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SPORTS PERFORMANCE

Effect of eccentric overload training on change of direction speed performance: A systematic review and meta-analysis

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ABSTRACT
This study systematically reviewed and quantified evidence regarding the effectiveness of eccentric overload training (EOT) on change-of-direction speed (CODS) performance. A keyword search was performed in 30 April 2020 in eight electronic bibliographic databases: SPORTDiscus, PubMed, Web of Science, Academic Search Complete, Cochrane Library, Scopus, CINAHL and Google Scholar. A meta-analysis was conducted to estimate the pooled effect size of EOT interventions on CODS performance compared to the control group. Study heterogeneity was assessed by the I^2 index. Publication bias was assessed by the Begg's and Egger's tests. Eleven studies, including nine randomized controlled trials, one randomized crossover trial, and one non-randomized controlled trial met the eligibility criteria and were included in the review. Time of overall change-of-direction task completion among the EOT group was 1.35 standard deviations (95% confidence interval [CI] = 0.18, 2.52) shorter than that in the control group. In conclusion, EOT was found effective in improving CODS performance compared to the control group. Future studies should adopt a randomized experimental design, recruit large and representative samples from professional team sports, and examine the effect of EOT on various measures of CODS performance among population subgroups.

ARTICLE HISTORY
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KEYWORDS
Overload training; eccentric strength; deceleration; change of direction; intervention

Introduction

Agility has been defined as a rapid whole-body movement with change of velocity or direction in response to a stimulus (Sheppard & Young, 2006). Change-of-direction speed (CODS) ability refers to a movement where no immediate reaction to a stimulus is required, so the direction change is pre-planned and is affected by strength, power, and speed (Sheppard & Young, 2006; Young et al., 2015). In most team sports, such as rugby, soccer, American football, Australian football, European handball, the vast majority of actions require high CODS ability when players attempt to closely mark opponents, evade opposition defenders, and gain positional advantages (Spencer et al., 2004; Spiteri et al., 2013). While perceptual performance is also related to an athlete's overall agility, CODS focuses on the physical components of agility without concerning cognitive processes and decision-making factors (Sheppard et al., 2014).

The importance of CODS performance to team sports is well acknowledged (Brughelli et al., 2008; Condello et al., 2013). Strength and conditioning practitioners constantly seek evidence-based practices pertaining to the most effective training methods for improving CODS performance. Traditionally, strength and power training (i.e., power clean, squat, and weightlifting exercises), was adopted as means to improve CODS performance (Asadi et al., 2016; Brughelli et al., 2008). Another popular method of enhancing CODS performance is through eccentric overload training (EOT) (Chaabene et al., 2020). Lockie and colleagues demonstrated that an eccentric-emphasizing deceleration agility training programme improved CODS performance among college athletes in teams (Lockie et al., 2014). Dos Santos and colleagues reported improvement in athletes' CODS performance during the braking and plant phases through EOT-enhanced eccentric strength (Dos' Santos et al., 2017). Additionally, de Hoyo and colleagues found that EOT improved kinetic parameters, including braking time, braking impulse, and relative peak braking in change-of-direction tasks (De Hoyo et al., 2016). Furthermore, increased braking impulse may enable athletes to generate more rapid reacceleration during change-of-direction tasks (Spiteri et al., 2013). However, Bourgeois and colleagues found that EOT only improved the performance of 180° change-of-direction task, but its effect on the performance in the 45° change-of-direction task polarized between elite and amateur athletes (Bourgeois et al., 2017). To date, only one narrative review existed that summarized the effect of EOT on CODS performance, with three interventions included (Chaabene et al., 2018).

This study expanded the previous review by systematically synthesizing and quantifying existing evidence regarding the effectiveness of EOT on CODS performance. Besides a narrative appraisal, this study conducted a meta-analysis to estimate the magnitude of EOT effect. We summarized study findings pertaining to the effect of EOT on CODS performance in comparison to the control (i.e., traditional training or regular training). Findings from this review may shed light on future evidenced-based EOT design and implementation to further improve CODS performance.

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Methods

A systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (Moher et al., 2009).

Study selection criteria

Studies that met all of the following criteria were included in the review: (1) Study design: randomized controlled trial, randomized crossover trial, and controlled non-randomized trial; (2) Study participants: healthy individuals without a history of injury; (3) Intervention type: EOT; (4) Intervention duration: four weeks or longer; (5) Outcome: CODS performance; (6) Article type: peer-reviewed publication; (7) Time window of search: from the inception of an electronic bibliographic database to 1 October 2019; and (8) Language: articles written in English.

Studies that met any of the following criteria were excluded from the review: (1) No outcome pertaining to EOT in relation to CODS performance; (2) No comparison or control group; (3) Intervention duration less than four weeks; (4) Letters, editorials, study protocols, conference proceedings, books, or review articles; and (5) Articles not written in English.

