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Training Interventions for Improved Deceleration Ability in Adult Team-Based Field Sports Athletes: A SYSTEMATIC REVIEW and META-ANALYSIS of the Literature

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Abstract

Background: Deceleration is a fundamental component of multidirectional speed by which athletes reduce the velocity of their centre of mass to stop or execute changes of direction following acceleration or running at a constant velocity. Enhancing deceleration abilities is crucial for athletes as successfully executing horizontal deceleration has important implications for match outcomes in sports requiring rapid multidirectional movements. However, specific training interventions targeting deceleration are scarce. The purpose of this systematic review and meta-analysis was to examine the effects of training interventions on deceleration performance in adult team-based field and court sports athletes.

Methods: A systematic literature search was conducted through electronic databases, SPORTdiscus, PubMed, and Web of Science from inception to February 2022, and re-run in May 2023. The search terms were related to different training interventions and kinetic, kinematic, and performance outcomes related to deceleration performance. Studies were included if they consisted of a randomised controlled trial which investigated the effects of training on deceleration-specific outcome measures in adult team-based field and court sports athletes. Risk of bias was assessed using the revised Cochrane risk-of-bias tool for randomised trials (RoB2). Post-intervention effect sizes (Hedge’s *g*) were calculated between the intervention and control groups and a meta-analysis was performed using a random effects model.

Results: Twelve studies were included, with 29 deceleration-specific outcomes measured in a total of 381 participants. There was inconsistency in methodological designs, including control group types, length and type of interventions and in reported deceleration-specific outcome measures resulting in a moderate degree of heterogeneity ($\tau^2 = 0.1560$). Across all observations of all outcomes there was a standardised mean difference of -0.2 (95% CI: -0.4, 0.1), favouring control groups, indicating little to no effect of training on deceleration performance. When broken down into their subgroups, results were inconclusive for performance outcomes (SMD: -0.06, 95% CI: -0.86, 0.75) and kinetics (SMD: -0.04, 95% CI: -0.36, 0.28). For joint kinetics (SMD: -0.18, 95% CI: -0.77, 0.40) and muscle activation patterns (SMD: -0.10, 95% CI: -0.39, 0.18) there were small difference favouring control groups, and for joint kinematics (SMD: 0.10, 95% CI: -0.08, 0.27), favouring the intervention groups.

Conclusion: For the deceleration-specific outcomes reported in the included studies, training was not likely to produce a performance improvement in participants compared to control groups. However, due to methodological inconsistencies between studies and observed high risk of bias, the results should be interpreted with caution. More rigorous research methods should be included in the future to address areas that may introduce potential biases. Future research should address the differences in the type, timing, frequency, and duration of the implemented training interventions for improving deceleration performance, and in the reported deceleration-specific outcome measures.

Registration: This systematic review was registered on the Open Science Framework (https://osf.io/cmwbr) (https://doi.org/10.17605/OSF.IO/CMWBR)

Keywords

Deceleration, systematic review, meta-analysis, athletic performance, training, field sports, team-based sports

Key Points

- Despite the crucial role of deceleration in multidirectional sports, our systematic review indicates a lack of conclusive evidence supporting the effectiveness of current training interventions for improving deceleration performance in team-based field and court sports athletes.
- The scarcity of targeted studies, coupled with methodological inconsistencies and a high risk of bias, underscores the need for more rigorous research to enhance our understanding of training approaches aimed at enhancing deceleration abilities.

- While our meta-analysis suggests limited impact of current interventions, the interpretation is cautioned by the study's limitations, emphasising the necessity for future research to address methodological gaps and provide clearer insights into effective training strategies for deceleration in athletic performance.

1 Background

Deceleration is an essential component of multidirectional speed whereby an athlete slows down their centre of mass following acceleration or running at a constant velocity to come to a stop, slow down, and/or change direction [1, 2]. In sports, such as soccer, basketball, and rugby, frequent and intense accelerations and decelerations are crucial elements of competitive match play and have an important impact on performance outcomes and match results [3, 4].

While considerable research has investigated the trainability, physiology, and influence on performance of linear speed, acceleration, change-of-direction (COD) and agility [5, 6], deceleration is rarely studied as an explicit skill [4]. However, recent research has highlighted the importance of horizontal deceleration [7] as this ability enables athletes to reduce momentum during very short time frames and distances to successfully evade or pursue opponents. Therefore, targeting deceleration capacities and motor skills [8] with effective training methods is warranted [4].

To-date intervention trials aimed at enhancing deceleration performance have not been widely examined [9]. Few studies have included deceleration-specific outcome measures or addressed how deceleration occurs in response to sports specific stimuli [4, 8, 9]. Most research has included indirect measures of deceleration performance. These have included the coordination patterns employed by the performer during the final steps to reduce velocity prior to coming to a complete stop or the preparatory phase, initiated 50 milliseconds before ground contact, and the ensuing loading phase, defined by the interaction of the foot with the ground during the final foot contact of a COD which requires momentarily coming to zero velocity. Outcome measures have included joint kinetics and kinematics of the hip, knee, and ankle; kinetics; and muscle activation patterns measured by surface electromyography (EMG). Deterministic models have identified predictors of deceleration ability, including eccentric strength, power, and reactive strength of the lower limbs [3]. Therefore enhancing these physical capacities may be beneficial to improve attributes associated with executing the skill. Additionally, athletes could benefit from being exposed to challenges which enhance the perceptual-cognitive skills essential for successful unplanned braking [4] emphasising the cognitive aspect of trainability. Acknowledging the complementary nature of both approaches, it is essential to recognise that training for effective deceleration performance involves a combination of improving physical capacities and refining perceptual-cognitive skills However, despite these theorised avenues to improve deceleration performance, there is no clear evidence for the effectiveness of such training methods for specifically improving deceleration ability.

Therefore, the aim of this systematic review and meta-analysis is to critically evaluate and summarise the results of studies examining the effectiveness of different training interventions to specifically improve deceleration ability in adult team-based field and court sports athletes. The review also aims to appraise the methodological approach of the included studies and determine the effectiveness of training interventions compared to normal or "as usual" training practices commonly employed by the respective sports. By examining interventions against established training norms, this review seeks to provide insights into the specific impact of targeted interventions on deceleration performance. The findings of our review aim to contribute to the development of evidence-based training recommendations to enhance deceleration performance and reduced injury risk in team-based field and court sports athletes.

2 Methods

The systematic review was performed according to the guidelines for the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [10] and the protocol registered with the Open Science Framework (https://doi.org/10.17605/OSF.IO/CMWBR, 16 February 2022).

2.1 Searches

A comprehensive search of the electronic bibliographic databases SPORTdiscus, PubMed, and Web of Science was conducted in February 2022 by one author (LM). The search strategy is outlined in Figure 1. No restrictions were placed on publication date or language

The keywords used in the database search were:

- "Team sport*" OR team-sport* OR "multi-direction*" OR multidirection* OR "field sport*" OR "field-based sport*" OR "intermittent sport*" OR soccer OR football* OR futsal OR rugby OR "American football" OR "Australian rules football" OR "Australian football" OR AFL OR basketball OR handball OR netball OR hockey OR "invasion sports" OR lacrosse OR hurling OR "Gaelic football"

AND

- Train* OR interven* OR exercis* OR "plyometric training" OR plyometrics OR "power training" OR "strength training" OR "resistance training" OR "speed training" OR practic* OR practis* OR program* OR "agility training"

AND

- Accelerat* OR decelerat* OR agility OR "change of direction" OR COD OR "side step" OR side-step OR reactive OR unplanned OR unanticipated OR manoeuvre* OR maneuver* OR cutting OR brak* OR "negative accelerat*" OR turn* OR stop*

The reference lists of all included articles were then manually searched to identify additional articles for inclusion in the review. Citation chaining was performed using Google Scholar and Web of Science. A revised searched was completed in the same databases up until June 2023 and eligible studies included for data extraction.

2.2 Eligibility Criteria

The eligibility criteria were specified following a scoping search of relevant studies. The included studies met the following population, intervention, comparator, outcome, and study design (PICOS) criteria.

All original journal articles identified in the initial search were included in this review if they met the following criteria:

- Population: trained adult (≥ 18 years) male and female athletes from any team-based field and court sports. Team-based field and court sports were defined as team sports played on a court or field as a supporting surface such as volleyball, basketball, or Australian football.
- Intervention: any training program (e.g. strength, plyometrics, agility) that was not part of participants' standard or as usual training.
- Comparator: studies had to compare to either a passive control condition (no training or as usual training) or active control condition (performing a different type of training that would be considered standard in the field) (examples of such training include traditional resistance training, or sprint and agility training).
- Outcome: a kinetic, kinematic, or performance-related measure specifically measuring deceleration ability, assessed pre- and post-intervention. Examples of such measures are peak and average deceleration, joint angles and moments, ground reaction forces (GRFs), etc during the final foot contact of a COD or deceleration.
- Study design: only randomised controlled trials (RCT) with a pre- and post-test design were considered.

The population of trained adult male and female team sports athletes was chosen to limit possible confounding effects of age and training status on deceleration ability that may be evident with the inclusion of children/youth athletes. Trained athletes referred to anyone with a history of regular participation in training and/or competing in their chosen sport, indicating relevant skill development and familiarity with the demands of their respective sports. Gender, age, and sport were not specified as it was necessary to gather a wide scope of data of a range of training interventions aimed at improving deceleration ability in all team-based field and court sports where deceleration is important for performance.

