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Flywheel resistance training and performance determinants in long-distance runners: A narrative review

Entrenamiento de fuerza con volante de inercia y determinantes del rendimiento en corredores de larga distancia: revisión narrativa

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Abstract
Flywheel resistance training, characterized by its emphasis on eccentric force production, has been supported by the scientific literature as an effective strategy for enhancing muscle power, muscle mass, running speed, and sport-specific performance capacities. Within this context, the aim of this narrative review was to provide an overview of the main determinants of performance in long-distance runners, describe how strength training may contribute to their improvement, and examine the potential role of flywheel resistance training in influencing these determinants based on the available scientific evidence.
To this end, a narrative review was conducted using the PubMed, Scopus, Web of Science, and ScienceDirect databases without date restrictions. Systematic reviews, meta-analyses, observational studies, and experimental studies were considered for inclusion.
The available evidence suggests that strength training, particularly programs emphasizing eccentric muscle actions and a high rate of force development, improves running economy and endurance performance without compromising maximal oxygen uptake (VO_2max). In this regard, flywheel resistance training, which induces high neuromuscular demands and running-specific mechanical stimuli, may promote adaptations related to the stretch-shortening cycle and musculotendinous stiffness. Nevertheless, the current evidence remains limited and heterogeneous.
In conclusion, flywheel resistance training, when combined with aerobic endurance training, appears to be a promising strategy for optimizing key performance determinants in long-distance runners. However, further high-quality experimental research is warranted to clarify its effectiveness and practical applications.

Keywords: long-distance running; marathon running; athletic performance; resistance training; flywheel resistance training.

Resumen
El entrenamiento con volante de inercia, orientado al desarrollo de la fuerza excéntrica, ha sido respaldado por la literatura científica como una estrategia eficaz para promover mejoras en la potencia muscular, masa muscular, velocidad de carrera y capacidades deportivas específicas. En este marco, el objetivo de esta revisión fue ofrecer una visión general de los principales determinantes del rendimiento en corredores de larga distancia, describir cómo el entrenamiento de fuerza puede influir en su mejora, con atención en el entrenamiento de fuerza con volante de inercia, explorando su potencial influencia sobre dichos determinantes según la evidencia científica disponible. Para ello, se realizó una revisión narrativa, consultando las bases de datos PubMed, Scopus Web of Science y ScienceDirect, sin restricciones de fecha, incluyendo revisiones sistemáticas, meta-análisis, estudios observacionales y experimentales.
La literatura sugiere que el entrenamiento de fuerza, particularmente aquel que enfatiza acciones excéntricas y una elevada tasa de desarrollo de la fuerza, mejora la economía de carrera y el rendimiento en corredores de resistencia sin comprometer el VO_2max. En este sentido, el entrenamiento con volante de inercia caracterizado por inducir altas demandas neuromusculares y mecánicas específicas de la carrera, puede favorecer las adaptaciones

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relacionadas con el ciclo estiramiento–acortamiento y la rigidez músculo-tendinosa. No obstante, la evidencia disponible aún es limitada y heterogénea.
En conclusión, el entrenamiento de fuerza con volante de inercia sumado al de resistencia aeróbica, emerge como una estrategia prometedora para optimizar determinantes clave del rendimiento en corredores de larga distancia, justificando la necesidad de investigaciones experimentales de mayor calidad metodológica.

Palabras clave: carreras de larga distancia; maratón; rendimiento atlético; entrenamiento de fuerza; entrenamiento de fuerza con volante de inercia.

Introduction

Long-distance running events are currently performed across a wide range of geographical settings and environmental conditions, encompassing distances from 10 km races to the full marathon in track, road, cross-country, and mountain-running disciplines (Competition and Technical Rules, 2024). These competitive demands require athletes to possess a unique combination of anatomical, physiological, biomechanical, and psychological characteristics that enable them to cope effectively with the specific challenges imposed by each event. The relative importance of these attributes varies according to race distance and competition demands (Llanos-Lagos et al., 2024b; Tiller & Millet, 2024).

The primary determinants of endurance running performance include maximal oxygen uptake (VO_2max), the fraction of maximal aerobic speed that can be sustained during exercise, the anaerobic threshold, and running economy (RE) (Moore, 2016; Li, Newton et al., 2021; Haugen et al., 2022; Llanos-Lagos et al., 2024a). Among these variables, RE has been considered a more specific predictor of endurance performance than VO_2max because it represents a multifactorial construct reflecting the integrated functioning of metabolic, cardiopulmonary, biomechanical, and neuromuscular systems.

Consequently, groups of runners with similar VO_2max values may exhibit differences of up to 30% in RE, partly attributable to variations in the efficiency of oxygen transport and utilization processes (Barnes & Kilding, 2015b; Beattie et al., 2017; Blagrove et al., 2018). Athletes with superior RE consume less oxygen than less economical runners when exercising at the same steady-state running velocity, a

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condition typically characterized by the maintenance of blood lactate concentrations near resting levels and a respiratory exchange ratio (RER) below 1.0 (Saunders et al., 2004).

Furthermore, neuromuscular efficiency is reflected in the interaction among athlete-specific anthropometric characteristics, intermuscular coordination, and muscle-tendon stiffness. When these factors are associated with force-production capacity and the storage and release of elastic energy within the locomotor muscle-tendon units (MTUs) involved in the running stride, they may explain substantial interindividual differences in endurance performance. Indeed, several studies have consistently reported that more economical runners exhibit greater plantar-flexor strength and increased tendon-aponeurosis stiffness within the triceps surae MTU compared with their less economical counterparts (Arampatzis et al., 2006; Albracht & Arampatzis, 2013; Eihara et al., 2024).

In this regard, numerous investigations have demonstrated that strength training interventions in endurance sports can induce neuromuscular adaptations that enhance mechanical efficiency, intra- and intermuscular coordination, motor-unit recruitment patterns, muscle and tendon stiffness, and kinematic variables associated with RE (Beattie et al., 2014; Blagrove et al., 2018; Howe et al., 2021; Li, Nassis et al., 2021; Llanos-Lagos et al., 2024a; Llanos-Lagos et al., 2024b). Accordingly, several meta-analyses have extensively documented the effectiveness of high-load resistance training, plyometric training, and combined training approaches. When integrated with athletes' habitual aerobic endurance training, these methods have demonstrated, with moderate-to-high certainty of evidence, significant improvements in RE across different running velocities, as well as enhanced performance in time-trial events representative of long-duration endurance performance. Nevertheless, further experimental research remains warranted to elucidate the potential effects of different strength-training modalities, particularly in understudied populations such as highly trained athletes and female endurance runners (Balsalobre-Fernández et al., 2016; Eihara et al., 2022; Llanos-Lagos et al., 2024b).

