**Chronic effects of flywheel training on physical capacities in soccer players: a systematic review**

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**Abstract**

**Purpose:**The aims of the current systematic review were to evaluate the current literature surrounding the chronic effect of flywheel training on physical capacities in soccer players, and to identify areas for future research to establish guidelines for its use.

**Methods:** Studies were identified following a search of electronic databases (PubMed and SPORTDiscus) in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA).

**Results:** Eleven studies met the inclusion criteria and were included.The methodological quality of the included studies ranged between 10 and 18 with an average score of 15 points using the PEDro scale. The training duration ranged from 6 weeks to 27 weeks, with volume ranging from 1 to 6 sets and 6 to 10 repetitions, and frequency from 1 to 2 times a week. This systematic review reported that a diverse range of flywheel training interventions can effectively improve strength, power, jump, and changes of direction in male soccer players of varying levels.

**Conclusion**: Flywheel training interventions improve physical capacities in soccer players of varying levels. Nonetheless, the current literature suggests contrasting evidence regarding flywheel training induced changes in sprint speed and acceleration capacity of soccer players. **Keywords:** Isoinertial, eccentric, resistance training, football

**Introduction**

 Modern day soccer matches require players to perform numerous high intensity actions including accelerations, decelerations, jumps, sprints and changes of direction (COD) (Morgans et al. 2014). Performance of such tasks require rapid production of force (Morgans et al. 2014) and often play pivotal roles in determining on-field performance and success (Faude et al. 2012). It is for this reason that soccer players require high levels of muscular strength to repeatedly achieve successful outcomes during contact situations (Beato et al. 2020c) and mitigate the risk of non-contact musculoskeletal injuries (Hawkins 2001; Lehance et al. 2008; Timmins et al. 2016). It is therefore paramount that strength and conditioning coaches identify and optimize methods that can efficiently enhance strength and consequently improve physical performance of soccer players (Beato et al. 2020c).

 Traditional resistance training programs involving free weights and weight stack machines based on the use of gravity dependent loads have shown to achieve desirable structural and neural adaptions in athletes (Vicens-Bordas et al. 2018a). Nonetheless, these training modalities are limited by the load lifted in the concentric phase and typically significantly underload the eccentric component of the exercise task (Dudley et al. 1991; Hollander et al. 2007; Beato and Dello Iacono 2020). In an attempt to achieve supramaximal eccentric loads using traditional training methods, external operators or weight releasers have previously been used (Maroto-Izquierdo et al. 2017b; Beato and Dello Iacono 2020). Nevertheless, current application of such methods has been deemed difficult to implement by practitioners and may not be well tolerated by athletes (Harden et al. 2020).

Alternatively, practitioners have employed flywheel-based exercises to enhance strength and sport specific performance (de Hoyo et al. 2016; Suarez-Arrones et al. 2018; Coratella et al. 2019; Gonzalo-Skok et al. 2019; Nuñez et al. 2019; Beato et al. 2020d; Raya-González et al. 2020a, 2021b). Berg and Tesch (1994) designed flywheel devices to support the maintenance of skeletal muscle mass in astronauts exposed to non-gravity environments during space travel (Berg and Tesch 1994). Flywheel ergometers (also referred to as isoinertial devices) achieve loading during the eccentric phase (Raya-González et al. 2020b) that replicates the movements involved in athletic tasks (Petré et al. 2018). Specifically, during the concentric phase, the athlete lengthens a cable, causing the flywheel to rotate, thus creating inertial torque. Once fully extended, the flywheel continues to spin, shortening the cable, which in turn requires the participant to resist the pull of the cable through braking, thereby producing a high linear resistance during the eccentric phase (Petré et al. 2018). This methodology appears to be a viable alternative to traditional resistance training with studies reporting higher electromyographic activity (Norrbrand et al. 2010), improved sprint, change of direction and jump performance (Raya-González et al. 2020a; Beato and Dello Iacono 2020) and positive hypertrophic adaptations (Maroto-Izquierdo et al. 2017a). Additionally, the chronic effects of flywheel training on performance variables such as power, strength, COD, and speed are well documented (Maroto-Izquierdo et al. 2017b).

 Despite these findings, the systematic synthesis of research evidence investigating the effects of flywheel training on strength, power and sport specific task performance on soccer players does not exist. Therefore, a summary of the literature pertaining to flywheel training studies involving soccer players is necessary to understand the benefits of this training methodology. The aim of the current systematic review is to (i) evaluate the current literature surrounding the chronic effect of flywheel training on physical capacities in soccer players, and (ii) identify areas for future research to establish guidelines for its use in soccer.

