Journal of Sports Sciences

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

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To cite this article: Utkarsh Singh, Jonathan D. Connor, Anthony S. Leicht, Sara M. Brice & Kenji Doma (2023) Acute effects of prior conditioning activity on change of direction performance. A systematic review and meta-analysis, Journal of Sports Sciences, 41:18, 1701-1717, DOI: 10.1080/02640414.2023.2293556

To link to this article: https://doi.org/10.1080/02640414.2023.2293556

JOURNAL OF SPORTS SCIENCES
2023, VOL. 41, NO. 18, 1701–1717
https://doi.org/10.1080/02640414.2023.2293556

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Acute effects of prior conditioning activity on change of direction performance. A systematic review and meta-analysis

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ABSTRACT
We performed a systematic review and meta-analysis on the acute effects of prior conditioning activity (CA) on change of direction (COD) performance. Eligible studies, involving healthy participants undergoing acute CA with at least one measure of COD performance, were analysed across diverse databases. A total of 34 studies were included for systematic review with 19 studies included for the meta-analysis. The intervention condition resulted in significantly faster (Z = 4.39; standard mean difference [SMD] = 0.49; $p < 0.05$) COD performance compared with the control condition. Both unloaded and light loaded CA resulted in significantly greater (SMD = 0.58–0.59) COD performance compared to the control condition. Moreover, heavy loaded CA demonstrated a significant but small (SMD = 0.24) improvement in COD performance compared to the control condition. Age and study design had no effect on the overall meta-analysis outcomes. Both males and females exhibited similar moderate effects with CA but only males demonstrated significantly greater COD performance compared to control conditions. Our findings indicate that a range of CA protocols can acutely improve COD performance with unloaded and light-loaded CA resulting in the greatest performance enhancements. These findings will assist practitioners with the design and implementation of appropriate acute CA to improve COD performance.

ARTICLE HISTORY
Received 3 October 2023
Accepted 4 December 2023

KEYWORDS
Change of direction; speed; conditioning activity; plyometrics; strength training

1 Introduction

The ability to move quickly in a new direction during high-intensity movements is commonly known as change of direction (COD) performance (Young et al., 2021). The COD movement is either assessed within a pre-planned condition, where athletes are instructed to run a prearranged direction or movement pattern (Brughelli et al., 2008; Young et al., 2015), or an unplanned condition – also known as agility, where athletes are required to respond to a stimulus provided during the run or movement (Young et al., 2021). An individual's COD ability is considered important for successful performance in team sports and can impart a physical and tactical advantage over an opponent (Nygaard Falch et al., 2019). Considering the importance of COD ability for sporting success, chronic training regimes such as strength, plyometric and sprint activities have consistently demonstrated long-standing improvement in COD performance (Nygaard Falch et al., 2019; Paul et al., 2019; Zouhal et al., 2019). However, acute bouts involving a priming activity have also been adopted with the aim to acutely enhance COD performance, commonly referred to as post-activation potentiation (PAP) (Boullosa et al., 2020). While PAP has been associated with improved sporting performances (Blazevich & Babault, 2019) the lack of evoked twitch verification, timeline and other potential contributors (e.g., temperature, water content) to explain improvements in subsequent sporting performances has led to the development of an alternative term for this response, post-activation performance enhancement (PAPE) (Blazevich & Babault, 2019). Thus, the term PAPE is more appropriate when considering the priming effects of acute conditioning activities (CA) on physical performance (e.g., COD) in team sports.

Many acute CA, such as plyometric and resistance exercises, have been reported to induce a short-term PAPE response for COD performance (Al Kitani et al., 2021; Dello Iacono et al., 2016; Maloney et al., 2014; Sener et al., 2021; Thapa et al., 2020). For instance, Thapa et al. (2020) reported a significant improvement in COD (Modified T-test) performance time following drop jumps as a CA compared to the condition without CA. In contrast, heavy-loaded resistance exercises have resulted in inconsistent changes for COD performance (Okuno et al., 2013; Orjalo et al., 2020; Sole et al., 2013; Zagatto et al., 2022). For example, Okuno et al. (2013) reported an improvement in COD (repeated sprint with COD) performance time following half-squat exercises performed at 50–90% of one repetition maximum (1RM) compared to a control setting in elite handball players. Conversely, Orjalo et al. (2020) reported no changes in COD (5-0-5) performance time following heavy-loaded barbell hip thrusts (85% 1RM) compared to a control condition in college-aged males and females. These inconsistent results highlight substantial variability of a PAPE response following a priming CA. The variability may be associated with several

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Supplemental data for this article can be accessed online https://doi.org/10.1080/02640414.2023.2293556

modulating factors including, but not limited to age, participant training experience, sex, performance test, and importantly the CA (Blazevich & Babault, 2019; Seitz & Haff, 2016). Further, the majority of these studies focussed on pre-planned COD tasks (Al Kitani et al., 2021; Dello Iacono et al., 2016; Maloney, Turner, & Miller, 201) whereas athletes engage in unplanned tasks during competition (Nimphius et al., 2018; Young et al., 2021) requiring further examination of a greater range of COD activities for application to real-world performances.

Given the lack of clarity for acute CA to induce a PAPE response for COD performance, a greater understanding of these acute CA is needed to help develop evidence-based recommendations for practitioners to improve COD performance. A narrative review synthesised prior work on the acute effects of strength-based CA noting that back squat exercises performed at 50–90% 1RM were able to improve COD performance (Lockie et al., 2018). Nonetheless, this review did not incorporate other established acute CA (e.g., plyometric, etc.) that have enhanced COD performance, did not assess unplanned COD tasks, and did not consider other modulating factors that impact COD performance. To our knowledge, there has been no systematic review and meta-analysis conducted to provide a comprehensive summary of the impact of CA on COD performance that considers modulating factors. Therefore, the primary aim of this study was to critically evaluate, via a systematic review, the effects of established acute CA on COD performance. A secondary aim was to identify the unique effects of these established acute CA on COD performance via a meta-analysis. Outcomes from this meta-analysis will help practitioners with the design and implementation of the most appropriate acute CA to enhance COD performance. We hypothesised that prior CA can acutely enhance COD performance.

2 Methods

The current systematic review was conducted as per the guidelines of PRISMA (Page et al., 2021).

2.1 Inclusion and exclusion criteria

Only full-text, peer-reviewed, original studies were examined for the current systematic review. Studies were considered eligible and included if they met the following criteria: 1) Population consisted of healthy participants with no restrictions on fitness and playing levels, sex or age; 2) Intervention involved voluntary muscle activity or any acute CA commonly associated with a PAPE response (Boullosa et al., 2020); and 3) Outcome included at least one measure of COD performance.

For the meta-analysis, COD performance was compared between intervention conditions that included a CA commonly associated with a PAPE response (e.g., heavy squats, plyometric exercises, etc.) to control conditions without a CA commonly associated with a PAPE response (e.g., dynamic/static stretching, typical standardised sport-specific warm-ups, or rest). If a study consisted of more than one intervention condition, then the intervention group for comparison with the control group was chosen based on the authors' hypothesis. For example, if authors of a study hypothesised that horizontal drop jumps (HDJ) would induce greater improvement in COD performance than vertical drop jumps (VDJ), when compared to a control condition, then the comparison between the intervention condition with HDJ and the control condition was used for the meta-analysis. If no clear hypothesis was provided, and the intervention groups were the same but with different loading conditions, then the group with the greatest loading was chosen and compared with the control condition (e.g., if a study examined 5% and 10% of body mass as the loads for the intervention groups, then the 10% body mass group was chosen).

Studies were excluded if: 1) Participants were unhealthy (e.g., injuries, recent surgery) precluding participation in an exercise session; 2) Intervention did not involve a prior voluntary muscle activity or any CA commonly associated with a PAPE response (Boullosa et al., 2020) (e.g., typical standardised sport-specific warm-up, stretching, etc.); 3) No COD performance measure was recorded; and 4) They were published as books, book chapters, congress abstracts, review papers, case reports, special communications, letters to the editor, invited commentaries, errata, and of irresolute quality or unclear peer-review process (Grudniewicz et al., 2019).

2.2 Literature search

Computerised literature searches were conducted across the electronic databases of PubMed, CINAHL, SportsDiscus, Web of Science and SCOPUS on 24.05.2022 and updated on 27.05.2023. The search strategy was conducted using (in different combinations) the Boolean operators AND/OR with the following MeSH terms (all database fields used): (Young adult[MeSH Terms] OR Adolescent[MeSH Terms] OR Athletes [MeSH Terms]) AND (Athletic Performance*[MeSH Terms] OR Athletic Performance/physiology*[MeSH Terms] OR Muscle strength[MeSH Terms] OR (Muscle Strength/physiology* [MeSH Terms]) AND (Muscle contraction*[MeSH Terms] OR Warm-Up Exercise*[MeSH Terms] OR Resistance Training* [MeSH Terms] OR Physical Education and Training/methods* [MeSH Terms] OR Plyometric Exercise*[MeSH Terms]) AND (Soccer*[MeSH Terms] OR Sports/physiology[MeSH Terms] OR Football/physiology*[MeSH Terms] OR (Basketball*/physiology[MeSH Terms] OR (Tennis/physiology*[MeSH Terms] OR Racquet Sports/physiology*[MeSH Terms]). Furthermore, the following keyword terms were also used: (postactivation potentiation OR post activation potentiation OR Warm-up) AND (COD OR Change of direction OR Agility OR unplan* OR plan* OR anticipat* OR unanticipat* OR side* OR cutt*). These keywords were truncated using the quotation marks.

2.3 Selection process

Two authors (US and KD) independently screened the titles, abstracts, and full-text versions of retrieved studies. During the search and review process, potential discrepancies between screening authors regarding inclusion and exclusion criteria were resolved through consensus with a third author (JC). From the selected articles to be included, reference lists were also examined to identify any additional relevant studies.

