Rudisill, SS, Varady, NH, Kucharik, MP, Eberlin, CT, and Martin, SD. Evidence-Based Hamstring Injury Prevention and Risk Factor Management: A Systematic Review and Meta-analysis of Randomized Controlled Trials. *Am J Sports Med* 51: 1927–1942, 2023.
49. Ryan, S, Ramirez-Campillo, R, Browne, D, Moody, JA, and Byrne, PJ. Intra- and Inter-Day Reliability of Inertial Loads with Cluster Sets When Performed during a Quarter Squat on a Flywheel Device. *Sports* 11: 121, 2023.
50. Sabido, R, Hernández-Davó, JL, Botella, J, Navarro, A, and Tous-Fajardo, J. Effects of adding a weekly eccentric-overload training session on strength and athletic performance in team-handball players. *Eur J Sport Sci* 17: 530–538, 2017.

51. Sabido, R, Hernández-Davó, JL, and Pereyra-Gerber, GT. Influence of Different Inertial Loads on Basic Training Variables During the Flywheel Squat Exercise. *Int J Sports Physiol Perform* 13: 482–489, 2018.
52. Sawczuk, T, Jones, B, Scantlebury, S, et al. Between-Day Reliability and Usefulness of a Fitness Testing Battery in Youth Sport Athletes: Reference Data for Practitioners. *Meas Phys Educ Exerc Sci* 22: 11–18, 2018.
53. Smajla, D, Kozinc, Ž, and Šarabon, N. Associations between lower limb eccentric muscle capability and change of direction speed in basketball and tennis players. *PeerJ* 10: e13439, 2022.
54. Smajla, D, Kozinc, Ž, and Šarabon, N. Associations between lower limb eccentric muscle capability and change of direction speed in basketball and tennis players. *PeerJ* 10: e13439, 2022.
55. Smajla, D, Spudić, D, Kozinc, Ž, and Šarabon, N. Differences in Force-Velocity Profiles During Countermovement Jump and Flywheel Squats and Associations With a Different Change of Direction Tests in Elite Karatekas. *Front Physiol* 13: 828394, 2022.
56. Smajla, D, Spudić, D, and Šarabon, N. Influence of Load and Phase of Contraction on Lateral Symmetries in Flywheel Squats. *Symmetry* 13: 111, 2021.
57. Spudić, D, Cvitkovič, R, and Šarabon, N. Assessment and Evaluation of Force–Velocity Variables in Flywheel Squats: Validity and Reliability of Force Plates, a Linear Encoder Sensor, and a Rotary Encoder Sensor. *Appl Sci* 11: 10541, 2021.
58. Spudić, D, Smajla, D, and Šarabon, N. Validity and reliability of force–velocity outcome parameters in flywheel squats. *J Biomech* 107: 109824, 2020.
59. Thomas, JR, Martin, P, Etnier, JL, and Silverman, SJ. Research Methods in Physical Activity. Human Kinetics, 2022.
60. Weakley, J, Fernández-Valdés, B, Thomas, L, Ramirez-Lopez, C, and Jones, B. Criterion Validity of Force and Power Outputs for a Commonly Used Flywheel Resistance Training Device and Bluetooth App. *J Strength Cond Res* 33: 1180–1184, 2019.
61. Worcester, KS, Baker, PA, and Bollinger, LM. Effects of Inertial Load on Sagittal Plane Kinematics of the Lower Extremity During Flywheel-Based Squats. *J Strength Cond Res* 36: 63–69, 2022.
62. Wren, C, Beato, M, McErlain-Naylor, SA, Iacono, AD, and De Keijzer, KL. Concentric Phase Assistance Enhances Eccentric Peak Power During Flywheel Squats: Intersession Reliability and the Linear Relationship Between Concentric and Eccentric Phases. *Int J Sports Physiol Perform* 18: 428–434, 2023.
63. Study Quality Assessment Tools | NHLBI, NIH. Available from: <https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools>

PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources

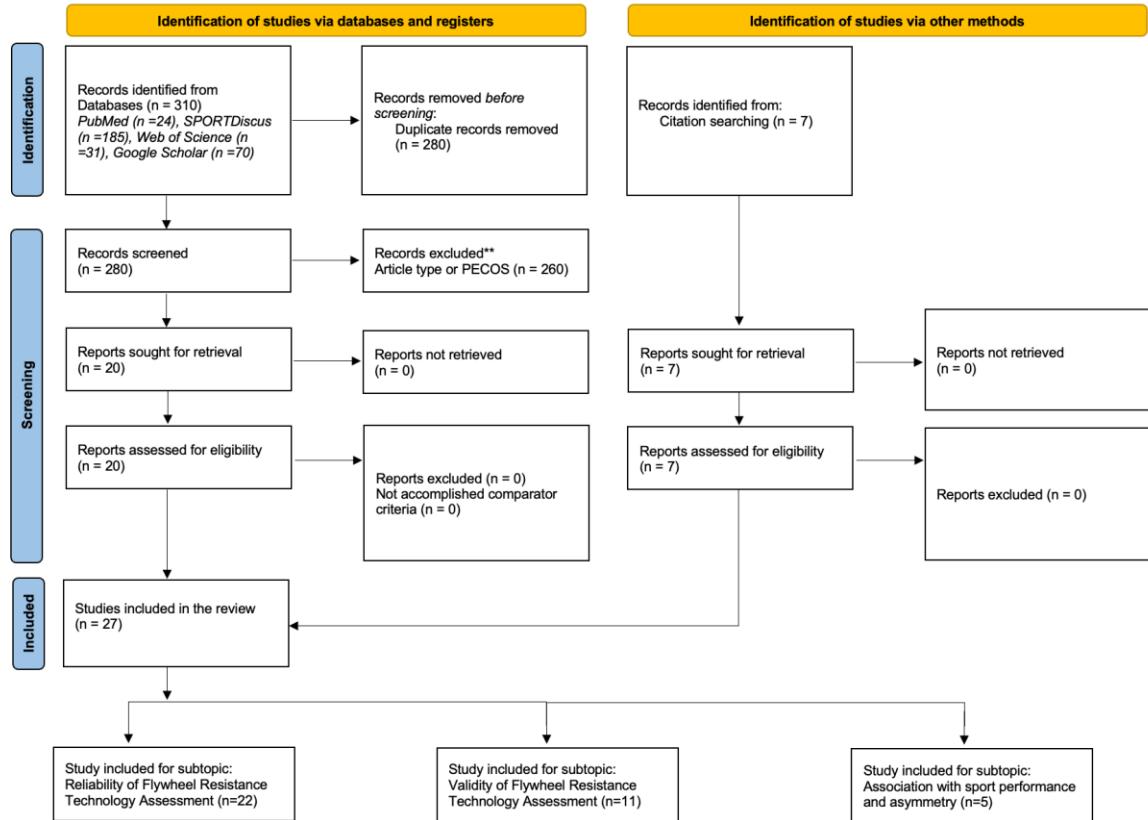


Figure 1. Prisma flow diagram



Figure 2. Distribution of the included studies by continent and age group.



Figure 3. Number of moments of inertia used in flywheel testing. Note: IU = information unknown.

Table 1*Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies*

References	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Beato et al.(8)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Bollinger et al.(12)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
De Keijzer et al.(18)	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	Yes	Yes	Yes	No	NA	NA	8
Fort-Vanmeerhaeghe et al. (23)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Lahuerta-Martín et al.(29)	Yes	No	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	5
Illera-Domínguez et al.(26)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Madruga-Parera et al.(32)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Madruga-Parera et al.(31)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Madruga-Parera et al.(30)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Maroto-Izquierdo et al.(34)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Martín-San Agustín et al.(37)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6

References	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Moreno-Azze et al.(39)	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	Yes	NA	Yes	No	NA	NA	7
Moreno-Azze et al.(40)	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	Yes	NA	Yes	No	NA	NA	7
Pino-Ortega et al.(44)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Piqueras-Sanchiz et al.(45)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Raya-González et al.(46)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Ryan et al.(49)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Sabido et al.(50)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Sabido et al.(51)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	Yes	Yes	No	NA	NA	7
Smajla et al.(56)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Smajla et al.(54)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Smajla et al.(55)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Spudić et al.(58)	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	Yes	NA	Yes	No	NA	NA	7
Spudić et al.(54)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Weakley et al.(60)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6
Worcester et al.(61)	Yes	Yes	Yes	Yes	No	NA	NA	NA	Yes	NA	Yes	No	NA	NA	6

References	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Wren et al.(62)	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	Yes	NA	Yes	No	NA	NA	7

Note. Yes

1. Was the research question or objective in this paper clearly stated?
2. Was the study population clearly specified and defined?
3. Was the participation rate of eligible persons at least 50%?
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?
5. Was a sample size justification, power description, or variance and effect estimates provided?
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
10. Was the exposure(s) assessed more than once over time?
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
12. Were the outcome assessors blinded to the exposure status of participants?
13. Was loss to follow-up after baseline 20% or less?
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

Table 2*Characterization and contextual information of the included studies*

Study	Sport	Training status	N	Sex
Beato et al.(8)	mixed in soccer, rugby, resistance trained athletes	amateur team sports athletes	20	M
Bollinger et al.(12)	IU	young, resistance trained subjects	12	M; F
De Keijzer et al.(18)	Soccer	healthy university athletes	20	M
Fort-Vanmeerhaeghe et al. (23)	Basketball	elite youth players	11	F
Lahuerta-Martín et al.(29)	IU	IU	29	M; F
Illera-Domínguez et al.(26)	IU	previously trained with the exercise device	10	M; F
Madruga-Parera et al.(32)	Soccer	semi-professional players	16	M
Madruga-Parera et al.(31)	Tennis	Elite players	22	M; F
Madruga-Parera et al.(30)	Handball	youth players	26	M
Maroto-Izquierdo et al.(34)	Recreationally trained individuals	healthy sports science undergraduate students	31	M
Martín-San Agustín et al.(37).	recreationally trained individuals and powerlifters	resistance trained	15	M
Moreno-Azze et al.(39)	Soccer	U-17 players in Spanish second division professional soccer	47	M

Study	Sport	Training status	N	Sex
Moreno-Azze et al.(40)	Soccer	U-17 players in Spanish second division professional soccer	45	M
Pino-Ortega et al.(44)	Soccer (football)	elite-level players	10	M
Piqueras-Sanchiz et al.(45)	mixed in soccer, tennis, volleyball, handball, and taekwondo	amateur university sports athletes	16	M; F
Raya-González et al.(46)	Soccer	Elite Youth soccer players	16	M
Ryan et al.(49)	field sport (partaking in Gaelic football, hurling, and soccer)	collegiate field sport male athletes	12	M
Sabido et al.(50)	Handball	First National Division	18	IU
Sabido et al.(51)	Handball	High Level players in Asobal League and the First National Division league	24	IU
Smajla et al.(56)	Experienced in strength training	physically active participants	422	M; F
Smajla et al.(54)	basketball and tennis	athletes with 6.1 ± 2.5 trainnig years	196	M; F
Smajla et al.(55)	Karate	international level	39	M; F
Spudić et al.(58)	IU	Physically active volunteers, experienced in resistance training	26	M; F
Spudić et al.(54)	IU	Physically active volunteers, experienced in resistance training	50	M; F