Within this framework, flywheel resistance training has emerged in recent years as a specific eccentric-oriented training modality capable of eliciting substantial eccentric overload and promoting adaptations in muscle power, muscle hypertrophy, running speed, and sport-specific performance capacities (Beato & Dello, 2020; de Keijzer et al.,

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2022). The unique mechanical characteristics of flywheel devices facilitate accentuated eccentric loading during the braking phase of movement, thereby enhancing neuromuscular stimuli beyond those typically achieved with traditional gravity-dependent resistance training. Consequently, studies implementing flywheel-based training interventions in athletes from various sporting disciplines (Puustinen et al., 2023; Xue et al., 2025; de Dios-Álvarez et al., 2025), physically active healthy individuals (Nakamura et al., 2021; Hu et al., 2024), and populations presenting physical impairments or functional limitations (Patrocinio de Oliveira et al., 2018; Kim et al., 2025; Santos et al., 2025) have highlighted the broad applicability and effectiveness of this training modality across diverse contexts.

Given the recognized role of eccentric muscle actions in enhancing MTU function, force-generating capacity, and neuromuscular performance, flywheel resistance training may represent a promising strategy for optimizing key physiological and biomechanical determinants of endurance running performance. Therefore, the aim of this narrative review is to provide an overview of the principal determinants of physical performance in long-distance runners, briefly discuss the training modalities that have been shown to improve these determinants, and subsequently describe the main characteristics of flywheel resistance training. Additionally, this review explores the mechanisms through which flywheel-induced eccentric overload may influence endurance-performance determinants in long-distance runners, based on the currently available scientific evidence.

Methodology

The present study was conducted following the methodological principles of a narrative review, characterized by a flexible literature-search approach aimed at describing, analyzing, and critically discussing a research topic without requiring the exhaustive and highly structured procedures typically associated with systematic reviews (Sukhera, 2022).

The literature search was performed in March 2025 across the electronic databases PubMed, Scopus, Web of Science, and ScienceDirect (Elsevier), which were selected because of their extensive coverage of biomedical research, sport sciences, and exercise

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science literature. In addition, a manual search of the reference lists of potentially relevant articles was conducted to identify studies that may not have been retrieved through the electronic database searches. No restrictions were imposed regarding publication date or study design.

The search strategy was organized into two complementary approaches according to the objectives of the review. The first approach aimed to identify literature addressing the main physiological and performance determinants in long-distance runners. To this end, terms related to the target population ("Running," "marathon running," "endurance athlete*," and "long distance runn*") were combined using the Boolean operator AND with terms associated with performance determinants ("adaptation, physiological," "athletic performance," "performance determinants," and "running economy").

The second search strategy was designed to identify studies related to strength training and, more specifically, flywheel resistance training in long-distance runners. In this case, population-related terms ("Running," "marathon running," "endurance athlete*," and "long distance runn*") were combined using the Boolean operator AND with strength-training-related terms ("resistance training," "strength training," "eccentric training," "flywheel," "flywheel training," and "flywheel resistance training"). Search strings were adapted to the specific indexing characteristics and search requirements of each database.

The eligibility criteria included: (1) peer-reviewed articles published in English involving human participants, including systematic reviews, meta-analyses, observational studies, and experimental investigations; (2) studies conducted in athletes older than 18 years who were trained in long-distance running disciplines; (3) investigations examining physiological, neuromuscular, biomechanical, and/or metabolic factors associated with endurance-running performance; and (4) publications evaluating the effects of flywheel resistance training on these factors or on performance-related determinants.

The exclusion criteria comprised: (1) studies focused on interventions other than strength training when they did not provide information relevant to the objectives of the review; (2) investigations primarily addressing clinical variables, rehabilitation processes, injury prevention, or general health outcomes without a direct relationship to athletic performance; and (3) articles presenting insufficient methodological information or unclear findings that limited their contribution to the narrative synthesis.

Subsequently, all identified records underwent an initial screening of titles and abstracts. Studies considered potentially relevant were then assessed through full-text review to determine their eligibility and relevance to the objectives of the review. Finally, a qualitative synthesis of the available evidence was conducted, organizing the findings from the principal determinants of performance in long-distance runners to the current perspectives regarding the potential effects of flywheel resistance training on these determinants within this athletic population.

Determinants of Physical Performance in Long-Distance Runners and the Role of Strength Training

As discussed previously, performance in long-distance running is the result of the interaction among multiple factors, including morphological, physiological, biomechanical, environmental, and psychological determinants (Blagrove et al., 2018; Denadai & Greco, 2022). Within this framework, understanding which factors contribute most substantially to athletic performance is further influenced by contextual variables such as race characteristics (distance, gradient, terrain, and environmental temperature), athletes' competitive level (recreational, amateur, or elite), and sex-specific differences.

From a physiological perspective, a substantial body of research has addressed this topic based on the premise that the majority of energy production during endurance running events is derived from oxidative metabolism (Bassett & Howley, 2000; Padulo et al., 2023). Accordingly, several key aerobic-fitness parameters have been identified as major predictors of endurance-running performance. Maximal oxygen uptake (VO_2max), the fractional utilization of VO_2max that can be sustained over prolonged periods (closely related to the anaerobic threshold), and running economy (RE) are widely recognized as the principal determinants of performance in road-based long-distance events, including the 10,000 m, half-marathon, marathon, and intermediate endurance distances (McLaughlin et al., 2010; Millet et al., 2012; Blagrove et al., 2018; Ehrström et al., 2018; de Waal et al., 2021).

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VO_2max represents the maximal capacity of the organism to uptake, transport, and utilize oxygen during incremental high-intensity exercise, integrating the coordinated function of the cardiovascular, respiratory, and skeletal-muscle systems. However, VO_2max alone does not fully explain performance differences among runners with comparable training status, particularly in well-trained athletes (Bassett & Howley, 2000; Lanferdini et al., 2020). Fractional utilization of VO_2max is influenced by peripheral adaptations, including enhanced skeletal-muscle oxidative capacity, increased mitochondrial density, and improved substrate-utilization efficiency. Consequently, this variable reflects not only the aerobic capacity of the system but also the athlete's metabolic tolerance to sustained exercise (Joyner & Coyle, 2008).

Running economy, in turn, constitutes a multifactorial variable that often differentiates performance between athletes with similar VO_2max values. Consequently, the runner exhibiting superior RE generally demonstrates enhanced endurance performance. The relevance of RE resides in the interaction among three interrelated dimensions of efficiency: metabolic efficiency, defined as the capacity to utilize available energy resources effectively to sustain performance; cardiopulmonary efficiency, referring to the ability to minimize the physiological cost associated with oxygen transport and utilization; and neuromuscular efficiency (Barnes & Kilding, 2015a).