2.4 Data extraction, quality assessment and risk of bias

The information pertaining to participant characteristics (e.g., age, height, mass, sex, sport, and training/playing experience), and study characteristics (e.g., CA, outcome measure, rest interval, assessment time following CA, and performance results) were retrieved and collated into a Microsoft Excel file (Microsoft Corporation, Redmond, WA, USA). The means and standard deviation (SD) of the outcome variables for both intervention (CA intervention) and control (no CA intervention) groups were extracted from the included studies and collated into a Microsoft Excel file. For studies that reported standard errors, the SD were calculated by multiplying the standard error with the square root of the sample size.

The physiotherapy evidence database (PEDro) scale was used to assess the methodological quality of the included studies, which were rated from 0 (lowest quality) to 10 (highest quality) (Singh et al., 2022). The validity and reliability of the PEDro scale has been reported previously (de Morton, 2009; Maher et al., 2003; Yamato et al., 2017) including agreement with other scales (e.g., Cochrane risk of bias tool) (Moseley et al., 2019). The methodological quality of each study was rated using the following thresholds: poor (<4), fair (4–5), good (6–8), and excellent (9–10) (Singh et al., 2022). Item 1 of the PEDro scale was not considered in the overall study quality rating as it pertained to external validity. The methodological quality for each included study was assessed independently by two authors (US and KD), and any discrepancies between them were resolved via consensus with a third author (JC). Publication bias was investigated using Egger's test (Egger et al., 1997) and a funnel plot. The funnel plot was generated with Review Manager Software (RevMan, Version 5.4, Copenhagen: The Nordic Cochrane Centre, 2014) by plotting the standard mean difference (SMD) against standard error (Sterne et al., 2011).

2.5 Statistical analysis

RevMan (version 5.4) statistical software (2020; The Nordic Cochrane Centre, Copenhagen, Denmark) was used to conduct the meta-analysis that compared outcome measures between intervention and control conditions. The forest plot was generated as a random effects model to control for inter-study heterogeneity. The heterogeneity of each study was determined using the I^2 statistic with values of <25%, 25–75%, and >75% representing low, moderate, and high levels of heterogeneity, respectively (Higgins and Thompson, 2002). The SMD and its associated standard error for each study was quantified using an equation appropriate for studies with a repeated measures design (Uanhoro, 2017). Therefore, magnitude of effect (effect size, ES) between conditions was reported as SMD and 95% confidence intervals with mean SMD values of 0.2, 0.5 and 0.8 classified as small, moderate and large ES, respectively (Cohen, 1988).

The typical timeframe in which CA enhanced anaerobic performance was reported to range from 3 to 10 minutes (Blazevich & Babault, 2019; Boullosa et al., 2020; Vargas-Molina et al., 2021). Therefore, when studies reported performance at multiple time points after the CA, the time points that were within the 3–10-minute range were chosen for the meta-analysis. For example, if a study reported COD performance at 4, 8 and 12 minutes, then the performance measures reported at 4 minutes and 8 minutes were averaged for the meta-analysis as these time-points were within the 3–10-minute range. This conservative approach was followed to eliminate any possible bias that may be caused by choosing one-time point. Furthermore, modulating factor analyses (i.e., subgroup and sensitivity) were conducted to investigate the effects of CA strenuousness (i.e., unloaded, light-loaded and moderate-heavy-loaded), performance test, sex, age, study design, training experience and bias. For age, comparisons were made between studies where the average age of participants was ≥18 years old (adults) and <18 years old (youth). The light-loaded CA was defined as a load of 10–30% of body mass while moderate-heavy loaded CA represented loads of 50–90% of 1RM or 75% of body mass (Liguori, 2020). The level of statistical significance was set at $p < 0.05$ for all analyses.

2.6 Certainty of evidence

The certainty of evidence for each outcome was evaluated by two authors (US and KD) using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) protocol with ratings ranging from very low to high levels of certainty (Guyatt et al., 2011; Zhang et al., 2019, 2019). Initially, the evidence was considered as a high level of certainty, but was downgraded based on the following criteria: (1) Risk of bias in studies: downgraded by one level if the average PEDro scores were moderate (<6) or by two levels if PEDro scores were poor (<4); (2) Indirectness: downgraded by one level if there was indirectness (e.g., use of inconsistent populations, interventions, comparators and outcomes) or by two levels if there was indirectness from various sources; (3) Risk of publication bias: downgraded by one level if publication bias was suspected (Egger's test); (4) Inconsistency: downgraded by one level when the inter-study heterogeneity (I^2) was high (>75%); and (5) Imprecision: downgraded by one level when <800 participants were available for a comparison (G. H. Guyatt et al., 2011) or if there was no obvious direction of the effects (SMD <0.2; $p > 0.05$). If both imprecision criteria were observed, then certainty was downgraded by two levels. Finally, the certainty of evidence for each outcome measure was evaluated as very low when the outcome was not included in the meta-analysis (Ramirez-Campillo et al., 2022).

3 Results

3.1 Study selection

A total of 6247 articles were identified from the database searches (Figure 1). Following the removal of duplicates and the elimination of articles based on title and abstract screening, 55 studies were evaluated that resulted in 34 studies satisfying the inclusion criteria. From the 34 studies, 19 studies were included for the meta-analysis (Figure 1).

3.2 Methodological appraisal of the included studies

Overall, the included studies were of fair ($n = 12$) to good ($n = 22$) quality with a mean PEDro score of 5.6 (Table 1).

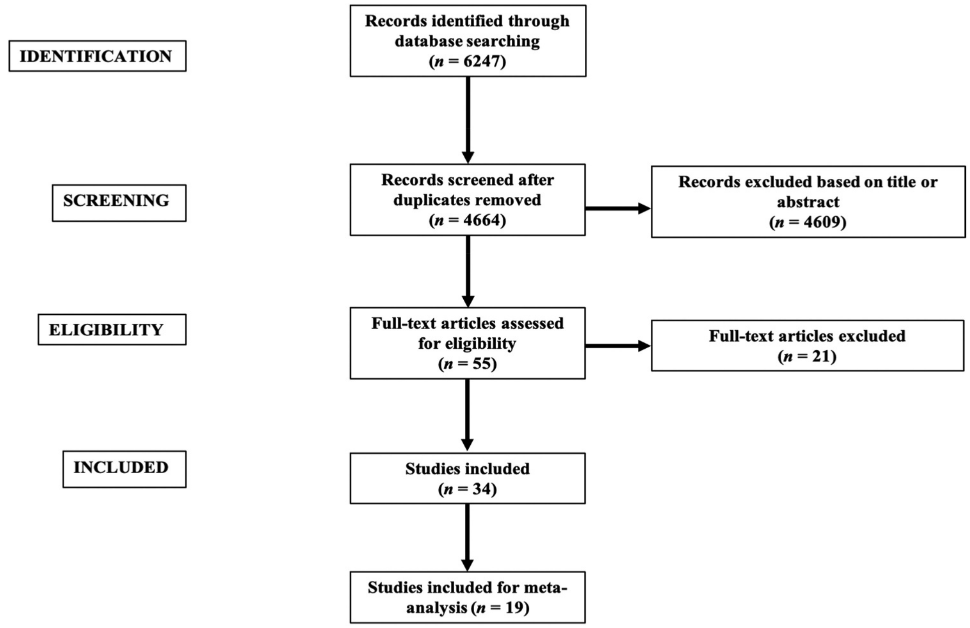

Figure 1. Flow chart illustrating the study selection process.

None of the included studies scored more than 7 points out of 10. Most of the studies addressed the following PEDro items: eligibility criteria, random allocation of subjects, outcome measures were reported from more than 85% of the participants, subjects received the desired treatment as per the allocation, between condition statistical comparison and reporting of point measure and/or measure of variability (either SD, standard error or confidence interval). The least

Table 1. Methodological quality of the included studies using the PEDro rating scale.

Study	1	2	3	4	5	6	7	8	9	10	11	Score*	Study quality
Al Kitani et al. (2021)*	NA	0	0	0	0	0	0	1	1	1	1	4	Fair
Beato et al. (2021)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Beato et al. (2019)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Chua et al. (2021)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Cochrane (2013)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Coutinho et al. (2022)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Dann et al. (2023)*	NA	1	0	0	0	0	0	1	1	1	1	5	Fair
Dello Iacono et al. (2016)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Escobar Hincapié et al. (2021)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Ishak et al. (2022	NA	0	1	0	0	0	0	1	1	1	1	5	Fair
Kalinowski et al. (2022)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Maloney et al. (2014)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Marshall et al. (2019)	NA	0	0	1	0	0	0	1	1	1	1	5	Fair
Mh et al. (2021)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Moreno-Pérez et al. (2021)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Munshi et al. (2022)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Okuno et al. (2013)*	NA	1	0	0	0	0	0	1	1	1	1	5	Fair
Orjalo et al. (2020)*	NA	0	0	1	0	0	0	1	1	1	1	5	Fair
Orjalo et al. (2020)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Ouergui et al. (2022)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Peng et al. (2021)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Pojskić et al. (2015)*	NA	1	0	0	0	0	0	1	1	1	1	5	Fair
Rumeau et al. (2023)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Sener et al. (2021)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Sole et al. (2013)*	NA	0	0	0	0	0	0	1	1	1	1	4	Fair
Thapa et al. (2020)*	NA	1	1	1	0	0	0	1	1	1	1	7	Good
Toprak et al. (2022)	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Turki et al. (2020)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good
Wu et al. (2021)	NA	0	0	1	0	0	0	1	1	1	1	5	Fair
Yang et al. (2017)	NA	0	1	1	0	0	0	1	1	1	1	6	Good
Yeung et al. (2021)*	NA	0	0	0	0	0	0	1	1	1	1	4	Fair
Zagatto et al. (2022)*	NA	1	0	0	0	0	0	1	1	1	1	5	Fair
Zagatto et al. (2022)*	NA	1	0	0	0	0	0	1	1	1	1	5	Fair
Zois et al. (2011)*	NA	1	0	1	0	0	0	1	1	1	1	6	Good

A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale.
NA – not assessed; Note: Studies with * symbol were included for meta-analysis.
From a possible maximal score of 10.

reported PEDro items included the following: allocation of concealment, and blinding of therapist, subjects and assessor.

