

# Effects of integrative neuromuscular training on change of direction performance in court-based sports players: A systematic review and meta-analysis

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## Abstract

This study systematically reviewed and quantified the scientific literature on the effects of integrative neuromuscular training (INT) on change of direction (COD) performance among court-based sports players. A comprehensive keyword search was conducted on December 15, 2022, across six electronic bibliographic databases: SPORTDiscus, PubMed, Web of Science, Academic Search Ultra, Scopus, and Google Scholar. Following the application of eligibility criteria, a total of 23 studies with 901 participants were included in this review. Meta-analysis was employed to estimate the pooled effect size of INT interventions on COD performance. The findings demonstrated that INT interventions resulted in a significant reduction in COD task completion time for court-based sports players, compared to control groups (standard deviation [SD] = 0.38, 95% CI = 0.27, 0.49;  $I^2 = 98.76\%$ ). However, it was observed that the efficacy of INT on COD performance was influenced by factors such as gender, sport type, and specific metrics of COD task measures. Consequently, it is imperative to consider these potential variations when interpreting the results and planning future research. In conclusion, INT exhibited superior effectiveness in improving COD performance compared to control groups among court-based sports players. We recommend that strength and conditioning professionals incorporate INT into their comprehensive conditioning programs. However, it is important to acknowledge the potential variations in outcomes attributable to participant-specific characteristics, including gender, sport type, and the nature of COD tasks. This understanding will facilitate the optimal application of INT, thereby enhancing athletic performance across diverse sporting contexts.

## Keywords

Agility, coordination, gender, injury prevention, kinaesthesia, proprioception

## Introduction

Court-based sports, including soccer, handball, basketball, netball, and volleyball, demand players to frequently execute rapid changes in direction during competition. The ability to perform such movements efficiently is crucial for success in these sports.<sup>1</sup> Bloomfield et al. (2007) reported an average of 727 body rotations and directional changes per player in each English Premier League match. Studies have demonstrated that soccer players perform approximately 700 directional changes per game with varying intensity, 600 of which involve 0–90° turns.<sup>2</sup> Póvoas et al. found that handball players exert a significant amount of force during tasks necessitating changes in direction.<sup>3</sup> In basketball, 20% of sprints involve rapid directional changes, with lateral shuffling movements accounting for up to 41% of

gameplay.<sup>4,5</sup> Additionally, Duthie et al. noted that 16% of all sprints in rugby include swift changes in direction.<sup>6</sup>

Agility, defined as the ability to rapidly change direction in response to a stimulus, is distinct from change-of-

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direction (COD) performance, which is limited to physical determinants in the absence of external stimuli.<sup>7,8</sup> COD is a multifaceted attribute encompassing physical qualities such as linear sprinting speed, reactive strength, concentric strength, and power.<sup>7</sup> Effective COD performance is critical for success in these sports, but can also put players at risk for injury, particularly when they lack the neuromuscular control necessary to decelerate, change direction, and accelerate again.<sup>9</sup>

Numerous training protocols have been employed to improve COD performance in players.<sup>10</sup> For instance, Polman et al. reported significant enhancements in left and right turning agility following a 12-week COD training program in soccer players.<sup>11</sup> Similarly, Miller et al. observed considerable improvements in COD performance after a 6-week plyometric training program in untrained individuals.<sup>12</sup> However, Sheppard and Young argued that single-mode training does not necessarily lead to improvements in COD performance.<sup>7</sup>

As an alternative, Myer et al. proposed integrative neuromuscular training (INT) as a means to optimize biomechanics and reduce injury risk.<sup>13</sup> INT is a comprehensive training approach that addresses key components of physical conditioning, such as dynamic stability, strength, plyometrics, coordination, speed, and agility. This method has been linked to injury prevention and overall performance enhancement in both young and adult players. INT aims to improve neuromuscular control by combining strength, plyometric, balance, and agility exercises in a single program.<sup>14</sup> While some studies have demonstrated positive effects of INT on COD performance, others have produced inconclusive or conflicting results.<sup>15</sup> Thus, the efficacy of INT in enhancing COD performance warrants further investigation in order to draw more definitive conclusions.

This study presents the first systematic review and meta-analysis synthesizing and quantifying the existing evidence on the effectiveness of integrative neuromuscular training (INT) for enhancing change-of-direction (COD) performance in court-based sports players. We provide a comprehensive summary of the study findings that compare the effects of INT on COD performance with control groups (i.e. regular training). Additionally, this review aims to identify the most influential variables (i.e. age, gender, sport, level, intervention frequency and duration, and measure) in improving COD performance. The insights gained from this review may inform future evidence-based INT design and implementation to further optimize COD performance.

Given these considerations, there is a need to further clarify the appropriate prescription of INT to maximize COD speed, enabling coaches to develop more targeted programs for their players. To address this gap in the literature, this systematic review and meta-analysis sought to characterize the effects of INT on COD speed in court-based sports players.

## Methods

A systematic review was conducted by following the Preferred Reporting Items for Systematic Reviews and Meta-analysis.<sup>16</sup>

### Study selection criteria

Studies that met all of the following criteria were included in the review: (1) study design: randomized controlled trial and randomized crossover trial; (2) study subjects: healthy court-based sports players without a history of injury; (3) intervention type: integrative neuromuscular training; (4) intervention duration: four weeks or longer; (5) Outcome: COD performance; (6) article type: peer-reviewed publication; (7) time search window: from the inception of an electronic bibliographic database to December 15, 2022; and (8) language: articles written in English.

Studies that met any of the following criteria were excluded from the review: (1) no outcome of INT concerning COD performance; (2) no comparison or control group; (3) intervention duration shorter than four weeks; (4) intervention frequency less than two times per week; (5) letters, editorials, study protocols, conference proceedings, books, or review studies; and (6) studies not written in English.