**Methods**

*Search Strategy*

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA) (Liberati et al. 2009). A systematic, computerized search of the databases PubMed and SPORTDiscus were conducted by two separate reviewers (WA and KDK) up until 12 October 2020. Since flywheel technology was established in 1994 (Berg and Tesch 1994), the time frame was restricted to studies between January 1994 and October 2020. An additional search of the literature was performed in January 2021 to ensure no relevant texts were missing prior to the submission of the review. Search terms included: ‘Flywheel’, ‘Flywheel Training’, ‘Isoinertial’, ‘Eccentric overload’, ‘Strength’, ‘Power’, ‘Speed’, ‘Change of direction’, ‘Speed’, ‘Soccer’, and ‘Football’. Boolean operators ‘OR’ and ‘AND’ were utilized to combine search terms. Filters (clinical trials, randomized control trials, full text) were used during the search and language was restricted to English. Articles involving participants <12 years old, >43 years old, or animals were excluded as these populations were not of interest. A secondary search was then conducted using the reference lists of eligible articles. Following both searches, studies were uploaded to a reference manager software (Zotero, version 5.0.85, Corporation for Digital Scholarship, Vienna, USA). All articles were reviewed and screened for duplicates. Based on the study title, author, year of publication, DOI, and ISBN fields; duplicates were identified and merged using the “*Duplicate Items*” function. The titles and abstracts were screened for eligibility. Following this, a final screen of all remaining full-text studies was conducted; with all those that did not meet the criteria removed (Figure 1).

**\*\*\*Please, Figure 1 here\*\*\***

*Study Selection*

An assessment for eligibility was conducted by two reviewers (WA and KDK) separately using the study selection process presented in Figure 1. Studies identified through the search were screened against the eligibility criteria (Table 1). Any contest related to study inclusion/exclusion was clarified with a third reviewer (MB).

**\*\*\*Please, Table 1 here\*\*\***

*Analysis of Results*

While the methodological quality of studies is often conducted using either: (i) the PEDro scale; (ii) the Dephi scale; or (iii) the Cochrane scale, previous research has illustrated that non-healthcare studies (*i.e.,* strength and conditioning) typically score low using these methodological scales (Markovic and Newton 2007; Brughelli et al. 2008). Subsequently, using methods similar to Brughelli et al. (Brughelli et al. 2008), the eleven selected studies were assessed separately by the same two reviewers (WA and KDK) using an evaluation derived from the three aforementioned scales. The aim of this analysis was to evaluate study quality and identify areas of methodological weakness (Table 2). The scale utilizes 10-item criteria ranging from 0-20 points and the score for each criterion was as follows: 0 = clearly no; 1 = maybe; and 2 = clearly yes. Despite the fact these scales provide little guidance regarding the classification of a study according to its score, previous researchers (Roig et al. 2008, 2009) have established the following criteria to determine study quality: score >15 = high quality, score 10-15 = moderate quality, <10 = low quality. Any differences between the reported quality were clarified and settled with a third reviewer (MB).

**Results**

*Methodological quality assessment*

Table 2 shows the individual scores for the quality assessment. Values ranged from 10 to 18 points (*moderate* to *high*), with an average score of 15 points (*moderate*). Regarding the individual quality assessment, six studies were categorized as *high*, while the five remaining studies were categorized as being of *moderate* quality. Some sources of bias arose from lack of random allocation to groups, lacking control groups or no testing for similarity at baseline for some studies. Although the studies were ranked as *moderate* or *high,* such limitations may increase the risk of bias and therefore affect the analysis and conclusions of specific studies.

*Criteria included:*

1. Inclusion criteria were clearly stated;
2. Subjects were randomly allocated to groups;
3. Intervention was clearly defined;
4. Groups were tested for similarity at baseline;
5. Use of a control group;
6. Outcome variables were clearly defined;
7. Assessments were practically useful;
8. Duration of intervention practically useful;
9. Between-group statistical analysis appropriate (*e.g.,* analysis of covariance);
10. Point measures of variability.

**\*\*\*Please, Table 2 here\*\*\***

*Participants*

Eleven studies met the inclusion criteria and were included in the review (Table 3). Intervention and participant data are reported as mean ± standard deviation (SD) unless stated otherwise. Hedges *g* was calculated from the original investigations to determine study outcomes and was interpreted as *trivial* < 0.2, *small* 0.2–0.6, *moderate* 0.6–1.2, *large* 1.2–2.0, *very large* > 2.0 (Hopkins et al. 2009). Such an approach allows for estimation of unbiased effects and standardized comparisons between protocols (Lakens, 2013). The equation d = Mdiff/Sav(Mdiff,mean difference, Sav average SD) was used for this purpose with the adjustment factor of:

 *g* = (1 – 3/ddf – 1) x d

 A total of 337 participants were included in the review such as 193 participants in the flywheel groups, 64 participants in alternative training groups, while 77 participants served as controls. Gonzalo-Skok *et al*., (2019) utilized and randomized study design dividing players into 3 groups (A-B-C) based on physical performance, while Suarez-Arrones *et al.,* (2018b) used a repeat measures design. Participants in eight of the 11 studies included elite academy soccer players (de Hoyo et al. 2015, 2016; Tous-Fajardo et al. 2016; Suarez-Arrones et al. 2018; Gonzalo-Skok et al. 2019; Nuñez et al. 2019; Fiorilli et al. 2020; Raya-González et al. 2021a). The remaining studies included players from 2 professional Swedish premier league teams (Askling et al. 2003), 2 semi-professional (Serie D) soccer teams (Coratella et al. 2019) and 38 recreational players from the fifth and sixth tier of the Norwegian National League (Sagelv et al. 2020).