3.3 Study characteristics

All of the included studies utilised a crossover study design with a total of 584 participants (male $n = 433$; female $n = 115$; unidentifiable for sex $n = 36$, Table 2). For the studies that were included in the meta-analysis, there were 323 (male $n = 209$; female $n = 94$; unidentified sex $n = 20$) participants (Table 2). The mean ± SD for age, height and body mass for all participants within the included studies were 20.5 ± 2.2 years, 1.78 ± 0.29 m and 73.9 ± 9.3 kg, respectively. Furthermore, six studies included participants with a mean age <18 years old while 28 studies included participants with a mean age >18 years old (Table 2). For the meta-analysis, four studies (Al Kitani et al., 2021; Ouergui et al., 2022; Rumeau et al., 2023; Zagatto et al., 2022) included participants with a mean age <18 years old and 15 studies included participants with a mean age >18 years old (Table 2). The COD protocols consisted of either pre-planned movements (i.e., athletes move in accordance with a predetermined movement pattern) or unplanned movements (i.e., agility) (Young et al., 2021). From the included 34 studies, two studies (Cochrane, 2013; Zois et al., 2011) reported outcomes from unplanned COD protocols with the remainder (32 studies) examining performance from pre-planned COD protocols (Suplementary Table S1).

From the studies included in the meta-analysis ($n = 19$), seven studies administered unloaded CA (Al Kitani et al., 2021; Cochrane, 2013; Dann et al., 2023; Ouergui et al., 2022; Sener et al., 2021; Thapa et al., 2020; Zagatto et al., 2022), five studies administered light-loaded CA (Maloney et al., 2014; Orjalo et al., 2020; Pojskić et al., 2015; Turki et al., 2020; Yeung, Bishop, Turner, Maloney, & Maloney, 2021), and the remaining seven studies administered moderate-heavy-loaded CA (Moreno-Pérez et al., 2021; Okuno et al., 2013; Orjalo et al., 2020; Rumeau et al., 2023; Sole et al., 2013; Zagatto et al., 2022; Zois et al., 2011). The time-period between the CA and anaerobic performance assessment varied between 15 seconds and 20 minutes (Table 3). Most studies ($n = 12$; Table 3) assessed COD performance once after the CA while six studies (Dann et al., 2023; Maloney et al., 2014; Orjalo et al., 2020, 2020; Sener et al., 2021; Turki et al., 2020) reported COD performance at multiple time points after the CA. Lastly, one study reported the best COD performance from assessments at 4, 8 and 12 minutes following the CA (Sole et al., 2013).

3.4 Qualitative analysis

Significant improvements in COD performance were reported following plyometric exercises comprising of drop jumps, and ankle and hurdle hops (Mh et al., 2021). Both HDJ and VDJ significantly improved COD performance at 8 minutes post the CA with HDJ producing greater improvements than VDJ (Al Kitani et al., 2021; Dello Iacono et al., 2016). Likewise, alternate leg bounding performed on a hard or natural grass surface significantly improved COD performance compared to the control condition at 8 minutes following the CA (Dann et al., 2023). Drop jumps performed at different heights significantly improved COD performance compared to the condition without drop jumps with the fastest COD performance occurring at 5 minutes post-CA (Sener et al., 2021). Similarly, a box jump followed immediately by a drop jump significantly improved COD performance compared to the control condition at 3 minutes post the CA (Thapa et al., 2020).

Apart from plyometric exercises, eccentric (Beato et al., 2019, 2021), isometric (Marshall et al., 2019; Pojskić et al., 2015) and dynamic (Coutinho et al., 2022; Escobar Hincapié et al., 2021; Ishak et al., 2022; Moreno-Pérez et al., 2021; Okuno et al., 2013; Orjalo et al., 2020; Rumeau et al., 2023; Sole et al., 2013) lower body strength exercises were used to improve COD performance. For example, eccentric overload exercises (squats), which included performing eccentric contractions on a flywheel, resulted in an improvement in COD performance at 3–6 minutes following the CA (Beato et al., 2019, 2021). Isometric squats significantly improved COD performance compared to the control condition at 5 minutes after the CA (Pojskić et al., 2015). Conversely, maximal isometric squats resulted in slower COD performance at 1 minute following the CA, with no significant differences occurring at 3, 5, or 7 minutes post-CA (Marshall et al., 2019). In regard to dynamic lower body exercises (e.g., squats, leg press, barbell hip thrust), significant improvements (5 minutes post-CA) in COD performance were noted after unilateral (large ES) and bilateral (moderate ES) squats (Escobar Hincapié et al., 2021). Ishak et al. (2022) assessed COD performance after 85% 1RM back squats and reported that COD performance was significantly quicker at 12 minutes after the CA compared to earlier recovery times (i.e., 4 and 8 minutes). Likewise, Rumeau et al. (Rumeau et al., 2023) reported improvements in COD performance at 7 minutes following a set of leg presses at 90% 1RM compared to the control condition. Half-squat (Okuno et al., 2013) and full-squat (Sole et al., 2013) exercises performed at 50–90% 1RM also significantly improved COD performance within 4–12 minutes following the CA compared to the control condition. In contrast, Coutinho et al. (2022) reported no improvement in COD performance (2 minutes post-CA) following regular half-squat movements at maximal concentric velocity. Likewise, a barbell hip-thrust exercise failed to improve the COD performance beyond that of the control condition (Orjalo et al., 2020). Only one study used variable resistance and reported an improvement in COD performance at 4 minutes after maximal (3- and 5-RM) squats with elastic bands (Peng et al., 2021) compared to the baseline.

Several studies have incorporated multiple CA in combination or isolation, noting variable outcomes in COD performance (Kalinowski et al., 2022; Toprak et al., 2022; Zagatto et al., 2022). For example, Toprak et al. (2022) incorporated squats at 85% 1RM and maximal isometric efforts with a knee angle of 120°–130°, and reported faster COD performance at 4 and 6 minutes, with peak performance occurring at 8 minutes post-CA compared to the control condition. Similarly, Alessandro M. Zagatto et al. (2022) incorporated two CA (drop jumps and heavy sled towing with 75% of body mass) and reported that drop jumps improved COD performance compared to the control (rest) condition however, heavy sled towing did not change the COD performance post-CA. Likewise, isometric half back squats

Table 2. Participant's characteristics of the included studies.