### Search strategy

A keyword search was performed in six electronic bibliographic databases: PubMed, Web of Science, Scopus, SPORTDiscus, Academic Search Ultra, and Google Scholar. The search algorithm has included all possible combinations of keywords from the following two groups: (1) “integrative neuromuscular training,” “INT,” “neuromuscular training,” “proprioceptive training,” “functional training,” “sensorimotor training,” “kinaesthetic training,” “coordination training,” “neuromuscular program,” “proprioceptive program,” “functional program,” “sensorimotor program,” “kinaesthetic program,” “coordination program,” “injury prevention program,” “neuromuscular exercise,” “proprioceptive exercise,” “functional exercise,” “sensorimotor exercise,” “kinaesthetic exercise,” “coordination exercise,” or “injury prevention exercise,” and (2) “agility,” “change of direction,” or “COD.” Titles and abstracts of the articles identified through the keyword search were screened against the study selection criteria. Potentially relevant articles were retrieved for an evaluation of the full text. Two coauthors independently screened the title and abstract and identified potentially relevant articles for the full-text review. Interrater agreement was assessed using Cohen’s kappa ( $\kappa = 0.93$ ). Discrepancies were resolved through face-to-face discussions between the two coauthors. Articles identified from the title and abstract screening were reviewed in full text. The two coauthors jointly determined the final pool of articles included in the review.

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

### Data extraction

A standardized data extraction form was employed to gather methodological and outcome variables from each study included in the meta-analysis. The extracted information comprised authors, publication year, study design, sample size, age, gender, sport, level, intervention frequency, intervention duration, measures, and main results.

### Meta-analysis

A meta-analysis was conducted to estimate the pooled effect of INT on COD performance, measured as the time of task completion in seconds. Effect sizes (ES), represented by the difference in completion time between the INT and control groups, were standardized using Cohen's *d*. Cohen's *d* was calculated using the following formula:

$$\text{Cohen's } d = (M1 - M2) / \text{SD}_{\text{pooled}}$$

where *M1* is the mean of the treatment group, *M2* is the mean of the control group, and *SD*<sub>pooled</sub> is the pooled standard deviation. The pooled standard deviation is calculated as follows:

$$\text{SD}_{\text{pooled}} = \sqrt{[(n1 - 1) * \text{SD1}^2 + (n2 - 1) * \text{SD2}^2] / (n1 + n2 - 2)}$$

where *n1* and *n2* are the sample sizes of the treatment and control groups, respectively, and *SD1* and *SD2* are the standard deviations of the treatment and control groups, respectively.

Study heterogeneity was assessed using the *I*<sup>2</sup> index.<sup>17</sup> A fixed-effect model (FE) was estimated when *I*<sup>2</sup> ≤ 50%, and a random-effect model (RE) was estimated when *I*<sup>2</sup> > 50%. Publication bias was evaluated through Egger's tests.<sup>18</sup> Statistical analyses were conducted using Stata 17 (StataCorp, College Station, TX). All analyses employed two-sided tests, and a *p*-value less than .05 was deemed statistically significant. The standardized effect size was interpreted following Hopkins's recommendations: 0.0–0.19: trivial, 0.2–0.59: small, 0.6–1.19: moderate, 1.2–2.0: large, and >2.0: very large.<sup>19</sup> Subgroup analyses were performed to identify potential covariates that might influence the effectiveness of the INT intervention.

### Study quality assessment

We utilized the National Institutes of Health's Quality Assessment Tool for Controlled Intervention Studies to assess the quality of each included study.<sup>20</sup> This assessment tool rates each study based on 14 criteria. For each criterion, a score of one was assigned if the response was "yes," while a score of zero was assigned otherwise. A study-specific global score ranging from zero to 14 was calculated by summing up scores across all criteria. The study quality assessment helped measure the strength of scientific evidence but was not used to determine the inclusion of studies.

