RESEARCH IN SPORTS MEDICINE
https://doi.org/10.1080/15438627.2021.1958813

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

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ABSTRACT

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

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).

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.

Flywheel training interventions improve the physical capacities of 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.

ARTICLE HISTORY
Received 14 April 2021
Accepted 12 July 2021

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). The performance of such tasks requires rapid production of force (Morgans et al., 2014) and often plays 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

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that strength and conditioning coaches identify and optimize methods that can efficiently enhance strength and consequently improve the physical performance of soccer players (Beato et al., 2020c).

Traditional resistance training programmes 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 (Beato & Dello Iacono, 2020; Dudley et al., 1991; Hollander et al., 2007). In an attempt to achieve supramaximal eccentric loads using traditional training methods, external operators or weight releasers have previously been used (Beato & Dello Iacono, 2020; Maroto-Izquierdo et al., 2017b). 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 (Beato et al., 2020d; Coratella et al., 2019; Gonzalo-Skok et al., 2019; De Hoyo et al., 2016; Nuñez et al., 2019; Raya-González et al., 2020a, 2021b; Suarez-Arrones et al., 2018). 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 & 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 the 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 (Beato & Dello Iacono, 2020; Raya-González et al., 2020a) 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, a systematic synthesis of research evidence investigating the effects of flywheel training on strength, power and sport-specific task performance of 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 of 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 was conducted by two separate reviewers (WA and KDK) up until 12 October 2020. Since the flywheel technology was established in 1994 (Berg & 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, U.S.A.). 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).

Study selection

An assessment of 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).

Analysis of results

While the methodological quality of studies is often conducted using either: (i) the PEDro scale; (ii) the Delphi 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 (Brughelli et al., 2008; Markovic & Newton, 2007). 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 to 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

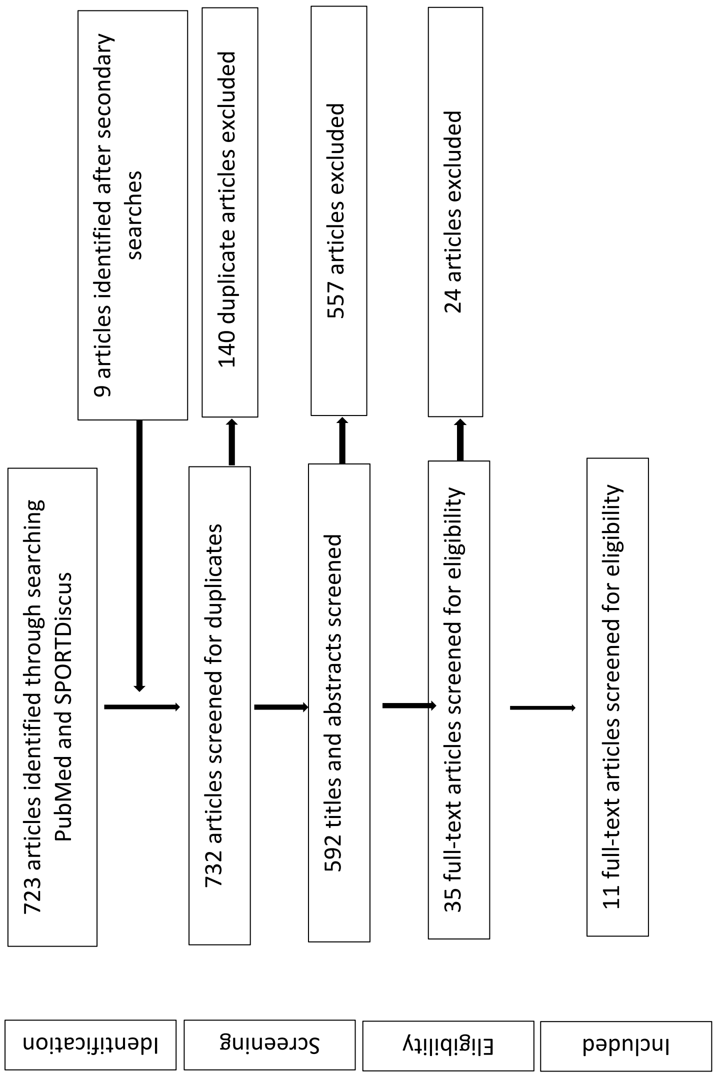

Figure 1. Flow chart illustrating the search and selection process in accordance with the PRISMA guidelines.