Search strategy

A keyword search was performed in eight electronic bibliographic databases: SPORTDiscus, PubMed, Web of Science, Academic Search Complete, Cochrane Library, Scopus, CINAHL and Google Scholar. The search algorithm included all possible combinations of keywords from the following two groups: (1) "eccentric training", "eccentric exercise", "eccentric resistance", "eccentric drill", "excentric contraction", "excentric contraction", "eccentric-overload", "eccentric emphasized", "flywheel", "FRTEO", "flywheel resistance", "flywheel device", "flywheel training", "flywheel overload training", "inertial training", "inertial resistance", "inertial exercise", "isoinertial training", "accentuated eccentric", "isoinertial exercise", "isoinertial resistance", "enhanced-eccentric", or "lengthening contraction"; and (2) "agility", "agility-test", "mobility", "change of direction", "COD", "side step", "cutting maneuver", "shuttle run", "sideways shuffle", "505 test", "5-0-5 test", "T-test", "Illinois agility test", "IAT", "Zigzag test", "Zig-zag test", "L run", "L-run", "Pro-agility", "3 Cone drill", "3-Cone test", "Y shaped agility", "spider agility", "slalom run", or "Up and Back test". The specific search algorithm is provided in Appendix A. Titles and abstracts of the articles identified through the keyword search were screened against the study selection criteria. Potentially relevant articles were retrieved for an evaluation of the full text. Two co-authors independently conducted the title and abstract screening and identified potentially relevant articles for the full-text review. Interrater agreement was assessed using the Cohen's kappa ($\kappa = 0.88$). Discrepancies were resolved through face-to-face discussions between the two co-authors. Articles identified from the title and abstract screening were reviewed in full texts. The two co-authors jointly determined the final pool of articles included in the review.

A reference list search (i.e., backward reference search) and cited reference search (i.e., forward reference search) were conducted based on the full-text articles that met the study selection criteria that were identified from the keyword search. Articles identified from the backward and forward reference search were further screened and evaluated using the same study selection criteria. Reference search was repeated on all newly identified articles until no additional relevant article was found.

Data extraction

A standardized data extraction form was used to collect methodological and outcome variables from each included study, including authors, publication year, study design, sample size, athlete type, sex, age, intervention type, intervention components, intervention dose, follow-up duration, CODS measure, and main study results and findings.

Data analysis and synthesis

Meta-analysis was performed to estimate the pooled effect of EOT on CODS performance. Standardized pooled effect sizes (i.e., Hedge's g), denoted by the difference in standard deviations in the time of change-of-direction task completion between the EOT and the control group, were estimated. Study heterogeneity was assessed by the I^2 index (Huedo-Medina et al., 2006). The level of heterogeneity represented by the I^2 index was interpreted as small ($I^2 \leq 25\%$), moderate ($25\% < I^2 \leq 50\%$), large ($50\% < I^2 \leq 75\%$), or very large ($I^2 > 75\%$). A fixed-effect model (FE) would be estimated when a small or moderate heterogeneity was present, and a random-effect model (RE) would be estimated when a large or very large heterogeneity was present. Publication bias was assessed by the Begg's and Egger's tests (Begg & Mazumdar, 1994; Egger et al., 1997). Statistical analyses were conducted using Stata 14.0 version (StataCorp, College Station, TX). Specific Stata commands included "metan" and "metabias". All analyses used two-sided tests, and a p-value less than 0.05 was considered statistically significant. Standardized effect size was interpreted following Hopkins's recommendations: 0.0–-0.2 = trivial, 0.2–0.6 = small, 0.6–1.2 = moderate, 1.2–2.0 = large, and >2.0 = very large (Hopkins et al., 2009). Ten out of 11 studies were included in the meta-analysis. We excluded one study because its outcome measures (i.e., kinetic parameters of change-of-direction test, including vertical ground reaction force, propulsive force, and contact time) were different from the other 10 studies (i.e., time of task completion measured in seconds) (De Hoyo et al., 2016).

Study quality assessment

We used the National Institutes of Health's Quality Assessment Tool for Controlled Intervention Studies to assess the quality of each included study (National Heart, L. and Blood Institute, 2015). This assessment tool rates each study based on 14 criteria. For each criterion, a score of one was assigned if "yes" was the response, whereas a score of zero was assigned otherwise. A study-specific global score ranging from zero to

14 was calculated by summing up scores across all criteria. The study quality assessment helped measure the strength of scientific evidence but was not used to determine the inclusion of studies.