Studies were excluded from the review if they were not an RCT, did not have a control group, or if measures of deceleration were not reported as primary or secondary outcomes. Further exclusionary criteria were letters, reviews, and books. Studies from grey literature or those published in languages other than English were not excluded from the analysis.

2.3 Study Selection

All articles retrieved through the search were exported into the web-based software platform Covidence where all duplicates were subsequently removed. Two authors (LM & SP) independently screened titles and abstracts for records identified during the initial search strategy. Studies included for full text review were then independently screened by the same two reviewers for extraction. At each stage of the study selection and extraction process the reviewers were blinded to each other's decisions. In the case of disagreement, decisions were made through discussion, and resolved by input from an additional independent screener (JF). In both screening stages, Cohen's kappa statistics were used to calculate the inter-rater agreement for study inclusion.

2.4 Data Extraction

Data were extracted and collated by one author (LM) using a customised excel spreadsheet (Online Resource 1). The information extracted from each eligible study included the publication details, population characteristics (number of participants, age (mean $\pm$ standard deviation [SD]), sex, sport), duration, frequency, and type of intervention and comparison, reported deceleration-specific outcome measures, statistical analyses used, and results. Descriptive statistics, including mean and standard deviations for outcome measures, confidence intervals, and effect sizes were extracted and reported. If the pre- and post-intervention test data were displayed in figures, or data were not provided within the manuscript [11, 12, 13, 14] the corresponding authors were contacted via email for further information. Where authors were unable to provide data [13], or did not respond [11, 12] these studies were not included in the final meta-analysis.

In the analysis of reported measures of deceleration, five main themes were considered separately: performance outcomes, kinetics, joint kinetics, joint kinematics, and muscle activation patterns. Across the reported outcomes, some outcomes are positively scored (i.e., higher values are related to better deceleration performance) such as in peak and average deceleration, peak vertical and posterior ground reaction forces, and knee flexion angles, while other outcomes such as knee valgus angles and moments, and ankle plantarflexion angle are scored negatively, and lower values would be deemed optimal (see Table 1). For this reason, each of the themes was analysed separately.

Table 1: Definition of all outcome variables assessed and their relevance to deceleration performance)

Outcome	Theme	Definition	Relevance to Deceleration
Ankle plantar / dorsi flexion	Joint kinematics	Joint angle of ankle during weight acceptance phase of final step	Lower values (more dorsiflexion) more beneficial for performance as ankle flexion contributes to lowering centre of mass to effectively orientate braking forces [15]
Average deceleration	Performance outcomes	Average of all instantaneous deceleration values ($m.s^{-2}$)	Direct measurement of ability to decelerate, higher numbers indicate greater ability to decelerate more rapidly and in shorter amount of time.
Hip abduction	Joint kinematics	Hip joint angle, relative to the trunk reference frame, with adduction-abduction	Lower values more beneficial for performance as too high values likely to be inefficient and increase risk of injury [14]
Hip adduction moment	Joint kinetics	Peak torque/rotational force about the hip joint resulting from forces acting to adduct the thigh	Lower values hypothesised to be more beneficial for performance [16] and reduce risk of injury
Hip flexion	Joint kinematics	Hip joint angle, relative to the trunk reference frame, with in flexion/extension	Higher values more beneficial for performance as hip flexion contributes to lowering centre of mass to effectively orientate braking forces [15]
Hip flexion moment	Joint kinetics	Peak torque/rotational force about the hip joint resulting from forces acting to flex the thigh	Higher values more beneficial for performance as this would be indicative of strong activation of hip flexor muscles
Hip internal rotation moment valgus	Joint kinetics	Peak torque/rotational force about the hip joint resulting from forces acting to internally rotate and adduct the thigh	Higher values more beneficial for performance as lower values would be associated with a more stable and controlled deceleration rather than rapid, forceful braking
Initial deceleration velocity	Performance outcomes	Running speed immediately prior to deceleration ($m.s^{-1}$)	Higher values indicate a better ability to decelerate more quickly from higher velocities, which indicates greater deceleration ability
Knee abduction moment	Joint kinetics	Peak torque/rotational force about knee joint resulting from forces acting to abduct the knee	Higher values more beneficial for performance as lower values would be associated with a more stable and controlled deceleration rather than rapid, forceful braking
Knee extension moment	Joint kinetics	Peak torque/rotational force about knee joint resulting from forces acting to extend the knee	Higher values more beneficial for performance as knee extensor muscles contract eccentrically to decelerate as fast as possible in a stable position [8, 17, 18]
Knee flexion at peak GRF	Joint kinematics	Angle of flexion about the knee joint taken at the time of peak impact GRF	Higher values more beneficial for deceleration performances as knee flexion contributes to lowering centre of mass to effectively orientate braking forces [15]

Knee flexion range of motion	Joint kinematics	Calculated as the difference between maximum knee flexion angle and the knee flexion angle at initial ground contact	Higher values more beneficial for deceleration performances as knee flexion contributes to lowering centre of mass to effectively orientate braking forces [15]
Knee rotation moment	Joint kinetics	Peak torque/rotational force about knee joint resulting from forces acting to externally rotate the knee	Higher values more beneficial for performance as lower values would be associated with a more stable and controlled deceleration rather than rapid, forceful braking.
Knee valgus moment	Joint kinetics	Peak torque/rotational force about the knee joint that causes the lower leg to move inward towards the midline of the body	Lower values more beneficial to deceleration performance due to decreasing risk for ACL injury [19] and better alignment and control of the knee joint
Knee valgus varus	Joint kinematics	Valgus (positive values) refers to the angulation of the knee joint inward, where the proximal part of the lower leg deviates towards the body's midline relative to the thigh, and the distal part is more lateral. Varus (negative values) refers to angulation of the knee joint where the lower leg deviates outward away from the body's midline relative to the thigh.	Lower values (indicating less valgus) more beneficial to deceleration performance due to decreasing risk for ACL injury [32] and better alignment and control of the knee joint
Loading phase lateral hamstrings activation	Muscle activation	Mean amplitude of muscle activity of the lateral hamstrings assessed using surface EMG while the foot was in contact with the ground	Higher values more beneficial for performance as adequate activation is required during final foot contact while they contract eccentrically to absorb impact and control knee joint, and act to limit excessive anterior tibial translation which could contribute to ACL injury risk [20]
Loading phase medial hamstrings activation	Muscle activation	Mean amplitude of muscle activity of the medial hamstrings assessed using surface EMG while the foot was in contact with the ground	Higher values more beneficial for performance as adequate activation is required during final foot contact while they contract eccentrically to absorb impact and control knee joint, and act to limit excessive anterior tibial translation which could contribute to ACL injury risk [20]
Loading phase rectus femoris activation	Muscle activation	Mean amplitude of muscle activity of the rectus femoris assessed using surface EMG while the foot was in contact with the ground	Higher values more beneficial for performance as adequate activation is required during final foot contact while they contract eccentrically to absorb impact and control knee joint, and act to limit excessive anterior tibial translation which could contribute to ACL injury risk [20]
Loading phase vastus medialis activation	Muscle activation	Mean amplitude of muscle activity of the vastus medialis assessed using surface EMG while the foot was in contact with the ground	Higher values more beneficial for performance as quadriceps help to stabilise and control leg when decelerating from high speeds and control descent of the body during deceleration
Peak deceleration	Performance outcomes	Peak value of instantaneous deceleration ($m.s^{-2}$)	Direct measurement of ability to decelerate, higher numbers indicate greater ability to decelerate more rapidly and in shorter amount of time.

Peak knee Flexion	Joint kinematics	Maximum angle of flexion of the knee joint	Higher values more beneficial for performance as knee flexion contributes to lowering centre of mass to effectively orientate braking forces [21]
Peak posterior GRF	Kinetics	Maximum value of the ground-reaction forces exerted in the backward direction with foot contact with the ground collected during final foot contact using force plates and normalized to body weight.	Higher values more beneficial for performance as they indicate more force being exerted in the opposite direction of movement helping to slow down the athlete's momentum and enable more effective deceleration
Peak vertical GRF	Kinetics	Maximum value of the ground reaction forces exerted vertically with foot contact with the ground collected during final foot contact using force plates and normalized to body weight.	Higher values more beneficial for performance indicate the athlete is using the ground effectively to brake their forward momentum indicating a more rapid and forceful deceleration.
Preparatory phase lateral hamstrings activation	Muscle activation	Mean amplitude of muscle activity of the lateral hamstrings assessed using surface EMG 50ms before final foot contact with the ground	Higher values more beneficial for performance as they act to resist forward momentum of the leg and control the descent of the limb prior to ground contact. Also act to limit excessive anterior tibial translation which could contribute to ACL injury risk [20]
Preparatory phase medial hamstrings activation	Muscle activation	Mean amplitude of muscle activity of the medial hamstrings assessed using surface EMG 50ms before final foot contact with the ground	Higher values more beneficial for performance as they act to resist forward momentum of the leg and control the descent of the limb prior to ground contact. Also act to limit excessive anterior tibial translation which could contribute to ACL injury risk [20]
Preparatory phase rectus femoris activation	Muscle activation	Mean amplitude of muscle activity of the rectus femoris assessed using surface EMG 50ms before final foot contact with the ground	Higher values more beneficial for performance as they act to resist forward momentum of the leg and control the descent of the limb prior to ground contact. Also act to limit excessive anterior tibial translation which could contribute to ACL injury risk [20]
Preparatory phase vastus medialis activation	Muscle activation	Mean amplitude of muscle activity of the vastus medialis assessed using surface EMG 50ms before final foot contact with the ground	Higher values more beneficial for performance as quadriceps work synergistically with hamstrings to prepare leg for ground contact
Tibial anterior shear force	Joint kinetics	Maximum shear force exerted in the anterior direction to the proximal tibia pulling the tibia forward relative to the femur during ground contact	Higher values more beneficial for performance as they indicate a more rapid or forceful deceleration as athlete generates significant braking force through the tibia. Can pose risk of knee injury
Tibial internal rotation moment	Joint kinetics	Peak torque/rotational force acting around the tibia where it inwardly rotates towards the body's midline	Higher values more beneficial for performance as lower values would be associated with a more stable and controlled deceleration rather than rapid, forceful braking

2.5 Data Analysis

Where possible, effect sizes (Hedge's *g*) and their 95% confidence intervals (CI) were calculated for all performance outcome measures of studies included in the review. Effect sizes were calculated between the intervention and control groups using the obtained mean and SD of the post-intervention results. Post-intervention results were used due to the assumption that since these were RCTs there would be limited between-group differences prior to the intervention since they were randomised. When not reported, the SD was estimated from the standard error (SE) of the mean, 95% CI, or p-value as per the methods suggested in the Cochrane handbook [21]. SDs were estimated for one study [22]. To calculate the effect sizes, the between-group difference in post-test means was divided by the pooled standard deviation.