The latter can be better understood by considering the four primary functions performed by the lower-limb musculature during running: (1) generating force and power (motor function), (2) attenuating impact forces through eccentric muscle actions during the initial contact phase (shock absorber function), (3) storing and releasing elastic energy (spring function), and (4) transmitting force with minimal deformation (strut function). These functions are directly linked to two fundamental neuromuscular mechanisms: the stretch-shortening cycle (SSC) and leg stiffness (Kleg) (Li, Newton et al., 2021; Burgos et al., 2023). Runners with a greater capacity to exploit SSC dynamics and optimize leg stiffness may generate approximately 50% greater propulsive force during the push-off phase through the effective reutilization of elastic energy (Vogt & Hoppeler, 2014). This mechanism may reduce the muscular activation required for locomotion, facilitate more efficient energy transfer throughout the running stride, decrease metabolic cost, and ultimately improve endurance performance (Midgley et al., 2007; Genitrini et al., 2023).

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Collectively, the available evidence suggests that RE is not exclusively dependent on aerobic capacity but rather emerges from the interaction of neuromuscular and biomechanical factors that determine how forces are generated, absorbed, stored, and reutilized during locomotion. This perspective reinforces the multifactorial model of endurance-running performance, in which neuromuscular determinants assume a pivotal role in explaining performance differences among athletes with comparable aerobic profiles. Within this context, strength training has emerged as one of the most evidence-based strategies for optimizing these determinants by inducing structural and functional adaptations within the neuromuscular system that may translate into improvements in RE and, ultimately, endurance-running performance (Blagrove et al., 2018; Li, Newton et al., 2021; Llanos-Lagos et al., 2024a; Ramos-Campo et al., 2025).

In support of this notion, Li, Nassis et al. (2021) compared the effects of three strength-training modalities combined with habitual endurance running in 38 amateur marathon runners: Complex Training (CPX), a multicomponent approach alternating high-intensity resistance exercises and plyometric exercises within the same training session; Heavy Strength Training (HST); and Endurance-Strength Training (EST). Their findings revealed that the HST and CPX groups achieved greater improvements across all neuromuscular and performance-related indicators, including one-repetition maximum (1RM), squat jump (SJ), countermovement jump (CMJ), concentric and eccentric leg-press strength, RE, and velocity at VO_2max (vVO_2max), whereas the EST group demonstrated no significant pre- to post-intervention changes.

Similarly, Prieto-González and Sedlacek (2022) reported that both running-specific strength training combined with endurance training and concurrent training approaches elicited significant improvements in maximal and explosive strength, as well as RE at submaximal running velocities. Moreover, concurrent training effectively integrated neuromuscular and aerobic adaptations—including improvements in VO_2max and anaerobic threshold—without evidence of detrimental interference effects.

Complementing these findings, Eihara et al. (2024) observed that both plyometric training and traditional resistance training improved RE in middle-aged recreational runners, regardless of the specific training stimulus employed. These findings suggest that neuromuscular adaptations—particularly those related to force-production capacity

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and efficient SSC utilization—play a central role in reducing the energetic cost of running.

The evidence supporting these observations is further strengthened by higher-level reviews. Ramos-Campo et al. (2025) comprehensively examined the effects of strength training on performance determinants in middle- and long-distance athletes, differentiating among maximal-strength training, explosive-strength training, and reactive-strength training (plyometric training). Their analysis revealed moderate-to-large improvements in RE across all strength-training modalities, while no significant changes were observed in VO_2max. These findings reinforce the notion that performance enhancements associated with strength training are primarily mediated by neuromuscular and biomechanical adaptations rather than by increases in maximal aerobic capacity.

More specifically, plyometric training—characterized by rapid eccentric muscle actions and substantial SSC involvement—demonstrated positive effects on endurance performance, with effect sizes ranging from small to large depending on the experimental context. These results underscore the importance of eccentric-induced adaptations and enhanced muscle-tendon stiffness as key mechanisms contributing to reductions in the energetic cost of running.

Although plyometric training has demonstrated effectiveness in promoting eccentric and reactive adaptations, the magnitude and control of eccentric loading are often constrained by technical and practical limitations. In this context, flywheel resistance training has emerged as a methodological alternative capable of providing substantial and highly specific eccentric overload. Through its unique capacity to impose accentuated eccentric loading, flywheel training may induce neuromuscular adaptations that are particularly relevant to improving RE, including enhancements in force-production capacity, SSC efficiency, muscle-tendon unit function, and musculotendinous stiffness. Consequently, this rationale supports a focused examination of the available evidence regarding the application of flywheel resistance training in long-distance runners and its potential influence on key determinants of endurance performance.

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General Characteristics of Flywheel Resistance Training and Its Application in Sport

Over the last decade, the scientific literature examining flywheel resistance training has expanded substantially, establishing this training modality as an effective method for enhancing muscular strength and physical performance capacities in both athletic and physically active populations (de Keijzer et al., 2022; Banks et al., 2024). Nevertheless, the most recent expert consensus on flywheel technology (Beato et al., 2024) highlighted several challenges that continue to affect the interpretation of findings within this research field. These include methodological and statistical inaccuracies originating from seminal studies that are still frequently cited, as well as inconsistencies in the terminology used to describe key concepts and outcomes. Consequently, the consensus provided evidence-based recommendations regarding the application of flywheel resistance technology in sport and identified three fundamental characteristics that define this training modality.

First, flywheel resistance training is characterized by the use of rotating discs or conical pulleys to generate resistance. The concentric phase is initiated by pulling a strap attached to the device shaft, thereby accelerating the flywheel or cone. As the strap rewinds around the shaft, an eccentric muscle action is required to decelerate the rotational momentum generated during the preceding concentric phase, producing a braking force during the eccentric action (Maroto-Izquierdo et al., 2017; Suchomel et al., 2019).

Second, a defining feature of flywheel training is its potential to generate eccentric overload, which is defined as greater mechanical output during the eccentric phase than during the concentric phase of the same repetition. The achievement of eccentric overload depends on several factors, including the selected moment of inertia, the athlete's training experience, and the braking technique employed during the eccentric phase (Beato et al., 2020). This concept leads directly to the third characteristic.

To maximize the training stimulus, athletes must perform each repetition with near-maximal intent while precisely timing the eccentric braking action. This strategy promotes near-maximal muscle activation and enables the attainment of high training intensities, thereby optimizing the neuromuscular stimulus provided by the exercise

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(Beato & Dello, 2020). In addition to these principles, the observations reported by Spudić and Nosaka (2026) regarding the mechanical behavior of concentric and eccentric actions within the same movement warrant particular consideration. These authors emphasized that true eccentric overload is achieved only when mechanical variables such as force, velocity, or power are demonstrably greater during the eccentric phase than during the concentric phase of each repetition. Such conditions may contribute to superior muscular adaptations and greater improvements in athletic performance.