Table 1. Eligibility Criteria.

Age	Participants included were between 12 and 43 years of age.
Injury status	Participants were free from injury or illness.
Population	Participants included were competitive male soccer athletes of various training levels (*i.e.* amateur, academy elite, professional).
Metrics	Data reported was specific to at least one of the following: strength, power, jumping, maximal running speed, changes of direction.
Intervention	The study utilised a flywheel device (*e.g.*, conical pulley, isoinertial machine) to elicit chronic adaptations.
Intervention period	The intervention period implemented was >4 weeks.
Supplement/ ergogenic aids	Participants were not prescribed supplements or ergogenic aids during the intervention period.

researchers (Roig et al., 2009, 2008) 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.

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

Table 2. Methodological quality of studies.

Author	Inclusion Criteria	Random Allocation	Intervention Defined	Groups Tested for Similarity at Baseline	Control Group	Outcome Variables Defined	Assessments Practically Useful	Duration of Intervention Practically Useful	Between-Group Stats Analysis Appropriate	Point Measures of Variability	Quality Assessment
Askling et al., (2003)	1	2	2	2	2	2	1	2	2	2	18 *high*
Coratella et al. (2019)	2	2	2	1	0	2	2	2	2	2	17 *high*
De Hoyo et al. (2015)	2	0	2	0	2	2	1	2	1	2	14 *moderate*
De Hoyo et al. (2016)	2	0	2	0	2	2	1	2	0	2	13 *moderate*
Fiorilli et al. (2020)	1	2	2	0	0	2	2	1	2	2	14 *moderate*
Gonzalo-Skok et al. (2019)	1	2	2	2	0	2	2	2	0	2	15 *high*
Raya-González et al., 2021a)	2	2	2	0	2	2	2	2	2	2	18 *high*
Suarez-Arrones et al. (2018)	2	0	2	0	0	2	1	2	0	1	10 *moderate*
Nuñez et al. (2019)	1	2	2	2	2	2	1	2	0	2	16 *high*
Sagelv et al. (2020)	2	2	2	2	2	2	1	1	1	2	17 *high*
Tous-Fajardo et al. (2016)	1	0	2	1	1	2	2	2	0	2	13 *moderate*

Table 3. Summary of studies that investigated chronic adaptations in soccer players following flywheel training.

Study (Year)	Participants (Age)	Intervention	Duration, Volume and Intensity	Findings	Hedges *g* and interpretation
Askling et al., (2003)	30 male Swedish Premier League professional soccer players EXP (24.0 ± 2.6 yrs.) CON (26.0 ± 3.6 yrs.)	EXP (n = 15) Flywheel prone leg curl CON (n = 15) Soccer training	10 wks – 1–2 sessions per week (16 in total) 4 sets × 8 reps Inertia not reported	EXP significantly improved isokinetic concentric and eccentric hamstring strength at 60°s^{-1}, no change in CON. EXP significantly improved flying 30 m sprint time, no change in CON.	Hamstring concentric peak torque (g = 0.79, *moderate*) Hamstring eccentric peak torque (g = 1.14, *moderate*) 30 m sprint (g = −0.79, *moderate*)
Coratella et al. (2019)	40 male Italian division 4 semi-professional players 23.0 ± 4.0 yrs.	EXP (n = 20) Flywheel squats CON (n = 20) Barbell squats (80%1RM) Pre-post, parallel two-group randomized trial.	8 wks – 1 session per week (8 in total) 4–6 sets × 8 reps EXP Inertia 0.11 kg·m^2 CON 80%1RM	EXP significantly improved 20 + 20 m shuttle, T-test agility, Quadriceps concentric and eccentric peak torque, and H_{ecc}:Q_{con} ratio at 60°s^{-1} more so than CON. EXP and CON both significantly improved squat jump, CMJ, squat 1RM, hamstring strength and lean mass. Neither EXP nor CON enhanced 10 m or 30 m sprint speed significantly.	20 + 20 m shuttle (g = −0.94, *moderate*) T-test agility (g = −1.41, *large*) Quadriceps concentric and eccentric peak torque (g = 0.36, *small*; g = 0.75, *moderate*) H_{ecc}:Q_{con} ratio (g = 0.29, *small*)
De Hoyo et al. (2015)	36 male Spanish U17-U19 academy soccer players EXP (18.0 ± 1.0 yrs.) CON (17.0 ± 1.0 yrs.)	EXP (n = 18) Flywheel half squat and prone leg curl CON (n = 15) Soccer training Controlled non-randomized study design	10 wks – 1–2 sessions per week (17 in total) 3–6 sets × 6 reps Inertia 2 or 4* was used depending on higher power output	Improvements after EXP in CMJ, flying 10 m, and 20 m sprint performance in comparison to CON. No differences between EXP and CON were reported for 10 m sprint performance.	CMJ height (g = 0.60, *moderate*) Flying 10 m sprint (g = −0.84, *moderate*)