To obtain the pooled standard deviation, the following formula was used:

$$\mathrm{SD_{pooled}} = \sqrt{\frac{(\mathrm{n_1} - 1) \times \mathrm{SD_1}^2 + (\mathrm{n_2} - 1) \times \mathrm{SD_2}^2}{(\mathrm{n_1} + \mathrm{n_2} - 2)}}$$

Where n_1 and n_2 are the sample sizes from the intervention and control groups respectively, and SD_1 and SD_2 are their respective standard deviations.

Hedge's *g* was then calculated using the formula:

$$g = \frac{\mathrm{M_1} - \mathrm{M_2}}{\mathrm{SD_{pooled}}}$$

Where M_1 and M_2 are the post-test means for the intervention and control groups.

A meta-analysis was performed in R (version 4.3.0) using *meta* package and applying a multi-level random effects model, clustered according to individual studies, to estimate the pooled effect of training on deceleration ability. The random effects model was applied due to high level of variance expected between studies due to sampling errors and differences between studies in intervention protocols (intervention length, type, session duration, and frequency). Following Cochrane guidelines, for any study that included two intervention groups and one control group [23], the sample size in the control group was evenly divided so a comparison could be made to each intervention. Variance of the distribution of the true effect sizes (τ^2) was used to measure heterogeneity [24] and was calculated using the restricted maximum likelihood estimator. Knapp-Hartung adjustments [25] were used to calculate the confidence intervals around the pooled effect. All analyses used two-sided tests, and $p < 0.05$ considered statistically significant. Results are displayed as the mean difference between pre- and post-intervention scores for both the intervention and control groups, with 95% confidence intervals.

2.6 Risk of Bias

The revised Cochrane risk of bias tool for randomised trials (RoB2) [26] was used to assess characteristics including the randomisation process, blinding, deviations from intended interventions, availability of outcome data, appropriateness of measurement methods, and reporting of results and analyses. This tool was used because it is a specialised methodological instrument allowing for the systematic assessment of the risk of bias in randomised trials. One reviewer (LM) independently performed quality and risk of bias assessments on each of the included articles to assess and weight the quality of the included studies with respect to the research question, and accuracy was assessed by a second author (JF). Disagreements between reviewers' judgements were resolved through discussion or by additional input from a 3rd independent reviewer.

3 Results

3.1 Study Selection

The search strategy and results are shown in Figure 1. The literature search yielded 13,348 studies. The initial search was intentionally kept broad to not introduce systematic bias by excluding for example studies which measured deceleration outcomes, but did not focus on deceleration per se. Once duplicates were removed, the titles and abstracts of 8,797 articles were screened for inclusion. From these, 8,521 studies were excluded and the full texts from the remaining 276 were assessed for eligibility. The percentage agreement between the two screeners for title and abstract screening was 97% with kappa 0.61. This level of inter-rater reliability is moderate-to-substantial [27, 28], likely because many publications don't specify in the title or abstract whether any deceleration components were reported separately to other measures of agility or change of direction, and title and abstract were screened independently hence erred on the side of inclusion to introduce as little systematic bias as possible. Of the 276 full-text articles assessed, 264 were excluded (Online Resource 2). The remaining 12 met the inclusion criteria and were included in the analysis for this systematic review. The percentage agreement between the two reviewers for studies included in the review was 94%, with kappa 0.53. Upon review and consultation with a third screener it was found that the moderate-to-substantial kappa score was due to the difficulty in discerning which results were true measures of deceleration performance. Of the included studies, 3 were unable to be used for the meta-analysis due to missing or incomplete data [11, 12, 13], leaving 9 studies for the meta-analysis.

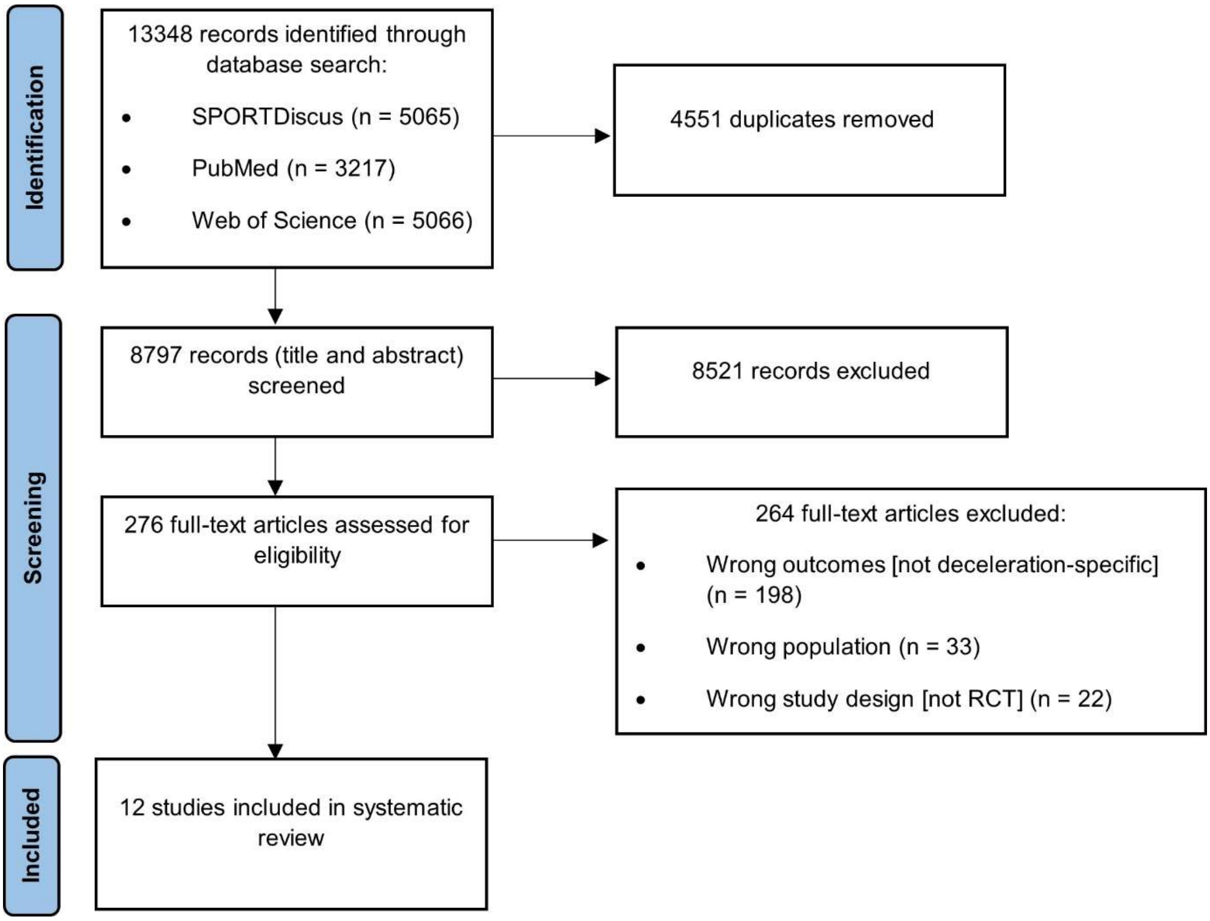

Figure 1: PRISMA flow diagram of systematic search and included studies

3.2 Study Characteristics

The descriptive results of the included studies are presented in Table 2. All were RCTs with pre- and post-intervention measures reported, including 380 participants with ages ranging from 15 to 34 years. The experience levels of included participants ranged from recreational (n=124) to professional (n=23), with most (n=176) reported to have some-to-moderate level of experience. The most common sport included was basketball (n = 4) with 87 participants [12, 20, 29, 30], while other sports examined were soccer (n = 2) with 44 participants[13, 23], AFL (n = 1) with 34 participants [11], American football (n = 1) with 21 participants [22], Gaelic football (n = 1) with 31 participants[14], rugby (n = 1) with 30 participants [31], and volleyball (n = 1) with 9 participants [29]. Two studies with 124 participants did not report the specific sports [16, 32].

3.3 Methodological approaches

One study [12] had a passive control group which only completed the testing procedures, while seven had control groups who performed their regular training [14, 16, 20, 23, 29, 30, 32]. The remaining control groups performed some form of standard training that is common in their sport such as traditional resistance exercise [13, 22, 31] or straight-line running and acceleration drills [11].