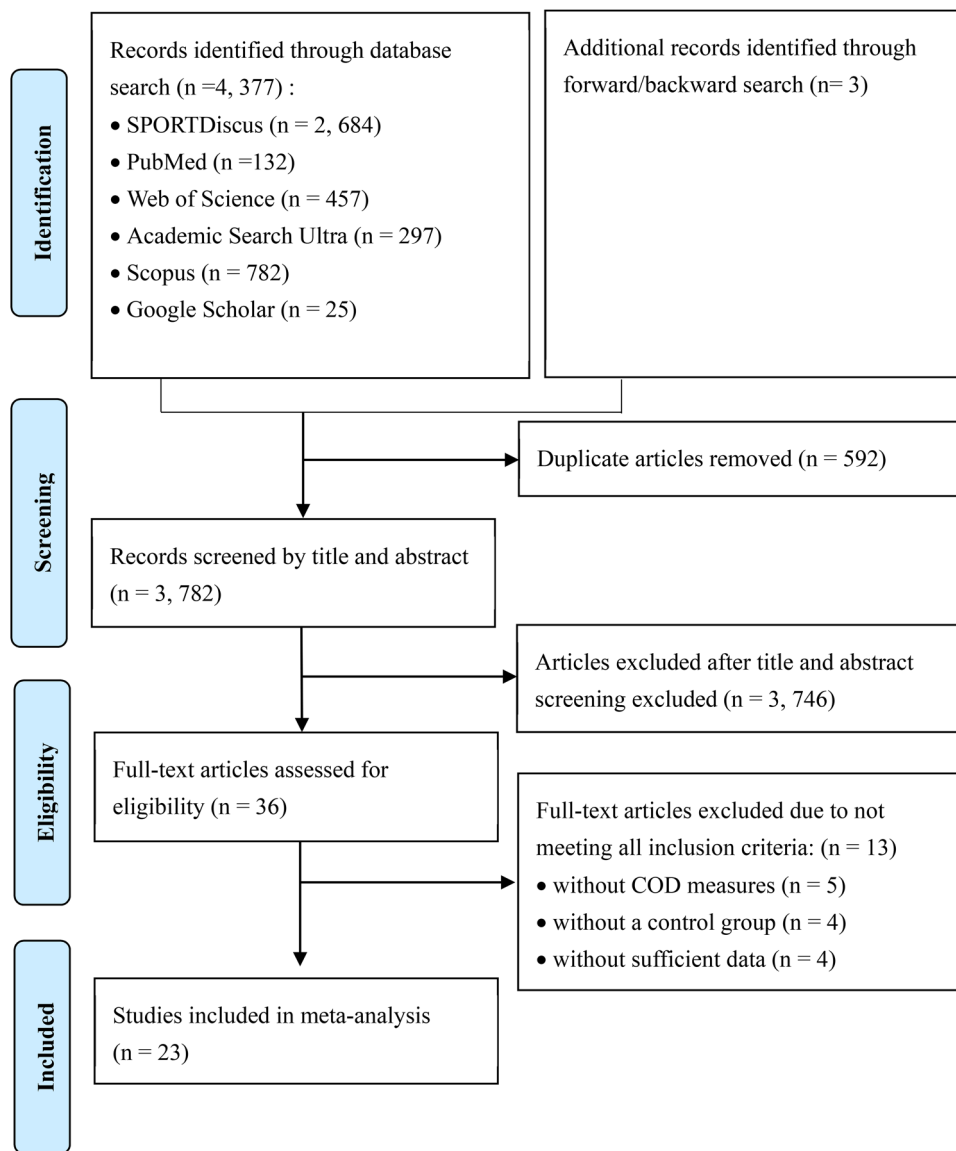
## Results

### Literature search

Figure 1 presents the study selection flowchart. We identified 4377 articles through the keyword search, including 2684 articles from SPORTDiscus, 132 from PubMed, 457 from Web of Science, 297 from Academic Search Ultra, 782 from Scopus, and 25 from Google Scholar. After removing duplicates, 3782 unique articles underwent title and abstract screening, from which 3746 were excluded. The full texts of the remaining 36 articles were reviewed against the study selection criteria. Among these, 13 articles were excluded for the following reasons: five lacked COD measures, four did not include a control arm, and four provided insufficient data. Ultimately, 23 studies met the selection criteria and were included in the meta-analysis.<sup>21–43</sup>

### Basic characteristics of the included studies

Table 1 summarizes the basic characteristics of the 23 articles, which encompass a total of 28 experimental groups included in the review. Among these, 16 were randomized controlled trials, six were quasi-experimental, and one was a prospective cohort study. The number of participants across the experimental groups ranged from 10 to 71, totaling 491. Participants' ages ranged from 8 to 25 years. Fourteen studies included only males, seven included only females, and the remaining two involved both genders. Sixteen studies recruited amateur players: nine focused on soccer players, two on basketball players, two on handball players, two on combined court-based sports players, and one on a volleyball player. Seven studies recruited elite players: two involved basketball players, two handball players, one tennis player, one badminton player, and one soccer player. Intervention durations in the included studies ranged from six to 24 weeks. The mean and median follow-up periods were nine and eight weeks, respectively. The intervention frequency varied between two and five sessions per week.



**Figure 1.** Study selection flowchart.

Regarding the measures, seven studies employed the shuttle run test, five used the agility T-test, three adopted the Illinois agility test (IAT), three utilized the Arrowhead agility test (AAT), two implemented the L-Run test, and two engaged the Square test. The remaining study adopted a basketball dribbling skill test. Of the 23 studies, 22 found INT to be more effective in improving COD performance than the control while one reported the opposite.

### Meta-analysis

Figure 2 presents the results of the meta-analysis. COD performance was measured in time (seconds). Compared to the control, INT interventions yielded a 0.38 standard deviation (SD; 95% CI = 0.27, 0.49;  $I^2 = 98.76\%$ ) reduction in COD

task completion time. A publication bias was detected based on Egger's test ( $p$ -value < .05).

Table 2 presents the results from the subgroup analyses. Subgroup analyses were conducted to determine the effects of INT on COD performance based on players' chronological age, gender, sports, competitive level, frequency and duration of training programs, and COD task measures. The effect of INT interventions was greater among male players (ES = 0.42; 95% CI = 0.29, 0.55) than female players (ES = 0.17; 95% CI = -0.02, 0.35). The effect of INT interventions was found to be more significant among basketball players (ES = 0.72; 95% CI = 0.45, 0.98) than handball players (ES = 0.55; 95% CI = 0.47, 0.64) and soccer players (ES = 0.33; 95% CI = 0.17, 0.50). The effect of INT interventions was greater for