Study	Sample Size	Sex	Age, Height, Body Weight	Sport	Training/Playing Experience
Al Kitani et al. (2021)*	12	NR	15.6 ± 0.7 years; 1.78 ± 0.08 m; 66.9 ± 11.5 kg	Elite Handball players	3.9 ± 0.97 years training experience
Beato et al. (2021)	12	Male	21 ± 3 years; 1.82 ± 0.07 m; 81 ± 13 kg	Soccer, American football, and weightlifting	-
Beato et al. (2019)	31	Male	21 ± 4 years; 1.82 ± 0.04 m; 77.0 ± 5.2 kg	Amateur soccer players	-
Chua et al. (2021)	14 (11 Male; 3 Female)	Male and Female	19 ± 2.6 years, 1.77 ± 0.07 m, 69 ± 6.8 kg	Badminton players	At least 2 years training experience
Cochrane (2013)*	8	Female	20.0 ± 1.2 years; 1.77 ± 0.07 m; 72 ± 1.6 kg	Premier club netball players	≥3 years sports training
Coutinho et al. (2022)	16	Male	16.2 ± 0.6 years; 1.73 ± 0.08 m; 65.3 ± 6.6 kg	Portuguese Club youth soccer players	8.3 ± 2.8 years
Dann et al. (2023)*	14	Female	20 ± 1 years; 1.66 ± 0.06 m; 62.9 ± 67.6 kg	Team sports players	At least 1 year plyometric training experience
Dello Iacono et al. (2016)	18	Male	19.6 ± 0.5 years; 1.82 ± 0.06 m; 83.8 ± 8.4 kg	Elite handball players	6 years of high-level practice and 4 years of specific jumping and sprinting training experience
Escobar Hincapié et al. (2021)	17 (12 Male; 5 Female)	Male and Female	25 ± 1.6 years; 171 ± 7.5 cm; 70 ± 9.8 kg	Healthy individuals with strength training experience	7.6 ± 2.3 years training experience
Ishak et al. (2022)	17	Male	23.6 ± 2.3 years; 1.79 ± 0.06 m; 72.5 ± 10.7 kg	University handball players	At least 1 year resistance training experience
Kalinowski et al. (2022)	13	Female	25 ± 4 years; 1.78 ± 0.04 m; 70.9 ± 8.4 kg	Semi-professional volleyball players	Volleyball training experience: 12 ± 5 years; resistance training experience: 4 ± 2 years
Maloney et al. (2014)*	8	NR	24.0 ± 2.4 years; 1.82 ± 5.6 m; 70.9 ± 10.0 kg	Professional British badminton athletes	At least 2 years training experience
Marshall et al. (2019)	16	NR	16 ± 0.41 years; 1.83 ± 0.07 m; 88.7 ± 12.1 kg	Elite academy rugby players	At least 2 years training experience
Mh et al. (2021)	20	Male	21.3 ± 1.5 years; 1.69 ± 0.06 m; 63.3 ± 9.5 kg	University football players	1–5 years playing experience
Moreno-Pérez et al. (2021)*	26	Male	19.22 ± 4.20 years; 1.77 ± 0.07 m; 67.37 ± 8.19 kg	Elite tennis players	10.37 ± 3.28 years tennis experienc
Munshi et al. (2022)	24	Male	20.8 ± 2.02 years; 1.79 ± 0.7 m; 71.2 ± 7.6 kg	University basketball players	>2 years playing experience
Okuno et al. (2013)*	12	Male	18.7 ± 1.7 years; 1.85 ± 0.07 m; 85.9 ± 9.6 kg	Elite handball players	3 years strength training experience
Orjalo et al. (2020)*	40 (20 Male; 20 Female)	Male and Female	23.28 ± 2.82 years; 1.70 ± 0.09 m; 73 ± 12.95 kg	Recreationally trained individuals	At least 1 year resistance training and 2 years field or court sport experience
Orjalo et al. (2020)*	40 (20 Male; 20 Female)	Male and Female	23.72 ± 2.45 years; 1.70 ± 0.10 m; 73.33 ± 12.46 kg	Recreationally trained individuals	At least 1 year resistance training and at least 2 years field or court sport experience
Ouergui et al. (2022)*	27 (14 Male; 13 Female)	Male and Female	16 ± 1 years; 1.69 ± 0.09 m; 60.1 ± 10.7 kg	Taekwondo athletes	7 ± 1 years taekwondo experience:
Peng et al. (2021)	15	Male	21.0 ± 1.0 years; 1.73 ± 0.04 m; 67.4 ± 6.6 kg	Collegiate physical education students	-
Pojskić et al. (2015)*	21	Male	20.14 ± 1.65 years; 1.79 ± 0.08 m; 74.4 ± 13.0 kg	College soccer players	-
Rumeau et al. (2023)*	11	Female	17.3 ± 1.1 years; 1.63 ± 0.06 m; 56.6 ± 7.2 kg	French U20 national ice hockey team	-
Sener et al. (2021)*	10	Male	19.90 ± 1.29 years; 1.75 0.02 m; 68.62 ± 7.52 kg	National-level field hockey	2 years training experience
Sole et al. (2013)*	10 (5Male, 5 Female)	Male and Female	Male: 20.6 ± 1.9 years; 1.93 ± 0.09 m; 79.36 ± 11.74 kg Female: 21.2 ± 2.7 years; 1.77 ± 0.08 m; 65.8 ± 10.18 kg	National Collegiate Athletic Association Division II athletes (tennis or basketball)	At least 1 year resistance training experience
Thapa et al. (2020)*	12	Male	21 ± 1.2 years; 1.70 ± 0.08 m; 66.8 ± 7 kg	University basketball players	-
Toprak et al. (2022)	14	Male	15.2 ± 0.69 years; 1.66 ± 0.08 m; 52.07 ± 6.70 kg	Adolescent soccer players	Training experience: 5.07 ± 0.61 years
Turki et al. (2020)*	19	Male	18 ± 0.88 years; 1.75 ± 0.07 m; 69.85 ± 7.68 kg	Soccer players	2 years resistance training, 5 years football
Wu et al. (2021)	20	Male	-	University Volleyball players	5 years volleyball
Yang et al. (2017)	14	Male	18–23 years; 1.75 ± 0.06 m; 84.2 ± 11.2 kg;	Rugby players	-
Yeung et al. (2021)*	21 (18 Male; 3 Female)	Male and Female	29.5 ± 8.4 years; 1.75 ± 0.12 m; 74.0 ± 13.7 kg	Amateur badminton players	8.4 ± 4.2 years playing history
Zagatto et al. (2022)*	10	Male	17.5 ± 1.2 years; 1.91 ± 0.07 m; 87.2 ± 15.4 kg;	Young basketball players	5.2 ± 1.5 years competitive experience
Zagatto et al. (2022)*	12	Male	24.8 ± 6.9 years; 2.0 ± 0.1 m; 97.0 ± 9.2 kg	First division basketball players	-
Zois et al. (2011)*	10	Male	23.3 ± 2.5 years, 1.78 ± 0.04 m, 69.1 ± 4.1 kg	Amateur soccer players	-

NR: not reported; m: metre; kg: kilogram; Note: Studies with * symbol were included for meta-analysis.

Table 3. Characteristics of the included studies.

Study	Conditioning Activity	Outcomes	Rest interval	Time period post	COD/Agility
Al Kitani et al. (2021)*	Condition 1: Warmup along with 5 repetitions of vertical drop jump from a 30 cm height; Condition 2: Warm-up along with 5 repetitions horizontal drop jump from a 30 cm height; Condition 3: Warm-up only	Change in R-COD time for Condition 2 > Conditions 1 and 3 ($p < 0.01$)	10 sec	~4 min approx.	R-COD
Beato et al. (2021)	Condition 1: High medium eccentric overload was performed by a half squat exercise using a flywheel ergometer (3 sets of 6 repetitions each at maximal velocity); Condition 2: Medium eccentric overload was performed by a half squat exercise using a flywheel ergometer (3 sets of 6 repetitions each at maximal velocity)	COD time was quicker following Conditions 1 and 2 ($p < 0.05$)-	2 min	30 sec, 3, and 6 min	COD-5 m
Beato et al. (2019)	Condition 1: Cross-cutting step using an inertial resistance (4 sets of 6 repetitions with each leg); Condition 2: flywheel leg-extension (4 sets for each limb; first 2 submaximal repetition and 6 following repetitions were maximal); Condition 3: unilateral squat exercise (4 sets with each Leg; first 2 submaximal repetition and 6 following repetitions were maximal)	A significant positive improvement in COD-5 m dominant leg and COD-5 m non-dominant leg after 4 minutes of recovery after all exercises.	Condition 1: 1 min between sets and 2 min between legs; Condition 2: Time between each unilateral set was 1 min with 2 min between exercise; Condition 3: 1 min between each set	4 min	Dominant-leg COD-5 m; Non-Dominant COD-5 m
Chua et al. (2021)	Condition 1: Warm-up exercises with weighted wearable resistance. Condition 2: Warm-up exercises with resistance band variable resistance; Condition 3: Warm-up exercises without resistance	COD was faster ($p < 0.05$) for condition 1 & 2 compared to the condition without resistance at baseline.	General mobility, dynamic stretching and activation: ≤15 s of passive recovery between exercises; Sports specific plyometric exercises with 1 min of passive recovery between each set of exercise	10 min	Badminton COD test
Cochrane (2013)*	Condition 1: Side-alternating vibration exercise (VbX) in static squat position (5 X 1 min exposures); Condition 2: Control (No vibration exercise)	VbX did not improve unplanned COD	1 min rest	Immediately	Unplanned COD
Coutinho et al. (2022)	Condition 1: Repetitive approach, 3 sets of 6 repetitions under regular half-squat movements at max concentric velocity; Condition 2: 3 sets of 6 repetitions of differential learning movements during the Half-Squat.	No potentiation effect was observed overall with any of the interventions	120 sec	Condition 1: 30 sec; Condition 2: 30 sec; Condition 1: 10 min; Condition A 2: 10 min	R-COD
Dann et al. (2023)*	Condition 1: 3 sets of 10 repetitions of alternate leg bounding on hard surface; Condition 2: 3 sets of 10 repetitions of alternate leg bounding on natural surface; Condition 3: Walking	Performance was similar between condition 1 and condition 2 at 4 min postintervention. Performance was quicker in both condition 1 & 2 at 8 min ($p < 0.05$) compared to control. No differences existed between condition 1 & 2 at any time points.	15 second active recovery between set	4 min, 8 min, 12 min	Pro-agility test
Dello Iacono et al. (2016)	Condition 1: 3 sets of 5 plyometric vertical-alternate single-leg drop jumps; Condition 2: 3 sets of 5 plyometric horizontal-alternate single-leg drop jumps	The HDJ led to greater improvement of the COD performance in comparison with the VDJ	The rest period between repetitions and sets was 10 and 120 sec, respectively	8 min	180°COD
Escobar Hincapié et al. (2021)	Condition 1: Unilateral squat (3 sets of 3 rep); Condition 2: Bilateral squat (3 sets of 3 rep)	Both conditions generated significant improvements in COD performance.	3 min	5 min	T-agility test (COD)

(*Continued*)

Table 3. (Continued).