Strength or resistance training that would not be considered standard practice was the most common intervention (n = 6) [16, 23, 29, 30, 31, 32]. Other interventions included technique instruction or feedback protocols (n = 3) [11, 12, 16], balance or stability exercises (n = 3) [11, 14, 22], plyometric training (n = 2) [13, 29], agility training (n = 1) [20], and small-sided games training (n = 1) [23].

The duration of the interventions ranged from 2 - 28 weeks, and 10-46 sessions were performed. One study [12] was classified as short-term (< 2 weeks), six studies were classified as intermediate-term (4 – 6 weeks) [13, 14, 20, 22, 23, 29], and five studies [11, 16, 30, 31, 32] were classified as long term (> 6 weeks). Sessions were performed twice-weekly in five studies [11, 13, 23, 30, 31], thrice-weekly in five studies [14, 16, 22, 29, 32], four times per week in one study [20], and daily in one study [12]. One study [11] also had participants start with two sessions per week for 18 weeks, before condensing training to one session per week for the remaining ten weeks of the study.

3.4 Outcome measures

Twenty-nine separate outcome measures specific to deceleration performance were identified in the included studies. There were five distinct themes in the outcome measures used by the included studies: joint kinematics, performance outcomes, joint kinetics, kinetics, and muscle activation patterns (Table 1). Joint kinematics were the most analysed, with seven studies [11, 12, 13, 14, 16, 20, 32]. Performance outcomes [11, 13, 23, 30, 31], joint kinetics [11, 14, 16, 22, 32], and kinetics [14, 16, 20, 29, 32] were analysed in five studies each. While only one study included measures of muscle activation patterns [20].

Table 2: Data extraction and descriptive results of included studies.

Study	Sport	Participants	Gender	Population Characteristics	Intervention Group	Control Group	Testing Protocol	Deceleration-Specific Outcomes	Hedge's g Intervention vs. Control (95%CI)
Arede et al (2022)	Basketball	20	Males	All (mean ± SD) Age: 19.45 ± 4.36yrs (15-34) Height: 183.05 ± 8.58cm Body mass: 86.36 ± 17.20kg Level: U/18s to amateur seniors	n = 10 Strength training 2 sessions/week for 10 weeks	n = 10 Training as usual	-V-cut test (25m sprint with 45° COD every 5m) - COD speed test - Game situation (5v5 full court simulation)	Deceleration properties: - Total decelerations ($n.min^{-1}$) - Total high intensity decelerations (n/min) - Peak deceleration ($m.s^{-2}$)	- Peak deceleration: -0.53 (-0.75, -0.32)
Donnelly et al (2012)	AFL	34	Males	Intervention (mean ± SD) - Age 21.0 ± 3.3yrs - Height 1.86 ± 0.08cm - Mass 81.2 ± 10.0kg Control (mean ± SD) - Age 20.9 ± 3.1yrs - Height 1.84 ± 0.08m - Mass 80.6 ± 10.2kg	n = 14 Balance & technique training 2 sessions/week for 18 weeks, then 1 session/week for 10 weeks	n = 20 Acceleration & straight-line running 2 sessions/week for 18 weeks, then 1 session/week for 10 weeks	- Motion analysis of knee joint biomechanics during random series of pre-planned & unplanned straight running, cross-over cuts, and side-step running tasks	- Mean pre-contact velocity - Mean COD angle & velocity - Mean knee flexion & knee flexion ROM - Mean peak externally applied flexion, valgus, and internal rotation knee moments	Not Reported

Herman et al (2009)	Not reported	58	Females	Intervention (mean ± SD) - Height 1.67 ± 0.07m - Age 22.5 ± 2.3yrs - Mass 64.1 ± 9.1kg Control (mean ± SD) - Height 1.66 ± 0.06m - Age 22.5 ± 3.8yrs - Mass 62.1 ± 7.3kg Recreational	n = 29 Strength training + feedback protocol 3 sessions/week for 9 weeks	n = 29 Feedback protocol only (no strength training) 3 sessions/week for 9 weeks	Motion analysis of stop-jump task	Kinetic variables (sampled at peak anterior tibial shear force): - Peak proximal tibial anterior shear force - Vertical GRF - Knee valgus & extension moments - Hip adduction moment Kinematic variables (sampled at peak anterior tibial shear force): - Knee & hip flexion angles - Knee valgus angle - Hip abduction angle	- Peak proximal tibial anterior shear force: -0.35 (-0.39, -0.31) - Vertical GRF: 0.12 (0.01, 0.23) - Knee flexion: 0.00 (-1.43, 1.43) - Knee valgus/varus: 0.16 (-0.74, 1.16) - Hip flexion: -0.05 (-2.42, 2.31) - Hip abduction: 0.35 (-1.93, 2.62) - Knee extension moment: -0.06 (-0.08, -0.05) - Knee valgus moment: 0.29 (0.28, 0.30) - Hip adduction moment: 0.44 (0.40, 0.47)

Herman et al (2008)	Not reported	66	Females	Intervention (mean ± SD) - Height 1.67 ± 0.07m - Age 22.47 ± 2.25yrs - Mass 63.52 ± 9.18kg Control (mean ± SD) - Height 1.66 ± 0.06m - Age 22.53 ± 3.81yrs - Mass 61.05 ± 8.35kg	n = 33 Strength training 3 sessions/week for 9 weeks	n = 33 Training as usual	Motion analysis of stop-jump task	Kinetic variables (sampled at peak anterior tibial shear force): - Peak proximal tibial anterior shear force - Vertical GRF - Knee valgus & extension moments - Hip adduction & IR valgus moments Kinematic variables (sampled at peak anterior tibial shear force): - Knee & hip flexion angles - Knee valgus angle	- Peak proximal tibial anterior shear force: 0.44 (0.40, 0.49) - Vertical GRF: 0.08 (-0.07, 0.23) - Knee flexion: 0.08 (-1.72, 1.88) - Knee valgus/varus: -0.27 (-1.15, 0.62) - Hip flexion: 0.01 (-2.84, 2.85) - Knee extension moment: 0.36 (0.35, 0.38) - Knee valgus moment: 0.24 (0.22, 0.25) - Hip adduction moment: 0.37 (0.36, 0.39) - Hip IR moment valgus: -0.14 (-0.15, -0.14)
Jamison et al (2012)	American football	21	Males	Recreational Trunk Stabilisation (mean ± SD) - Height 1.82 ± 0.06m - Age 20.5 ± 1.2yrs - Mass 82.8 ± 7.6kg Resistance Training (mean ± SD) - Height 1.81 ± 0.05m - Age 20.3 ± 1.5yrs - Mass 82.9 ± 5.4kg	n = 10 Trunk stabilisation + strength training 3 sessions/week for 6 weeks	n = 11 Strength training only 3 sessions/week for 6 weeks	Motion analysis of biomechanical loading during 45° unanticpated run-to-cut manoeuvre	Peak moments: - Knee abduction - Tibial IR	- Peak knee abduction moment: -1.86 (-2.27, -1.45) - Peak tibial IR moment: -1.31 (-1.40, -1.21)

Kato et al (2006)	Basketball	10	Females	University students All (mean ± SD) - Height 162.3 ± 2.8cm - Mass 55.4 ± 4.6kg - Age 20.4 ± 0.5yrs - 11.7 ± 1.3yrs of athletic hx	n = 5 Technique instruction 7 sessions/week for 2 weeks	n = 5 Passive control group	Motion analysis of stop-motion task	- Knee flexion angle - Angle on anterior surface - Torsion angle of two sides - 2 week compliance with exercise instructions - Shot success (success rate of 10 shots)	Not Reported
Nevado-Garrosa et al (2021)	Soccer	23	Females	U23 female soccer players from the 2nd team of a professional Spanish club All (mean ± SD) Age 19.3 ± 1.7 (16-23) Mass 53.9 ± 7.3kg Height 161.1 ± 6.1cm	n = 8 Eccentric overload training (EOT) 2 sessions/week for 5 weeks n = 8 Small-sided games training (SSG) 2 sessions/week for 5 weeks	n = 7 Training as usual	6v6+1 training task	Maximum decelerations (DCC max) The average of all the values was calculated as average DCC. Initial velocity deceleration (Initial V DCC), the running speed immediately before the start of deceleration	EOT vs. Control - Max. deceleration: 0.37 (0.18, 0.57) - Avg. deceleration: -0.48 (-0.56, -0.41) - Initial velocity of deceleration: 0.46 (0.09, 0.84) SSG vs. Control - Max. deceleration: -0.45 (-0.64, -0.26) - Avg. deceleration: -0.24 (-0.31, -0.17) - Initial velocity of deceleration: 0.30 (-0.05, 0.65)
Raedergard et al (2020)	Soccer	21	Males	Strength (mean ± SD) - Height 181.4 ± 6cm - Age 22.2 ± 3yrs - Mass 77.1 ± 7.2kg Plyometric (mean ± SD) - Height 182.3 ± 5.7cm - Age 22.6 ± 2.6yrs - Mass 82.5 ± 7.3kg	n = 11 Plyometric training 2 sessions/week for 6 weeks	n = 10 Strength training 2 sesisons/week for 6 weeks	- Motion analysis of COD task; either 4m or 20m approach with cut angles of 45°, 90°, 135° & 180°	- COM displacement - Contact time - Hip flexion & abduction	Not Reported