**\*\*\*Please, Table 3 here\*\*\***

*Interventions*

Excluding Suarez-Arrones *et al.,* (2018b), whose intervention included 54 training sessions over 27-weeks, the rest of the literature utilised 8-18 training sessions over 6-11 weeks. Single and multi-exercise interventions were performed as parts of strength training circuits or in isolation. The review also reports that different types of fixed and portable equipment involving different pulley systems (conical and cylinder) have been utilized within soccer. Progressive stages of training included varying training volume, intensity and frequency. In the 11 selected studies, volume ranged from 1-6 sets of 5-10 repetitions with frequency varying from 1-2 sessions a week. Seven studies utilized inertias ranging from 0.025 Kg.m2 to 0.27 Kg.m2 (de Hoyo et al. 2015; Tous-Fajardo et al. 2016; Suarez-Arrones et al. 2018; Coratella et al. 2019; Gonzalo-Skok et al. 2019; Sagelv et al. 2020; Raya-González et al. 2021a), while the inertia used in the remaining studies was not reported (Askling et al. 2003; de Hoyo et al. 2015, 2016; Nuñez et al. 2019; Fiorilli et al. 2020). Eight of the eleven studies followed a progressive program, gradually increasing training volume or intensity over the intervention period (de Hoyo et al. 2015, 2016; Tous-Fajardo et al. 2016; Suarez-Arrones et al. 2018; Coratella et al. 2019; Nuñez et al. 2019; Sagelv et al. 2020; Raya-González et al. 2021a). Finally, five studies individualized intensity by selecting inertias reporting the highest power outputs (de Hoyo et al. 2015, 2016; Suarez-Arrones et al. 2018; Nuñez et al. 2019; Sagelv et al. 2020).

*Strength and power*

Strength and power outcomes were evaluated in five of the eleven studies included in the review (Table 3) (Askling et al. 2003; Suarez-Arrones et al. 2018; Coratella et al. 2019; Nuñez et al. 2019; Sagelv et al. 2020). Although Coratella et al. (2020) reported excellent test-retest reliability (α = 0.900-0.944) for isokinetic testing, Askling et al. (2003) did not report any reliability measures. Only Sagelv et al. (2020) reported a reliability measure for the 1RM squat (CV = 2.9%) although this was obtained from another study. Nuñez and colleagues (2019) reported good reliability for all lower limb power measures recorded with a flywheel device (ICC= 0.80-0.81, CV= 8.3-10.4%). Similarly, Suarez Arrones and colleagues (2018) also reported reliability (0.52 ± 0.17%) for the velocity measurements recorded with a flywheel device.

*Jump*

Seven studies reported jumping outcome measures using a variety of tests (bi- and uni-lateral CMJ, single leg hop and triple hop, horizontal jump, rebound jump, hopping, squat jump) (de Hoyo et al. 2015; Tous-Fajardo et al. 2016; Coratella et al. 2019; Gonzalo-Skok et al. 2019; Fiorilli et al. 2020; Raya-González et al. 2021a). Performance was measured on devices referred to as infrared devices, infrared-light platforms, portable force plates, photocells systems, and photoelectric cells. Coratella and colleagues (2019) used an infrared device, reporting excellent reliability for SJ (α = 0.934) and CMJ (α = 0.903). Others authors reported the CV of the device from previous studies but did not report ICC (Fiorilli et al. 2020; Sagelv et al. 2020). On the other hand, Raya Gonzalez et al. 2021 reported both the ICC and CV for the CMJ with dominant leg (0.97 and 3.1%) and non-dominant leg (0.99 and 1.4%). Tous Fajardo et al. (2016) reported the ICC for CMJ (0.97) and hopping (0.83), while Gonzalo-Skok et al. (2019) reported that all tests had CV values <10% and good to excellent ICC values. Specifically, the study reported reliability measures for single leg hops (ICC = 0.79-0.84, CV = 4.5-5.3%), triple single-leg horizontal jumps (ICC = 0.83-0.85, CV = 4.2-4.3%), unilateral (ICC = 0.91-0.94, CV = 5.4-6.6%) and bilateral CMJ (ICC = 0.96, CV = 3.3%).

*Running Speed/Sprinting*

Nine of the eleven investigations included in the review investigated acceleration or maximal running speed (Table 3) (Askling et al. 2003; de Hoyo et al. 2015; Tous-Fajardo et al. 2016; Suarez-Arrones et al. 2018; Coratella et al. 2019; Nuñez et al. 2019; Fiorilli et al. 2020; Sagelv et al. 2020; Raya-González et al. 2021a). Investigations reported using photo or photoelectric cells, infrared devices, single and dual-beam electronic timing gates. Five of the eleven investigations did not report any reliability measures for sprint measurements (Askling et al. 2003; de Hoyo et al. 2015; Tous-Fajardo et al. 2016; Suarez-Arrones et al. 2018; Nuñez et al. 2019). Coratella et al. 2019 reported excellent reliability for standing start 10m (α = 0.920) and 30m (α = 0.902) sprint times. Raya Gonzalez et al. (2021) reported the ICC and CV for 10m (0.74 and 1.6%), 20m (0.84 and 1.6%) and 30m (0.90 and 1.3%). Finally, Sagelv et al. (2020) and Fiorilli et al. (2020) both reliability measures from other studies.