Results

Literature search

Figure 1 shows the study selection flowchart. We identified 665 articles by the keyword search, including 68 articles from PubMed, 98 articles from Web of Science, 128 articles from SPORTDiscus, 116 articles from Scopus, 21 articles from CINAHL, 54 articles from Cochrane Library, 163 articles from Academic Search Complete, and 17 articles from Google Scholar. After removing duplicates, 413 unique articles entered title and abstract screening, from which 256 articles were excluded. The full texts of the remaining 18 articles were reviewed against the study selection criteria. Of these, seven articles were excluded: (three without a control arm (Gonzalo-Skok et al., 2017; Núñez et al., 2018; Sabido et al., 2019; Santos et al., 2010), two without an EOT arm (Coratella et al., 2018; Hoffman et al., 2005), and the remaining one with an intervention duration less than 4 weeks (de Hoyo et al., 2015). In total, 11 studies met the selection criteria and were included in the qualitative synthesis (Bourgeois et al., 2017; Chaabene et al., 2020; Coratella et al., 2019; de Hoyo et al., 2015, 2016; Fiorilli et al., 2020; Lockie et al., 2014; Maroto-Izquierdo et al., 2017; Sanchez-Sanchez et al., 2019; Siddle et al., 2019; Tous-Fajardo et al., 2016) and 10 studies were included in meta-analysis (Bourgeois et al., 2017; Chaabene et al., 2020; Coratella et al., 2019; de Hoyo et al., 2015; Fiorilli et al., 2020; Lockie et al., 2014; Maroto-Izquierdo et al., 2017; Sanchez-Sanchez et al., 2019; Siddle et al., 2019; Tous-Fajardo et al., 2016).

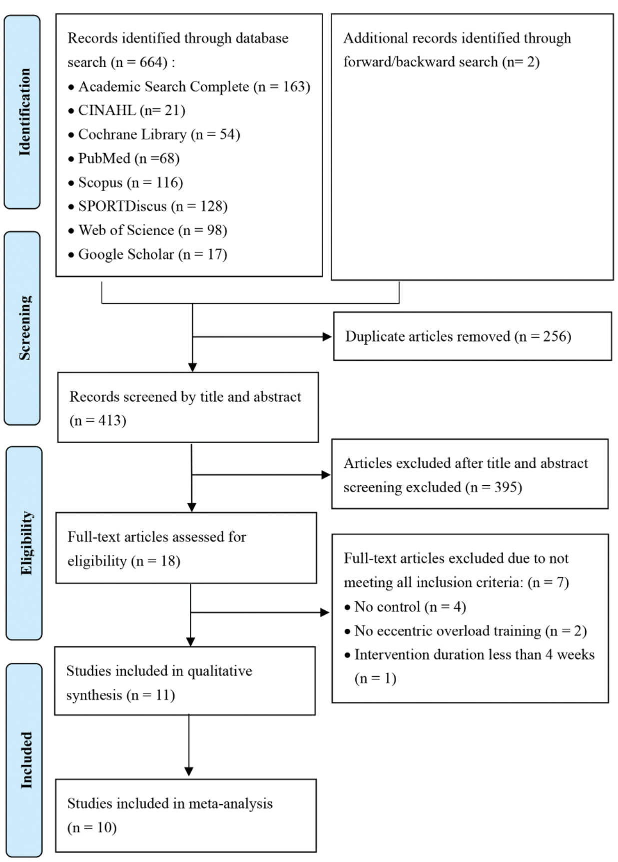

Figure 1. Study selection flowchart.

Basic characteristics of the included studies

Table 1 summarizes the basic characteristics of the 11 articles included in the review. Of these, nine were randomized controlled trials, one was a controlled non-randomised trial (De Hoyo et al., 2016), and the remaining one was a randomized crossover trial (Bourgeois et al., 2017). Sample size ranged from 14 to 40, with a mean of 25 participants. Five studies focused on adolescent athletes aged 13–17 years (Bourgeois et al., 2017; Chaabene et al., 2020; Fiorilli et al., 2020; De Hoyo et al., 2016; Tous-Fajardo et al., 2016), whereas the other six focused on young adults aged 19 years and older. Eight studies included males only, one included females only (Chaabene et al., 2020), one had a female/male ratio of 4/1 (Lockie et al., 2014), and the remaining one did not report sex distribution (Bourgeois et al., 2017). Five studies recruited elite players (two elite handball players and three elite soccer players) (Chaabene et al., 2020; Fiorilli et al., 2020; De Hoyo et al., 2016; Maroto-Izquierdo et al., 2017; Tous-Fajardo et al., 2016). Five studies recruited amateur or semi-professional player: two recruited rugby players (Bourgeois et al., 2017; Siddle et al., 2019), two recruited combined team-sport players (Lockie et al., 2014; Sanchez-Sanchez et al., 2019), and one recruited amateur football players (Coratella et al., 2019). The remaining one study recruited physically active males (de Hoyo et al., 2015). Ten out of 11 studies measured the completion time of change-of-direction tasks, whereas the remaining one measured the kinetic parameters of CODS (De Hoyo et al., 2016). Four studies adopted *T*-test (Chaabene et al., 2020; Coratella et al., 2019; Lockie et al., 2014; Maroto-Izquierdo et al., 2017), three adopted 180° change-of-direction task (Bourgeois et al., 2017; Coratella et al., 2019; Siddle et al., 2019), two adopted Illinois test (Fiorilli et al., 2020; Sanchez-Sanchez et al., 2019), two adopted 45° change-of-direction task (Bourgeois et al., 2017; De Hoyo et al., 2016), one adopted 60° change-of-direction task (De Hoyo et al., 2016), one adopted change-of-direction and acceleration test (CODAT) (Lockie et al., 2014), one adopted V-cut test (25-m sprint with 4 × 45° COD every 5 metres) (Tous-Fajardo et al., 2016), and the remaining one adopted Zigzag test (four 5 metre sections set out at 100°) (De Hoyo et al., 2016).