Eccentric strength training has consistently demonstrated effectiveness in promoting favorable adaptations in both untrained individuals and athletes (Wagle et al., 2017). The physiological mechanisms underlying these adaptations involve molecular, neural, and energetic processes. At the molecular level, eccentric contractions stimulate satellite-cell activation and anabolic signaling pathways, particularly in fast-twitch muscle fibers, which are more susceptible to mechanical stress and remodeling. Moreover, eccentric loading enhances muscle-protein synthesis when high-force production is combined with muscle lengthening, thereby facilitating skeletal-muscle hypertrophy and increases in muscle cross-sectional area (Douglas et al., 2018).

From a mechanical perspective, eccentric contractions enable greater force production at a lower metabolic cost owing to the contribution of passive sarcomeric structures and enhanced neuromuscular efficiency. Furthermore, eccentric actions promote the recruitment of high-threshold motor units and increase cortical excitability, thereby enhancing neural drive and force-generating capacity (Douglas et al., 2017; Hody et al., 2019). Collectively, these characteristics provide a strong rationale for the use of flywheel resistance training as an effective tool for inducing both acute and chronic physiological adaptations.

Regarding acute adaptations, one of the most relevant phenomena is post-activation performance enhancement (PAPE), which refers to the transient improvement in physical performance following the completion of a conditioning activity (Wallace et al., 2019). This response is primarily associated with the phosphorylation of myosin regulatory light chains, which enhances muscle contractile function. Although PAPE has traditionally been investigated using conventional resistance-training exercises, emerging evidence suggests that flywheel-based exercises may also elicit this response. The

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capacity of flywheel training to generate high levels of neuromuscular activation, improve motor-unit synchronization, and produce elevated forces at high eccentric velocities indicates that it may represent a promising conditioning modality for PAPE protocols.

Beato et al. (2023) investigated PAPE-related improvements in quadriceps and hamstring isokinetic torque following flywheel squat and flywheel deadlift exercises compared with a control condition. Using a randomized crossover design involving 15 male athletes, the authors observed a significant condition effect (PAPE; $p = 0.008$) for hamstring eccentric peak isokinetic torque following both the flywheel squat and flywheel deadlift interventions. However, no significant effects were observed for concentric peak torque. These findings indicate that both flywheel exercises are capable of eliciting PAPE responses in hamstring eccentric torque. Such outcomes may have practical implications for the development of sport-specific warm-up strategies aimed at enhancing subsequent strength and power performance. Nevertheless, further research is required before evidence-based practical recommendations can be established.

With respect to chronic adaptations, flywheel resistance training has been shown to induce favorable changes in muscle architecture and improve functional strength performance (Maroto-Izquierdo et al., 2017). These benefits are primarily attributed to the combination of maximal-effort concentric actions and overloaded eccentric phases. The interaction between these two components provides a more comprehensive muscular stimulus than training methods relying predominantly on concentric contractions, thereby enhancing the overall adaptive response (Petré et al., 2018).

A highly regarded umbrella review, recognized by the expert consensus for its methodological rigor, quality of evidence appraisal, interpretation of findings, and comprehensiveness, was conducted by de Keijzer et al. (2022). This review synthesized evidence from 11 systematic reviews examining the effects of flywheel resistance training on strength and physical-performance outcomes in healthy and athletic populations. Regarding chronic performance adaptations, six systematic reviews consistently supported the effectiveness of flywheel training for improving strength-related outcomes, while four reviews concluded that flywheel training constitutes a valid alternative to traditional resistance-training approaches.

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Within the same synthesis, Petré et al. (2018) suggested that the reported strength gains may be attributable to adaptations involving both peripheral and central mechanisms, including enhanced muscle activation, alterations in muscle morphology, and improvements in the muscle length–tension relationship. Furthermore, the available evidence indicates that meaningful performance improvements typically emerge after approximately 5–10 weeks of flywheel training (Maroto-Izquierdo et al., 2017; Vicens-Bordas et al., 2018; Petré et al., 2018). These adaptations have been associated with improvements in sport-specific skills such as jumping performance, linear sprint speed, and change-of-direction ability.

Additionally, flywheel training has demonstrated effectiveness as an injury-prevention strategy, particularly for hamstring muscle injuries, largely due to the eccentric-strength adaptations induced by repeated exposure to eccentric overload. Taken together, these findings support the use of flywheel resistance training as an efficient tool for both athletic-performance enhancement and injury prevention. Nevertheless, future research is still required to establish evidence-based recommendations regarding optimal training frequency, exercise specificity, individualized prescription strategies, and appropriate progression criteria to further refine the practical application of flywheel resistance training in sport settings (Raya-González et al., 2021).

Studies examining flywheel resistance training in long-distance athletes: strengths, limitations, and implications for performance determinants

Flywheel resistance training has been proposed as a strategy capable of eliciting neuromuscular adaptations relevant to performance enhancement in long-distance athletes. However, empirical evidence in this population remains scarce, with only two studies currently available: the first conducted in recreational runners (Festa et al., 2019) and the second in well-trained young endurance athletes (Weng et al., 2022). To provide a structured synthesis of the available evidence, Table 1 summarizes the study designs, participant characteristics, intervention protocols, and principal findings.

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Table 1.

Characteristics of the included studies

Item	Study 1 (Festa et al., 2019)	Study 2 (Weng et al., 2022)
Objective	To evaluate the effects of FST, LIT, and HIT training protocols on running economy (RE) and strength-related parameters in recreational runners.	To investigate the effects of flywheel-based accentuated eccentric loading (AEL) training on running economy in well-trained young male distance runners.
Design	Three-arm parallel CCT. Two control groups and one experimental group.	Two-arm parallel RCT. One experimental group and one control group.
Population characteristics		
N	29	22
Sex	♂: 18 / ♀: 11	♂
Group allocation	FST: ♂ 6 / ♀ 5 HIT: ♂ 6 / ♀ 3 LIT: ♂ 6 / ♀ 3	FG:12 CG: 10
Age (years)	FST: 44.2 ± 6.0 HIT: 42.2 ± 8.6 LIT: 45.4 ± 8.0	FG: 22.2 ± 2.6 CG: 21.4 ± 2.5
VO_2max ($mL\cdot kg^{-1}\cdot min^{-1}$)	FST: 48.8 ± 5.2 HIT: 50.3 ± 3.7 LIT: 50.2 ± 6.8	FG: 58.3 ± 3.4 CG: 57.8 ± 3.3
Intervention characteristics		
Training content	**FST:** Flywheel leg press (Yo-Yo device), 4 × 7 repetitions + LIT at 70–105% of reference velocity (RV), corresponding to the mean velocity between VT1 and VT2. **HIT:** 95–140% of RV. **LIT:** 70–105% of RV.	**FG:** Flywheel squat performed with maximal effort (flywheel inertia = 0.06 $kg\cdot m^2$), 4 × 7 repetitions + aerobic training (10-km continuous run). **CG:** Traditional squat training (85% 1RM), 4 × 6 repetitions + aerobic training (10-km continuous run).
Intervention duration	8 weeks	6 weeks
Weekly frequency	**FST:** 1 flywheel session·week^{-1} + 3 LIT sessions·week^{-1} **HIT:** 3 sessions·week^{-1} **LIT:** 3 sessions·week^{-1}	**FG:** 3 sessions·week^{-1} **CG:** 3 sessions·week^{-1}
Findings		
Experimental group	• Significant improvement in maximal strength (1RM) ($p \le 0.05$). • Significant improvement in RE at 75% VO_2max ($p \le 0.01$). • Significant improvements in 2-km and 10-km time-trial performance ($p \le 0.05$). • No significant changes in body-composition variables (body mass, fat-free mass, and body-fat percentage).	• Significant improvements in RE at 75% VO_2max both within-group ($p \le 0.001$) and between-group ($p \le 0.033$). • Significant within-group improvements in jump-performance variables: SJ ($p \le 0.001$), CMJ ($p \le 0.001$), EUR ($p \le 0.04$), SJ-RFD ($p = 0.013$), and CMJ-RFD ($p = 0.002$).