Whyte et al (2018)	Gaelic football	31	Males	Intervention (mean ± SD) - Age 22.05 ± 1.47 years - Height 180.71 ± 6.29cm - Mass 78.5 ± 8.35kg Control (mean ± SD) - Age 21.76 ± 1.59 years - Height 180.16 ± 5.62cm - Mass 79.13 ± 10.24 kg	n = 16 Core stability training 3 sessions/week for 6 weeks	n = 15 Training as usual	- Motion analysis of anticipated & unanticipated crossover & side-cutting manoeuvres	Sagittal, frontal, & transverse plane: - Kinematics of the trunk, hip, knee, and ankle - Internal moments of the hip, knee and ankle - GRFs during first 30% of stance phase	Side-cutting - Knee valgus moment: -0.18 (-3.16, 2.81) - Hip flexion/extension moment: 1.12 (-5.11, 7.34) - Knee rotation moment: -0.43 (-1.24, 0.37) - Anterior/posterior GRF: -1.23 (-1.77, -0.70) & -0.92 (-1.33, -0.52) Crossover-cutting - Ankle plantar/dorsiflexion: 0.37 (-4.00, 4.73) - Anterior/posterior GRF: -0.81 (-1.25, -0.36); -1.42 (-2.24, -0.60); & -1.01 (-2.02, 0.01)

Wilderman et al (2009)	Basketball	30	Females	Intervention (mean ± SD) - Age 21.07 ± 3.62 years - Height 171.49 ± 5.65 cm - Mass 67.58 ± 7.71 kg Control (mean ± SD) - Age 21.07 ± 1.83 years - Height 171.06 ± 3.60 cm - Mass 65.13 ± 7.14 kg	n = 15 Agility training 4 sessions/week for 6 weeks	n = 15 Training as usual	- Side-step pivot manoeuvre - 4m run then 45° in opposite direction to plant leg, wearing electromagnetic tracking sensors	Preparatory & loading phase activation (% MVIC) of: -Vastus Medialis Oblique - Rectus femoris - Medial hamstrings - Lateral hamstrings Knee flexion (degrees) - At initial ground contact - Maximum - Displacement Peak vertical GRF normalised to body weight	Preparatory phase activation (% MVIC) of: -Vastus Medialis Oblique: -0.12 (-6.16, 5.92) - Rectus femoris: -0.30 (-4.27, 3.67) - Medial hamstrings: -0.58 (-3.98, 2.82) - Lateral hamstrings: -0.25 (-3.26, 2.76) Loading phase activation (% MVIC) of: - Vastus Medialis oblique: 0.28 (-64.02 - 64.59) - Rectus femoris: -0.54 (-29.57, 28.48) - Medial hamstrings: 0.70 (-16.43, 17.82) - Lateral hamstrings: -0.02 (-23.44, 23.41) Knee flexion (degrees) - At initial ground contact: 0.19 (-4.74, 5.12) - Maximum: 0.23 (-3.95, 4.42) - Displacement: 0.01 (-2.20, 2.23) Peak vertical GRF: -0.75 (-0.91, -0.59)

Winwood et al (2015)	Rugby	30	Males	Strongman (mean ± SD) - Age 23.4 ± 5.6 years - Height 180.1 ± 6.8 cm - Mass 91.2 ± 14.8 kg - 3.9 ± 2.3 years resistance training experience Traditional (mean ± SD) - Age 22.5 ± 3.4 years - Height 181.3 ± 5.9 cm - Mass 93.7 ± 12.3 kg - 4.7 ± 3.3 years resistance training experience	n = 15 Strongman training 2 sessions/week for 7 weeks	n = 15 Traditional strength training 2 sessions/week for 7 weeks	505 COD test	505 COD -5 to -2m time	505 COD deceleration: -0.05 (-0.06, -0.04)

Yang et al (2018)	Basketball Volleyball	36		Males Females	17 Male basketball players, 10 female basketball players, 1 male volleyball player, 8 female volleyball players Intervention (mean ± SD) - Height 1.87 ± 0.09m (male), 1.78 ± 0.04m (female) - Mass 82.45 ± 16.54 kg (male), 70.21 ± 4.4kg (female) Control (mean ± SD) - Height 1.89 ± 0.04m (male), 1.77 ± 0.07m (female) - Mass 79.04 ± 8.15kg (male), 65.96 ± 7.83kg (female)	n = 18 Strength & plyometric training 3 sessions/week for 4 weeks	n = 18 Training as usual	- Motion analysis of stop-jump & side-cutting tasks	o Knee flexion angle at peak impact posterior GRF o Peak impact posterior and vertical GRF	Knee flexion angle at peak impact posterior GRF - Male, stop-jump: 0.88 (-2.95, 4.72) - Male, side-cutting: -0.86 (-3.99, 2.28) - Female, stop-jump: 0.18 (-3.49, 3.84) - Female, side-cutting: -0.61 (-4.64, 3.41) Peak impact posterior GRF - Male, stop-jump: 0.10 (0.00, 0.20) - Male, side-cutting: 0.07 (-0.14, 0.28) - Female, stop-jump: 0.26 (0.11, 0.41) - Female, side-cutting: 0.55 (0.37, 0.73) Peak impact vertical GRF - Male, stop-jump: -0.38 (-0.63, -0.13) - Male, side-cutting: 0.18 (-0.24, 0.60) - Female, stop-jump: 0.25 (-0.10, 0.61) - Female, side-cutting: 0.22 (-0.20, 0.63)

3.5 Effectiveness of interventions

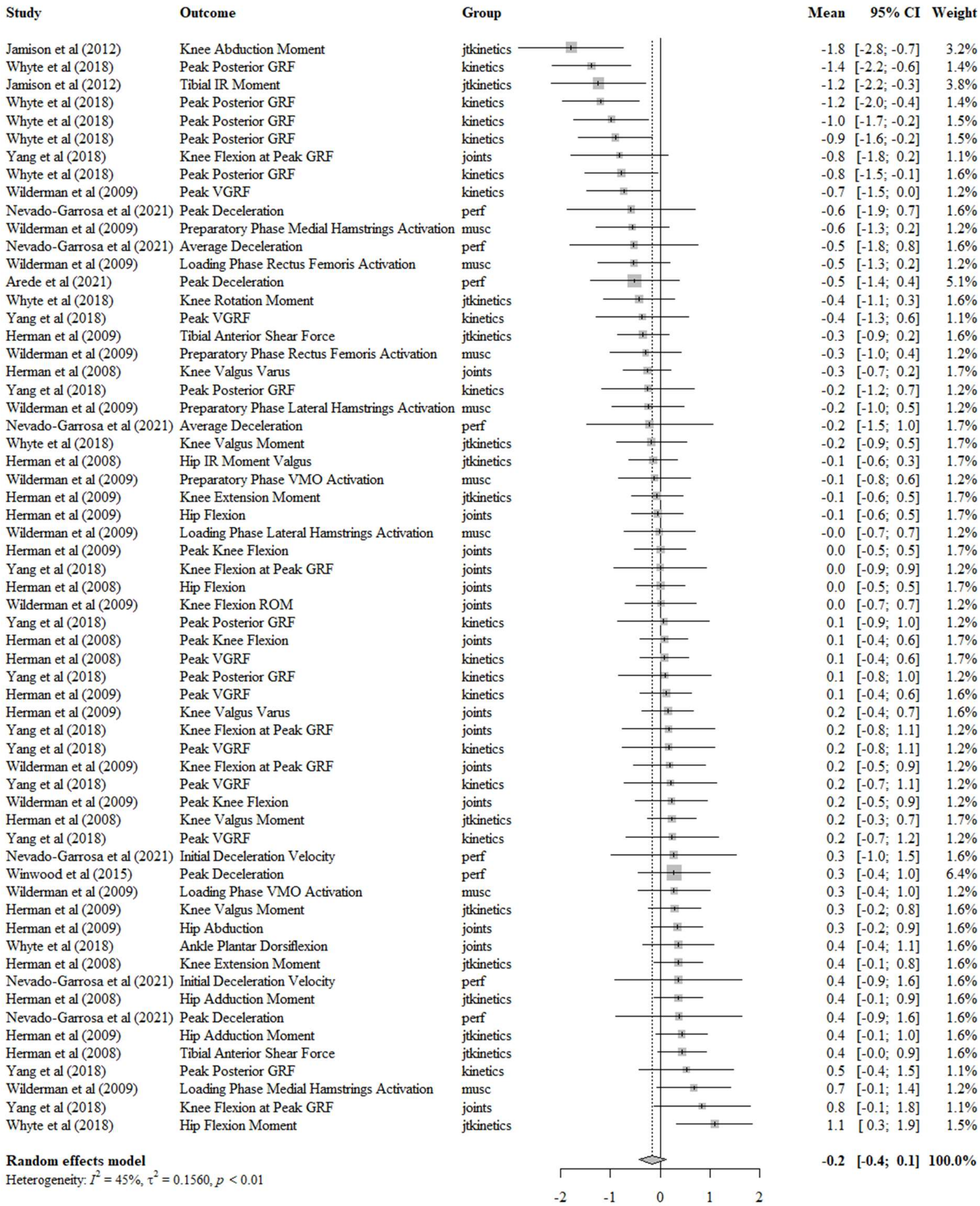

Figure 2: Forest plot displaying the standardised mean differences (SMD) and 95% confidence intervals (CIs) for all observations of all deceleration-specific outcome variables. Negative values favour control groups, positive values favour interventions. Size of the box refers to the weight of the study in relation to the pooled estimate.