(*Continued*)

Table 3. (Continued).

Study (Year)	Participants (Age)	Intervention	Duration, Volume and Intensity	Findings	Hedges *g* and interpretation
De Hoyo et al. (2016)	34 male Spanish U19 academy soccer players 17.0 ± 1.0 yrs.	EXP (n = 17) Flywheel half-squat and prone leg curl CON (n = 14) Soccer training Controlled non-randomized study design	10 wks – 1-2 sessions per week (18 in total) 3–6 sets × 6 reps Inertia 2 or 4 was used depending on higher power output [a]	Side-step cutting contact and braking time was improved more so after EXP than CON. No differences reported between groups in propulsive phase, relative peak braking and propulsive force, relative total, relative braking and propulsive impulse. Crossover cutting relative propulsive force and relative braking impulse improved more so after EXP than CON. No differences reported between contact and braking time.	Side-step cutting Contact time (g = −1.43, *large*) Braking time (g = −0.95, *moderate*) Crossover cutting Relative propulsive force (g = 0.97, *moderate*) Relative braking impulse (g = 0.92, *moderate*)
Fiorilli et al. (2020)	34 male academy players EXP (13.2 ± 1.2 yrs.) CON (13.36 ± 0.8 yrs.)	EXP (n = 18) Flywheel acceleration and kicking movements CON (n = 16) Plyometric training Controlled randomized repeated-measure design	6 wks – 2 sessions per week (12 in total) 4 sets × 7 reps Inertia not reported	Significant increases in drop jump height and contact time, repeated hop height, Y agility test, and 60 m sprint performance were reported after EXP but not CON. EXP and CON significantly enhanced squat jump height, Illinois agility test, and Loughborough soccer shooting test. Neither EXP nor CON significantly improved drop jump reactive strength index or repeated hop contact time and reactive strength index.	Drop jump height (g = 0.84, *moderate*) Drop jump contact time (g = 0.94, *moderate*) Repeated hop height (g = 0.83, *moderate*) Y-agility test (g = −1.71, *large*) 60 m sprint (g = −0.43, *small*)

(*Continued*)

Table 3. (Continued).