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Control group	• No significant changes in body composition, maximal strength, or RE in either control group. • Significant improvements in 2-km and 10-km time-trial performance ($p \leq 0.01$).	• No significant differences in RE or power outcomes.

Note. CCT = Controlled Clinical Trial; RCT = Randomized Controlled Trial; AEL = accentuated eccentric loading. Study 1: FST = Flywheel Strength Training + Low-Intensity Training; HIT = High-Intensity Training; LIT = Low-Intensity Training. Study 2: FG = Flywheel Group (Flywheel Strength Training + Traditional Endurance Training); CG = Control Group (Traditional Strength Training + Traditional Endurance Training); TST = Traditional Strength Training; TET = Traditional Endurance Training; VT1 = first ventilatory threshold; VT2 = second ventilatory threshold; RV = reference velocity; ♂ = male; ♀ = female; RE = running economy; SJ = squat jump; CMJ = countermovement jump; EUR = eccentric utilization ratio; RFD = rate of force development.

Following the methodological-quality appraisal and assessment of reporting completeness according to the standards proposed in the CONSORT 2025 Statement (Hopewell et al., 2025), both studies were found to demonstrate moderate methodological quality. Although both investigations employed parallel-group designs with control groups and incorporated randomization procedures, the descriptions of sequence generation and allocation concealment were incomplete, introducing a moderate risk of selection bias. Furthermore, both studies shared important structural limitations, including relatively small sample sizes, the absence of a passive control group, and short intervention durations. These limitations should be considered when interpreting the magnitude and generalizability of the reported effects.

Despite these limitations, an important strength common to both studies was the detailed and reproducible description of the flywheel-training protocols, together with the monitoring and control of concomitant endurance training. These methodological features strengthen internal validity and facilitate a more accurate interpretation of the observed adaptations. Moreover, the selected outcome measures included functional, neuromuscular, and performance-related variables specifically relevant to long-distance runners, thereby enhancing the practical applicability of the findings.

The integrated evidence from both studies reinforces the notion that endurance-running performance is determined by the multifactorial interaction of physiological, neuromuscular, and biomechanical factors. Notably, both investigations reported significant improvements in running economy, particularly at 75% of VO_2max, indicating

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a reduced energetic cost at a given running velocity. Such adaptations may enable athletes to sustain competitive race paces with lower metabolic demands.

Regarding neuromuscular determinants, Weng et al. (2022) provided substantial evidence suggesting that improvements in RE were associated with increases in neuromuscular power, enhanced utilization of the stretch-shortening cycle (SSC), and greater rates of force development (RFD). These adaptations may contribute to shorter ground-contact times and more effective force transmission throughout the locomotor system, factors that directly influence stride efficiency—a critical determinant of performance in trained endurance runners (Moore, 2016). These findings are consistent with those reported by Li, Newton et al. (2021), who concluded that superior RE in endurance runners may be associated with greater eccentric strength, enhanced utilization of elastic energy, and increased lower-limb stiffness during running.

Similarly, these results align with more recent evidence indicating that RE depends on the ability to generate force rapidly within time frames compatible with foot-ground contact duration and to optimize the overall stiffness of the muscle-tendon system (Zhang et al., 2022). These mechanisms are specifically targeted by flywheel resistance training through the application of eccentric overload and high neuromuscular demands.

Conversely, the absence of significant changes in VO_2max despite clear improvements in submaximal performance supports the notion that the potential for further enhancement of maximal aerobic capacity becomes increasingly limited in well-trained athletes. As athletes approach elite performance levels, improvements in athletic performance become progressively more difficult to achieve (Venturini & Giallauria, 2022). Consequently, the observed benefits of flywheel resistance training appear to be primarily mediated through peripheral and neuromuscular adaptations rather than through increases in maximal aerobic capacity.

Overall, the currently available evidence suggests that flywheel resistance training represents a promising strategy for modulating key neuromuscular determinants of endurance performance, particularly those associated with running economy and the efficient production of force. However, the limited number of sport-specific studies and the methodological constraints identified across the available literature preclude the

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formulation of definitive recommendations regarding the systematic implementation of flywheel resistance training within long-distance running programs.

Conclusion

The available evidence suggests that flywheel resistance training represents a promising strategy for modulating key neuromuscular determinants of endurance-running performance, particularly those related to stretch-shortening cycle (SSC) function and leg stiffness (Kleg). By providing a low-volume yet highly neuromuscular-specific training stimulus, flywheel training appears capable of enhancing running economy (RE) and force-production capacity without adversely affecting body composition or negatively interfering with aerobic-endurance training. Furthermore, the current body of literature highlights the importance of thoroughly reporting participant characteristics, intervention conditions, and all relevant flywheel-loading parameters, including inertia-related variables and exercise execution procedures. Such methodological transparency is essential for facilitating the interpretation, comparison, and reproducibility of research findings.

Nevertheless, the limited number of randomized controlled trials specifically conducted in long-distance athletes, together with the heterogeneity observed across intervention protocols and outcome measures, underscores the need for additional high-quality controlled studies. Future investigations are required to confirm the preliminary findings currently available and to establish robust causal relationships between flywheel resistance training and the primary determinants of endurance-running performance.

In particular, future research should incorporate larger and more heterogeneous samples, including female athletes and runners across different performance levels, while standardizing study reporting according to the CONSORT 2025 guidelines. Additionally, more comprehensive biomechanical and neuromuscular assessments should be integrated to improve understanding of the mechanisms underpinning performance adaptations. Comparative studies examining flywheel resistance training as a standalone intervention versus its combination with traditional strength-training approaches are also warranted. Finally, future investigations should explore dose–response relationships associated with key training variables—including flywheel inertia, weekly training frequency, and

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intervention duration—to optimize evidence-based prescription strategies for long-distance runners.