Table 2 reports intervention arms, components, dose, follow-up duration, and main findings of the 11 studies. Alternative EOTs were adopted: seven studies adopted flywheel eccentric overload training (Bourgeois et al., 2017; Coratella et al., 2019; de Hoyo et al., 2015, 2016; Fiorilli et al., 2020; Maroto-Izquierdo et al., 2017; Tous-Fajardo et al., 2016), two adopted Nordic-hamstring exercise training (Chaabene et al., 2020; Siddle et al., 2019), one adopted concurrent high-intensity interval training and eccentric overload training (Sanchez-Sanchez et al., 2019), and the remaining one adopted enforced deceleration training (Lockie et al., 2014). Intervention dose and follow-up duration differed across studies. Intervention durations in the 11 studies varied from 5 to

Table 1. Basic characteristics of the studies included in the review.

Study ID	First author, year	Study design	articipants	Sex (%)	Sample size*	Age (years)	Measures
1	Fiorilli et al. (2020)	RCT	Elite soccer players	Male (100)	34	13	Illinois test
2	Coratella et al. (2019)	RCT	Amateur soccer players	Male (100)	40	23	T-test; 180° COD test
3	Sanchez-Sanchez et al. (2019)	RCT	Amateur soccer and basketball players	Male (100)	22	23	Illinois test
4	Chaabene et al. (2020)	RCT	Elite handball players	Female (100)	19	16	T-test
5	Siddle et al. (2019)	RCT	Amateur rugby players	Male (100)	14	21	180° COD test
6	Maroto-Izquierdo et al. (2017)	RCT	Elite handball players	Male (100)	29	EOT: 20; CG: 24	T-test
7	Bourgeois et al. (2017)	Randomized crossover trial	Rugby union adolescent players	/	18	15	45° COD test, and 180° COD test
8	Tous-Fajardo et al. (2016)	RCT	Elite young soccer players	Male (100)	24	17	V-cut test
9	de Hoyo et al. (2016)	Controlled non-randomised trial	Elite football Players	Male (100)	34	17	45° side-step cutting; 60° crossover cutting
10	de Hoyo et al. (2015)	RCT	Healthy and physically active males	Male (100)	23	EOT: 22; CG: 23	Zigzag test
11	Lockie et al. (2014)	RCT	Amateur team sport players	Male = 15 (79) Female = 4 (21)	19	24	T-test; CODAT

* Number of participants at the end of the studies; RCT, randomized controlled trial; EOT, eccentric overload training; CG, control group; CODAT, change-of-direction and acceleration test.

12 weeks. The mean follow-up period was eight weeks. Three interventions two times per week (Fiorilli et al., 2020; Lockie et al., 2014; Sanchez-Sanchez et al., 2019), two interventions took place one time per week (Coratella et al., 2019; Tous-Fajardo et al., 2016), two interventions three times per week (Bourgeois et al., 2017; de Hoyo et al., 2016), two interventions one to two times per week (de Hoyo et al., 2016; Siddle et al., 2019), one intervention one to three times per week (Chaabene et al., 2020), and the remaining one two to three times per week (Maroto-Izquierdo et al., 2017).

Meta-analysis

Figure 2 reports the results from meta-analysis. Compared to the control, EOT interventions yielded a 1.35 standard deviation (SD; 95% confidence interval [CI] = 0.18, 2.52; I^2 = 99.7%; RE) reduction in the time of change-of-direction task completion. No publication bias was identified based on the Egger's test and Begg's test (p values > 0.05).