Study (Year)	Participants (Age)	Intervention	Duration, Volume and Intensity	Findings	Hedges *g*and interpretation
Gonzalo-Skok et al. (2019)	45 male Spanish Division 2 U17 academy soccer players 15.4 ± 0.7	EXP (n = 35) Flywheel unilateral lateral squat [b] SVW (n = 10) DVW (n = 11) SVS (n = 14) Randomized parallel group study design	10 wks – 1 session per week (10 in total) 2 sets × 8 reps each side Inertia 0.27 kg·m^2	CMJ performance and asymmetry was slightly improved after SVW, DVW, and SVS. DVW improved triple-hop asymmetry more so than SVW and SVS. Considerations should be made for additional volume and starting sets with the weaker leg. No enhancement reported for any single-leg horizontal jumping performance after SVW, DVW or SVS.	CMJ height (g = 0.27 to 0.46, *small*) SL CMJ asymmetry (g = −0.31 to −0.55, *small*) Triple hop asymmetry (g = −0.58, *small*)
Raya-González et al., 2021a)	22 male Spanish U16 academy soccer players Age not reported	EXP (n = 11) Flywheel lateral squats CON (n = 11) Soccer training Randomized control trial design	10 wks – 1 session per week (10 in total) 2–4 sets of 8–10 reps Inertia 0.025 kg·m^2	EXP reported significant changes in CMJ height with both dominant and non-dominant legs than CON. EXP reported improvements in all COD and CODdef variables analysed whereas CON reported significant improvements in COD10d, CODdef10d. No differences reported between EXP and CON for 10 m, 20 m, and 30 m sprint performance.	SL CMJ height (g = 0.66 to 1.11, *moderate*) COD 10 m (g = −1.48 to −1.98, *large*) COD deficit 10 m (g = −1.35 to −1.47, *large*) COD20m (g = −1.40 to −2.05, *large to very large*) COD deficit 20 m (g = −0.91 to −1.43, *moderate to large*)
Suarez-Arrones et al. (2018)	14 male Italian Division 1 academy soccer players 17.5 ± 0.8 yrs.	EXP (n = 14) Flywheel unilateral and bilateral training as part of strength programme[c] Repeated-measures research design	27 wks – 2 per week (54 in total) 1–2 sets of 5–10 repetitions Inertia [d]0.05 or 0.10 kg·m^2 and [e]0.19 or 0.26 kg·m^2 Inertia with highest speed selected	Improvements were reported in uni- and bilateral half-squat power after EXP. EXP also enhanced 10 m, 30 m, and 40 m sprint time.	Unable to calculate Hedges *g*

(*Continued*)

Table 3. (Continued).

Study (Year)	Participants (Age)	Intervention	Duration, Volume and Intensity	Findings	Hedges *g*and interpretation
Nuñez et al. (2019)	20 male Spanish elite academy soccer players 17.0 ± 1.0 yrs.	EXP (n = 10) Flywheel horizontal front step CON (n = 10) Resistance training involving sled and plyometric training	9 wks – 1 session per week (9 in total) 2–3 × 6 (each leg) Inertia not reported	Improvements were reported for EXP in front-step mean eccentric power and ECC:CON ratio in comparison to CON. CON reported greater concentric mean power than EXP. EXP and CON reported no differences in 10 m, 10–20 m, nor 20 m sprint times.	Front-step mean ECC power (g = 1.38, *large*) ECC:CON ratio (g = 1.69, *large*)
Sagelv et al. (2020)	38 male Norwegian amateur (Tier 5 and 6) league soccer players EXP (23.1 ± 3.2 yrs.) BS(23.23 ± 2.1 yrs.) CON (25.3 ± 2.4 yrs.)	EXP (n = 13) Flywheel squats and Nordic curls (n = 13) BS (n = 13) Barbell squats and Nordic curls CON (n = 12) Soccer training Randomized control trial study design	6 wks – 2 sessions per week (12 in total) 3–4 sets × 6–10 reps EXP Inertia 0.025, 0.05, 0.075, or 0.1 kg·m^2. If > 4 watts per kg·m^2 per rep of set, inertia was increased. BS ±70 to >85% 1RM	Significant improvements in 10 m sprint time and CMJ height in both flywheel and barbell squats group compared to CON. Significant 1RM squat strength improvement after BS in comparison to EXP.	10 m sprint (g = −0.40, *small*) CMJ (g = 1.00, *moderate*)
Tous-Fajardo et al. (2016)	24 male Spanish U18 academy soccer players 17 ± 0.5 yrs.	EXP (n = 12) Functional eccentric overload and vibratory training circuit CON (n = 12) Plyometric, linear speed and loaded vertical exercises Non-randomized controlled study design	11 wks – 1 session per week (11 in total) 2 sets × 6–10 reps [f] Inertia 0.27 kg·m^2 or 0.11 kg·m^2	EXP enhanced V-cut test and mean average relative power during hopping more so than CON. Neither CON nor EXP enhanced 10 m, 30 m or repeated sprint (best, mean, or decrement) time, repeated mean jump height, muscle stiffness or contact time. CON enhanced CMJ more so than EXP.	V-cut performance (g = −1.21, *large*) Hopping mean average relative power (g = 0.45, *small*)