Study	Conditioning Activity	Outcomes	Rest interval	Time period post	COD/Agility
Ishak et al. (2022)	Condition 1: 1 set of 5 repetitions of back-squat at 85% 1-RM, COD test after 4 min of rest post CA; Condition 2: 1 set of 5 repetitions of back-squat at 85% 1-RM, COD test after 8 min of rest post CA; Condition 3: 1 set of 5 repetitions of back-squat at 85% 1-RM, COD test after 12 min of rest post CA;	The COD time was quicker ($p < 0.05$) in condition 3 compared to condition 1 & 2	none	Condition 1: 4 min; Condition 2: 8 min; Condition 3: 12 min	Modified T-agility test (COD)
Kalinowski et al. (2022)	Condition 1: Bilateral isometric half back squats followed by bilateral drop jumps; Condition 2: Unilateral isometric half back squats followed by unilateral drop jumps	None of the condition influenced modified t-agility test time ($p > 0.05$)	3 min between sets	~6 min	Modified T-agility test (COD
Maloney et al., 2014*	Condition 1: Weighted vest equivalent to 5% body mass; Condition 2: Weighted vest equivalent to 10% body mass; Condition 3: No weighted vest (Control condition)	COD time was quicker ($p < 0.05$) for both condition 1 and condition 2 compared with the control condition. COD time was not significantly different between the 5% and 10% loaded conditions	60 sec (speed and power drill exercise)	15 sec 2 min, 4 min, 6 min	Badminton COD test
Marshall et al. (2019)	3 X 3 sec maximal isometric squats	Pro-agility times were slower ($p < 0.05$) at 1 minute post-CA compared with the baseline (3.3%), with no significant differences occurring at 3-, 5-, or 7-minutes post-CA.	2 min	1 min, 3 min, 5 min, 7 min	Pro-agility test (COD)
Mh et al. (2021)	Plyometric exercise (2 sets of 10 ankle hops, 3 sets of 5 hurdle hops, and 5 drop jumps)	Significant improvement in COD performance compared to the baseline.	30 sec between ankle hops and hurdle hops, and 15 sec between the repetitions of the drop jump and lower limb bounding	1 min, 5 min	T-agility test (COD)
Moreno-Pérez et al. (2021)*	Condition 1: 1 set of 3 repetitions heavy load leg press at 85% 1RM; Condition 2: Dynamic stretching (Control condition)	Both conditions led improvement in COD. Nevertheless, trivial differences in performance improvements in COD was found when comparing condition 1 and condition 2	Condition 2: 15 sec	~4 min approx.	Modified 5-0-5 agility test (COD)
Munshi et al. (2022)	Condition 1: Plyometric training protocol-double-legged vertical (5 sets of 10 repetitions each), broad jumps (2 repetitions of 15 m distance), single and double legged bounding (single repetition of 30 m distance) and depth jumps (single set of 5 repetitions), all were completed from a height of 40 cm for a duration of 30 s each; Condition 2: Single bout of WBV training during two 30-s squatting exercise sets and two 30-s single-leg squatting exercise	Both the conditions improved COD time, with COD time better in the plyometric group.	Condition 1: 15–30 sec; Condition 2: 30 sec	4 min, 12 min	T-agility test (COD)
Okuno et al. (2013)*	Condition 1: 1 set of 5 X 50% 1RM, 1 set of 3 X 70% 1RM, and 5 sets of 1 X 90% 1RM of half squat exercise; Condition 2: No conditioning activity (Control condition)	Repeated and mean COD time improved ($p < 0.05$) post the CA compared to the control condition.	2 min	5 min	RCOD
Orjalo et al. (2020)*	Condition 1: 3 sets X 5 repetitions of the barbell hip thrust (BHT) at 85% 1RM; Condition 2: 6 min rest (control condition)	The 85% 1RM BHT did improved the 505 COD 4–16 min post-CA but no more than the control condition.	2 min	4 min, 8 min, 12 min, and 16 min	5-0-5 COD
Orjalo et al. (2020)*	Condition 1: 3 × 5LB (Lateral Bound); Condition 2: 3 × 5weighted LB (10% body mass provided by a weighted vest); Condition 3: 4 min rest (control condition)	The best potentiated 505 time was faster ($p < 0.001$) than baseline for condition 1 & 2, with no differences between condition 1 & 2.	Condition 1: Work rest ratio = 1:1; Condition 2: Work rest ratio = 1:1	15 sec, 4 min, 8 min, 12 min and 16 min	5-0-5 COD

(*Continued*)

Table 3. (Continued).

Study	Conditioning Activity	Outcomes	Rest interval	Time period post	COD/Agility
Ouergui et al. (2022)*	Condition 1: Repeated high intensity techniques (3 sets of alternate kicks); Condition 2: Plyometric exercise (3 sets of consecutive vertical jumps) Condition 3: Control	COD time improved for both condition 1 and condition 2 compared to the control condition.		~10 min approx.	Taekwondo specific agility (COD)
Peng et al. (2021)	Condition 1: 3 RM squats with elastic bands; Condition 2: 5 RM squats with elastic bands	COD test times at the 4-minute recovery time point both conditions we shorter than the pre-test values ($p < 0.05$) with no significant differences between both the conditions.	-	15 sec, 4 min, and 8 min	T-agility (COD)
Pojskić et al. (2015)*	Condition 1: Static squats (5 times per min) at 100°; Condition 2: Static squats (5 times per min) at 100° with additional load of 30% body weight; Condition 3: Dynamic stretching; Condition 4: 7 min rest (control condition)	No significant difference in COD time was observed in all three conditions.	Condition 1: 30 sec; Condition 2: 30 sec	5 min	Modified T-Agility (COD)
Rumeau et al. (2023)*	Condition 1: 5 reps on leg press at 90% 1RM; Condition 2: Motor imaginary task; Condition 3: Rest	Both condition 1 & 2 enhanced COD performance ($p < 0.05$) compared to condition 3, with no difference between condition 1 & 2.	-	~7 min approx	Arrowhead agility test (COD)
Sener et al. (2021)*	Condition 1: High intensity plyometric warm up (HIPW) (5 depth jumps from a height of the lateral femoral condyle); Condition 2: Low intensity plyometric warm up (LIPW) (5 depth jumps from half of a height of the lateral femoral condyle); Condition 3: Rest (control condition)	COD times was quicker relative to baseline immediately and 5 min time-points post both condition 1 & 2 ($p < 0.05$). Condition 1 & 2 resulted better COD times compared to condition 3, at all time-points ($p < 0.05$). COD times were similar between condition 1& 2 at all other time-points ($p > 0.05$).	10–15 sec	15 sec, 5 min and 10 min	Illinois Agility Test (COD)
Sole et al. (2013)*	Condition 1: Heavy resistance warm-up (3 sets of squats at 50, 60, and 90% of 1RM) Condition 2: Dynamic warm-up (Control condition)	Heavy resistance warm-up protocol produced faster COD times compared to the control protocol ($p = 0.074$).	2 min	4 min/8 min/12 min (Reported best times)	Agility shuttle test (COD)
Thapa et al. (2020)*	Condition 1: 3 × 5 repetitions of a combination of box jump and immediate drop jump (BDJ) Condition 2: 3 min walk (Control condition)	Significant large improvement in COD performance was observed after BDJ compared to baseline ($p < 0.001$, d = 0.982) and control condition.	10 sec between repetitions and 60 sec between sets.	3 min	Modified T-Agility (COD)
Toprak et al. (2022)	Condition 1: 3 repetitions of squats at 85% of 1RM; Condition 2: 3 maximal isometric (knee angle 120°-130°) efforts for 3 seconds; Condition 3: Rest	At 15 sec and 2 min COD performance was quicker ($p < 0.05$) in condition 3 compared to condition 1 & 2. However, condition 1 & 2 resulted faster COD performance at 4 & 6 min compared to condition 3 ($p < .001$). At 8 min, condition 1 & 2 resulted peak performance ($p < 0.05$). Performance reduced in condition 1 & 2 at 10, 12 & 14 min, but quicker compared to the condition 3 ($p < 0.05$).	Condition 2: 1 min between reps	15 sec, 2 min, 4 min, 6 min, 8 min, 10 min, 12 min, 14 min	Illinois Agility Test
Turki et al. (2020)*	Condition 1: Warm-up with weighted-vest (WUV) with a loading of 5% of body mass; Condition 2: Warm-up with weighted-vest with a loading of 10% body mass; Condition 3: Warm-up with weighted-vest with a loading of 15% body-mass; Condition 4: Unloaded Warm-up (Control condition)	For each post-warm-up tested, recovery-times (i.e., 15-s, 4-min, and 8-min), both total, and peak times were faster following condition 1, 2 and 3 compared to the condition 4. There were no significant differences in-between recovery times in both total and peak times following condition 1, 2 and 3.	-	15 sec, 4 min and 8 min	R-COD
Wu et al. (2021)	WBV 1-min warm-up exercise on a vibration platform at a frequency of 30 Hz and peak-to-peak displacement of 2 mm (120° knee angle)	The participants' BAT performance improved significantly 1 min after the vibration stimulation ($p < 0.01$).	-	Immediately, 1 min, and 2 min	Block agility test, T-agility (COD)

(*Continued*)

Table 3. (Continued).

Study	Conditioning Activity	Outcomes	Rest interval	Time period post	COD/Agility
Yang et al. (2017)	Condition 1: 4 min partial squat (60° knee angle) dual-frequency WBV protocol (DFW); Condition 2: 4 min partial squat (60° knee angle) single-frequency (35 Hz) WBV; Condition 3: 4 min partial squat (60° knee angle) single-frequency (45 Hz) WBV	Only the DFW significantly improved COD ability ($p = 0.001$ for the pre – post comparison	-	~3 min approx.	5-0-5 COD
Yeung et al., 2021*	Condition 1: Loaded warm-up (LWU) with 10% body mass; Condition 2: Normal dynamic warm-up (Control condition)	No significant differences between condition 1 and 2 were observed for COD. However, small effect sizes suggested faster CODS following loaded warm-up.	-	~20 min approx.	Badminton specific COD
Zagatto et al. (2022)*	Condition 1: 1 set with 3 drop jumps from four different heights (40, 60, 80, and 100 cm); Condition 2: Heavy sled towing protocol-1 sprint of 15 m with a load 75% of the body mass; Condition 3: 5 min rest (control condition)	The drop jumps improved the RCOD mean time ($P = 0.033$), total time ($P = 0.031$), and slowest time ($P = 0.029$) compared to control condition. Heavy sled towing did not change RCOD outcomes ($P > 0.05$).	15 sec	CA 1: 5 min; CA 2: 8 min	RCOD
Zagatto et al. (2022)*	Condition 1: First DJ (drop jump) protocol: 5 reps; Second DJ protocol: 3 reps; Condition 2: Control condition	Faster RCOD mean time was observed post DJ compared to control, however, non-significant ($p = 0.215$).	15 sec	1st RCOD was performed post 4 min of first DJ protocol, 2nd RCOD was performed post 30 sec of second DJ	RCOD
Zois et al. (2011)*	Condition 1: 5 RM leg press; Condition 2: Small sided games (SSG); Condition 3: Team sport warm-up	Unplanned COD improved after the SSG and leg-press warm-ups, when compared to baseline	CA 2: 2 min; CA 3: 30–60 sec	~4 min approx.	Unplanned COD

Time period post: time period between the conditioning activity and performance assessment; CA: conditioning activity; RM: repetition maximum; rep: repetition; min: minute; COD: change of direction; RCOD: repeated sprint with change of direction; WBV: whole body vibration; Note: Studies with * symbol were included for meta-analysis.

followed by bilateral drop jumps resulted in no change in COD performance at 6 minutes following the CA (Kalinowski et al., 2022).