References

Albracht, K., & Arampatzis, A. (2013). Exercise-induced changes in triceps surae tendon stiffness and muscle strength affect running economy in humans. European journal of applied physiology, 113(6), 1605-1615. https://doi.org/10.1007/s00421-012-2585-4

Arampatzis, A., De Monte, G., Karamanidis, K., Morey-Klapsing, G., Stafilidis, S., & Brüggemann, G. P. (2006). Influence of the muscle-tendon unit's mechanical and morphological properties on running economy. The Journal of experimental biology, 209(Pt 17), 3345-3357. https://doi.org/10.1242/jeb.02340

Balsalobre-Fernández, C., Santos-Concejero, J., & Grivas, G. V. (2016). Effects of Strength Training on Running Economy in Highly Trained Runners: A Systematic Review With Meta-Analysis of Controlled Trials. Journal of strength and conditioning research, 30(8), 2361-2368. https://doi.org/10.1519/JSC.0000000000001316

Banks, N. F., Berry, A. C., Rogers, E. M., & Jenkins, N. D. M. (2024). Flywheel resistance training promotes unique muscle architectural and performance-related adaptations in young adults. European journal of sport science, 24(12), 1765-1778. https://doi.org/10.1002/ejsc.12215

Barnes, K. R., & Kilding, A. E. (2015a). Strategies to improve running economy. Sports medicine (Auckland, N.Z.), 45(1), 37-56. https://doi.org/10.1007/s40279-014-0246-y

Barnes, K. R., & Kilding, A. E. (2015b). Running economy: measurement, norms, and determining factors. Sports medicine - open, 1(1), 8. https://doi.org/10.1186/s40798-015-0007-y

Bassett, D. R., Jr, & Howley, E. T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. Medicine and science in sports and exercise, 32(1), 70-84. https://doi.org/10.1097/00005768-200001000-00012

Beato, M., de Keijzer, K. L., Fleming, A., Coates, A., La Spina, O., Coratella, G., & McErlain-Naylor, S. A. (2023). Post flywheel squat vs. flywheel deadlift potentiation of lower limb isokinetic peak torques in male athletes. Sports biomechanics, 22(11), 1514-1527. https://doi.org/10.1080/14763141.2020.1810750

Beato, M., & Dello Iacono, A. (2020). Implementing Flywheel (Isoinertial) Exercise in Strength Training: Current Evidence, Practical Recommendations, and Future Directions. Frontiers in physiology, 11, 569. https://doi.org/10.3389/fphys.2020.00569

Beato, M., de Keijzer, K. L., Muñoz-Lopez, A., Raya-González, J., Pozzo, M., Alkner, B. A., Dello Iacono, A., Vicens-Bordas, J., Coratella, G., Maroto-Izquierdo, S., Gonzalo-Skok, O., McErlain-Naylor, S. A., Martin-Rivera, F., Hernandez-Davo, J. L., Arrones, L. S., Sabido, R., de Hoyo, M., Fernandez-Gonzalo, R., & Norrbrand, L. (2024). Current Guidelines for the Implementation of Flywheel Resistance Training Technology in Sports: A Consensus Statement. Sports medicine (Auckland, N.Z.), 54(3), 541-556. https://doi.org/10.1007/s40279-023-01979-x

Beattie, K., Kenny, I. C., Lyons, M., & Carson, B. P. (2014). The effect of strength training on performance in endurance athletes. Sports medicine (Auckland, N.Z.), 44(6), 845-865. https://doi.org/10.1007/s40279-014-0157-y

Beattie, K., Carson, B. P., Lyons, M., Rossiter, A., & Kenny, I. C. (2017). The Effect of Strength Training on Performance Indicators in Distance Runners. Journal of strength and conditioning research, 31(1), 9-23. https://doi.org/10.1519/JSC.0000000000001464

Blagrove, R. C., Howatson, G., & Hayes, P. R. (2018). Effects of Strength Training on the Physiological Determinants of Middle- and Long-Distance Running Performance: A Systematic Review. Sports medicine (Auckland, N.Z.), 48(5), 1117-1149. https://doi.org/10.1007/s40279-017-0835-7

Burgos-Jara, C., Cerda-Kohler, H., Aedo-Muñoz, E. & Miarka, B. (2023). "Eccentric Resistance Training: A Methodological Proposal of Eccentric Muscle Exercise Classification Based on Exercise Complexity, Training Objectives, Methods,

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and Intensity" Applied Sciences 13, no. 13: 7969. https://doi.org/10.3390/app13137969

Competition And Technical Rules (2024). COMPETITION AND TECHNICAL RULES. World Athletics. https://worldathletics.org/about-iaaf/documents/book-of-rules

Denadai, B. S., & Greco, C. C. (2022). Could middle- and long-distance running performance of well-trained athletes be best predicted by the same aerobic parameters?. Current research in physiology, 5, 265-269. https://doi.org/10.1016/j.crphys.2022.06.006

de Dios-Álvarez, V., Rey, E., Padrón-Cabo, A., & Castellano, J. (2025). Impact of Weekly Eccentric Overload Training on Locomotor and Mechanical Performance in Youth Soccer Players. Journal of sports science & medicine, 24(2), 351-362. https://doi.org/10.52082/jssm.2025.351

de Keijzer, K. L., Gonzalez, J. R., & Beato, M. (2022). The effect of flywheel training on strength and physical capacities in sporting and healthy populations: An umbrella review. PloS one, 17(2), e0264375. https://doi.org/10.1371/journal.pone.0264375

de Waal, S. J., Gomez-Ezeiza, J., Venter, R. E., & Lamberts, R. P. (2021). Physiological Indicators of Trail Running Performance: A Systematic Review. International journal of sports physiology and performance, 16(3), 325-332. https://doi.org/10.1123/ijspp.2020-0812

Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2018). Effects of Accentuated Eccentric Loading on Muscle Properties, Strength, Power, and Speed in Resistance-Trained Rugby Players. Journal of strength and conditioning research, 32(10), 2750-2761. https://doi.org/10.1519/JSC.0000000000002772

Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2017). Eccentric Exercise: Physiological Characteristics and Acute Responses. Sports medicine (Auckland, N.Z.), 47(4), 663-675. https://doi.org/10.1007/s40279-016-0624-8

Ehrström, S., Tartaruga, M. P., Easthope, C. S., Brisswalter, J., Morin, J. B., & Vercruyssen, F. (2018). Short Trail Running Race: Beyond the Classic Model for Endurance Running Performance. Medicine and science in sports and exercise, 50(3), 580-588. https://doi.org/10.1249/MSS.0000000000001467

REVISTA INTERNACIONAL SPORTIS Scientific Journal of School Sport, Physical Education and Psychomotricity
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Edited by Campus Educa Sportis. A Coruña. Spain