*Change of Direction*

Six studies investigated the effects of flywheel training on COD performance (Table 3) (de Hoyo et al. 2015, 2016; Tous-Fajardo et al. 2016; Coratella et al. 2019; Fiorilli et al. 2020; Raya-González et al. 2021a). Studies investigated COD performance with a variety of reported systems (infrared device, force plates and photoelectric cells). Coratella and colleagues (2019) reported good reliability for 20+20 m shuttle (α = 0.867) and T-Test agility (α = 0.884). Fiorilli et al. (2020) performed the Y-agility and Illinois COD test, reporting the intra class correlation from another study only for the latter. Tous Fajardo et al. (2016) reported excellent reliability for the V cut test (ICC = 0.91), good reliability for the repeated sprint ability mean time (ICC = 0.87), and moderate reliability for percentage decrement during the RSA test (ICC = 0.57). Raya Gonzalez et al. (2021) utilized 2 pairs of photoelectric cells, reporting moderate to excellent ICC during various COD tasks. Specifically, the test reliability is reported here: COD10d (ICC= 0.99 and CV= 0.5%); COD10nd (ICC= 0.87 and CV= 1.7%); COD20d (ICC= 0.74 and CV= 1.9%); 20CODnd (ICC= 0.93 and CV= 1.0%). Other studies did not report reliability measures for their investigation (de Hoyo et al. 2015, 2016) .

**Discussion**

The aims of the current systematic review were to (i) evaluate the current literature surrounding the chronic effect of flywheel training on physical capacities in soccer players, and (ii) to identify areas for future research to establish guidelines for its use in soccer. Eleven studies were included in the review (Table 3), spanning youth academy players to professional adult soccer players. The review reports varying levels of improvement in strength, jump, sprint and COD ability after uni- and bi-lateral flywheel training protocols. The current review supports the notion that flywheel training enhances performance variables in soccer players; however, further research is required before standardized recommendations can be made with this specific population.

*Strength and power*

The present systematic review suggests that flywheel training can effectively improve strength in adult male soccer players. Flywheel protocols involving lower volume and training frequency are particularly attractive for modern-day time-stricken soccer practitioners who may struggle to practically implement sufficient strength training in-season (Harden et al. 2020). In support of this, semi-professional and professional soccer players reported improvements in concentric and eccentric isokinetic knee flexor strength after the application of flywheel training programs (Askling et al. 2003; Coratella et al. 2019). Both investigations were performed in-season and with only brief exposure to flywheel training (1-2 weekly sessions) (Askling et al. 2003; Coratella et al. 2019). Similarly, a small bi-weekly dose of flywheel deadlifts over a 35-week period improved knee flexor eccentric strength of semi-professional Australian football league players by 19% (*large*) (Timmins et al. 2021). Although the benefits related to flywheel training have been thoroughly investigated and explained (Norrbrand et al. 2007, 2010; Petré et al. 2018; Beato and Dello Iacono 2020), inconsistency regarding efficacy on maximal strength in the literature remains (Vicens-Bordas et al. 2018a; Sagelv et al. 2020). In fact, although both flywheel and traditional squat training significantly enhanced maximal squat strength of amateur male soccer players, the traditional squat protocol was more effective (Sagelv et al. 2020). Nonetheless, a recent systematic review and meta-analysis investigating the effects of flywheel training on strength reported *large* improvements for maximal strength (Petré et al. 2018). In agreement with our findings of a greater response in well-trained soccer players, the aforementioned meta-analysis also reported that well-trained individuals respond more positively than moderately trained individuals to flywheel training (Petré et al. 2018). Differences in strength outcomes may possibly be due to several differences in maximal neural activation and ability to recover between sessions (Petré et al. 2018). In contrast to measurement of strength, whereby only adult players were investigated, only elite youth soccer players were investigated for power development (Nuñez Sanchez and Sáez de Villarreal 2017; Suarez-Arrones et al. 2018). When exposed to 27 weeks of flywheel leg curl and 9 weeks of horizontal front step training, youth elite soccer players increased flywheel half-squat and front step power, respectively (Nuñez Sanchez and Sáez de Villarreal 2017; Suarez-Arrones et al. 2018). In support of such findings, the literature involving recreationally active adults and professional team sport athletes support the efficacy of flywheel training (Fernandez-Gonzalo et al. 2014; Maroto-Izquierdo et al. 2017b). The physiological advantages related to flywheel training may elicit favorable adaptations and improve an athlete’s capability to produce power (Beato and Dello Iacono 2020) and perform the high intensity demands of soccer (Turner and Stewart 2014). To enhance practical application and conclusions, future investigations analyzing strength or power should utilize different exercises (Beato et al. 2020a), apply control groups (Suarez-Arrones et al. 2018; Coratella et al. 2019), account for inertial load and consider training experience (Sabido et al. 2017; Raya-González et al. 2020b). Furthermore, it is recommended that validity and reliability of devices and tests be considered when measuring performance changes (Beato et al. 2020b). Although the optimal strategy for applying flywheel training remains unclear (Petré et al. 2018; Beato and Dello Iacono 2020; Timmins et al. 2021), the overarching evidence suggests it can be effectively implemented in male soccer environments to enhance strength and power. Investigation into the response of female soccer players to flywheel training protocols will also enhance implementation.