Study	Sport	Training status	N	Sex
Weakley et al.(60)	Rugby	university rugby union players	11	M
Worcester et al.(61)	IU	apparently healthy, recreationally resistance trained subjects	9	M; F
Wren et al.(62)	IU	Amateur University athletes	20	M

Note. IU: information unavailable; F: Female; M: men; N: number of participants

Table 3

Study characteristics regarding Reliability of Flywheel Resistance Technology Assessment

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
Beato et al.(8)	Study Design: test-retest Familiarisation sessions: 1 Experimental sessions: 2	1. Flywheel half squat test	Set and reps on exercise: 3 sets X 6 + 2 reps Moment of Inertia: 0.061 kg/m ² Instrument used: 1. a standardized ergometer (D11 Full, Desmotec, Biella, Italy)	1. Peak Concentric Power 2. Peak Eccentric power	ICC=0.94–0.95	CV=5.9%-6.8%, TE=67-68, SWC=55-61	The FW-squat test is a valid and reliable test to assess lower limb performance given its correlation with isokinetic test, as well as its excellent relative and acceptable absolute reliability.
Bollinger et al.(12)	Study Design: test-retest Familiarisation sessions: 1 Experimental sessions: 2	1. Bent-over row 2. Romanian deadlift 3. Biceps curl	Set and reps on exercise: 3 sets X 5 + 1 reps each load Moment of Inertia: 0.050, 0.075, and 0.100 kg/m ² Instrument used: 1. Exxentric kbox 4 Pro	1. Average power 2. Peak concentric and eccentric power 3. Average force 4. Average speed 5. Total work	Bent-over Row: r = 0.76-0.92 RDL: r = 0.90–0.97 Biceps curls: r=0.69-0.98	Bias: Bent-over Row: Average Speed: Trial 1 was greater by 0.04 m/s (p < 0.0001). Total Work: Trial 1 was greater by 0.3 kJ (p < 0.05). Romanian Deadlift (RDL): Average Force: Trial 2 was greater by 41.8 N (p < 0.05).	The test-retest reliability of flywheel data seems to be dependent on individual exercises as well as the parameter being evaluated. Coefficient of repeatability for all outcomes was relatively high, indicating poor repeatability.

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
De Keijzer et al.(18)	test-retest	1. Flywheel Knee Flexion 2. Flywheel Hip extension	Set and reps on exercise: 3 sets X 6 + 2 reps Moment of Inertia: 0.029, 0.061, and 0.089 kg/m ² Instrument used: 1. Flywheel in-built rotational encoder (V11Full, Desmotec, Biella, Italy)	1. Concentric peak power 2. Eccentric peak power 3. Eccentric: concentric ratio	Hip extension peak power, ICC=0.94-0.97. In E:C ratio peak power, ICC=0.29-0.64 Leg Curl, ICC=0.74-0.89.	Biceps Curl: Average Power: Trial 1 was greater by 24.0 W (p < 0.01). Average Force: Trial 1 was greater by 18.4 N (p < 0.05). CR: Bent-over Row: 19.5%-55.1% RDL: 20.8%-43.1% Biceps Curl:23.8% - 79.3%	Leg curl reliability and all hip extension reliability highlighting that such parameters can be used by practitioners while the eccentric: concentric ratio should not be utilized for monitoring training outcomes.
						IU	

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
Fort-Vanmeerhaeghe et al.(23)	Study Design: single time point studies Familiarisation sessions: 1 Experimental sessions: 1	1. Acceleration step 2. Deceleration Step 3. Crossover step 4. Side Step	Set and reps on exercise: 8 reps on each limb Moment of Inertia: 0.10 and 0.29 kg/m ² Instrument used: 1. Eccotek Training Force device (Byomedic System; SCP, Barcelona, Spain)	1. Mean concentric power 2. Mean eccentric power	ICC=0.94-0.98	CV=11.77%-22.46%	To ensure the correct technique and use of the eccentric overload that this kind of technology allows, a long period of familiarization is required.
Lahuerta-Martin et al.(29)	Study Design: single time point studies Familiarisation sessions: 1 Experimental sessions: 1	1. Flywheel Hip Internal Rotation 2. Flywheel Hip External Rotation	Set and reps on exercise: 2 set of 3 + 7 reps Moment of Inertia: IU Instrument used: 1. Conic Power Move® flywheel (TMR World, Barcelona, Spain)	1. velocity 2. peak velocity 3. power 4. peak power 5. force 6. peak force.	ICC= 0.85-0.98	CV = 4.7–18.6%, SEM=0.02-46.33, SEM%=2.35-10.81, MDC: 0.05-128.42	The rotational encoder-flywheel system demonstrated good to excellent relative reliability for assessing hip rotation exercises. Peak force and power values exhibit CV >10%. The use of mean and peak velocity, mean force, and mean power seems more adequate for measurements with the rotary axis encoder-flywheel system.
Madrugaga-Parera et al.(32)	Study Design: test-retest Familiarisation sessions: 0, previously familiarized subject Experimental sessions: 2	1. leg extension strength 2. leg curl strength 3 closed Crossover step	Set and reps on exercise: 3 sets of 8 repetitions with each leg Moment of Inertia: 0.194 kg/m ² Instrument used: 1. Eccotek Training Force device (Byomedic System; SCP, Barcelona, Spain)	1. Max concentric power 2. Max eccentric power	ICC=0.82-1.00	CV=2.70-7.61.	There is a lack of knowledge of the relationships between the loads to be applied in iso-inertial devices.