Given the differences in the scales and variables used to measure deceleration performance, standardised mean differences were used to compare the between-groups differences post-intervention period. Figure 2 reports a summary of the meta-analyses performed for each deceleration-specific outcome measure reported in this review. Across all observations of all outcome measures combined, when clustered by study, the implementation of a training intervention had on average a smaller effect (SMD = -0.2, 95% CI = -0.4, 0.1) than for control groups. The estimated variance of the true effect sizes (τ^2) was found to be 0.156, and I^2 45%, indicating moderate heterogeneity, and was statistically significant ($p < 0.01$). Approximately 28% of the total variability in effect sizes is attributed to differences within studies and 72% to differences between studies. The overall heterogeneity indicates that the overall proportion of variability across all studies is due to true differences. An analysis of the outcomes, clustered according to study, according to their subgroups can be seen in figures 3 through 7, and all effect sizes calculated can be found in Online Resources 3 and 4.

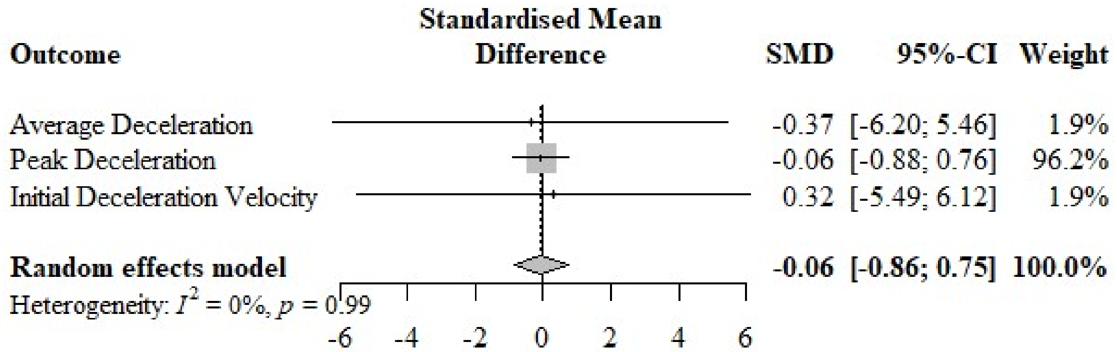

Figure 3: Forest plot displaying the standardised mean differences (SMD) and 95% confidence intervals (CIs) for performance outcome variables. Negative values favour control groups, positive values favour interventions. Size of the box refers to the weight of the study in relation to the pooled estimate.

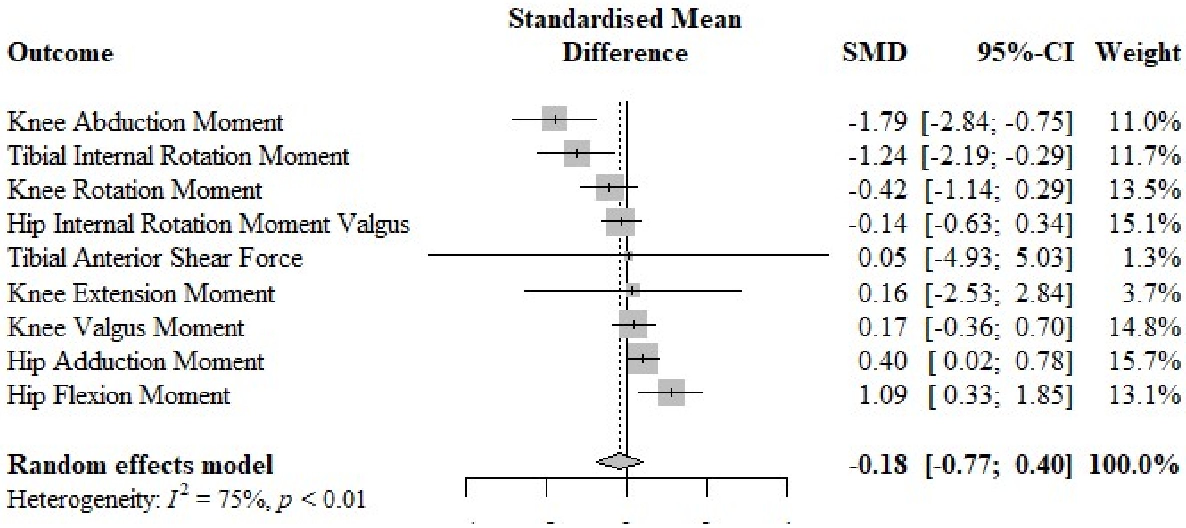

Figure 4: Forest plot displaying the standardised mean differences (SMD) and 95% confidence intervals (CIs) for joint kinetics outcome variables. Negative values favour control groups, positive values favour interventions. Size of the box refers to the weight of the study in relation to the pooled estimate.

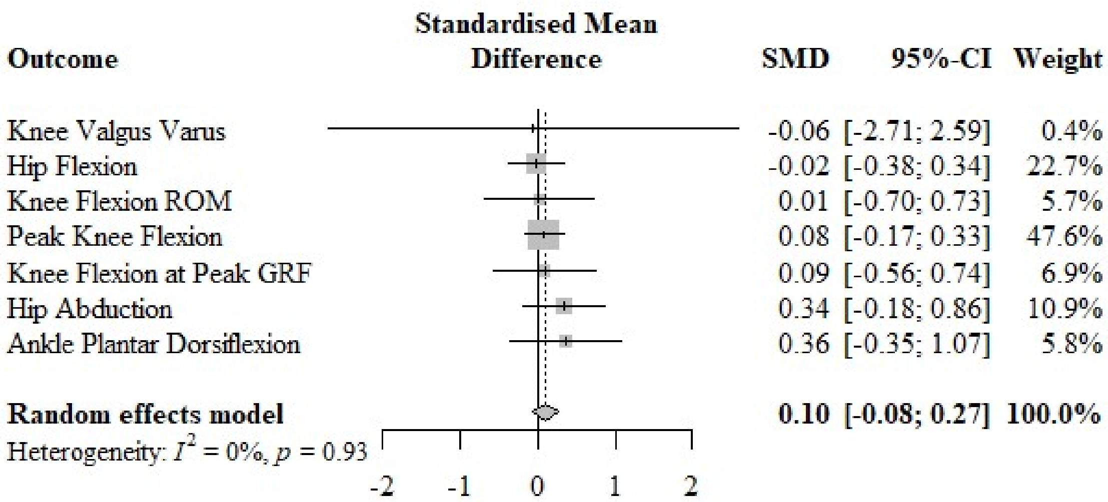

Figure 5: Forest plot displaying the standardised mean differences (SMD) and 95% confidence intervals (CIs) for joint kinematics outcome variables. Negative values favour control groups, positive values favour interventions. Size of the box refers to the weight of the study in relation to the pooled estimate. ROM: range of motion; GRF: ground reaction force

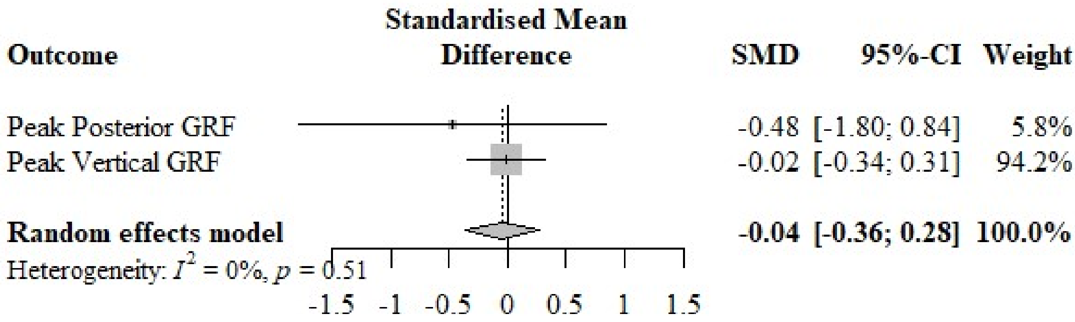

Figure 6: Forest plot displaying the standardised mean differences (SMD) and 95% confidence intervals (CIs) for kinetics outcome variables. Negative values favour control groups, positive values favour interventions. Size of the box refers to the weight of the study in relation to the pooled estimate. GRF: ground reaction force

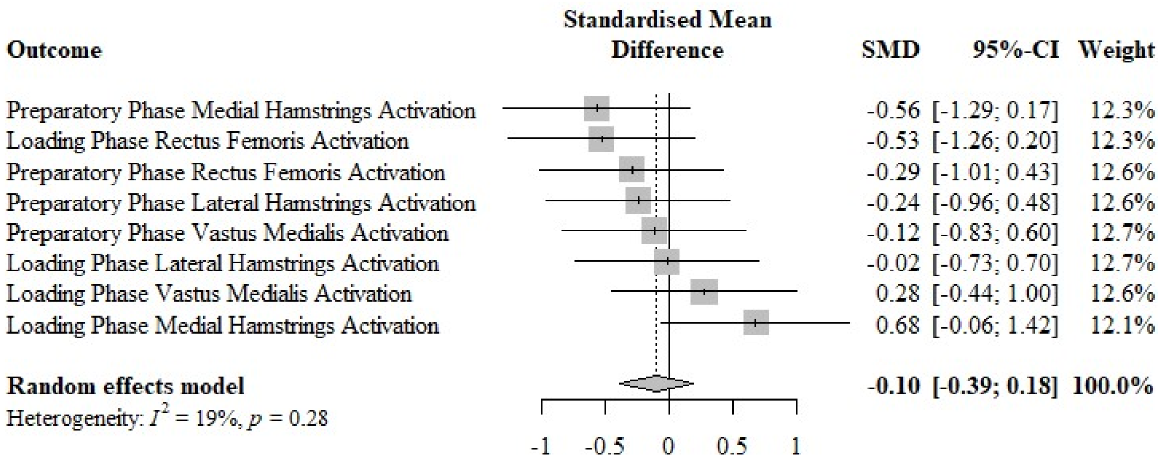

Figure 7: Forest plot displaying the standardised mean differences (SMD) and 95% confidence intervals (CIs) for muscle activation outcome variables. Negative values favour control groups, positive values favour interventions. Size of the box refers to the weight of the study in relation to the pooled estimate.