Study quality assessment

Table 3 reports criterion-specific and global ratings from the study quality assessment. The included studies scored 9.9 out of 14 on average, with a range from 7 to 14. All studies stated that the control and intervention arms were similar at baseline on key characteristics that could affect outcomes, strictly adhered to the pre-specified intervention protocols, had an overall dropout rate lower 20%, and had outcomes assessed using valid and reliable measures. Ten of the 11 studies adopted an RCT design, and the differential drop-out rate (between treatment groups) at endpoint was 15 percentage points or lower. Nine of the 11 studies concealed treatment allocations, and assessed outcomes blinded to participants' group assignments. Five of the 11 studies analysed the results based on the initial treatment assignment. Only two studies conducted a power analysis.

Discussion

This study systematically synthesized and quantified existing evidence regarding the effectiveness of EOT on CODS performance. In total of 11 studies, including nine randomized controlled trials, one controlled non-randomised trial and one randomized crossover trial, met the eligibility criteria and were included in the review. Meta-analysis found that in comparison to the control group, time of overall change-of-direction task completion among the EOT group was 1.35 standard deviations shorter.

CODS performance is thought to be determined by multiple factors, among which eccentric strength plays an essential role (Brughelli et al., 2008; Sheppard & Young, 2006; Young et al., 2002). EOT, through improving eccentric strength, optimizes deceleration capability and stabilizes the body during CODS performance (Spiteri et al., 2013; Tous-Fajardo et al., 2016). Brughelli and colleagues reported improvement in eccentric strength to be highly related to CODS gains (Brughelli et al., 2008). Spiteri and colleagues found eccentric lower-body strength determined CODS performance in basketball athletes (Spiteri et al., 2014). Greig and colleagues found eccentric hamstring strength to be a primary predictor for *T*-test performance (Greig & Naylor, 2017). Eccentric hamstring strength may facilitate the generation of eccentric hip extensor torque to maintain trunk position during penultimate and final foot contact with the ground during change-of-direction movements (Jones et al., 2017). Moreover, evidence showed that eccentric hamstrings strength could improve knee joint stability, thus facilitating a more efficient transfer of torque through the kinetic chain (Jones et al., 2017). Besides improving eccentric strength, EOT can be useful in enhancing muscle activation (Norrbrand et al., 2010), which enables athletes to achieve greater braking

Table 2. Intervention arms, components, results and main findings of EOT vs. CG.