*Jump*

The current review in soccer players is in agreement with previous evidence that flywheel training can effectively enhance jumping ability (Petré et al. 2018; Beato and Dello Iacono 2020). The improved utilization of elastic potential energy during the stretch shortening cycle that is developed with flywheel training may be a key contributor to enhanced jump performance (Bridgeman et al. 2018). A systematic review investigating the effect of flywheel training on team sport athletes reported a significant *moderate* effect on CMJ performance, supporting the findings of other systematic reviews (Maroto-Izquierdo et al. 2017b; Raya-González et al. 2020b). In support of this, semi-professional players performing only 8 weeks of flywheel squat sessions in-season significantly enhanced squat jump (*moderate*) and CMJ performance (*moderate*) (Coratella et al. 2019). Similarly, when 38 amateur adult male soccer players were exposed to bi-weekly flywheel squats over a 6 week period, CMJ performance was significantly enhanced (Sagelv et al. 2020). In youth male soccer players, single leg CMJ performance was significantly improved after weekly flywheel lateral squat sessions over a 10 week period (*moderate*) (Raya-González et al. 2021a). Similarly, bi-weekly flywheel training over a 6 week period also *moderately* enhanced drop jump and repeated hop performance of youth soccer players (Fiorilli et al. 2020). Two more protocols, involving only 8-10 sessions, also enhanced jump performance in youth soccer players (*small to moderate*) (de Hoyo et al. 2015; Gonzalo-Skok et al. 2019), further highlighting the value of flywheel training for developing jumping performance suggested in the literature (Maroto-Izquierdo et al. 2017b; Petré et al. 2018; Raya-González et al. 2020a, b; Beato and Dello Iacono 2020). In contrast, Tous Fajardo and colleagues (2016) did not report beneficial changes in CMJ and only *small* improvements in hopping ability after weekly training circuits involving flywheel training with youth soccer players (Tous-Fajardo et al. 2016). Such differences in results may be explained by lacking random allocation, baseline testing for similarity, or lacking specificity between intervention and testing (Tous-Fajardo et al. 2016; Gonzalo-Skok et al. 2017; Vicens-Bordas et al. 2018b; Raya-González et al. 2020a). Differences in outcomes may also be due to the limited (weekly) flywheel training sessions, which may not always be sufficient to stimulate enhancement of jumping ability (Raya-González et al. 2020b). In support of this, weekly flywheel squat and lunge training sessions did not enhance jumping performance of volleyball and basketball players or handball players, respectively (Gual et al. 2016; Sabido et al. 2017). The literature suggests that 2-3 weekly flywheel sessions ideally be performed to enhance jump performance parameters in team sports (Maroto-Izquierdo et al. 2017b; Raya-González et al. 2020b), although weekly application of flywheel training in soccer populations has also shown to be effective (de Hoyo et al. 2015; Coratella et al. 2019; Gonzalo-Skok et al. 2019; Fiorilli et al. 2020; Raya-González et al. 2021a).

*Running Speed/Sprinting*

The present review presents contrasting conclusions regarding the efficacy of flywheel training for enhancing sprint speed in male soccer players. Previous systematic reviews and meta analyses reported *small* to *large* enhancements in sprinting performance of healthy populations and team sport athletes (Maroto-Izquierdo et al. 2017b; Petré et al. 2018; Raya-González et al. 2020b). In agreement with these findings, the present systematic review supports a variety of weekly or bi-weekly flywheel protocols (*i.e.,* squats, leg curl, and multi-exercise programs) over 6-27 week periods (Askling et al. 2003; Núñez et al. 2018; Fiorilli et al. 2020; Sagelv et al. 2020). Over a 6-week period involving bi-weekly flywheel squat training, amateur soccer players enhanced their 10-meter sprint time (*small*). Similarly, flywheel leg curl protocols specifically targeting the hamstrings were effective for enhancing maximal speed performance in youth and professional adult soccer players (*moderate*) (Askling et al. 2003; de Hoyo et al. 2015). In support of this, semi-professional team sport athletes exposed to weekly or bi-weekly hip-dominant flywheel training for 35 weeks also enhanced maximal sprinting performance (Timmins et al. 2021). Although flywheel training provides practitioners with a versatile and effective method for enhancing sprint performance (Raya-González et al. 2020a), several studies suggest it may not always be effective for enhancing sprint performance (Raya-González et al. 2020a; Beato and Dello Iacono 2020). In fact, five investigations involving semi-professional adult and youth soccer players reported either no enhancement or inconsistent linear sprint performance improvement (de Hoyo et al. 2015; Tous-Fajardo et al. 2016; Coratella et al. 2019; Nuñez et al. 2019; Raya-González et al. 2021a). For example, a randomized control trial involving U16 elite soccer players reported no enhancement of 10m, 20m, or 30m linear sprint performance after 10 weekly flywheel lateral squat sessions (Raya-González et al. 2021a). Similarly, eight weekly flywheel squat sessions did not enhance sprint performance over 10 or 30 m sprint performance in semi-professional adult soccer players (Coratella et al. 2019). Variation in exercise instructions (e.g., delaying the eccentric action), session frequency, and training experience may all be key variables that affected outcomes in the aforementioned studies (Raya-González et al. 2021a). Furthermore, a recent meta-analysis highlighted the importance of specificity and that potential differences in reported outcomes may be due to differences in distance and start type (standing vs. flying) of the test utilized (Petré et al. 2018). In support of this theory, enhancement in maximal speed but not acceleration capacity has been reported after flywheel training in a variety of team sports, including soccer (*moderate*) (de Hoyo et al. 2015). A greater understanding of low-dose flywheel training for enhancement of acceleration and sprint performance in soccer populations is still necessary to optimize training outcomes.