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
Madrugá-Parera et al.(31)	Study Design: single time point studies Familiarisation sessions: 0, previously familiarized subject Experimental sessions: 1	1. Shuffle lateral step 2. crossover step	Set and reps on exercise: The set was stopped after doing 2 consecutive reps under the maximal registered value. Moment of Inertia: 0.12 and 0.27 kg/m ² Instrument used: 1. isoinertial device (Byomedic System SCP, Barcelona, Spain) with by SmartCoach Power Encoder (SmartCoach Europe AB, Stockholm, Sweden)	1. Max concentric power 2. Max eccentric power	ICC=0.7-0.91	CV=9.1-18.8. TEM=77.1-156.3	It is critical that athletes are familiar with test protocols.
Madrugá-Parera et al.(30)	Study Design: single time point studies Familiarisation sessions: 0, previously familiarized subject Experimental sessions: 1	1. Shuffle lateral step 2. crossover step	Set and reps on exercise: completing 8 repetitions or by a decrease of 10% of the maximum value of the set. Moment of Inertia: 0.12 and 0.27 kg/m ² Instrument used: 1. isoinertial device (Byomedic System SCP, Barcelona, Spain) with by SmartCoach Power Encoder (SmartCoach Europe AB, Stockholm, Sweden)	1. Max concentric power 2. Max eccentric power	ICC=0.70-0.87	CV=9.9%-17.5%. TEM=35.9-59.7	There is a lack of knowledge of the “most suitable” iso-inertial load to achieve the most representative CODS action in sport.
Maroto - Izquier	Study Design: test-retest Familiarisation sessions: 1	1. Flywheel squat	Set and reps on exercise: 3 sets of 4 repetitions with each load Moment of Inertia: 0.02, 0.05, 0.11 kg/m ²	1. Mean concentric velocity (MV) 2. maximum velocity (Vmax)	All variables between testing day 1 and 2, ICC=0.88-0.95.	All variables between testing day 1 and 2, CV=0.150%-	For all the data, it indicates the high precision of the measurement.

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
do et al.(34)	Experimental sessions: 2		Instrument used: 1. Epte Inertial Concept (Ionclionis and Deionic, LAlcúdia, ValenciaSpain) 2. a linear-position transducer (LPT) which acted as criterion measure (1000 Hz sampling rate, T-Force, Ergotest, Murcia, Spain) 3. the IMS (1000 Hz sampling rate, IonClinics & Deionic S.L, L'Alcudia, Spain)	3. mean propulsive velocity (MPV) in Concentric		0.206%, SEM=0.038-0.088	
Moreno-Azpet al.(39)	Study Design: test-retest Familiarisation sessions: 1 Experimental sessions: 2	1. Lateral Squat Test	Set and reps on exercise: 2 set, 10 reps Moment of Inertia: 0.27 kg/m ² Instrument used: 1. Versapulley, Costa Mesa, CA, USA	1. Con Mean Power 2. Ecc Mean Power	Con Mean Power: ICC=0.84-0.85 Ecc Mean Power: ICC=0.74-0.81	Con Mean Power, CV=19.91-23.36, TEM70.27-85.31 Ecc Mean Power, CV=23.79-31.63, TEM=67.82-88.13	When considering the CV, the strength test showed poor reliability, When considering ICC data, all tests showed moderate to good reliability.
Moreno-Azpet al.(40)	Study Design: test-retest Familiarisation sessions: 1 Experimental sessions: 4	1. Lateral Squat Test	Set and reps on exercise: 1 set, 10 reps Moment of Inertia: 0.27 kg/m ² Instrument used: 1. Versapulley, Costa Mesa, CA, USA	1. Con Mean Power 2. Ecc Mean Power 3. Con Peak Power 4. Ecc Peak Power	Con Mean Power: ICC=0.75-0.78 Ecc Mean Power: ICC=0.66-0.76 Con Peak Power: ICC=0.8-0.81 Ecc Peak Power: ICC=0.82-0.84	Con Mean Power: CV=16.86-19.46 TEM=51.81-71.45 Ecc Mean Power: CV=18.97-24.87 TEM=56.32-76.9 Con Peak Power: CV=16.28-18.88 TEM=93.11-132.45	CV values were >10% (range 16.28% to 24.87%), and all tests showed between a good and moderate reliability (ICC = 0.66 to 0.84), Eccentric power CV values suggested poor reliability (17.48–24.87%).