While most studies have employed plyometrics or traditional resistance exercises as the priming CA protocols prior to COD assessments, several studies have also employed loaded warm-ups (Chua et al., 2021; Maloney et al., 2014; Turki et al., 2020; Yeung et al., 2021) or whole-body vibration (WBV) training as part of the CA (Munshi et al., 2022; Wu et al., 2021; Yang et al., 2017). Faster COD performances were observed for up to 8 minutes following loaded warm-up (5–15% of body mass) compared to the unloaded condition (Maloney et al., 2014; Turki et al., 2020). However, Yeung et al. (Yeung et al., 2021) observed no significant differences between loaded (10% body mass) and unloaded conditions, although small effect sizes were noted suggesting faster COD performance following the loaded condition. For WBV, Wu et al. (Wu et al., 2021) reported improvements immediately after 1 minute of a WBV squat exercise performed on a vibration platform at a frequency of 30 Hz. Yang et al. (Yang et al., 2017) reported improvements (~3 minutes post-WBV exercise) in COD performance after 4 minutes of partial squats (60° knee angle) and dual frequency WBV (35–45 Hz applied individually to each leg) but showed no improvement after 4 minutes of partial squats (60° knee angle) and single-frequency WBV (35–45 Hz applied to both legs). A significant improvement in COD performance (at 4- and 12-minute intervals) was also reported following separate plyometric and WBV protocols (with unilateral and bilateral squats) with COD performance better for the plyometric condition (Munshi et al., 2022).

There were only two studies (Cochrane, 2013; Zois et al., 2011) that examined performance from unplanned COD as an outcome measure. Cochrane (2013) reported no change in unplanned COD performance after a CA of side-alternating vibration exercise during a static squat position. On the contrary, Zois et al. (2011) reported an improvement in unplanned COD performance at ~4 minutes following a CA of leg-press exercises (5RM).

3.5 Results from meta-analysis

3.5.1 Effect of CA on COD performance

Overall, there was a significant, but small, effect of CA protocols on COD performance with moderate, inter-study heterogeneity (Figure 2). The results from the Egger's test suggested absence of publication bias ($p = 0.131$). Through visual inspection of the funnel plot, three studies (Orjalo et al., 2020; Pojskić et al., 2015; Sener et al., 2021) were identified as outliers, falling outside the 95% CI (Figure 3). Removing these outliers from the meta-analysis yielded a similar small effect (SMD = 0.40, $p < 0.05$) of CA protocols on COD performance with elimination of the observed interstudy heterogeneity ($I^2 = 0\%$; $p = 0.49$).

Study or Subgroup	Std. Mean Difference	SE	Weight	Std. Mean Difference IV, Random, 95% CI
AlKitnai 2016	0.48	0.31	4.9%	0.48 [−0.13, 1.09]
Cochrane 2013	0.07	0.36	4.3%	0.07 [−0.64, 0.78]
Dann 2022	0.97	0.34	4.5%	0.97 [0.30, 1.64]
Maloney 2014	0.7	0.41	3.8%	0.70 [−0.10, 1.50]
Moreno-Pérez 2021	0.27	0.21	6.1%	0.27 [−0.14, 0.68]
Okuno 2013	0.35	0.3	5.0%	0.35 [−0.24, 0.94]
Orjalo 2020a	0.19	0.16	6.8%	0.19 [−0.12, 0.50]
Orjalo 2020b	−0.02	0.16	6.8%	−0.02 [−0.33, 0.29]
Ouergui 2022	0.73	0.23	5.9%	0.73 [0.28, 1.18]
Pojskić 2015	1.22	0.31	4.9%	1.22 [0.61, 1.83]
Rumeau 2023	0.45	0.32	4.8%	0.45 [−0.18, 1.08]
Sener 2020	1.07	0.09	7.5%	1.07 [0.89, 1.25]
Sole 2013	0.16	0.32	4.8%	0.16 [−0.47, 0.79]
Thapa 2020	0.32	0.3	5.0%	0.32 [−0.27, 0.91]
Turki 2020	0.9	0.28	5.2%	0.90 [0.35, 1.45]
Yeung 2021	0.31	0.23	5.9%	0.31 [−0.14, 0.76]
Zagatto 2022a	0.23	0.32	4.8%	0.23 [−0.40, 0.86]
Zagatto 2022b	0.14	0.29	5.1%	0.14 [−0.43, 0.71]
Zois 2011	0.78	0.38	4.1%	0.78 [0.04, 1.52]
Total (95% CI)			**100.0%**	**0.49 [0.27, 0.70]**

Heterogeneity: $Tau^2 = 0.15$; $Chi^2 = 69.66$, df = 18 ($P < 0.00001$); $I^2 = 74\%$
Test for overall effect: Z = 4.39 ($P < 0.0001$)

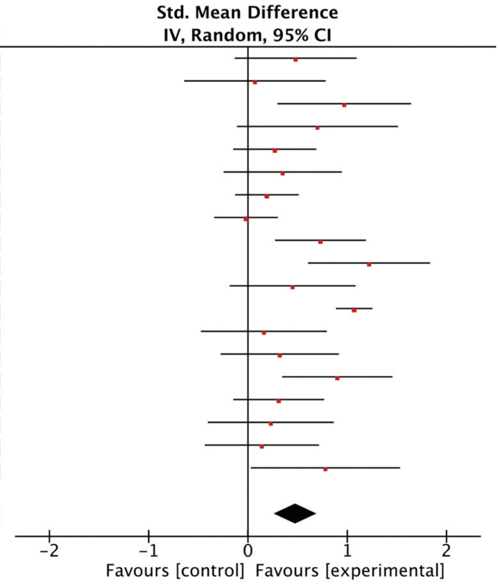

Figure 2. Forest plot for COD performance.

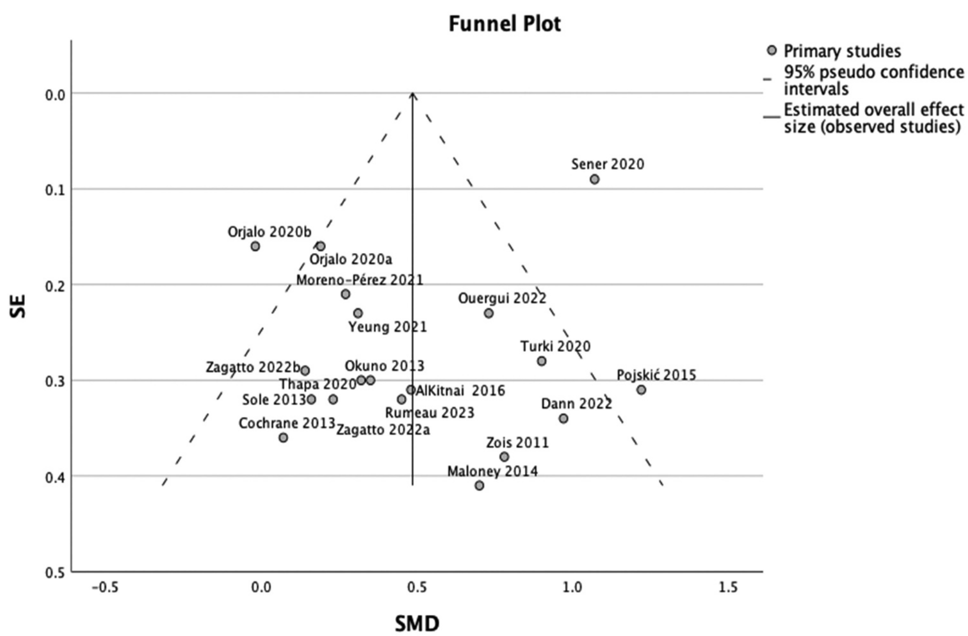

Figure 3. Funnel plot of standard mean difference (SMD) vs. standard error (SE) denoting outliers for the COD outcome.

3.5.2 Modulating factors' analysis

There was a significant moderate effect of unloaded and light-loaded CA on COD performance with moderate-high, inter-study heterogeneity (Figure 4). There was a significant small effect of moderate-heavy loaded CA on COD performance with no interstudy heterogeneity (Figure 4). Further, when differentiated based on type of assessment (i.e., pre-planned and unplanned COD protocols), a slightly greater PAPE response was observed for pre-planned COD with only the pre-planned COD performance significantly enhanced, and high inter-study heterogeneity, compared to the control condition (Figure 5).

When examining the effects of sex on COD performance following CA, both males and females exhibited similar moderate effects with only males exhibiting significantly greater COD performance compared to control conditions (Figure 6). In contrast, age had no effect on meta-analysis outcomes with exclusion of studies involving participants aged <18 years old (Al Kitani et al., 2021; Ouergui et al., 2022; Rumeau et al., 2023; Zagatto et al., 2022) still resulting in significantly greater COD performance following the CA compared to the control condition (SMD = 0.49; $p < 0.05$).