*Change of Direction*

The present review highlights the efficacy of flywheel training for enhancing COD performance in male soccer players. This review supports a previous systematic review reporting improvement in COD performance of team sport athletes after flywheel training (ES = 1.37) (Raya-González et al. 2020b). Another systematic review, whereby eight of eleven studies included flywheel training, reported enhanced COD outcomes after eccentric overload training (Liu et al. 2020). Such enhancements may be related to the similarities between COD tasks and flywheel training (Tous-Fajardo et al. 2016). Flywheel training appears particularly effective for stimulating the repeated rapid braking and propulsive actions experienced when performing COD (Maroto-Izquierdo et al. 2017a; Raya-González et al. 2020b; Beato and Dello Iacono 2020). Specifically, youth soccer players exposed to 10 weeks of flywheel training improved braking and propulsive contact time and forces during COD tasks (*moderate to large*) (de Hoyo et al. 2015). Similarly, a recent RCT involving 10 weekly flywheel lateral squat sessions also enhanced COD (*large to very* large) and COD deficit performance in U16 elite soccer players (*moderate to large*) (Raya-González et al. 2021a). Similarly,Tous-Fajardo *et al.,* (2016) and Fiorilli *et al.,* (2020) reported improvements in COD performance (*large*) after 6 and 11 weeks of flywheel training amongst elite academy players. Such improvements in braking impulse are likely to enable greater storage of elastic energy that contributes to greater force output during COD performance (Meylan et al. 2008), possibly playing a pivotal role in soccer match outcomes (Raya-González et al. 2020b; Beato and Dello Iacono 2020). Coratella and colleagues (2019) also reported 8 weekly flywheel squat sessions improved 20+20 m shuttle (*moderate*) and T-Test agility (*large*) performance, while the traditional squat group (80%1RM) did not (Coratella et al. 2019). Although flywheel training may effectively reduce braking time and enhance braking impulse (de Hoyo et al. 2016; Coratella et al. 2019), appropriate familiarization (involving at least 2 sessions) and technique appear to be prerequisites to effective implantation and desirable outcomes (Raya-González et al. 2020b).

**Limitations, future research, and training indications**

The main limitation of the present review is that different types of study designs were included and considered equivalent when analyzed, regardless of scientific rigor. Furthermore, certain aspects of the training protocol, such as inertial loads, were not always clearly reported in investigations included in the review. Although the review presents the reliability of individual studies, the variation of reliability measures utilized cannot be standardized, which could affect the comparability of the studies. Most investigations included in the review were performed with male elite youth, semi-professional, or amateur adult soccer players, limiting conclusions with professional soccer players. Investigation into the effects of flywheel training on physical performance of youth and adult female soccer players is also necessary. Further comparison of flywheel and traditional resistance training methods for enhancement of strength and power in soccer are necessary to understand if differences between methods exist. Likewise, investigating the effects of training volume and frequency on jumping and sprinting performance may highlight relevant information not currently available in the soccer literature. Further investigation of inertial load among other critical factors related to training prescription will further enhance the application of flywheel training in soccer. The present review also highlights that bias due to study designs employed should also be critical considerations when establishing appropriate conclusions and future directions.

**Conclusions**

This systematic review reported that a diverse range of flywheel training interventions can effectively improve strength, power, jump, and COD measures in male soccer players of varying levels. Nonetheless, the current literature suggests contrasting evidence regarding flywheel training induced changes in sprint speed and acceleration capacity of soccer players. The present review is mostly in agreement with previous systematic reviews and investigations reporting the efficacy of flywheel training with sports and athletic populations.

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**References**

Askling C, Karlsson J, Thorstensson A (2003) Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. Scand J Med Sci Sports 13:244–250. https://doi.org/10.1034/j.1600-0838.2003.00312.x

Beato, M., de Keijzer, K. L., Fleming, A., Coates, A., La Spina, O., Coratella, G., & McErlain-Naylor, S. A. (2020a). Post flywheel squat vs. flywheel deadlift potentiation of lower limb isokinetic peak torques in male athletes. *Sports Biomechanics*, 1–14. 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. Front Physiol 11:. https://doi.org/10.3389/fphys.2020.00569

Beato, M., Fleming, A., Coates, A., & Dello Iacono, A. (2020b). Validity and reliability of a flywheel squat test in sport. *Journal of Sports Sciences*, 1–7. https://doi.org/10.1080/02640414.2020.1827530

Beato M, Maroto-Izquierdo S, Turner AN, Bishop C (2020c) Implementing Strength Training Strategies for Injury Prevention in Soccer: Scientific Rationale and Methodological Recommendations. Int J Sports Physiol Perform 1–6. https://doi.org/10.1123/ijspp.2020-0862

Beato M, McErlain-Naylor SA, Halperin I, Dello Iacono A (2020d) Current evidence and practical applications of flywheel eccentric overload exercises as postactivation potentiation protocols: A brief review. Int J Sports Physiol Perform 15:154–161. https://doi.org/10.1123/ijspp.2019-0476