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
Pino-Ortega et al.(44)	Study Design: single time point studies Familiarisation sessions: 1 Experimental sessions: 1	1. one-hand standing row exercise	Set and reps on exercise: 10 set of 5 repetitions in a one-hand standing row exercise (5 series with each arm) Moment of Inertia: IU Instrument used: 1. An Eccotek Training Force® inertial flywheel (Byomedic System, Barcelona, Spain) 2. WIMU PROTM (RealTrack Systems, Almeria, Spain) 3. Smart Coach Versapulley Sensor® (SmartCoach Europe, Estocolm, Sweden)	1. velocity (v)	ICC=0.999	Ecc Peak Powe: CV=17.48-18.14 TEM=128.84-159.9 CV=0.840	Great between-device reliability was found (Bias= -0.01; CV=0.017%). IMU is a reliable and valid device to assess angular velocity in inertial flywheel workout objectively.
Piqueras-Sanchez et al.(45)	Study Design: test-retest Familiarisation sessions: IU Experimental sessions: 4	1. Flywheel Leg Curl Exercise	Set and reps on exercise: 5 sets of 8 repetitions (one repetition was necessary to activate the inertia) Moment of Inertia: 0.083, 0.132, 0.182, 0.266 and 0.350 kg/m ² Instrument used: 1. “Eccophysic” (Byomedic System SCP, Barcelona, Spain)	1. Peak Concentric power 2. Peak Eccentric power 3. the ECC/CON ratio	CON power, α =0.93-0.97, ECC power, α =0.85-0.96, while the α values for the ECC/CON ratio ranged from poor to moderate α =0.24-0.7.	IU	An increase in power reliability in CON and ECC phases were found across the testing sessions, with $\alpha > 0.90$, very high, for all inertial loads in session 4. However, inconsistent differences among inertial loads were observed in the ECCCON ratio. These authors confirm the necessity of gaining a certain amount of

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
							coordination by a familiarization procedure (e.g., 2-4 FW sessions), in order to execute the exercise with high to very high reliability.
Raya-González et al.(46)	Study Design: single time point studies Familiarisation sessions: 1 Experimental sessions: 1	1. lateral squat exercise	Set and reps on exercise:2 sets of 6 repetitions Moment of Inertia:0.10 kg/m ² Instrument used:1. K-Box 3; Exxentric R ©, Stockholm, Sweden with a rotary encoder (SmartCoach™ Power Encoder; SmartCoach Europe AB, Stockholm, Sweden)	1. Mean Power 2. Peak power	ICC=0.93-0.97	CV=2.9-7.3%	All tests showed excellent reliability.
Ryan et al.(49)	Study Design: test-retest Familiarisation sessions: IU Experimental sessions: 4	1. Quarter Squat	Set and reps on exercise:4 sets of 15 (5 + 5 + 5) repetitions using 4 inertial loads Moment of Inertia:0.025, 0.050, 0.075, and 0.100 kg/m ² Instrument used:1. kBox 4, Exxentric, AB TM, Bromma, Sweden	1. Mean Power 2. Peak Concentric Power 3. Peak Eccentric Power 4. the ECC/CON ratio	Cronbach's α=0.88-0.98, ICC=0.70-97.	CV=3.56%-16.14%, TE=9.07-43.71, SWC=10.68-52.72, SEM=19.71-49.91	The first testing session reported the greatest variance in CV% (internal group = 8.44–15.41%; external group = 7.37–16.14%). This report stating that a minimum of 2–3 sessions were required to observe stability in FW output, depending on the exercise involved.
Sabido et al.(50)	Study Design: test-retest Familiarisation sessions: 1	1. bilateral half squats 2. unilateral lunges	Set and reps on exercise:2 set of 8 repetitions Moment of Inertia: IU	1. Con Mean Power 2. Ecc Mean Power 3. Con Peak Power 4. Ecc Peak Power	ICC= 0.79-0.93	CV=7.5-13.2%	IU

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
Sabido et al.(51)	Experimental sessions: 2	1. Quarter Squat	Instrument used: 1. SmartCoach Power Encoder, SmartCoach Europe AB, Stockholm, Sweden				The main findings of our study were that at least 2 familiarization sessions are required to find stabilization in the values obtained in the flywheel quarter-squat exercise. No differences were found for any variable comparing day 4 versus day 3.
	Study Design: test-retest Familiarisation sessions: IU Experimental sessions: 4		Set and reps on exercise: 4 sets of 10 repetitions Moment of Inertia: 0.025, 0.050, 0.075, and 0.100 kg/m ² Instrument used: 1. kBox 3; Exxentric AB™, Bromma, Sweden	1. Concentric Peak power 2. Eccentric Peak power 3. the ECC/CON ratio	ICC=0.2-0.9.	CV=6.5%-16.6%.	
Smajla et al.(56)	Study Design: IU Familiarisation sessions: IU Experimental sessions: IU	1. Flywheel lateral squat	Set and reps on exercise: 1 set X 6 + 2 (The first two repetitions were used to accelerate FW and stabilize squat amplitude and were excluded from data analysis.) Moment of Inertia: 0.05, 0.125, and 0.2 kg/m ² Instrument used: 1. A draw-wire sensor (Way-Con SX-50, Taufkirchen, Germany; range 1250 mm, linearity ±0.02%) 2. A bilateral force plate system (type 9260AA, Kistler Instrumente AG, Winterthur, Switzerland)	1. Concentric Mean Force 2. Concentric Peak Force 3. Eccentric Mean Force 4. Eccentric Peak Force	the mean and peak force :ICC=0.92-0.96. symmetry: ICC=0.33-0.80.	CV=5.23%-10.61%	Absolute mean and peak forces of concentric and eccentric phases of contraction have excellent reliability, while lateral symmetry values are more reliable when the eccentric force is used for their calculation.