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

Study ID	First author, year	Study design	Sample size*	Age (years)	Female (%)	Subjects	Intervention protocol	Intervention frequency (week <sup>-1</sup> )	Intervention duration (weeks)	Measure	Main Results
1	Gidu, 2022	RCTs	EG = 48 CG = 48	EG = 14.2 ± 0.4 CG = 14.0 ± 0.0	0	Amateur soccer players	Proprioceptive training	4	8	AATL; AATR	EG > CG
2	Ling, 2022	Prospective cohort study	EG = 71 CG = 40	EG = 15.8 ± 1.2 CG = 15.4 ± 1.3	47	Amateur basketball and soccer players	FIFA 11 + and Prevent Injury and Enhance Performance programs	2-3	12	L-Run test	EG > CG
3	Kooroshfard, 2022	Quasi-experimental study	EG1 = 11 EG2 = 10 CG = 10	EG1 = 20.4 ± 2.0 EG2 = 21.8 ± 1.9 CG = 20.7 ± 1.9	100	Elite basketball players	Strength, plyometric training	3	6	20-yard shuttle run	EG > CG
4	Menezes, 2022	Quasi-experimental study	EG = 20 CG = 18	EG = 8.2 ± 1.2 CG = 8.5 ± 1.3	100	Amateur soccer players	Strength, plyometric, core stability, and balance training	2	12	4m Square test	EG > CG
5	Aloui, 2021	RCTs	EG = 17 CG = 16	EG = 14.6 ± 0.4 CG = 14.6 ± 0.4	0	Amateur soccer players	CPSCoD training	5	8	4 × 5 m shuttle run	EG > CG
6	Boraczyński, 2021	RCTs	EG1 = 22 EG2 = 24 CG = 21	EG1 = 11.2 ± 0.4 EG2 = 11.1 ± 0.2 CG = 11.0 ± 0.3	0	Amateur soccer players	Intensity-modulated total-body circuit training	3	24	10 × 5 m shuttle run	EG > CG
7	González-Fernández, 2021	Quasi-experimental study	EG = 20 CG = 20	EG = 14.5 ± 0.51 CG = 14.7 ± 0.47	0	Amateur soccer players	Combined coordination and agility training	3	10	IAT	EG > CG
8	Hovsepia, 2021	RCTs	EG = 10 CG = 10	EG = 23.5 ± 3.0 CG = 21.0 ± 1.5	100	Elite basketball players	HIFT	4	10	Agility T-test	EG > CG
9	Puzi, 2021	Quasi-experimental study	EG = 15 CG = 15	EG = 14.1 ± 0.8 CG = 13.6 ± 0.9	43	Amateur handball players	CoBAgi Training	3	6	L-Run Test	EG > CG
10	Zhao, 2021	Quasi-experimental study	EG = 22 CG = 16	EG = 17 ± 1.8 CG = 18 ± 1.1	100	Elite badminton players	Strength, plyometric, core stability, speed, balance, and coordination training	4	8	AAT	EG > CG
11		RCTs			0			3	8	Modified	(continued)

Table 1. (continued)

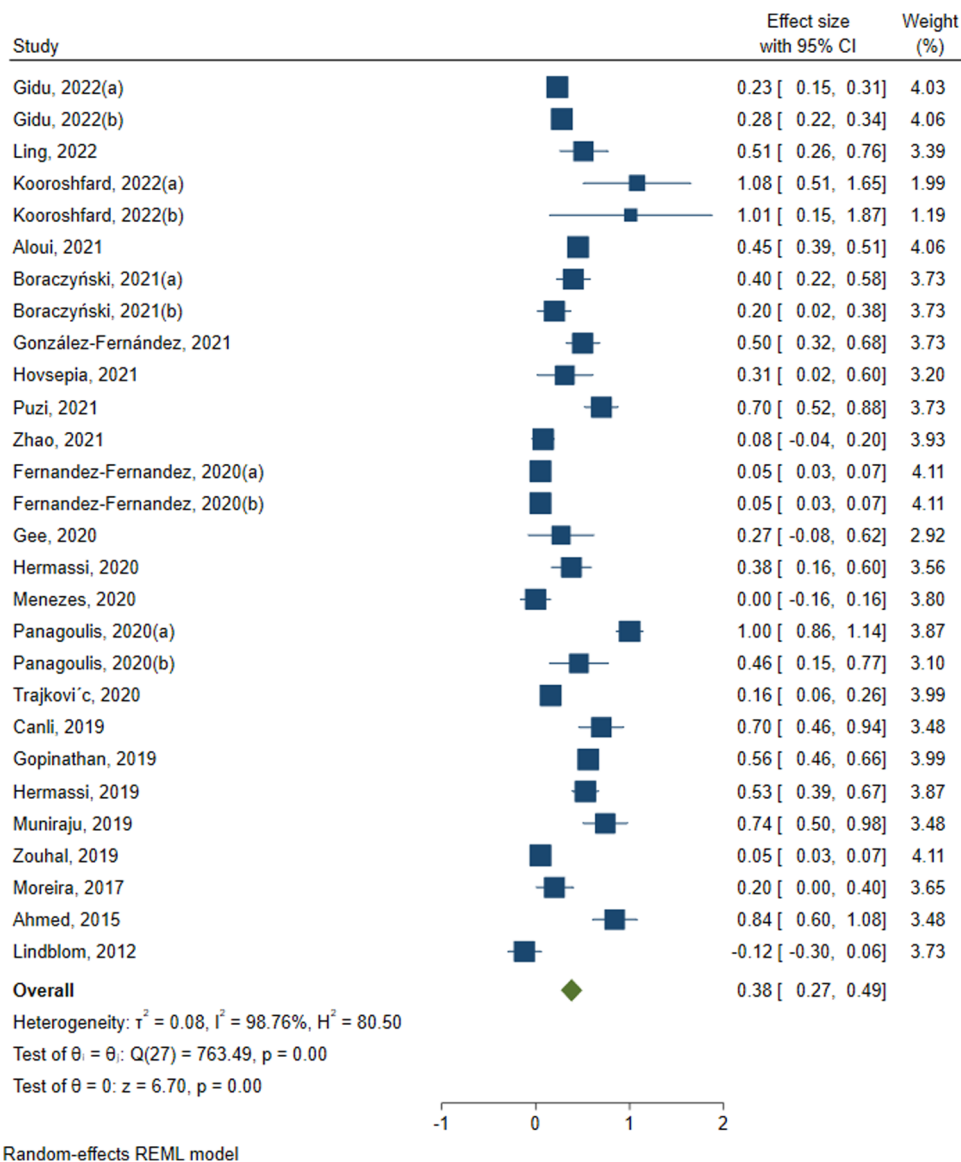
Study ID	First author, year	Study design	Sample size*	Age (years)	Female (%)	Subjects	Intervention protocol	Intervention frequency (week <sup>-1</sup> )	Intervention duration (weeks)	Measure	Main Results
12	Fernandez-Fernandez, 2020 Gee, 2020	RCTs	EG = 14 CG = 15 EG = 10 CG = 10	EG = 15.0 ± 0.9 CG = 15.21 ± 1.2 EG = 22.3 ± 2.0 CG = 22.3 ± 2.0	100	Elite tennis players Amateur badminton, squash, futsal, netball, basketball and volleyball players	Neuromuscular warm-up program Modified FIFA 11 + program	2	8	5-0-5 Test IAT	EG > CG EG > CG
13	Hermassi, 2020	RCTs	EG = 10 CG = 9	EG = 18.5 ± 0.9 CG = 18.5 ± 0.9	0	Elite handball players	Strength, plyometric, and COD training	2	12	Agility T-test	EG > CG
14	Panagoulis, 2020	RCTs	EG = 14 CG = 14	EG = 11.2 ± 0.5 CG = 11.4 ± 0.6	0	Amateur soccer players	Strength, core stability, and balance training	3	8	AATL; AATR	EG > CG
15	Trajkovic, 2020	RCTs	EG = 32 CG = 34	EG = 11.1 ± 0.7 CG = 11.0 ± 0.8	100	Amateur volleyball players	Strength, plyometric, core stability, and agility training	2	8	Modified T-test	EG > CG
16	Canli, 2019	RCTs	EG = 12 CG = 12	EG = 10.6 ± 0.8 CG = 10.8 ± 0.7	0	Amateur basketball players	Strength, plyometric, core stability, and balance training	2	8	Agility T-test	EG > CG
17	Gopinathan, 2019	Quasi-experimental study	EG = 15 CG = 15	19-25	0	Amateur handball players	Strength, plyometric, core stability, and agility training	3	6	4 × 10 m shuttle run	EG > CG
18	Hermassi, 2019	RCTs	EG = 12 CG = 10	EG = 20.3 ± 0.5 CG = 20.1 ± 0.5	0	Elite handball players	Strength, plyometric, and COD training	2	10	Agility T-half test	EG > CG
19	Muniraju, 2019	RCTs	EG = 15 CG = 15	10-14	0	Amateur soccer players	Strength, agility, and leg explosive power training	5	6	30 feet shuttle run	EG > CG
20	Zouhal, 2019	RCTs	EG = 10 CG = 10	EG = 17.7 ± 0.4 CG = 16.8 ± 0.7	0	Elite soccer players	Strength, plyometric, core	2	6	5 m	EG > CG