Berg HE, Tesch PA (1994) A gravity-independent ergometer to be used for resistance training in space. Aviat Sp Environ Med

Bridgeman LA, McGuigan MR, Gill ND, Dulson DK (2018) Relationships between concentric and eccentric strength and countermovement jump performance in resistance trained men. J Strength Cond Res 32:255–260. https://doi.org/10.1519/JSC.0000000000001539

Brughelli M, Cronin J, Levin G, Chaouachi A (2008) Understanding change of direction ability in sport. Sport Med 38:1045–1063. https://doi.org/10.2165/00007256-200838120-00007

Coratella G, Beato M, Cè E, et al (2019) Effects of in-season enhanced negative work-based vs traditional weight training on change of direction and hamstrings-to-quadriceps ratio in soccer players. Biol Sport 36:241–248. https://doi.org/10.5114/biolsport.2019.87045

de Hoyo M, Pozzo M, Sañudo B, et al (2015) 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. https://doi.org/10.1123/ijspp.2013-0547

de Hoyo M, Sañudo B, Carrasco L, et al (2016) Effects of 10-week eccentric overload training on kinetic parameters during change of direction in football players. J Sports Sci 34:1380–1387. https://doi.org/10.1080/02640414.2016.1157624

Dudley GA, Tesch PA, Miller BJ, Buchanan P (1991) Importance of eccentric actions in performance adaptations to resistance training. Aviat Space Environ Med 62:543–50

Faude O, Koch T, Meyer T (2012) Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci 30:625–631. https://doi.org/10.1080/02640414.2012.665940

Fernandez-Gonzalo R, Lundberg TR, Alvarez-Alvarez L, de Paz JA (2014) Muscle damage responses and adaptations to eccentric-overload resistance exercise in men and women. Eur J Appl Physiol 114:1075–1084. https://doi.org/10.1007/s00421-014-2836-7

Fiorilli G, Mariano I, Iuliano E, et al (2020) Isoinertial eccentric-overload training in young soccer players: Effects on strength, sprint, change of direction, agility and soccer shooting precision. J Sport Sci Med

Gonzalo-Skok O, Moreno-Azze A, Arjol-Serrano JL, et al (2019) A comparison of 3 different unilateral strength training strategies to enhance jumping performance and decrease interlimb asymmetries in soccer players. Int J Sports Physiol Perform 14:1256–1264. https://doi.org/10.1123/ijspp.2018-0920

Gonzalo-Skok O, Tous-Fajardo J, Suarez-Arrones L, et al (2017) Single-Leg Power Output and Between-Limbs Imbalances in Team-Sport Players: Unilateral Versus Bilateral Combined Resistance Training. Int J Sports Physiol Perform 12:106–114. https://doi.org/10.1123/ijspp.2015-0743

Gual G, Fort-Vanmeerhaeghe A, Romero-Rodríguez D, Tesch PA (2016) Effects of in-season inertial resistance training with eccentric overload in a sports population at risk for patellar tendinopathy. J Strength Cond Res 30:1834–1842. https://doi.org/10.1519/JSC.0000000000001286

Harden M, Bruce C, Wolf A, et al (2020) Exploring the practical knowledge of eccentric resistance training in high-performance strength and conditioning practitioners. Int J Sports Sci Coach 15:41–52. https://doi.org/10.1177/1747954119891154

Hawkins RD (2001) The association football medical research programme: an audit of injuries in professional football. Br J Sports Med 35:43–47. https://doi.org/10.1136/bjsm.35.1.43

Hollander DB, Kraemer RR, Kilpatrick MW, et al (2007) Maximal eccentric and concentric strength discrepancies between young men and women for dynamic resistance exercise. J Strength Cond Res. https://doi.org/10.1519/00124278-200702000-00007

Hopkins WG, Marshall SW, Batterham AM, Hanin J (2009) Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41:3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, (4), 863. https://doi.org/10. 3389/fpsyg.2013.00863

Lehance C, Binet J, Bury T, Croisier JL (2008) Muscular strength, functional performances and injury risk in professional and junior elite soccer players. Scand J Med Sci Sports 19:243–251. https://doi.org/10.1111/j.1600-0838.2008.00780.x

Liberati A, Altman DG, Tetzlaff J, et al (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ 339:b2700–b2700. https://doi.org/10.1136/bmj.b2700

Liu R, Liu J, Clarke CV, An R (2020) Effect of eccentric overload training on change of direction speed performance: A systematic review and meta-analysis. J Sports Sci 38:2579–2587. https://doi.org/10.1080/02640414.2020.1794247

Markovic G, Newton RU (2007) Does plyometric training improve vertical jump height? A meta-analytical review. Br J Sports Med 41:349–355. https://doi.org/10.1136/bjsm.2007.035113

Maroto-Izquierdo S, García-López D, de Paz JA (2017a) Functional and muscle-size effects of flywheel resistance training with eccentric-overload in professional handball players. J Hum Kinet 60:133–143. https://doi.org/10.1515/hukin-2017-0096

Maroto-Izquierdo S, García-López D, Fernandez-Gonzalo R, et al (2017b) Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. J Sci Med Sport 20:943–951. https://doi.org/10.1016/j.jsams.2017.03.004

Meylan C, Cronin J, Nosaka K (2008) Isoinertial assessment of eccentric muscular strength. Strength Cond J 30:56–64. https://doi.org/10.1519/SSC.0b013e31816a7037

Morgans R, Orme P, Anderson L, Drust B (2014) Principles and practices of training for soccer. J. Sport Heal. Sci.