There was little to no difference between intervention and control groups for deceleration performance outcomes (SMD = -0.06, 95% CI = -0.86, 0.75, I^2 = 0%, p = 0.99) and kinetics (SMD = -0.04, 95% CI = -0.36, 0.28, I^2 = 0%, p = 0.51). Training interventions resulted in a slightly greater, but non-significant effect across all measures of joint kinematics (SMD = 0.10, 95% CI = -0.058, 0.247, I^2 = 0%, p = 0.93). Whereas for joint kinetics (SMD = -0.18, 95% CI = -0.77, 0.40, I^2 = 75%, p < 0.01) and muscle activation (SMD = -0.10, 95% CI = -0.39, 0.18, I^2 = 19%, p = 0.28) the effect for training interventions was less than for control groups.

3.7 Quality assessment

A summary of the quality assessment results is available in Figure 8, with detailed results made available in Online Resource 5. A high overall risk of bias was observed in all studies included in this review. With respect to the randomisation sequence, one study was subject to high risk of bias due to lack of random sequence generation and lack of allocation concealment. One study was considered low risk, while the rest presented some concerns due to a lack of information regarding the randomisation process. Nine studies were high risk for deviations from intended interventions due to a low compliance rate with the intervention or an inappropriate analysis used to estimate the effect of assignment to intervention and potential for this to substantially bias the studies' findings. One study was considered low risk of bias while the remaining two had some concerns. Three of the studies were observed to be low risk for having all or nearly all available outcome data, while nine were high risk for missing outcome data due to high dropouts or a lack of information. All studies presented a low risk of bias for measurement of the outcome as all measurements were objective and all participants performed the same assessments and at the same time periods in all included studies. Finally, all studies presented some concerns when addressing bias in selection of the reported result as it was not reported if the data were analysed against a pre-specified plan.

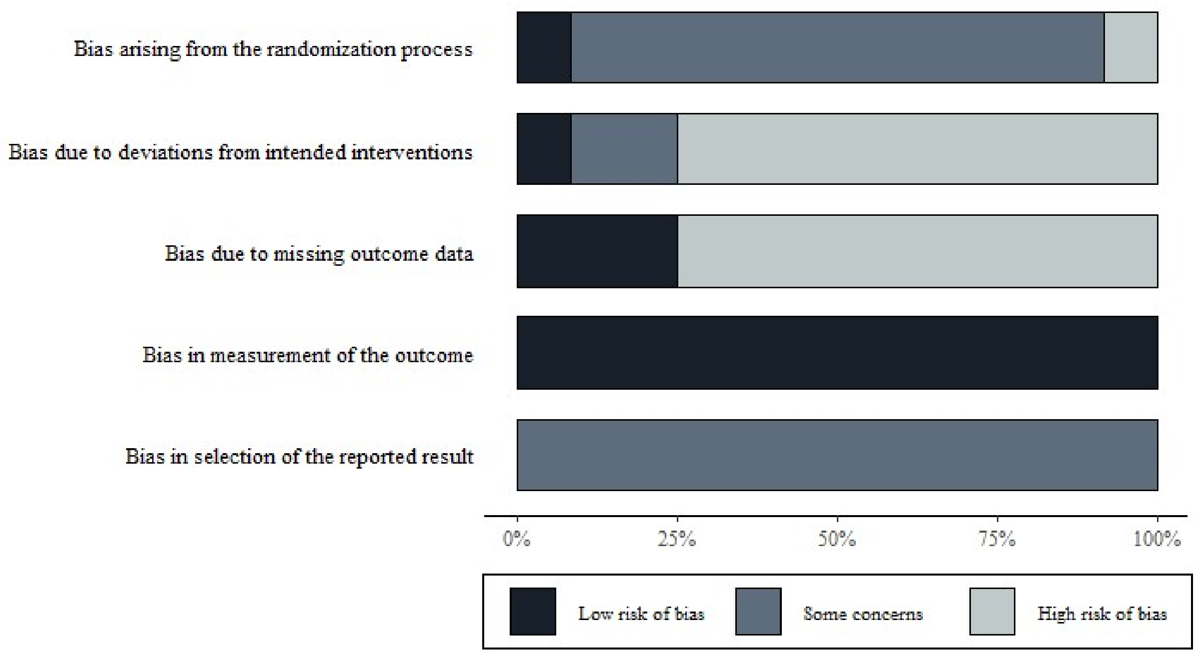

Figure 8: Summary of risk of bias assessment results

4 Discussion

The purpose of this systematic review was to critically evaluate and summarise the results of studies examining the effectiveness of different training interventions to improve measures of deceleration performance in adult team-based field and court sports athletes, compared to control groups. By assessing the effectiveness of training interventions utilised (i.e. type of training, timing, frequency, and duration) against performing no training, sport-typical training, or continuing “as usual training”, this review also aimed to guide sporting practitioners who wish to improve their athletes’ deceleration performance through evidence-based practice. All RCTs that measured deceleration performance, kinetics, or kinematics during the final deceleration steps to reduce velocity prior to coming to a complete stop or the final foot contact of a severe COD which required coming to zero velocity were included. The main finding from our meta-analysis was that across the reported deceleration-specific outcomes there was an overall small effect which favoured control groups over the implementation of training interventions.

In analysing the 9 studies included in the meta-analysis, we showed moderate heterogeneity with a statistically significant τ^2 value of 0.156, suggesting there was a moderate degree of variability between the studies. This is supported by the I^2 value where 45% of the total variability in effect estimates is due to true heterogeneity, rather than chance. These data indicate the true effect sizes may differ across the included studies and this must be considered when interpreting the results of the meta-analysis. Irrespective of the study designs used (all RCTs), there was large variability in the type, timing, frequency, and duration of the intervention protocols. Different forms of training were used, such as strength, balance, plyometric, agility, and small-sided games training. The duration of these interventions also ranged widely, from as short as 2 weeks to as long as 28 weeks, with varying session frequencies. Furthermore, there was a lack of consistency in reporting of the results, with 29 separate deceleration-specific outcomes reported across the included studies. This meant there were few observations for each outcome variable, most likely influencing the interpretation of the results of our meta-analysis. With a limited number of data points across a wide number of outcomes, we cannot confidently say that the estimates of the effect sizes in this review are likely to be the true effect sizes.

For the performance outcomes (Figure 3), the effect for intervention versus control groups was inconclusive. While this was surprising, it may be explained by the fact that none of the training interventions were deceleration-specific, targeting stopping, changes of direction or deceleration mechanics. Instead, the interventions included strength training [30, 31], eccentric overload training [23], and small-sided games training [23] in which some outcome measures could be related to deceleration performance. Additionally, there were few observations of average and peak deceleration performance to contribute to the meta-analysis and the confidence intervals were very wide, indicating our findings are unable to elucidate the true effect and further research is [33].

Kinetic measures were used in some studies [14, 16, 20, 29, 32] to measure deceleration performance. The ability to decelerate effectively requires the application of rapid braking forces to reduce forward momentum [34]. Peak posterior ground reaction force refers to the maximum force exerted by an athlete against the ground in the backward direction during activities such as stopping, changing direction, or slowing down. Dos'Santos et al. demonstrated a substantial association between horizontal braking forces (HBF) and faster 505 COD times [35]. Athletes who exhibited higher HBF during specific phases, particularly in the penultimate step and the final ground contact, demonstrated superior performance in COD tasks. This underscores the significance of effective braking forces, particularly in the horizontal plane, for deceleration performance. Here, a negative SMD was observed, showing a slightly smaller effect in the intervention group compared to the control group. However this difference was not statistically significant, indicating that training interventions did not produce a meaningful difference in deceleration performance compared to control groups. Peak posterior GRF was lower following the training interventions, however the wide confidence intervals prevent a definitive conclusion about the true effect size. Peak vertical GRF remained relatively unchanged, indicating little difference between intervention & control groups. Greater braking forces would be expected after successful training interventions to enable the execution of decelerations in shorter time frames and distances [7] provided the intervention was applied effectively and cued appropriately to ensure training transfer such as Dos'Santos et al. who provided external verbal coaching cues such as "slam on the brakes" and "push/punch the ground away" to promote rapid braking and faster COD performance [36]. Since the results of this meta-analysis show that training interventions had no effect on increasing braking forces when compared to control groups, an analysis of the content of the intervention such as exercise selection, intensity, volume, and the integration of sport-specific cues, could shed light on the factors influencing the observed outcomes.