In regard to study design, the timing of post-CA assessment had minimal impact on the meta-analysis results. Specifically, exclusion of studies that reported COD performance at > 10 minutes after the CA (Yeung et al., 2021), immediately after the CA (Cochrane, 2013) and the best COD performance time at 4–12 minutes after the CA (Sole et al., 2013), resulted in a marginal increase in ES from small (SMD = 0.49; $p < 0.05$) to moderate (SMD = 0.54; $p < 0.05$)

Study or Subgroup	Std. Mean Difference	SE	Weight	Std. Mean Difference IV, Random, 95% CI
10.1.1 CON VS Unloaded CA				
AlKitnai 2016	0.48	0.31	13.0%	0.48 [−0.13, 1.09]
Cochrane 2013	0.07	0.36	11.4%	0.07 [−0.64, 0.78]
Dann 2022	0.97	0.34	12.0%	0.97 [0.30, 1.64]
Ouergui 2022	0.73	0.23	15.9%	0.73 [0.28, 1.18]
Sener 2020	1.07	0.09	20.6%	1.07 [0.89, 1.25]
Thapa 2020	0.32	0.3	13.4%	0.32 [−0.27, 0.91]
Zagatto 2022b	0.14	0.29	13.7%	0.14 [−0.43, 0.71]
Subtotal (95% CI)			**100.0%**	**0.59 [0.24, 0.93]**
Heterogeneity: $Tau^2 = 0.14$; $Chi^2 = 21.59$, df = 6 (P = 0.001); $I^2 = 72\%$				
Test for overall effect: Z = 3.31 (P = 0.0009)				
10.1.2 CON VS Light Loaded CA				
Maloney 2014	0.7	0.41	15.3%	0.70 [−0.10, 1.50]
Orjalo 2020b	−0.02	0.16	24.2%	−0.02 [−0.33, 0.29]
Pojskić 2015	1.22	0.31	18.8%	1.22 [0.61, 1.83]
Turki 2020	0.9	0.28	19.9%	0.90 [0.35, 1.45]
Yeung 2021	0.31	0.23	21.8%	0.31 [−0.14, 0.76]
Subtotal (95% CI)			**100.0%**	**0.58 [0.10, 1.06]**
Heterogeneity: $Tau^2 = 0.22$; $Chi^2 = 17.74$, df = 4 (P = 0.001); $I^2 = 77\%$				
Test for overall effect: Z = 2.37 (P = 0.02)				
10.1.3 CON VS Moderate-Heavy Loaded CA				
Moreno-Pérez 2021	0.27	0.21	20.8%	0.27 [−0.14, 0.68]
Okuno 2013	0.35	0.3	10.2%	0.35 [−0.24, 0.94]
Orjalo 2020a	0.19	0.16	35.8%	0.19 [−0.12, 0.50]
Rumeau 2023	0.45	0.32	9.0%	0.45 [−0.18, 1.08]
Sole 2013	0.16	0.32	9.0%	0.16 [−0.47, 0.79]
Zagatto 2022a	0.23	0.32	9.0%	0.23 [−0.40, 0.86]
Zois 2011	0.78	0.38	6.3%	0.78 [0.04, 1.52]
Subtotal (95% CI)			**100.0%**	**0.28 [0.10, 0.47]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 2.55$, df = 6 (P = 0.86); $I^2 = 0\%$				
Test for overall effect: Z = 2.97 (P = 0.003)				

Test for subgroup differences: $Chi^2 = 3.00$, df = 2 (P = 0.22), $I^2 = 33.3\%$

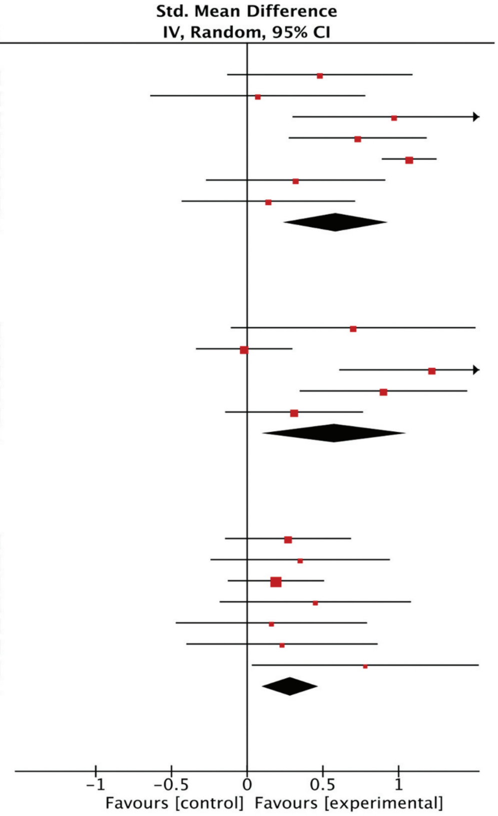

Figure 4. Forest plot on COD performance based on loading.

Study or Subgroup	Std. Mean Difference	SE	Weight	Std. Mean Difference IV, Random, 95% CI
9.1.1 CON VS Pre-planned COD				
AlKitnai 2016	0.48	0.31	5.3%	0.48 [−0.13, 1.09]
Dann 2022	0.97	0.34	5.0%	0.97 [0.30, 1.64]
Maloney 2014	0.7	0.41	4.2%	0.70 [−0.10, 1.50]
Moreno-Pérez 2021	0.27	0.21	6.7%	0.27 [−0.14, 0.68]
Okuno 2013	0.35	0.3	5.5%	0.35 [−0.24, 0.94]
Orjalo 2020a	0.19	0.16	7.3%	0.19 [−0.12, 0.50]
Orjalo 2020b	−0.02	0.16	7.3%	−0.02 [−0.33, 0.29]
Ouergui 2022	0.73	0.23	6.4%	0.73 [0.28, 1.18]
Pojskić 2015	1.22	0.31	5.3%	1.22 [0.61, 1.83]
Rumeau 2023	0.45	0.32	5.2%	0.45 [−0.18, 1.08]
Sener 2020	1.07	0.09	8.1%	1.07 [0.89, 1.25]
Sole 2013	0.16	0.32	5.2%	0.16 [−0.47, 0.79]
Thapa 2020	0.32	0.3	5.5%	0.32 [−0.27, 0.91]
Turki 2020	0.9	0.28	5.7%	0.90 [0.35, 1.45]
Yeung 2021	0.31	0.23	6.4%	0.31 [−0.14, 0.76]
Zagatto 2022a	0.23	0.32	5.2%	0.23 [−0.40, 0.86]
Zagatto 2022b	0.14	0.29	5.6%	0.14 [−0.43, 0.71]
Subtotal (95% CI)			**100.0%**	**0.49 [0.26, 0.72]**
Heterogeneity: $Tau^2 = 0.16$; $Chi^2 = 67.30$, df = 16 (P < 0.00001); $I^2 = 76\%$				
Test for overall effect: Z = 4.20 (P < 0.0001)				
9.1.2 CON VS Unplanned COD				
Cochrane 2013	0.07	0.36	51.5%	0.07 [−0.64, 0.78]
Zois 2011	0.78	0.38	48.5%	0.78 [0.04, 1.52]
Subtotal (95% CI)			**100.0%**	**0.41 [−0.28, 1.11]**
Heterogeneity: $Tau^2 = 0.12$; $Chi^2 = 1.84$, df = 1 (P = 0.17); $I^2 = 46\%$				
Test for overall effect: Z = 1.17 (P = 0.24)				

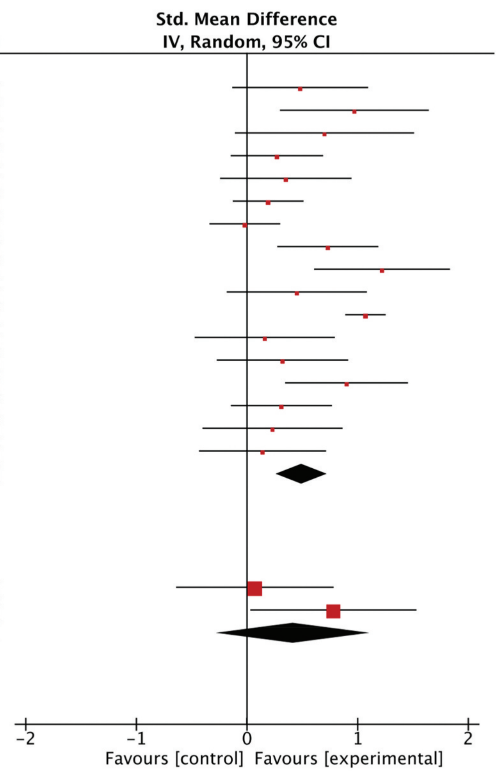

Figure 5. Forest plot on COD performance based on pre-planned and unplanned COD.

Study or Subgroup	Std. Mean Difference	SE	Weight	Std. Mean Difference IV, Random, 95% CI
11.1.1 Males				
Moreno-Pérez 2021	0.27	0.21	12.9%	0.27 [−0.14, 0.68]
Okuno 2013	0.35	0.3	10.5%	0.35 [−0.24, 0.94]
Pojskić 2015	1.22	0.31	10.2%	1.22 [0.61, 1.83]
Sener 2020	1.07	0.09	15.7%	1.07 [0.89, 1.25]
Thapa 2020	0.32	0.3	10.5%	0.32 [−0.27, 0.91]
Turki 2020	0.9	0.28	11.0%	0.90 [0.35, 1.45]
Zagatto 2022a	0.23	0.32	10.0%	0.23 [−0.40, 0.86]
Zagatto 2022b	0.14	0.29	10.7%	0.14 [−0.43, 0.71]
Zois 2011	0.78	0.38	8.6%	0.78 [0.04, 1.52]
Subtotal (95% CI)			**100.0%**	**0.60 [0.29, 0.92]**
Heterogeneity: Tau² = 0.16; Chi² = 30.45, df = 8 (P = 0.0002); I² = 74%				
Test for overall effect: Z = 3.76 (P = 0.0002)				
11.1.2 Females				
Cochrane 2013	0.07	0.36	31.0%	0.07 [−0.64, 0.78]
Dann 2022	0.97	0.34	33.3%	0.97 [0.30, 1.64]
Rumeau 2023	0.45	0.32	35.7%	0.45 [−0.18, 1.08]
Subtotal (95% CI)			**100.0%**	**0.51 [0.01, 1.00]**
Heterogeneity: Tau² = 0.08; Chi² = 3.36, df = 2 (P = 0.19); I² = 40%				
Test for overall effect: Z = 1.99 (P = 0.05)				
Test for subgroup differences: Chi² = 0.10, df = 1 (P = 0.75), I² = 0%				

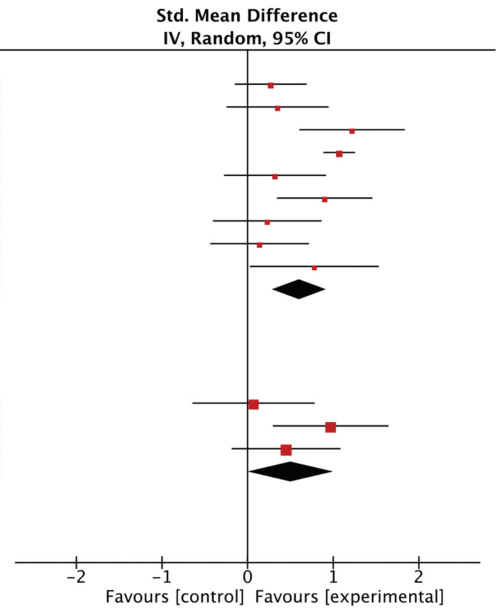

Figure 6. Forest plot on COD performance based on gender.