EXP = Experimental group; CON = Control; 1RM = 1 repetition maximum; H_{ecc}:Q_{con} ratio = Eccentric hamstring to concentric quadriceps peak torque ratio; CMJ = Countermovement jump; m = metres; COD = Change of direction; ECC:CON ratio = eccentric to concentric ratio.
[a]De Hoyo et al. (2015; 2016) reported using two different inertial loads but did not specify what these loads were.
[b]SVW = Same volume with both; starting with weaker leg; DVW: Double volume and starting with weaker leg; SVS: Same volume with both; starting with stronger leg. [c] Unilateral Yo-Yo leg curl, flywheel lunge, hip extension and half squat variations.
[d]For the K Box device.
[e]For Versa Pulley device.
[f]Inertia for diagonal trunk rotations (reverse wood chops), backward lunges and unilateral hamstring kicks was 0.27 kg·m^2 and 0.11 kg·m^2 for lateral squats.

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 $d = M_{diff}/S_{av}(M_{diff}$, mean difference, S_{av} average SD) was used for this purpose with the adjustment factor of:

$$g = (1 - -3/d_{df} - -1)xd$$

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 three groups (A-B-C) based on physical performance, while Suarez-Arrones et al., (2018) used a repeated measures design. Participants in 8 of the 11 studies included elite academy soccer players (Fiorilli et al., 2020; Gonzalo-Skok et al., 2019; De Hoyo et al., 2015, 2016; Nuñez et al., 2019; Raya-González et al., 2021a; Suarez-Arrones et al., 2018; Tous-Fajardo et al., 2016). 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).

Interventions

Excluding Suarez-Arrones et al. (2018b), whose intervention included 54 training sessions over 27 weeks, the rest of the literature utilized 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 to 6 sets of 5–10 repetitions with frequency varying from 1 to 2 sessions a week. Seven studies utilized inertias ranging from 0.025 to 0.27 $kg{\cdot}m^2$ (Coratella et al., 2019; Gonzalo-Skok et al., 2019; De Hoyo et al., 2015; Raya-González et al., 2021a; Sagelv et al., 2020; Suarez-Arrones et al., 2018; Tous-Fajardo et al., 2016), while the inertia used in the remaining studies was not reported (Askling et al. 2003; Fiorilli et al., 2020; De Hoyo et al., 2015, 2016; Nuñez et al., 2019). Eight of the eleven studies followed a progressive programme, gradually increasing training volume or intensity over the intervention period (Coratella et al., 2019; De Hoyo et al., 2015, 2016; Nuñez et al., 2019; Raya-González et al., 2021a; Sagelv et al., 2020; Suarez-Arrones et al., 2018; Tous-Fajardo et al., 2016). Finally, five studies individualized intensity by selecting inertias reporting the highest power outputs (De Hoyo et al., 2015, 2016; Nuñez et al., 2019; Sagelv et al., 2020; Suarez-Arrones et al., 2018).

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; Coratella et al., 2019; Nuñez et al., 2019; Sagelv et al., 2020; Suarez-Arrones et al., 2018). Although Coratella et al. (2019) reported an 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 et al. (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 et al. (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 unilateral CMJ, single leg hop and triple hop, horizontal jump, rebound jump, hopping, squat jump) (Coratella et al., 2019; Fiorilli et al., 2020; Gonzalo-Skok et al., 2019; De Hoyo et al., 2015; Raya-González et al., 2021a; Tous-Fajardo et al., 2016). Performance was measured on devices referred to as infrared devices, infrared-light platforms, portable force plates, photocells systems, and photoelectric cells. Coratella et al. (2019) used an infrared device, reporting excellent reliability for SJ ($\alpha = 0.934$) and CMJ ($\alpha = 0.903$). 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-González et al. (2021b) 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 11 investigations included in this review investigated acceleration or maximal running speed (Table 3) (Askling et al. 2003; Coratella et al., 2019; Fiorilli et al., 2020; De Hoyo et al., 2015; Nuñez et al., 2019; Raya-González et al., 2021a; Sagelv et al., 2020; Suarez-Arrones et al., 2018; Tous-Fajardo et al., 2016). Investigations reported using photo or photoelectric cells, infrared devices, single- and dual-beam electronic timing gates. Five of the 11 investigations did not report any reliability measures for sprint measurements (Askling et al. 2003; De Hoyo et al., 2015; Nuñez et al., 2019; Suarez-Arrones et al., 2018; Tous-Fajardo et al., 2016). (Coratella et al., 2019) reported excellent reliability for standing start 10 m ($\alpha = 0.920$) and 30 m ($\alpha = 0.902$) sprint times. Raya-González et al. (2021b) reported the ICC and CV for 10 m (0.74% and 1.6%), 20 m (0.84% and 1.6%) and 30 m (0.90% and 1.3%). Finally, Sagelv et al. (2020) and Fiorilli et al. (2020) analyzed both reliability measures from other studies.