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
Spudić et al.(58)	Study Design: single time point studies Familiarisation sessions: IU Experimental sessions: 1	1. Flywheel squat	Set and reps on exercise: 2 sets X 5 reps each load Moment of Inertia: 0.025; 0.05; 0.075; 0.1; 0.125; 0.15; 0.175; 0.2; 0.0225; 0.25 kg/m ² Instrument used: 1. Custom-made FW device with A draw-wire sensor (Way-Con SX-50, Taufkirchen, Deutschland) 2. Bilateral force plate system (Type 9260AA, Kistler Instrumente AG, Winterthur, Switzerland)	1. Mean Force in Concentric phase 2. Mean Velocity in Concentric phase	Force: ICC=0.97-0.99 Velocity: ICC=0.87-0.98	CV=3.87%-9.92% in both metric, TE=0.63-1.32 in force and 0.02-0.08 in velocity.	Similar to mean F and v values, the averaging of six consecutive peak F and v repetitions showed trustworthy intersession reliability. Nevertheless, we found excellent inter-set reliability using each of the FW loads. Based on our study, we suggest averaging six consecutive mean squat repetitions in one session to obtain trustworthy primary outcome variables (i.e. at a single load condition).
Spudić et al.(54)	Study Design: single time point studies Familiarisation sessions: 3 Experimental sessions: 1	1. Flywheel squat	Set and reps on exercise: 2 sets X 6 + 4 each load (first two repetitions were used to achieve correct squat execution, and the last two to safely decelerate the spinning FW) Moment of Inertia: 0.025, 0.075, 0.225, and 0.25 kg/m ² Instrument used: 1. Custom-made FW device with A draw-wire sensor (Way-Con SX-50, Taufkirchen, Germany) + A bilateral force plate system (type 9260AA, Kistler Instruments AG,	1.Ground reaction force (GRF) 2.Velocity 3.Force–velocity–power (F–v–P) F–v–P outcomes from mean variables during the concentric phase of the squat were calculated.	GRF: ICC=0.874-0.963 Velocity: ICC=0.93-0.99 F–v–P outcomes ICC=0.737–0.943).	CV=8.6%-39.5%, TE=0.23-0.93	Good to excellent reliability was found for GRF and v (ICC > 0.85), regardless of the measure and the variable type. The F–v–P outcomes showed moderate to good reliability (ICC > 0.74).

Study Author	Test setting	Exercise Selection	Description of testing details	Outcome measure	Relative reliability (ICC, Pearson's r)	Absolute reliability (CV, CR, TE, TEE, SWC, SEM)	Comments about reliability
Worcester et al.(61)	Study Design: single time point studies Familiarisation sessions: 1 Experimental sessions: 1	1. Flywheel squat	Winterthur, Switzerland) 2. the shaft rotation sensor (slot type Optocoupler Module Speed Measuring Sensor for Arduino/51/AVR/PICCG, JingJiang, China) Set and reps on exercise: 3 set of 6 reps Moment of Inertia: 0.050, 0.075, and 0.100 kg/m ² Instrument used: 1. kBox4 Pro; Exxentric AB, Bromma, Sweden 2. Canon Vixia HF R52, Tokyo, Japan	1. average power 2. peak concentric power 3. peak eccentric power 4. average force 5. total work 6. repetition duration 7. vertical displacement	All: R2 > 0.900, p < 0.0001	IU	The second visit, which was identical to the third (testing) visit, served as a familiarization session indicated a high intraclass correlation.
Wren et al.(62)	Study Design: test-retest Familiarisation sessions: 2 Experimental sessions: 4	1. Flywheel squat 2. Assisted flywheel squat	Set and reps on exercise: 3 sets X 6 + 2 reps Moment of Inertia: 0.06 kg/m ² Instrument used: 1. flywheel ergometer (D11 Full, Desmotec)	1. Peak power 2. Eccentric: Concentric ratio 3. Rating of perceived exertion(RPE)	Peak power measures, ICC= 0.96-0.98 RPE and eccentric: concentric ratio, ICC=0.76-0.81	Peak power measures, CV=2.8%-5.8% RPE and eccentric: concentric ratio, CV=3.8%-11.2% Peak power measures, TEE=40-102. RPE and eccentric: concentric ratio, TEE=0.04-7.3	Our findings suggest that peak power measures are excellent for both squat conditions, while the E:C ratio reliability estimates ranging from acceptable to good.

Note. E:C: Eccentric: concentric ratio; FW: Flywheel; IU: information unavailable; COD: Change of direction; CON: Concentric; DL: Dominant Leg; FW: flywheel; SLCJ-L: single leg lateral countermovement jump; HPL: High-performance leg; LPL: Low-performance leg; N-DL: Non-Dominant Leg.

Table 4

Study characteristics regarding Validity (criterion-related validity) of Flywheel Resistance Technology Assessment

Authors	Exercise Selection	Moment of Inertia	Instrument used	Outcome measure in flywheel	Validity (ICC, R2 to other measurement, Bland-Altman)
Martín-San Agustín et al.(37)	1. bilateral stiff-leg deadlift 2. 45degree hip extension 3.unilateral straight knee bridge	IU	1. Encoder EPTEÒ IMS (Ionclinics SL, L'Alcudia, Spain) 2. MuscleLab 4020e (Ergotest Technology AS, Porsgrunn, Norway)	1. Peak velocity (m/s) 2. Average velocity (m/s) 3. Peak Force (N) 4. Average Force (N) 5. Peak Power (W) 6. Average Power (W)	Consistency between IMS and MuscleLab was good to excellent for all variables, with r ranges from 0.824 to 0.966 in SDL, from 0.822 to 0.971 in HE, and from 0.806 to 0.969 in SKB.
					Acceptable levels of agreement between devices were observed in general for all exercises, the “bias” ranging from 1.1% to 13.2%, except for the concentric power peak in SKB (17.4%). Furthermore, ‘imprecision’ values were acceptable, ranging between 5.5% and 15.2% for most of the parameters, except for the power values of HE and SKB (14.9–19.6% and 12.6–42.8%, respectively).
Pino-Ortega et al.(44)	1. one-hand standing row exercise	IU	1. An Eccotek Training Force® inertial flywheel (Byomedic System, Barcelona, Spain) 2. WIMU PROTM (RealTrack Systems, Almeria, Spain) 3. Smart Coach Versapulley Sensor® (SmartCoach Europe, Estocolm, Sweden)	1. velocity (v)	IMS is a new and valid system to monitor inertial hamstring exercises on a new flywheel device. The results obtained show the nearly perfect accuracy of the WIMU PROTM inertial device for angular velocity measurement in resistance training with an inertial flywheel (r=.999).
Maroto-Izquierdo et al.(34)	1. Flywheel squat	0.02, 0.05, 0.11 kg/m ²	1. Epte Inertial Concept (Ionclionis and Deionic, LAlcúdia, ValenciaSpain)	1. Mean concentric velocity (MV)	Validity test results by ordinary least products (OLP) regression (Intercept, Slope) and Lin’s concordance correlation coefficient (CCC),