The remaining outcomes (joint kinetics and kinematics, and muscle activation patterns) were indirect measures of deceleration performance relating to coordination patterns employed by the performer during the final steps to reduce velocity prior to coming to a complete stop or the final foot contact of a severe COD which required coming to momentary zero velocity. Some of the technical movement characteristics are associated with reducing injury risk (e.g. knee valgus and tibial internal rotation) while others are related to effective deceleration performance (e.g. knee and hip flexion) [34, 37, 38]. Across the measures of joint kinetics (Figure 5), there was an overall small but non-significant effect for the control groups compared to training interventions. However there was considerable heterogeneity indicative of significant variability among the studies' results. Knee abduction moment, tibial internal rotation moment, knee rotation moment, and hip internal rotation moment valgus were lower following training interventions than in control groups which would be conducive to a reduced risk of injury. The relationship between moments and deceleration performance is complex, and it is important to consider that sometimes safe movement mechanics and performance can be in conflict [37]. Larger moments, indicative of a more forceful deceleration, may not always align with improved performance. The effectiveness of deceleration can depend on the specific strategy employed. For instance, a wide lateral foot plant strategically employed to evade opponents can increase knee abduction moment, but athletes may employ strategies to mitigate this and reduce this moment without compromising performance. Deceleration performance involves various factors and strategies and should be considered in light of the specific demands and objectives within the sporting context. Hip flexion moment was significantly greater for the intervention groups which would also favour better deceleration performance as the strong hip flexor muscles would be activated to rapidly flex the thigh allowing for quick steps to slow down. High angular velocities produced by these moments acting about the joints are typically observed during decelerations where rapid triple flexion of the hip, knee, and ankle are required to effectively orientate braking forces [15, 39]. Hip adduction moment and knee valgus moments saw greater effects following interventions than for controls, however attributing a straightforward interpretation of these values may oversimplify the complex nature of deceleration strategies especially in the sporting context. While lower values for these kinetic measures would be considered more optimal for reducing high-risk technique deficits [15, 16, 32], it is important to recognise the context-dependent nature of these mechanics. In agility and COD, the movement strategy will emerge within the constraints imposed by the task. For example, a wider lateral foot plant during deceleration is a strategy athletes frequently employ when evading opponents and executing more pronounced changes of direction (greater than 70^{o}) and is associated with an increase in valgus and knee abduction moments. This highlights the limitations in just measuring deceleration or COD mechanics without considering the task and environmental constraints under which they occur. A comprehensive understanding of deceleration mechanics requires a consideration of these contextual factors.

There was no substantial effect of training on measures of joint kinematics (Figure 6) compared to control groups. Both hip abduction and ankle plantarflexion were slightly higher for the training intervention groups, although this was non-significant. These would be detrimental to deceleration performance due to their associations with injury risk through increasing knee varus loading and potential ACL strain [14]. Additionally, lower ankle plantarflexion angles are typically observed in better decelerators [15]. However, the wide confidence intervals about these results indicate a degree of uncertainty and caution should be taken when drawing conclusions. For hip flexion and measures of knee flexion, greater values, within a specific bandwidth, would indicate better deceleration performance as they are necessary to lower the athlete's centre of mass to increase stability and place the athlete in a better position to produce more horizontally orientated braking force [15]. However it should be noted that there is an optimal range for these angles, as excessive knee flexion may be associated with a more compliant strategy, potentially hindering deceleration performance. Effective deceleration into COD requires a balance between knee flexion, centre of mass, and leg stiffness. Differences between intervention and control groups were inconclusive.

Regarding muscle activation patterns (Figure 7) there was also little difference between intervention and control groups. Muscle activation, as measured through surface EMG, refers to the electrical activity generated within skeletal muscles during contraction. Unlike muscle contraction, which generally implies the shortening of muscle fibres resulting in movement, muscle activation encompasses the entire process of neuromuscular activity, including the initiation and transmission of electrical signals from the nervous system to the muscle fibres [40]. During running deceleration, a high degree of muscle activation is required to attenuate the large external moments generated during forceful ground contact and allow for the required external braking impulse to be generated to reduce horizontal momentum [17, 39]. The results of this meta-analysis showed that hamstring and quadricep activation during the preparatory phase favoured control groups, potentially indicating a detriment to deceleration performance. Within the literature it is typically suggested that plyometrics can increase muscle pre-activation. The findings from this meta-analysis indicating little difference in preparatory phase muscle activation patterns prompts consideration of the specificity and representativeness of the employed training interventions. Training for improved deceleration performance should aim to replicate the demands of these movements, such as those encountered during dynamic, sport-specific scenarios. Training specificity and representativeness may be essential to effectively enhance appropriate muscle pre-activation and consequently improve deceleration performance. On the other hand, loading phase medial hamstring and quadriceps activation were higher for the intervention groups suggesting benefits to deceleration as the hamstring act eccentrically to absorb impact and control the knee joint during high knee flexion angular velocities [17], while the quadriceps stabilise and control the leg and descent of the body during deceleration. However, wide confidence intervals were observed for all observations of muscle activation patterns which indicates substantial variability in the reported data and a need for caution when interpreting these findings.

There was an overall high risk of bias observed in all studies included in this review (Figure 8) suggesting caution should be applied when interpreting the findings from our review. The majority of these biases were due to lack of reporting in the randomisation process, low compliance rate with the intervention or an inappropriate analysis used to estimate the effect of assignment to intervention, and selection of the reported result. Compliance rates were not described by all studies, and where explanations were provided for the low compliance rates, it was attributed to scheduling conflicts, transport issues, or lower extremity injuries. Notably, only one study was at low risk of bias regarding the randomisation process, with the remaining raising concerns due to a lack of transparency in reporting of the process. Concerns regarding deviations from intended interventions primarily arose from low compliance rates and inappropriate analyses used to estimate the intervention effects. These deviations, present in nine studies, potentially introduced substantial biases. Additionally, issues related to outcome data were common, with nine studies exhibiting high risk due to significant dropouts or insufficient data documentation which raises questions about the completeness of the reported results, impacting the overall confidence in the findings. All studies displayed a low risk of bias in outcome measurement, as objective assessments were used across participants and time periods. However, there were concerns in addressing bias related to the selection of reported results, as the analysis against a pre-specified plan was not consistently reported. Future research investigating the effectiveness of training interventions for improving deceleration performance should be done with more rigorous methodological designs and more complete reporting within the manuscript to address these areas.

5 Future Research

The findings of this systematic review and meta-analysis highlight several critical areas that warrant further research including the trainability of deceleration in team-based field and court sports athletes. While there is a plethora of literature investigating the trainability of linear speed, acceleration, COD, and agility in team-based field and court sports athletes [5, 6], deceleration as an explicit skill has not been so widely researched [4]. As such, there are few high quality RCTs specifically examining the effectiveness of training interventions for specifically enhancing deceleration performance. Future research should also include more rigorous methodological reporting to address areas that may introduce potential biases. This could involve providing more detail regarding randomisation processes, ensuring intervention protocols are adequately described, and accurately reporting participant compliance.

Since movement outcomes are a product of both skill and physical capacity, the lack of specificity and representativeness of the training interventions employed may compromise training transfer. More integration is needed of more detailed and sport-specific training protocols that closely replicate the dynamic and context-specific demands of deceleration performed in sporting scenarios. Robust training designs tailored explicitly to deceleration would contribute to a greater understanding of effective training strategies. Implementing detailed guidelines for intervention design, clearly outlining the components and structure of training programs, would contribute to increased methodological consistency across studies and improved comparability. Standardised protocols for interventions, including consistent type, timing, frequency, and duration, of training are recommended. Additionally, collaboration among researchers in the field could lead to the development of consensus guidelines for deceleration intervention protocols to promote a more consistent and comprehensive approach to studying deceleration performance.

Furthermore, future research should prioritise standardisation of the reported outcomes specifically related to deceleration ability. Crucial to this process would be achieving consensus among researchers regarding the most appropriate objective measures of deceleration ability that are reliable, valid, and precise and establishing gold standard protocols for assessing deceleration performance. This would provide a foundation for meaningful comparisons and facilitate comprehensive evaluations of deceleration performance across different interventions and athlete populations.

6 Conclusion

The purpose of this systematic review and meta-analysis was to critically examine the current evidence to determine effectiveness of training interventions aimed at improving deceleration performance in team-based field and court sports athletes. It is pertinent to acknowledge that very few studies have specifically targeted this construct and measured relevant outcomes directly related to deceleration ability. This scarcity, coupled with a high risk of bias reported across all studies, leads to an overall uncertainty regarding the effectiveness of training interventions for improving deceleration performance. The findings from this review revealed that, for the deceleration-specific outcomes reported in the included studies, training interventions did not demonstrate a significant performance improvement when compared to control groups. Despite the results of this systematic review and meta-analysis not supporting the effectiveness of training interventions for improving deceleration performance, these null/negative findings should be interpreted within the context of the study limitations. The limited number of included studies, inconsistencies in experimental designs and reported outcomes, and the observed high risk of bias demonstrate that more research and greater methodological transparency are needed to provide a comprehensive understanding of training to improve deceleration performance.

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List of Abbreviations

ACL: Anterior cruciate ligament

COD: Change of direction

COM: Centre of mass

CI: Confidence interval

EMG: Electromyography

EOT: Eccentric overload training

GRF: Ground reaction force

HBF: Horizontal braking force

IR: Internal rotation

MVIC: Maximal voluntary isometric contraction

PICOS: Population, intervention, comparator, outcome, and study design

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RCT: Randomised controlled trial

RoB2: Cochrane risk-of-bias tool for randomised trials

ROM: Range of motion

SD: standard deviation

SMD: standardised mean difference

SSG: Small-sided games

VGRF: Vertical ground reaction force

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and material: The datasets generated and/or analysed during the current study are available in the Open Science Framework repository.
https://osf.io/sg4qu/?view_only=c958a5ef838d4d2ebedfc718bc5c37ba

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