(continued)

Table 1. (continued)

Study ID	First author, year	Study design	Sample size*	Age (years)	Female (%)	Subjects	Intervention protocol	Intervention frequency (week <sup>-1</sup> )	Intervention duration (weeks)	Measure	Main Results
21	Moreira, 2017	RCTs	EG = 12 CG = 12	EG = 15.6 ± 0.5 CG = 15.3 ± 0.5	0	Amateur soccer players	stability, sprint, balance, and COD training Strength, plyometric, agility, and balance training	3	9	shuttle run Square test	EG > CG
22	Ahmed, 2015	RCTs	EG = 22 CG = 22	EG = 18.0 ± 0.7 CG = 18.0 ± 0.5	0	Amateur basketball players	Strength, plyometric, core stability, and balance training	3	8	Basketball dribbling skill test	EG > CG
23	Lindblom, 2012	RCTs	EG = 23 CG = 18	EG = 14.2 ± 0.7 CG = 14.2 ± 1.1	100	Amateur soccer players	Strength, plyometric, core stability, and balance training	2	11	IAT	EG < CG

Note: \*number of participants at the end of the studies; RCTs, randomized controlled trials; AATR, Arrowhead agility test with right; AATL, Arrowhead agility test with left; CPSCoD, combined plyometric and short sprints with change-of-direction training; HIFT, high-intensity functional training; IAT, Illinois agility test.



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

AAT (ES = 0.41; 95% CI = 0.09, 0.72), T-test (ES = 0.41; 95% CI = 0.22, 0.60), and Shuttle run (ES = 0.38; 95% CI = 0.18, 0.57) compared to IAT (ES = 0.21; 95% CI = -0.17, 0.59). However, no significant training effects were observed for the L-drill and Square tests ( $p$ -value > .05).

Regarding the subgroup analysis based on players' chronological age, no differential training effects were detected between younger players (aged less than 17 years old) and adult players ( $p$ -value > .05). No differential training effects were observed between elite and amateur players ( $p$ -value > .05). Additionally, no differential training effects of INT intervention were found between low training frequencies (less than three sessions per week) and higher training frequencies ( $p$ -value > .05). No

differential training effect of INT intervention was identified between short ( $\leq 8$  weeks) and longer intervention durations ( $> 8$  weeks).