Authors	Exercise Selection	Moment of Inertia	Instrument used	Outcome measure in flywheel	Validity (ICC, R2 to other measurement, Bland-Altman)
Spudić et al.(58)	1. Flywheel squat	0.025; 0.05; 0.075; 0.1; 0.125; 0.15; 0.175; 0.2; 0.0225; 0.25 kg/m ²	2. a linear-position transducer (LPT) which acted as criterion measure (1000 Hz sampling rate, T-Force, Ergotest, Murcia, Spain) 3. the IMS (1000 Hz sampling rate, IonClinics & Deionic S.L, L' Alcudia, Spain) 1. Custom-made FW device with A draw-wire sensor (Way-Con SX-50, Taufkirchen, Deutschland) 2. Bilateral force plate system (Type 9260AA, Kistler Instrumente AG, Winterthur, Switzerland)	2. maximum velocity (Vmax) 3. mean propulsive velocity (MPV) 1. Mean Force in Concentric phase 2. Mean Velocity in Concentric phase	Intercept is -0.09 - 0.02; Slope is 0.99-1.04, Lin's CCC is 0.96-0.99 in all metric in at moment At the secondary level, Bland-Altman statistics showed decreasing bias and limits of agreement in combination with more loads. Theoretical maximal force and power showed smaller bias as F-v slope and theoretical maximal velocity for three loads or more. Four loads (0.025, 0.075, 0.225 and 0.25 kg·m2) lowered bias to a 5% in relation to the reference F-v slope.
Spudić et al.(54)	1. Flywheel squat	0.025, 0.075, 0.225, and 0.25 kg/m ²	1. Custom-made FW device with A draw-wire sensor (Way-Con SX-50, Taufkirchen, Germany) 2. A bilateral force plate system (type 9260AA, Kistler Instruments AG, Winterthur, Switzerland) 3. the shaft rotation sensor (slot type	1. Ground reaction force (GRF) 2.Velocity	Inter-measure bias (p < 0.05) was found in the majority of GRF and v variables, as well as for all the calculated F–v–P outcomes (trivial to large TEs) with very large to perfect correlations for v (r 0.797–0.948), GRF (r 0.712–0.959), Rotary encoder overestimated the force plates and linear encoder variables, and the differences were dependent on the level of inertia. Despite high reliability, FW device users should be aware of the discrepancy between the measures.

Authors	Exercise Selection	Moment of Inertia	Instrument used	Outcome measure in flywheel	Validity (ICC, R2 to other measurement, Bland-Altman)
Illera-Domínguez et al.(26)	1. bilateral half-squats	0.075 and 0.025 kg/m ²	Optocoupler Module Speed Measuring Sensor for Arduino/51/AVR/PICCG, JingJiang, China)		
			1. “YoYo squat” flywheel device (YoYo Technology, Stockholm, Sweden) 2. low-cost friction encoder (Chronojump, Barcelona, Spain) 3. a strain gauge combined with a linear encoder attached to the harness	1. Mean repetition velocity 2. Mean repetition force 3. Mean repetition power	Compared to criterion measures, mean bias for the practical measures of Vrep, Frep and Prep were moderate (-0.95 [-0.99 to -0.92]), small (0.53 [0.50 to 0.56]) and moderate (-0.68 [-0.71 to -0.65]) respectively. The typical error of estimate (TEE) was small for all three parameters; Vrep (0.23 [0.20 to 0.25]), Frep (0.20 [0.18 to 0.22]) and Prep (0.18 [0.16 to 0.20]). Correlations with MuscleLab were nearly perfect for all measures in all load configurations.
Weakley et al.(60)	1. the harness squat	0.05, 0.10, and 0.15 kg/m ²	1. synchronized dual force plate and high-speed camera setup 2. a commonly used flywheel monitoring system (kMeter II)	1. Average force 2. Average power	Regression equations Slope = 0.782- 0.9238. Correlation coefficients of mean force and power at all loads demonstrated very large to nearly perfect relationships between the criterion and practical measure. The primary finding of this study is that the kMeter app provides acceptable levels of agreement with the criterion measure in both mean force and power at a range of different isoinertial loads.