Eihara, Y., Takao, K., Sugiyama, T., Maeo, S., Kanehisa, H., & Isaka, T. (2024). The effects of plyometric versus resistance training on running economy and 5-km running time in middle-aged recreational runners. European journal of sport science, 24(12), 1820-1829. https://doi.org/10.1002/ejsc.12197

Festa, L., Tarperi, C., Skroce, K., Boccia, G., Lippi, G., La Torre, A., & Schena, F. (2019). Effects of Flywheel Strength Training on the Running Economy of Recreational Endurance Runners. Journal of strength and conditioning research, 33(3), 684-690. https://doi.org/10.1519/JSC.0000000000002973

Genitrini, M., Fritz, J., Stöggl, T., & Schwameder, H. (2023). Performance Level Affects Full Body Kinematics and Spatiotemporal Parameters in Trail Running-A Field Study. Sports (Basel, Switzerland), 11(10), 188. https://doi.org/10.3390/sports11100188

Haugen, T., Sandbakk, Ø., Seiler, S., & Tønnessen, E. (2022). The Training Characteristics of World-Class Distance Runners: An Integration of Scientific Literature and Results-Proven Practice. Sports medicine - open, 8(1), 46. https://doi.org/10.1186/s40798-022-00438-7

Hody, S., Croisier, J. L., Bury, T., Rogister, B., & Leprince, P. (2019). Eccentric Muscle Contractions: Risks and Benefits. Frontiers in physiology, 10, 536. https://doi.org/10.3389/fphys.2019.00536

Hopewell, S., Chan, A. W., Collins, G. S., Hróbjartsson, A., Moher, D., Schulz, K. F., Tunn, R., Aggarwal, R., Berkwits, M., Berlin, J. A., Bhandari, N., Butcher, N. J., Campbell, M. K., Chidebe, R. C. W., Elbourne, D., Farmer, A., Fergusson, D. A., Golub, R. M., Goodman, S. N., Hoffmann, T. C., … Boutron, I. (2025). CONSORT 2025 statement: updated guideline for reporting randomised trials. BMJ (Clinical research ed.), 389, e081123. https://doi.org/10.1136/bmj-2024-081123

Howe, C. C. F., Swann, N., Spendiff, O., Kosciuk, A., Pummell, E. K. L., & Moir, H. J. (2021). Performance determinants, running energetics and spatiotemporal gait parameters during a treadmill ultramarathon. European journal of applied physiology, 121(6), 1759-1771. https://doi.org/10.1007/s00421-021-04643-2

Hu, Z., Liu, Y., Huang, K., Huang, H., Li, F., & Yuan, X. (2024). Comparing the Effect of Isoinertial Flywheel Training and Traditional Resistance Training on Maximal Strength and Muscle Power in Healthy People: A Systematic Review and Meta-Analysis. Life (Basel, Switzerland), 14(7), 908. https://doi.org/10.3390/life14070908

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: the physiology of champions. The Journal of physiology, 586(1), 35-44. https://doi.org/10.1113/jphysiol.2007.143834

Kim, Y., Oh, S., Kim, D. Y., & Lim, J. Y. (2025). Effects of eccentric contraction-based resistance exercise on physical performance in chronic stroke patients: A randomized controlled trial. Medicine, 104(32), e43491. https://doi.org/10.1097/MD.0000000000043491

Lanferdini, F. J., Silva, E. S., Machado, E., Fischer, G., & Peyré-Tartaruga, L. A. (2020). Physiological Predictors of Maximal Incremental Running Performance. Frontiers in physiology, 11, 979. https://doi.org/10.3389/fphys.2020.00979

Li, F., Nassis, G. P., Shi, Y., Han, G., Zhang, X., Gao, B., & Ding, H. (2021). Concurrent complex and endurance training for recreational marathon runners: Effects on neuromuscular and running performance. European journal of sport science, 21(9), 1243-1253. https://doi.org/10.1080/17461391.2020.1829080

Li, F., Newton, R. U., Shi, Y., Sutton, D., & Ding, H. (2021). Correlation of Eccentric Strength, Reactive Strength, and Leg Stiffness With Running Economy in Well-Trained Distance Runners. Journal of strength and conditioning research, 35(6), 1491-1499. https://doi.org/10.1519/JSC.0000000000003446

Llanos-Lagos, C., Ramirez-Campillo, R., Moran, J., & Sáez de Villarreal, E. (2024a). The Effect of Strength Training Methods on Middle-Distance and Long-Distance Runners' Athletic Performance: A Systematic Review with Meta-analysis. Sports medicine (Auckland, N.Z.), 54(7), 1801-1833. https://doi.org/10.1007/s40279-024-02018-z

Llanos-Lagos, C., Ramirez-Campillo, R., Moran, J., & Sáez de Villarreal, E. (2024b). Effect of Strength Training Programs in Middle- and Long-Distance Runners' Economy at Different Running Speeds: A Systematic Review with Meta-analysis. Sports medicine (Auckland, N.Z.), 54(4), 895-932. https://doi.org/10.1007/s40279-023-01978-y

Maroto-Izquierdo, S., García-López, D., Fernandez-Gonzalo, R., Moreira, O. C., González-Gallego, J., & de Paz, J. A. (2017). Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. Journal of science and medicine in sport, 20(10), 943-951. https://doi.org/10.1016/j.jsams.2017.03.004

McLaughlin, J. E., Howley, E. T., Bassett, D. R., Jr, Thompson, D. L., & Fitzhugh, E. C. (2010). Test of the classic model for predicting endurance running performance. Medicine and science in sports and exercise, 42(5), 991-997. https://doi.org/10.1249/MSS.0b013e3181c0669d

Midgley, A. W., McNaughton, L. R., & Jones, A. M. (2007). Training to enhance the physiological determinants of long-distance running performance: can valid recommendations be given to runners and coaches based on current scientific knowledge?. Sports medicine (Auckland, N.Z.), 37(10), 857-880. https://doi.org/10.2165/00007256-200737100-00003

Millet, G. Y., Hoffman, M. D., & Morin, J. B. (2012). Sacrificing economy to improve running performance--a reality in the ultramarathon?. Journal of applied physiology (Bethesda, Md. : 1985), 113(3), 507-509. https://doi.org/10.1152/japplphysiol.00016.2012

Moore I. S. (2016). Is There an Economical Running Technique? A Review of Modifiable Biomechanical Factors Affecting Running Economy. Sports medicine (Auckland, N.Z.), 46(6), 793-807. https://doi.org/10.1007/s40279-016-0474-4

Nakamura, M., Ikezu, H., Sato, S., Yahata, K., Kiyono, R., Yoshida, R., Takeuchi, K., & Nunes, J. P. (2021). Effects of Adding Inter-Set Static Stretching to Flywheel Resistance Training on Flexibility, Muscular Strength, and Regional Hypertrophy in Young Men. International journal of environmental research and public health, 18(7), 3770. https://doi.org/10.3390/ijerph18073770