**Study quality assessment**

Table 3 presents both criterion-specific and global ratings from the study quality assessment. The included studies scored an average of nine out of 14, with scores ranging from five to 13. All studies reported that the control and intervention groups were similar at baseline regarding key characteristics that could influence outcomes, and the outcomes were assessed using valid and reliable measures. Common limitations included small sample sizes and a lack of blinding procedures. In 19 of the 23 studies

**Table 2.** Subgroup analysis assessing potential moderating factors for COD performance of INT versus control group.

Population characteristics	Studies		INT versus control			
	No.	References	Pooled ES (95% CI)	I <sup>2</sup> index (%)	P	P <sub>diff</sub>
Age (years)						
<17	15	Gidu, 2022; Ling, 2022; Kooroshfard, 2022; Aloui, 2021; Puzi, 2021; Fernandez-Fernandez, 2020; Gee, 2020; Hermassi, 2020; Panagoulis, 2020; Canli, 2019; Gopinathan, 2019; Hermassi, 2019; Muniraju, 2019; Zouhal, 2019; Moreira, 2017	0.35 (0.22, 0.49)	98.75	<0.05	0.48
≥ 17	9	Aloui, 2021; Boraczyński, 2021; González-Fernández, 2021; Hovsepia, 2021; Zhao, 2021; Menezes, 2020; Trajković, 2020; Ahmed, 2015; Lindblom, 2012	0.44 (0.24, 0.64)	94.93	<0.05	
Gender						
Female	7	Kooroshfard, 2022; Hovsepia, 2021; Zhao, 2021; Gee, 2020; Menezes, 2020; Trajković, 2020; Lindblom, 2012	0.17 (−0.02, 0.35)	85.94	<0.05	0.03
Male	14	Gidu, 2022; Aloui, 2021; Boraczyński, 2021; González-Fernández, 2021; Fernandez-Fernandez, 2020; Hermassi, 2020; Panagoulis, 2020; Canli, 2019; Gopinathan, 2019; Hermassi, 2019; Muniraju, 2019; Zouhal, 2019; Moreira, 2017; Ahmed, 2015	0.42 (0.29, 0.55)	99.04	<0.05	
Sport						
Soccer	10	Gidu, 2022; Aloui, 2021; Boraczyński, 2021; González-Fernández, 2021; Menezes, 2020; Panagoulis, 2020; Muniraju, 2019; Zouhal, 2019; Moreira, 2017; Lindblom, 2012	0.33 (0.17, 0.50)	97.91	<0.05	0.02
Basketball	4	Kooroshfard, 2022; Hovsepia, 2021; Canli, 2019; Ahmed, 2015	0.72 (0.45, 0.98)	64.55	<0.05	
Handball	4	Puzi, 2021; Hermassi, 2020; Gopinatha, 2019; Hermassi, 2019	0.55 (0.47, 0.64)	23.93	<0.05	
Level						
Amateur	16	Gidu, 2022; Ling, 2022; Aloui, 2021; Boraczyński, 2021; González-Fernández, 2021; Puzi, 2021; Gee, 2020; Menezes, 2020; Panagoulis, 2020; Trajković, 2020; Canli, 2019; Gopinathan, 2019; Muniraju, 2019; Moreira, 2017; Ahmed, 2015; Lindblom, 2012	0.42 (0.29, 0.55)	94.97	<0.05	0.23
Elite	7	Kooroshfard, 2022; Hovsepia, 2021; Zhao, 2021; Fernandez-Fernandez, 2020; Hermassi, 2020; Hermassi, 2019; Zouhal, 2019	0.28 (0.09, 0.47)	99.42	<0.05	
Intervention characteristics						
Frequency						
<3 week <sup>-1</sup>	9	Ling, 2022; Gee, 2020; Hermassi, 2020; Menezes, 2020; Trajković, 2020; Canli, 2019; Hermassi, 2019; Zouhal, 2019; Lindblom, 2012	0.26 (0.09, 0.42)	99.35	<0.05	0.08
≥ 3 week <sup>-1</sup>	14	Gidu, 2022; Kooroshfard, 2022; Aloui, 2021; Boraczyński, 2021; González-Fernández, 2021; Hovsepia, 2021; Puzi, 2021; Zhao, 2021; Fernandez-Fernandez, 2020; Panagoulis, 2020; Gopinathan, 2019; Muniraju, 2019; Moreira, 2017; Ahmed, 2015	0.29 (0.15, 0.43)	82.65	<0.05	
Duration						
≤ 8 weeks	14	Gidu, 2022; Kooroshfard, 2022; Aloui, 2021; Puzi, 2021; Zhao, 2021; Fernandez-Fernandez, 2020; Gee, 2020; Panagoulis, 2020; Trajković, 2020; Canli, 2019; Gopinathan, 2019; Muniraju, 2019; Zouhal, 2019; Ahmed, 2015	0.44 (0.28, 0.60)	99.35	<0.05	0.15
>8 weeks	9	Ling, 2022; Boraczyński, 2021; González-Fernández, 2021;	0.29 (0.15, 0.43)	82.65	<0.05	

(continued)

**Table 2.** (continued)

Population characteristics	Studies		INT versus control			
	No.	References	Pooled ES (95% CI)	I <sup>2</sup> index (%)	P	P <sub>diff</sub>
		Hovsepia, 2021; Hermassi, 2020; Menezes, 2020; Hermassi, 2019; Moreira, 2017; Lindblom, 2012				
Measure						
AAT	3	Gidu, 2022; Zhao, 2021; Panagoulis, 2020;	0.41 (0.09, 0.72)	97.89	<0.05	0.01
IAT	3	González-Fernández, 2021; Gee, 2020; Lindblom, 2012	0.21 (−0.17, 0.59)	88.83	<0.05	
T-test	5	Hovsepia, 2021; Hermassi, 2020; Trajković, 2020; Canli, 2019; Hermassi, 2019;	0.41 (0.22, 0.60)	82.92	<0.05	
L-drill test	2	Ling, 2022; Puzi, 2021	0.63 (0.45, 0.81)	30.75	0.23	
Shuttle run	7	Kooroshfard, 2022; Aloui, 2021; Boraczyński, 2021; Fernandez-Fernandez, 2020; Gopinathan, 2019; Muniraju, 2019; Zouhal, 2019	0.38 (0.18, 0.57)	99.53	<0.05	
Square test	2	Menezes, 2020; Moreira, 2017	0.09 (−0.10, 0.29)	59.00	0.12	

Note: No., Number of the included studies; CI, confidence interval; I<sup>2</sup>, heterogeneity; ES, effect size; P, test for overall effect; P<sub>diff</sub>, test for subgroup differences. COD, change of direction; INT, integrative neuromuscular training; IAT, Illinois agility test; AAT, Arrowhead agility test.

analyzed, the results were strictly consistent with the pre-specified intervention protocols, and 21 studies exhibited a drop-out rate lower than 20%.