Note. E:C: Eccentric: concentric ratio; FW: Flywheel; IU: information unavailable

Table 5

Study characteristics regarding Validity (Construct-related validity) of Flywheel Resistance Technology Assessment

Authors	Exercise Selection	Moment of Inertia	Instrument used	Outcome measure in flywheel	Validity (ICC, R2 to other measurement, Bland-Altman)
Beato et al.(8)	1. Flywheel half squat test	0.061 kg/m ²	1. a standardized ergometer (D11 Full, Desmotec, Biella, Italy)	1. concentric Power 2. Eccentric power	Isokinetic test ham concentric, R2 = 0.465 to 0.472 Isokinetic test ham eccentric, R2= 0.502 to 0.516
Bollinger et al.(12)	1. Bent-over row 2. Romanian deadlift 3. Biceps curl	0.050, 0.075, and 0.100 kg/m ²	1. Excentric kbox 4 Pro	1. Average power 2. Average force 3. Total work	There was a linear relationship between predicted and measured values for average power (0.9582x + 2.6063; R2 = 0.9788), average force (0.9994x + 27.734; R2 = 0.9753), and total work (0.9669x + 0.2099; R2 = 0.9392).
Smajla et al.(54)	1. flywheel squats	0.025, 0.075, 0.225 and 0.25 kg/m ²	1. A bilateral force plate system (type 9260AA, Kistler, Winterthur, Switzerland) 2. a custom-made FW device with draw-wire sensor (WayCon SX-50, Taufkirchen, Germany, range 1,250 mm, linearity ±0.02%)	1. theoretical maximal force 2. maximal unloaded velocity 3. theoretical maximal power 4. F-v slope	The only significant negative correlation regarding FW squats F-v outcome variables was seen between Pmax and short KST (r = -0.37, p < 0.05). This result suggests that more powerful karatekas could be faster during KST performance. During the short KST, karatekas perform multiple Cod on short distances (0.5 m), stressing deceleration and acceleration ability.
Smajla et al.(55)	1. 90°knee angle to full extension squat	0.05, 0.125 and 0.2 kg/m ²	1. A bilateral force plate system (type 9260AA, Kistler, Winterthur, Switzerland) 2. a custom-made FW device with draw-wire sensor (WayCon SX-50, Taufkirchen, Germany, range 1,250 mm, linearity ±0.02%)	1. Peak eccentric force (N)	FW 0.05 kg/m ² and CMJPF (r =0.335, p <0.001). FW 0.05 & FW 0.0125 kg/m2 with CMJPF (r =0.22–0.224, both p=0.002). CoD 90° time, r = -0.14 to -0.19, p=0.008–0.049), CoD 180° time, (r = -0.190 to -0.262, p = 0.001–0.008).

Note. E:C: Eccentric: concentric ratio; FW: Flywheel; IU: information unavailable; KST: karate specific test; Pmax: Maximum power; CMJPR:

countermovement peak force; CoD; change of direction

Table 6

Significant Correlation between FW testing Asymmetries with performance testing

Authors	Significant Correlation between FW testing Asymmetries with performance testing	Correlation between FW testing Asymmetries with performance testing (Spearman's r or Pearson r)
Fort-Vanmeerhaeghe et al. (23)	Sidestep - Concentric symmetries were associated with reduced performance in single-leg countermovement jumps and change of direction deficits.	1. Sidestep-CON to SLCJ-L in HPL, $r=-0.61$ 2. Sidestep-CON to COD deficit 135 in HPL, $r=0.78$ 3. Sidestep-CON to COD deficit 135 in LPL, $r=0.72$ 4. Sidestep-CON to COD deficit 90 in HPL, $r=0.81$ 5. Sidestep-CON to COD deficit 90 in LPL, $r=0.74$
Madruga-Parera et al.(32)	1. Crossover Steps - Concentric asymmetries were associated with slower 20M sprint times and reduced change of direction speed in both dominant and no-dominant legs in both CODS90 and CODS180. 2. Lateral shuffle steps - Concentric asymmetries were associated with reduced change of direction speed in no-dominant leg in CODS90.	1. Crossover Steps-CON to CODS90 in DL, $r=0.48$ 2. Crossover Steps-CON to CODS90 in N-DL, $r=0.51$ 3. Crossover Steps-CON to CODS180 in DL, $r=0.51$ 4. Crossover Steps-CON to CODS180 in N-DL, $r=0.41$ 5. Crossover Steps-CON to 20M speed, $r=0.46$ 6. Lateral shuffle steps-CON to CODS90 in N-DL, $r=0.44$
Madruga-Parera et al.(31)	There is no Significant Correlation between FW testing Asymmetries with performance testing	N/A
Madruga-Parera et al.(30)	1. Asymmetries observed for the concentric phase of the Leg extension test decreased performance in the eccentric phase of the Crossover Steps test for the right leg 2. Crossover Steps- Concentric asymmetries reduced performance in the COD 3. Crossover Steps – eccentric asymmetries reduced performance in the leg extension	1. Crossover Steps-CON to COD in Left, $r=0.51$ 2. Crossover Steps-CON to COD in Right, $r=0.59$ 3. Crossover Steps-ECC to leg extension CON(left), $r=-0.57$ 4. Crossover Steps-ECC to leg extension CON(right), $r=-0.51$ 5. Crossover Steps-ECC to leg extension ECC(left), $r=-0.58$ 6. Crossover Steps-ECC to leg extension ECC(right), $r=-0.50$ 7. Leg extension-CON to Crossover Steps ECC(right), $r=-0.63$

Authors	Significant Correlation between FW testing Asymmetries with performance testing	Correlation between FW testing Asymmetries with performance testing (Spearman's r or Pearson r)
Raya-González et al.(46)	There is no Significant Correlation between FW testing Asymmetries with performance testing	N/A

Note. E:C: Eccentric: concentric ratio; FW: Flywheel; IU: information unavailable; KST: karate specific test; CON; Concentric power; SLCJ: single leg countermovement jump; COD; change of direction; L: left; R:right; DL: dominant leg; N-DL; non-dominant leg; ECC; Eccentric power