With regards to training experience, three studies reported that participants had >2 years of training experience (Al Kitani et al., 2021; Maloney et al., 2014; Sener et al., 2021). Five studies reported that participants had ≥3 years of playing experience (Cochrane, 2013; Moreno-Pérez et al., 2021; Ouergui et al., 2022; Yeung et al., 2021; Zagatto et al., 2022). One study reported at least 1 year of plyometric training experience for participants (Dann et al., 2023). Three studies reported that participants had both ≥2 years playing experience and ≥1-year resistance training experience (Orjalo et al., 2020, 2020; Turki et al., 2020) while two studies reported that participants had at least 1 year of resistance training experience (Okuno et al., 2013; Sole et al., 2013). The degree of training experience for participants was not reported in the remaining five studies (Pojskić et al., 2015; Rumeau et al., 2023; Thapa et al., 2020; Zagatto et al., 2022; Zois et al., 2011). Due to the inconsistent and variable levels/types of training experience reported, a sensitivity or subgroup analysis could not be performed.

3.6 Certainty of evidence

The certainty of evidence for the COD outcomes was low based primarily on limited sample size for comparison ($n < 800$) and PEDro scores of <6.

4. Discussion

The primary aim of this systematic review and meta-analysis was to critically examine the effects of established CA on COD performance. Thirty-four fair-to-good quality studies, involving 584 participants, were identified with the qualitative and meta-analysis confirming that most CA can significantly improve COD performance compared to a control condition. From the modulating factor analyses, unloaded and light-loaded CA showed significant moderate effects, whereas moderate-heavy loaded CA demonstrated significant, but small effects on COD performance compared to the control condition. When examining sex, males exhibited slightly greater and significant COD performance improvements compared to females. Likewise, the improvements were slightly and significantly greater for pre-planned COD tasks compared to unplanned COD tasks. In contrast, age and timing of CA had no substantial effect on COD performance. The findings from our study suggest unloaded CA (i.e., plyometric exercises) and light-loaded (10–30% body mass) warm-up can acutely enhance COD performance. These findings can assist practitioners in selecting appropriate CA protocols to enhance COD performance when considering a range of modulating factors.

Our meta-analysis identified that CA protocols, known to induce a PAPE response, significantly improved COD performance when compared to a control condition. These results extend upon findings from a previous narrative review (Lockie et al., 2018) that qualitatively reported the beneficial effects of strength-based CA protocols on COD performance. The current review included a variety of CA protocols including, but not limited to, plyometric exercises, strength-based (i.e., light-loaded and moderate-heavy loaded) and a range of "other" CA protocols. The modulating factors analyses characterised that unloaded (plyometric exercises) and light loaded CA exhibited significant moderate and greater effects on COD performance compared to moderate-heavy loaded CA. This result was in line with a previous meta-analysis where plyometric exercises produced greater PAPE effects (ES = 0.47) on a variety of performance measures (i.e., jump, sprint, throw and upper-body ballistic-bench press throw, etc.) compared to traditional high (≥85% 1RM) and moderate intensity (30–85% 1RM) resistance exercises (Seitz & Haff, 2016). Potentially, plyometric exercises and light-loaded CA improve stretch shortening cycle mechanics via greater muscle recruitment (Seitz & Haff,

2016) and leg stiffness (Maloney et al., 2014; Pearson & McMahon, 2012) compared to heavy loaded resistance exercises, resulting in greater performance. It has been purported that by utilising high velocity and power movements, there is greater preferential recruitment of Type II motor units, resulting in a greater PAPE response (Brink et al., 2022; Seitz & Haff, 2016). In contrast, the moderate-heavy loaded CA protocols may have resulted in more fatigue compared to plyometric and light-loaded CA, impairing the PAPE response. The lower PAPE response with moderate-heavy loading may also be influenced by participant training experience (Wilson et al., 2013). Previous studies reported that individuals with prior resistance training experience exhibited a considerably larger PAPE effect compared to those with no prior experience (Seitz & Haff, 2016; Wilson et al., 2013). In the current review, training experience was not clearly reported in the included studies and therefore it was difficult to evaluate the effect of training experience on COD performance within our meta-analysis. Future research may clarify the role, if any, of training experience for a COD PAPE response. Additionally, the current review provides guidance for coaches who may utilize plyometric exercises or light-loaded warm-ups as a CA to acutely enhance pre-planned COD performance. Employing plyometric and light-loaded approaches may be advantageous for athletes and coaches, given their minimal equipment demands and the ease with which they can be implemented on fields or during athletes' travels for competitive events. For instance, exercises such as vertical jumps, drop jumps, horizontal drop jumps, and similar activities can be effectively utilized by athletes for the acute enhancement of COD performance. Coaches/athlete's use of these exercises should also consider loading levels when implementing CA protocols for COD performance and the range of factors that influence PAPE highlighted in this and other studies.

Previously, sex and age were reported to be important factors that influence the magnitude of a PAPE effect (Arabatzi et al., 2014; Hancock et al., 2015). Superior PAPE effects were reported to be associated with greater recruitment of Type II muscle fibres (Fontanetti et al., 2023) with males exhibiting a greater proportion of Type II muscle fibres compared to females, and adults exhibiting a higher percentage of Type II muscle fibres (Arabatzi et al., 2014). In the current review, moderate-effect PAPE responses were observed for both males and females with slightly greater and significant PAPE effects for males only. This potential sex effect may reflect the difference in fibre-type composition (Fournier et al., 2022). However, there were limited studies on females in the current review, which might have biased the sex outcomes with further work needed to clearly identify the effects of sex on CA to enhance COD performance. Further, our modulating factor analysis identified similar SMD values when studies were excluded/included based on age (i.e., <18 and >18 years) with the disparity possibly due to the limited number of studies in youth within the current review and/or the influence of other modulating factors such as sex (Hancock et al., 2015).

With respect to unplanned COD tasks, our systematic review identified two studies (~6%) that examined the acute effects of CA on unplanned COD performance (Cochrane, 2013; Zois et al., 2011), a movement pattern that is common within team sport settings (Young et al., 2021). Specifically, heavy lower body resistance exercise (5RM leg press) enhanced unplanned COD performance (Zois et al., 2011). However, WBV exercise as a CA did not result in any acute benefits for unplanned COD performance (Cochrane, 2013), suggesting that heavy lower body resistance exercise is more beneficial to induce a PAPE response for unplanned COD tasks. These findings were in contrast to the overall findings in our systematic review for pre-planned COD performance, whereby unloaded exercises (i.e., plyometrics), or light-loaded exercises as a CA exhibited a greater PAPE response than moderate-heavy resistance exercises. In fact, none of the studies to date have examined unloaded, or light-loaded CA on unplanned COD performance as far as we are aware. Given that unplanned COD tasks are far more complex than pre-planned COD tasks, and of greater application to conditioning practitioners who work in team sport settings, more research is required to confirm of the effect of CA on physical and/or cognitive skills during unplanned COD tasks (Sheppard & Young, 2006). Nonetheless, practitioners could still consider implementing heavy loaded lower body resistance exercises as a CA to improve unplanned COD performance.

Our systematic review with meta-analysis makes a novel and significant addition to practitioners' existing knowledge of CA to enhance COD performance. Specifically, we collated the acute effects of various types of CA on COD performance via meta-analysis, extending prior work (Lockie et al., 2018). Based on our work, we recommend that coaches implement plyometrics or light-loaded warm-ups as a CA for pre-planned COD tasks. Further, these findings highlight the need for further research on modulating factors such as sex, age, training experience, and type of assessment (i.e., pre-planned and unplanned COD). Despite these critical findings, our systematic review has some limitations that should be considered. First, a sensitivity/subgroup analysis could not be performed based on training experience as this information was not clearly reported. Second, we could not identify the optimal time point for the best COD performance following the CA due to the limited number of studies with 3–10 minutes being the typical timeframe examined (Vargas-Molina et al., 2021). Third, the variation in the type of COD task and range of other factors such as population, age, CA, etc., might have contributed to the moderate-to-high inter-study heterogeneity. Lastly, the certainty of evidence was low due to low PEDro scores and insufficient number of participants. Future studies are encouraged to employ an *a priori* sample size power analysis (Abt et al., 2020) and recruit an appropriate number of participants to improve the overall quality of the study.

5. Conclusion

We found significant, but small effects of various CA protocols on COD performance, which support practitioner's use of CA protocols to enhance COD performance. Modulating factor analysis, considering CA difficulty, suggested that plyometric exercises or warm-up exercises with lighter loads (10–30% body mass) may be preferentially used by practitioners to induce significantly greater COD performance effects compared to moderate-heavy intensity exercises. Other modulating factors (e.g., age, sex, task, etc.) had variable effects on PAPE responses and COD performance and should be considered by coaches/practitioners when implementing pertinent CA protocols to acutely enhance COD performance.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The author(s) received no financial support for the research, authorship and/or publication of this article.

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