## Discussion

This systematic review evaluated the effectiveness of INT interventions on COD performance among court-based sports players. Compared to the control group, INT interventions resulted in a 0.38 standard deviation (SD; 95% CI = 0.27, 0.49; I<sup>2</sup> = 98.76%) reduction in COD task completion time. The effectiveness of INT on COD performance varied by gender, sports, and COD task measures.

Based on the current research, one potential mechanism of INT's action could be the enhancement of the sensory-motor system through the integration of multisensory information, control by the central nervous system, and motor output of skeletal muscles. This process facilitates local sensation, neuromuscular control, and posture control. Improved COD performance might be achieved through increased motor unit recruitment and synchronization, as well as rate coding (firing frequency), which could be among the primary mechanisms contributing to enhanced COD performance.

Another potential action mechanism linking INT to physiological and musculoskeletal characteristics is associated with COD performance. Improved COD performance might be due to increased power output resulting from plyometric and explosive exercises. Leg muscle quality, an umbrella term encompassing reactive strength, concentric strength and power, eccentric strength, and left-right muscle imbalance, appears to be a crucial predictor of COD performance.<sup>44</sup> In accordance with Newton's laws of motion, strength capacity is vital for overcoming inertia

during braking and effectively changing the momentum in a new direction. COD performance requires a rapid transition from eccentric to concentric muscle action in the leg-extensor muscles. Thus, the hypothesized adaptations of INT could enhance the ability to switch rapidly from deceleration to acceleration. Strength training improves motor programming by enhancing neuromuscular function and nerve adaptations in muscle spindles, Golgi tendon organs, or proprioceptive receptors. Additionally, strength training enhances COD performance by increasing balance and controlling body position during movements. Core stability exercises improve dynamic trunk control, allowing for the production, transfer, and control of force and motion to distal segments of the kinetic chain.<sup>45</sup> Balance improvement following INT facilitates a more economical change of direction and efficient acceleration. During deceleration, improved balance ensures better body stability, counteracting inertia and preventing body segments from moving in the previous direction. Similarly, plyometric training has been documented to enhance COD performance by reducing ground-reaction times (i.e. improving the stretch-shortening cycle (SSC) function), increasing muscle-force output, and promoting movement efficiency. Furthermore, plyometric training has been shown to improve the speed of step initiation, thereby contributing to decreased contact time and increased rate of force development, resulting in a greater capacity to accelerate.<sup>46,47</sup>

Another potential mechanism linking INT to improved COD performance could be enhancements in technical adjustments during COD tasks. During the acceleration phase of COD, a forward shift in the center of mass is required in response to forward leaning, enabling the production of horizontal forces. Deceleration necessitates a

**Table 3.** Study quality assessment.

Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1. Was the study described as randomized, a randomized trial, a randomized clinical trial, or an RCT?	0	0	0	1	1	0	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1
2. Was the method of randomization adequate (i.e. use of randomly generated assignment)?	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	0	0	1	0	1	1	1	1	1
3. Was the treatment allocation concealed (so that assignments could not be predicted)?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
4. Were study participants and providers blinded to treatment group assignment?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
5. Were the people assessing the outcomes blinded to the participants' group assignments?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
6. Were the groups similar at baseline on important characteristics that could affect outcomes (e.g. demographics, risk factors, co-morbid conditions)?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7. Was the overall drop-out rate from the study at endpoint 20% or lower of the number allocated to treatment?	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
8. Was the differential drop-out rate (between treatment groups) at endpoint 15 percentage points or lower?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9. Was there high adherence to the intervention protocols for each treatment group?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10. Were other interventions avoided or similar in the groups (e.g. similar background treatments)?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11. Were outcomes assessed using valid and reliable measures, implemented consistently across all study participants?	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12. Did the authors report that the sample size was sufficiently large to be able to detect a difference in the main outcome between	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1

(continued)

**Table 3.** (continued)

Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
groups with at least 80% power?																								
13. Were outcomes reported or subgroups analyzed pre-specified (i.e. identified before analyses were conducted)?	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0
14. Were all randomized participants analyzed in the group to which they were originally assigned, i.e. did they use an intention-to-treat analysis?	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	0
Total scores	8	5	8	9	10	8	9	9	8	9	9	11	7	8	8	8	7	13	9	10	10	10	11	

Note: 1 denotes yes and 0 denotes no.

backward lean, while a sideways lean generates lateral forces for changing direction. Rapid postural adjustments and limb positioning in COD are crucial for producing force in the desired direction.<sup>8</sup> Additionally, stride adjustments for acceleration and deceleration, as well as arm actions, are vital technical factors to develop when enhancing COD performance.<sup>8</sup>