Padulo, J., Buglione, A., Larion, A., Esposito, F., Doria, C., Čular, D., di Prampero, P. E., & Peyré-Tartaruga, L. A. (2023). Energy cost differences between marathon runners and soccer players: Constant versus shuttle running. Frontiers in physiology, 14, 1159228. https://doi.org/10.3389/fphys.2023.1159228

Patrocinio de Oliveira, C. E., Moreira, O. C., Carrión-Yagual, Z. M., Medina-Pérez, C., & de Paz, J. A. (2018). Effects of Classic Progressive Resistance Training Versus Eccentric-Enhanced Resistance Training in People With Multiple Sclerosis. Archives of physical medicine and rehabilitation, 99(5), 819-825. https://doi.org/10.1016/j.apmr.2017.10.021

Petré, H., Wernstål, F., & Mattsson, C. M. (2018). Effects of Flywheel Training on Strength-Related Variables: a Meta-analysis. Sports medicine - open, 4(1), 55. https://doi.org/10.1186/s40798-018-0169-5

Prieto-González, P., & Sedlacek, J. (2022). Effects of Running-Specific Strength Training, Endurance Training, and Concurrent Training on Recreational Endurance Athletes' Performance and Selected Anthropometric Parameters. International journal of environmental research and public health, 19(17), 10773. https://doi.org/10.3390/ijerph191710773

Puustinen, J., Venojärvi, M., Haverinen, M., & Lundberg, T. R. (2023). Effects of Flywheel vs. Traditional Resistance Training on Neuromuscular Performance of Elite Ice Hockey Players. Journal of strength and conditioning research, 37(1), 136-140. https://doi.org/10.1519/JSC.0000000000004159

Ramos-Campo, D. J., Andreu-Caravaca, L., Clemente-Suárez, V. J., & Rubio-Arias, J. Á. (2025). The Effect of Strength Training on Endurance Performance Determinants in Middle- and Long-Distance Endurance Athletes: An Umbrella Review of Systematic Reviews and Meta-Analysis. Journal of strength and conditioning research, 39(4), 492-506. https://doi.org/10.1519/JSC.0000000000005056

Raya-González, J., Castillo, D., & Beato, M. (2021). The flywheel paradigm in team sports: A soccer approach. Strength & Conditioning Journal, 43(1), 12-22. https://doi.org/10.1519/SSC.0000000000000561

Santos, L. V., Freitas, K. R. D. S. R., Pereira, E. T., Leite, L. B., Forte, P., de Oliveira, C. E. P., & Moreira, O. C. (2025). Comparative Effects of Resistance Training Modalities on Mental Health and Quality of Life in Individuals with Spinal Cord

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Injury. Sports (Basel, Switzerland), 13(2), 60. https://doi.org/10.3390/sports13020060

Saunders, P. U., Pyne, D. B., Telford, R. D., & Hawley, J. A. (2004). Factors affecting running economy in trained distance runners. Sports medicine (Auckland, N.Z.), 34(7), 465-485. https://doi.org/10.2165/00007256-200434070-00005

Spudić, D., & Nosaka, K. (2026). Do Flywheel Exercises Provide Eccentric-Overload Training? Sports medicine - open, 12(1), 4. https://doi.org/10.1186/s40798-025-00974-y

Suchomel, T. J., Wagle, J. P., Douglas, J., Taber, C. B., Harden, M., Haff, G. G., & Stone, M. H. (2019). Implementing Eccentric Resistance Training-Part 2: Practical Recommendations. Journal of functional morphology and kinesiology, 4(3), 55. https://doi.org/10.3390/jfmk4030055

Sukhera J. (2022). Narrative Reviews: Flexible, Rigorous, and Practical. Journal of graduate medical education, 14(4), 414-417. https://doi.org/10.4300/JGME-D-22-00480.1

Tiller, N. B., & Millet, G. Y. (2024). Decoding Ultramarathon: Muscle Damage as the Main Impediment to Performance. Sports medicine (Auckland, N.Z.), 10.1007/s40279-024-02127-9. Advance online publication. https://doi.org/10.1007/s40279-024-02127-9

Venturini, E., & Giallauria, F. (2022). Factors Influencing Running Performance During a Marathon: Breaking the 2-h Barrier. Frontiers in cardiovascular medicine, 9, 856875. https://doi.org/10.3389/fcvm.2022.856875

Vicens-Bordas, J., Esteve, E., Fort-Vanmeerhaeghe, A., Bandholm, T., & Thorborg, K. (2018). Is inertial flywheel resistance training superior to gravity-dependent resistance training in improving muscle strength? A systematic review with meta-analyses. Journal of science and medicine in sport, 21(1), 75-83. https://doi.org/10.1016/j.jsams.2017.10.006

Vogt, M., & Hoppeler, H. H. (2014). Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. Journal of applied physiology (Bethesda, Md.: 1985), 116(11), 1446-1454. https://doi.org/10.1152/japplphysiol.00146.2013

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Wagle, J. P., Taber, C. B., Cunanan, A. J., Bingham, G. E., Carroll, K. M., DeWeese, B. H., Sato, K., & Stone, M. H. (2017). Accentuated Eccentric Loading for Training and Performance: A Review. Sports medicine (Auckland, N.Z.), 47(12), 2473-2495. https://doi.org/10.1007/s40279-017-0755-6

Wallace, B. J., Shapiro, R., Wallace, K. L., Abel, M. G., & Symons, T. B. (2019). Muscular and Neural Contributions to Postactivation Potentiation. Journal of strength and conditioning research, 33(3), 615-625. https://doi.org/10.1519/JSC.0000000000003011 Weng, Y., Liu, H., Ruan, T., Yang, W., Wei, H., Cui, Y., Ho, I. M. K., & Li, Q. (2022). Effects of flywheel resistance training on the running economy of young male well-trained distance runners. Frontiers in physiology, 13, 1060640. https://doi.org/10.3389/fphys.2022.1060640

Xue, J., Gao, W., Zhang, C., Peng, S., Chen, Z., Zou, R., Wu, W., Zhang, L., Tang, W., & Liu, W. (2025). A Comparative Study of High-Intensity Flywheel Eccentric Training and Traditional Barbell Training on Athletic Performance in Female Basketball Players. Journal of sports science & medicine, 24(4), 824-838. https://doi.org/10.52082/jssm.2025.824

Zhang, Q., Nassis, G. P., Chen, S., Shi, Y., & Li, F. (2022). Not Lower-Limb Joint Strength and Stiffness but Vertical Stiffness and Isometric Force-Time Characteristics Correlate With Running Economy in Recreational Male Runners. Frontiers in physiology, 13, 940761. https://doi.org/10.3389/fphys.2022.940761