Study ID	Intervention arms	Intervention components	Intervention dose	Follow- up (weeks)	Results of EOT vs. Control	Main findings of EOT vs. Control
1	EOT (n = 20): flywheel eccentric-overload training; CG (n = 20): plyometric training	EOT: athletes were encouraged to apply the maximum effort during the concentric phase of sprinting forward and then asked to resist the eccentric phase of movement by back-pedalling; CG: training was based on exercises oriented towards improving vertical components of strength, such as drop jumps; in the second week, exercises to improve horizontal jumping ability were chosen.	EOT: 2 sessions per week; 4 sets of 7 repetitions for each exercise with 120–180 s of rest between sets. CG: The plyometric protocol consisted of 4 exercises (3/4 sets × 7/10 reps for each one).	6	Between-group analyses revealed large effect in favour of EOT for COD Test (ES = 6.56).	Compared to CG, EOT improved greater COD performance in elite junior soccer players.
2	EOT (n = 20): flywheel eccentric-overload training; CG (n = 20): conventional training group.	Both EOT and CG sessions started with 20 weight-free squats. Then, EOT performed 10 submaximal flywheel squats and CG performed 10 squats with 50% 1-RM. EOT: performed10 submaximal flywheel squats using a flywheel ergometer (inertia: 0.11 $kg \cdot m^{-2}$); CG: performed squats with 80% 1-RM.	One session per week; Week 1, 4 sets × 8 reps, week 2, 5 sets × 8 reps, week 3–8, 6 sets × 8 reps, interspersed by 3 min of passive recovery.	8	Between-group analyses revealed large effect in favour of EOT for T-test (ES = 1.08) and 180° COD test (ES = 0.83).	Compared to CG, EOT improved greater COD performance in soccer amateur players.
3	EOT (n = 12): concurrent High-intensity training (HIT) and flywheel eccentric-overload training; CG (n = 10): HIT.	EOT: consists of EOT and HIT sessions. EOT consists of backwards lunges and unilateral hamstrings "kicks" using an iso-inertial portable conical pulley (Inertia 0.27 $kg \cdot m^{-2}$) and half-squats employing the kBox3 (Inertia 0.05 $kg \cdot m^{-2}$); CG: consists of HIT sessions, with 6 min warm-up and two sets × 8 reps linear running for 30 s at 90–100% of the maximum heart rate (HRmax) interspersed with 30 s of active recovery between reps (60% HRmax) and 3 min passive recovery between sets, lasted 26 min.	Two session per week; 2 sets × 6 reps during the first 5 training sessions, 3 sets × 6 reps during the following 5 training sessions, between sessions, passively recover 10 min, between sets and exercises, 1 and 2 min of passive recovery, respectively.	5	Between-group analyses revealed large effect in favour of EOT for Illinois test (ES = 0.56).	Compared to CG, EOT improved greater COD performance in basketball and soccer amateur players.
4	EOT (n = 10): Nordic-hamstring exercise; CG (n = 9): regular handball training.	EOT: participants attempted to resist forward motion of the upper body by eccentrically activating the hamstrings muscles; CG: regular handball training.	1–3 sessions per week; EOT: 5–12 reps per set, 2–3 sets per session, and 60–90 s rest interval between each set; CG: 5–6 sessions per week with 60–90 min.	8	Between-group analyses revealed large effect in favour of EOT for T-test (ES = 1.39).	EOT was more effective than CG in improving T-test performance in young female handball players.
5	EOT (n = 7): Nordic hamstring curl exercise; CG (n = 7): regular training and matches only.	EOT: performing exercise involves slowly lowering torso to the ground, while maintaining a straight back, and resisting the effects of gravity using their hamstring muscles for as long as possible; CG: Regular training and matches only.	Week 1, 2 sets × 5 reps, 1 session per week; weeks 2–6, 2 sessions per week; week 2, 2 sets × 6 reps; week 3, 3 sets × 6 reps; week 4, 3 sets × (6, 7, 8) reps; week 5, 3 sets × (8, 9, 10) reps; week 6, 3 sets × (10, 9, 8) reps.	6	Between-group analyses revealed large effect in favour of EOT for 180° COD Test (ES = 2.00).	EOT was an effective training method in improving 180° COD performance in male team sports athletes.
6	EOT (n = 15): flywheel eccentric-overload training; CG (n = 14): traditional weight training.	EOT: flywheel leg-press resistance training at a maximum-concentric effort; CG: traditional leg-press resistance training using a weight-stack machine.	2–3 sessions per week, 15 sessions, 4 sets × 7 reps.	6	Between-group analyses revealed positive effects of EOT for T-Test (ES = 3.38).	EOT was an effective training method in improving T-Test performance in professional handball player.

(*Continued*)

Table 2. (Continued).

Study ID	Intervention arms	Intervention components	Intervention dose	Follow- up (weeks)	Results of EOT vs. Control	Main findings of EOT vs. Control
7	EOT (n = 12): flywheel eccentric-overload training; CG (n = 6): traditional strength training with no constraints on tempo.	EOT: performing upper and lower body isoinertial eccentric resistance exercises with controlled, followed by a concentric action performed as "fast as possible" in a safe manner; CG: completed the same exercises in a conventional manner – i.e., with no constraints on tempo.	Three sessions per week, 60 min per session, 3 s eccentric durations.	12	Between-group analyses revealed positive effects of EOT for left leg 180° COD Test (ES = 0.73) and negative for left leg 45° COD Test (ES = 1.21).	Positive performance changes in COD tasks were category- and condition-specific. Compared with CG, EOT shows potential enhancement for left leg 180° COD Test in young team sport athletes.
8	EOT (n = 12): flywheel eccentric-overload training; CG (n = 12): conventional combined training.	EOT: consists of 8 exercises (diagonal trunk rotations, backward lunges, unilateral hamstrings kicks, lateral squats, vibration-platform unilateral squat, Nordic-hamstring exercise, rotational side-bridge, and partner-resisted hip abductions and adductions); CG: consists of comparable volume of conventional combined weight, plyometric, and linear speed exercises.	EOT: weeks 1–2, familiarization with exercise mode; weeks 3–5, 2 sets × 6 reps; weeks 6–8, 2 sets × 8 reps; and weeks 9–11, 2 sets × 10 reps, 1 session per week; CG: 2 sets × 6–10 reps in 3 sequences of 3 exercises.	11	Between-groups analyses showed more better results of V-cut test (ES = 0.98) in EOT than CG.	EOT showed better result than CG in improving V-cut test in soccer players.
9	EOT (n = 17): flywheel eccentric-overload training; CG (n = 17): regular American football training.	All participants were involved in usual American football training with a similar weekly training volume (4–5 sessions/week of 60–90 min and 1 match per week). EOT: flywheel (half squat and leg curl) eccentric training; CG: regular football training.	EOT: 1–2 sessions per week; weeks 1–2, 3 sets × 6 reps; weeks 3–4, 3 sets × 6 reps; weeks 5–6, 4 sets × 6 reps; weeks 7–8, 5 sets × 6 reps; and weeks 9–10, 6 sets × 6 reps.	10	Between-group results showed greater improvement for side-step cutting (ES = 0.72–0.74), and crossover cutting (ES = 0.72–0.84) in EOT than CG.	EOT led to an improvement in kinetic parameters during COD football tasks in football players.
10	EOT (n = 11): flywheel eccentric-overload training; CG (n = 12): traditional training.	EOT: flywheel eccentric-overload front step exercise with Pmax (maximal power) load; CG: half squat exercise with Pmax load on a smith machine.	EOT: 4 repetitions with each leg, 3 sessions per week; CG: week 1, 5 sets × 8 res, the volume increases one set every 2 weeks (e.g., 6 sets for weeks 3 and 4, 7 sets for weeks 5 and 6), 3 sessions per week.	6	Comparisons within groups revealed no significant difference.	Both groups showed no effect for 20-m Zigzag test following the intervention in healthy and physically active males.
11	EOT (n = 9): enforced stopping programme emphasizing deceleration; CG (n = 10): traditional speed and agility training programme.	EOT: the drills were organized into 4 groups of following exercises: speed and sprint technique; speed ladder drills; agility/change-of-direction speed; and total-body power using medicine ball throws. CG: participants completed each drill maximally and decelerated at the end of a drill without restriction until they comfortably slowed down.	Two sessions per week, the sets and the repetitions were different between 4 groups, and training programme adjusting the technical complexity and intensity of the drills from week-to-week.	6	Comparisons within groups revealed no significant difference.	Both groups improved CODAT and T-Test performance in team sport athletes.