Norrbrand L, Fluckey JD, Pozzo M, Tesch PA (2007) Resistance training using eccentric overload induces early adaptations in skeletal muscle size. Eur J Appl Physiol 102:271–281. https://doi.org/10.1007/s00421-007-0583-8

Norrbrand L, Pozzo M, Tesch PA (2010) Flywheel resistance training calls for greater eccentric muscle activation than weight training. Eur J Appl Physiol 110:997–1005. https://doi.org/10.1007/s00421-010-1575-7

Nuñez FJ, Hoyo M de, López AM, et al (2019) Eccentric-concentric Ratio: A key factor for defining strength training in soccer. Int J Sports Med 40:796–802. https://doi.org/10.1055/a-0977-5478

Núñez FJ, Santalla A, Carrasquila I, et al (2018) The effects of unilateral and bilateral eccentric overload training on hypertrophy, muscle power and COD performance, and its determinants, in team sport players. PLoS One. https://doi.org/10.1371/journal.pone.0193841

Nuñez Sanchez FJ, Sáez de Villarreal E (2017) Does Flywheel Paradigm Training Improve Muscle Volume and Force? A Meta-Analysis. J Strength Cond Res 31:3177–3186. https://doi.org/10.1519/JSC.0000000000002095

Petré H, Wernstål F, Mattsson CM (2018) Effects of flywheel training on strength-related variables: a meta-analysis. Sport Med - Open 4:55. https://doi.org/10.1186/s40798-018-0169-5

Raya-González J, Castillo D, Beato M (2020a) The flywheel paradigm in team sports. Strength Cond J Publish Ah: https://doi.org/10.1519/SSC.0000000000000561

Raya-González J, Castillo D, de Keijzer KL, Beato M (2021a) The effect of a weekly flywheel resistance training session on elite U-16 soccer players’ physical performance during the competitive season. A randomized controlled trial. Res Sport Med 1–15. https://doi.org/10.1080/15438627.2020.1870978

Raya-González J, Castillo D, Domínguez-Díez M, Hernández-Davó JL (2020b) Eccentric-overload production during the flywheel squat exercise in young soccer players: implications for injury prevention. Int J Environ Res Public Health 17:3671. https://doi.org/10.3390/ijerph17103671

Raya-González J, de Keijzer KL, Bishop C, Beato M (2021b) Effects of flywheel training on strength-related variables in female populations. A systematic review. Res Sport Med 1–18. https://doi.org/10.1080/15438627.2020.1870977

Roig M, O’Brien K, Kirk G, et al (2009) The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. Br J Sports Med 43:556–568. https://doi.org/10.1136/bjsm.2008.051417

Roig M, Shadgan B, Reid WD (2008) Eccentric exercise in patients with chronic health conditions: a systematic review. Physiother Canada 60:146–160. https://doi.org/10.3138/physio.60.2.146

Sabido R, Hernández-Davó JL, Botella J, et al (2017) 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. https://doi.org/10.1080/17461391.2017.1282046

Sagelv EH, Pedersen S, Nilsen LPR, et al (2020) Flywheel squats versus free weight high load squats for improving high velocity movements in football. A randomized controlled trial. BMC Sports Sci Med Rehabil 12:61. https://doi.org/10.1186/s13102-020-00210-y

Suarez-Arrones L, Saez de Villarreal E, Núñez FJ, et al (2018) In-season eccentric-overload training in elite soccer players: Effects on body composition, strength and sprint performance. PLoS One 13:e0205332. https://doi.org/10.1371/journal.pone.0205332

Timmins RG, Bourne MN, Shield AJ, et al (2016) Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. Br J Sports Med 50:1524–1535. https://doi.org/10.1136/bjsports-2015-095362

Timmins RG, Filopoulos D, Nguyen V, et al (2021) Sprinting, strength and architectural adaptations following hamstring training in Australian footballers. Scand J Med Sci Sports. https://doi.org/10.1111/sms.13941

Tous-Fajardo J, Gonzalo-Skok O, Arjol-Serrano JL, Tesch P (2016) Enhancing change-of-direction speed in soccer players by functional inertial eccentric overload and vibration training. Int J Sports Physiol Perform 11:66–73. https://doi.org/10.1123/ijspp.2015-0010

Turner AN, Stewart PF (2014) Strength and conditioning for soccer players. Strength Cond J 36:1–13. https://doi.org/10.1519/SSC.0000000000000054

Vicens-Bordas J, Esteve E, Fort-Vanmeerhaeghe A, et al (2018a) Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. J Sci Med Sport 21:2–3. https://doi.org/10.1016/j.jsams.2017.09.001

Vicens-Bordas J, Esteve E, Fort-Vanmeerhaeghe A, et al (2018b) Is inertial flywheel resistance training superior to gravity-dependent resistance training in improving muscle strength? A systematic review with meta-analyses. J Sci Med Sport 21:75–83. https://doi.org/10.1016/j.jsams.2017.10.006