Change of Direction

Six studies investigated the effects of flywheel training on COD performance (Table 3) (Coratella et al., 2019; Fiorilli et al., 2020; De Hoyo et al., 2015, 2016; Raya-González et al., 2021a; Tous-Fajardo et al., 2016). Studies investigated COD performance in a variety of reported systems (infrared device, force plates and photoelectric cells). Coratella et al. (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-González et al. (2021b) utilized two 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 of 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 bilateral 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 programmes (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 (Beato & Dello Iacono, 2020; Norrbrand et al., 2007, 2010; Petré et al., 2018), inconsistency regarding efficacy on maximal strength in the literature remains (Sagelv et al., 2020; Vicens-Bordas et al., 2018a). 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 & 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 & 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 favourable adaptations and improve an athlete's capability to produce power (Beato & Dello Iacono, 2020) and perform the high intensity demands of soccer (Turner & Stewart, 2014). To enhance practical application and conclusions, future investigations analysing strength or power should utilize different exercises (Beato et al., 2020a), apply control groups (Coratella et al., 2019; Suarez-Arrones et al., 2018), account for inertial load and consider training experience (Raya-González et al., 2020b; Sabido et al., 2017). 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 (Beato & Dello Iacono, 2020; Petré et al., 2018; 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 of soccer players is in agreement with previous evidence that flywheel training can effectively enhance jumping ability (Beato & Dello Iacono, 2020; Petré et al., 2018). 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 young 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*) (Gonzalo-Skok et al., 2019; De Hoyo et al., 2015), 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 & Dello Iacono, 2020). In contrast, Tous-Fajardo et al. (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 a lack of random allocation, baseline testing for similarity, or a lack of specificity between intervention and testing (Gonzalo-Skok et al., 2017; Raya-González et al., 2020a; Tous-Fajardo et al., 2016; Vicens-Bordas et al., 2018b). 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 (Coratella et al., 2019; Fiorilli et al., 2020; Gonzalo-Skok et al., 2019; De Hoyo et al., 2015; 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 have 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 programmes) over 6–27 week periods (Askling et al. 2003; Fiorilli et al., 2020; Núñez et al., 2018; Sagelv et al., 2020). Over a 6-week period involving bi-weekly flywheel squat training, amateur soccer players enhanced their 10-metre 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 (Beato & Dello Iacono, 2020; Raya-González et al., 2020a). In fact, five investigations involving semi-professional adult and youth soccer players reported either no enhancement or inconsistent linear sprint performance improvement (Coratella et al., 2019; De Hoyo et al., 2015; Nuñez et al., 2019; Raya-González et al., 2021a; Tous-Fajardo et al., 2016). For example, a randomized control trial involving U16 elite soccer players reported no enhancement of

10, 20, or 30 m 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 8 out of 11 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 (Beato & Dello Iacono, 2020; Maroto-Izquierdo et al., 2017a; Raya-González et al., 2020b). 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 (Beato & Dello Iacono, 2020; Raya-González et al., 2020b). Coratella et al. (2019) also reported 8 weekly flywheel squat sessions that 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 (Coratella et al., 2019; De Hoyo et al., 2016), appropriate familiarization (involving at least 2 sessions) and technique appear to be prerequisites for 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 analysed, regardless of scientific rigour. 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.

Acknowledgments

This investigation did not receive any grant and was not performed in accordance with any funding agency.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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