EOT, eccentric overload training; CG, control group; CODAT, change-of-direction and acceleration test.

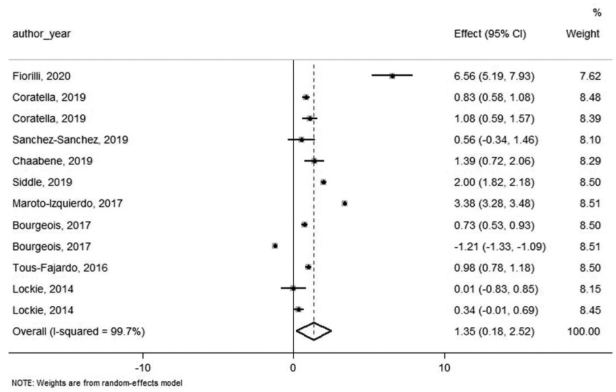

Figure 2. Effect size (ES) of all studies meeting the inclusion criteria. Diamonds represent the pooled ES estimate across trials.

impulses for rapid reacceleration during a change-of-direction task as a result of the storage and utilization of elastic energy (de Hoyo et al., 2016; Spiteri et al., 2013).

The effectiveness of EOT on CODS performance may be explained by the modifications in kinematics variables such as contact time, braking time, and impulse. Previous literature indicates that EOT allows athletes to achieve better deceleration performance involving a large braking component (Dos' Santos et al., 2017; de Hoyo et al., 2016; Jones et al., 2017). de Hoyo and colleagues reported that the braking and propulsive forces significantly improved following EOT (de Hoyo et al., 2016). Spiteri and colleagues emphasized the importance of the braking ability in improving reacceleration after changing direction (Spiteri et al., 2013). Spiteri and colleagues also indicated that a larger braking impulse contributed to both the storage and utilization of elastic energy during change-of-direction tasks, enabling an increased force output (Spiteri et al., 2013) and subsequently improving propulsive ability to facilitate a rapid reacceleration in the new direction (Young et al., 2002). Green and colleagues found that the players who generated greater braking forces were able to accelerate into the new direction earlier, so they can accomplish the change-of-direction task more quickly (Green et al., 2011). In addition, faster athletes undergoing several change-of-direction tests produced shorter contact times when compared to slower athletes (Spiteri et al., 2015). Studies showed that shorter braking time may enable a faster transition into the propulsive phase of the movement, increase propulsive force application, and improve CODS performance (Glaister et al., 2008; Spiteri et al., 2013). Therefore, the improvement of kinematics parameters following the EOT may enhance the propulsive ability to effectively perform change-of-direction tasks.

The limitations pertaining to this review and the included studies warrant future research. A small and heterogeneous set of studies were included in the review. The included studies were conducted using diverse study designs (i.e., randomized controlled trial, pre-post trial, and randomized crossover trial), and with relatively small samples of different age groups (i.e., adolescents vs. adults), genders, types of sports (i.e., soccer vs. rugby), and athletic levels (i.e., amateur vs. professional). Besides, different EOTs and CODS performance measures were adopted in the included studies, and the intervention doses and durations varied across the studies. Furthermore, one study used the "traditional speed and agility group" as the control group (Lockie et al., 2014). It is likely that a comparison between EOT and a control group without speed and agility training would result in a larger effect size estimate. All the above study heterogeneities confined the generalizability of review findings.

Future studies should adopt a randomized experimental design, recruit large representative samples from professional team sports, and examine the effect of EOT on CODS performance among population subgroups (e.g., by age and gender). In addition, future studies focusing on various measures of change-of-direction tasks (addressing different angles and distances) are warranted to deepen the understanding of the EOT effects on CODS performance. It may also be fruitful to examine the relationship between different change-of-direction tasks and eccentric strength, as deceleration ability inferred from those tasks can be vital for gains in CODS performance.

Table 3. Study quality assessment.

Criteria	1	2	3	4	5	6	7	8	9	10	11
1. Was the study described as randomized, a randomized trial, a randomized clinical trial, or an RCT?	1	1	1	1	1	1	1	1	0	1	1
2. Was the method of randomization adequate (i.e., use of randomly generated assignment)?	1	1	1	1	1	1	1	1	0	1	1
3. Was the treatment allocation concealed (so that assignments could not be predicted)?	1	0	0	0	1	0	0	0	0	0	0
4. Were study participants and providers blinded to treatment group assignment?	1	0	0	0	1	0	0	0	0	0	0
5. Were the people assessing the outcomes blinded to the participants' group assignments?	1	0	0	0	1	0	0	0	0	0	0
6. Were the groups similar at baseline on important characteristics that could affect outcomes (e.g., demographics, risk factors, co-morbid conditions)?	1	1	1	1	1	1	1	1	1	1	1
7. Was the overall drop-out rate from the study at endpoint 20% or lower of the number allocated to treatment?	1	1	1	1	1	1	1	1	1	1	1
8. Was the differential drop-out rate (between treatment groups) at endpoint 15 percentage points or lower?	1	1	0	1	1	1	1	1	1	1	1
9. Was there high adherence to the intervention protocols for each treatment group?	1	1	1	1	1	1	1	1	1	1	1
10. Were other interventions avoided or similar in the groups (e.g., similar background treatments)?	1	1	1	1	1	1	1	1	1	1	1
11. Were outcomes assessed using valid and reliable measures, implemented consistently across all study participants?	1	1	1	1	1	1	1	1	1	1	1
12. Did the authors report that the sample size was sufficiently large to be able to detect a difference in the main outcome between groups with at least 80% power?	1	0	0	0	0	0	0	0	0	0	1
13. Were outcomes reported or subgroups analysed pre-specified (i.e., identified before analyses were conducted)?	1	1	1	1	1	1	1	1	1	1	1
14. Were all randomized participants analysed in the group to which they were originally assigned, i.e., did they use an intention-to-treat analysis?	1	1	0	1	0	0	1	1	0	0	0
Total scores	14	10	8	10	12	9	10	10	7	9	10

1 denotes Yes and 0 denotes No.

Conclusion

This study systematically synthesized and quantified existing evidence regarding the effectiveness of EOT on CODS performance. A total of 11 studies met the eligibility criteria and were included in the review. EOT was found effective in improving CODS performance compared to the control group. Future studies should adopt a randomized experimental design, recruit large and representative samples from professional team sports, and examine the effect of EOT on various measures of CODS performance among population subgroups.

Disclosure statement

The authors have no conflicts of interest relevant to this article to disclose.

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Appendix A. Searching algorithm in PubMed

("eccentric training" OR "eccentric exercise" OR "eccentric resistance" OR "eccentric
drill" OR "excentric contraction" OR "excentric contraction" OR "eccentric-overload"
OR "eccentric emphasized" OR "flywheel" OR "FRTEO" OR "flywheel resistance" OR
"flywheel device" OR "flywheel training" OR "flywheel overload training" OR "inertial
training" OR "inertial resistance" OR "inertial exercise" OR "isoinertial training" OR
"accentuated eccentric" OR "isoinertial exercise" OR "isoinertial resistance " OR
"enhanced-eccentric" OR "lengthening contraction") AND ("agility" OR "agility-test"
OR "reactive agility" OR "agility performance" OR "mobility" OR "change of direction" OR "COD" OR "Side step " OR "cutting maneuver" OR "shuttle run" OR
"sideways shuffle" OR "505 test" OR "5-0-5 test" OR "T-test" OR "Illinois agility test"
OR "IAT" OR "Zigzag test" OR "Zig-zag test" OR "L run" OR "L-run" OR "Pro-agility"
OR "3 Cone drill" OR "3-Cone test" OR "Y shaped agility" OR "spider agility" OR
"Slalom run" OR "Up and Back test")