Subgroup analysis according to players' gender revealed that the effect of INT interventions was more significant among male players than female players. Consistent with our findings, de Villarreal et al. reported greater performance improvements for men than women.<sup>48</sup> Previous studies have indicated that men exhibit greater SSC ability than women in court-based sports.<sup>49</sup> During an anticipated 180° COD test, males demonstrated greater trunk forward flexion and lateral flexion compared to females.<sup>50</sup> De Luca et al. introduced the concept of a "common drive" between the quadriceps (Q) and hamstrings (H), suggesting that a central co-activation mechanism controls simultaneous increases in activation between agonist and antagonist muscles.<sup>51</sup> This common drive governs the motor units of each muscle, treating both muscles as a single entity and effectively minimizing anterior tibial shear forces at the knee joint. Hanson et al. found that male soccer players displayed a Q: H co-activation ratio of 0.88 during side-step cutting tasks, while female soccer players exhibited a ratio of 1.26. Consequently, female soccer players utilized a Q-dominant activation pattern, while male soccer players demonstrated a more balanced or H-dominant muscle activation pattern during cutting tasks. Prior research has shown that females exhibit greater activation of the quadriceps muscles than males during cutting tasks and larger knee valgus angles during side-stepping.<sup>52</sup> Most studies have reported that sex significantly influences knee mechanics during athletic maneuvers.<sup>52,53</sup> Females tend to display increased knee

abduction angles (up to 11° more) and decreased knee flexion angles (15° less) compared to males during side-stepping.<sup>54,55</sup> Additionally, female soccer and basketball players have been observed to experience increased abductor moments (up to 0.42 Nm/kg/m greater) and decreased peak flexor moments (0.70 Nm/kg less) in comparison to males during side-stepping.<sup>52,53</sup> A stronger association between increased peak abductor moments and knee abduction angles has also been noted for females.<sup>53</sup>

Regarding the subgroup analysis based on the players' sports, the effect of INT interventions was more significant among basketball players compared to handball and soccer players. Asadi et al. observed greater improvements following plyometric training (a central component of the INT program) in basketball players than in other athletes, such as soccer or rugby players.<sup>56</sup> Plyometric training appears to be more specific to basketball than to other sports. Arazi et al. suggested that the nature of basketball, characterized by horizontal and lateral running, rapid and agile movements between opposing players, may elicit more significant responses to INT and, consequently, greater enhancements in COD performance.<sup>57</sup>

Subgroup analysis according to COD task measures revealed that the effect of INT interventions was more pronounced for the AAT, T-test, and Shuttle run compared to the IAT. Different court-based sports necessitate a variety of movement patterns and footwork. Each COD test differs in length, duration, number of direction changes, and angle of direction changes.<sup>58</sup> Distinct COD tests may demand varying degrees of physical requirements (e.g. eccentric, isometric, or concentric strength) and technical necessities (e.g. curvilinear running patterns for maintaining velocity, termed maneuverability, vs COD that requires rapid deceleration).<sup>59</sup> The IAT test involves a longer running distance, which may emphasize endurance. AAT, T-test, and Shuttle run may include as few as two or three

directional changes, while the IAT can incorporate up to 12 changes in direction. IAT may be long enough in time and distance that anaerobic capacity becomes a critical performance factor, making it difficult to determine if changes in performance result from increases in COD ability or enhancements in anaerobic capacity.<sup>59</sup>

There are several limitations to this review and the included studies that should be acknowledged. First, a small and heterogeneous set of studies were included in the review. The studies were conducted with relatively small samples of varying age groups (e.g. adolescents vs. adults), genders, and athletic levels (e.g. amateur vs elite). Second, intervention frequencies and durations differed across the studies. Additionally, the various COD tests used in the studies encompass distinct aspects or task-specific characteristics of COD. Collectively, these study heterogeneities have limited the generalizability of the review findings.

## Conclusion

In conclusion, this meta-analysis demonstrates that INT significantly improves COD performance. However, the effectiveness of INT on COD performance varies depending on factors such as gender, sports, and COD task measures.

## Practical applications

INT can be recommended as an effective form of physical conditioning for enhancing COD ability, but it is important to consider the potential variation in effects due to factors such as participant characteristics (e.g. gender), sport type, and COD task measures. Strength and conditioning professionals should take these variables into account when designing optimal INT programs to enhance COD ability for court-based sports players. Improved athletic performance related to INT may increase adherence to the programs, as coaches would have an additional incentive to train the players. Consequently, strength and conditioning professionals are encouraged to incorporate INT into comprehensive conditioning programs for court-based sports players to achieve optimal COD performance.

## Author contributions

All authors made significant contributions, including preparation of the first draft of the manuscript, data collection, analysis of data, interpretation of data, and provided significant revision and feedback, read, and approved the final manuscript.


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## References

1. Benis R, Bonato M and Torre AL. Elite female basketball players' body-weight neuromuscular training and performance on the Y-balance test. *J Athl Train* 2016; 51: 688–695.
2. Bloomfield J, Polman R, O'Donoghue P, et al. Turning movements performed during FA premier league soccer matches. *J Sports Sci Med* 2007; 6: 9–10.
3. Póvoas SC, Seabra AF, Ascensão AA, et al. Physical and physiological demands of elite team handball. *J Strength Cond Res* 2012; 26: 3365–3375.
4. Conte D, Favero TG, Lupo C, et al. Time-motion analysis of Italian elite women's basketball games: individual and team analyses. *J Strength Cond Res* 2015; 29: 144–150.
5. Abdelkrim NB, El Fazaa S and El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med* 2007; 41: 69–75.
6. Duthie GM, Pyne DB, Marsh DJ, et al. Sprint patterns in rugby union players during competition. *J Strength Cond Res* 2006; 20: 208.
7. Sheppard JM and Young WB. Agility literature review: classifications, training and testing. *J Sports Sci* 2006; 24: 919–932.
8. Young W and Farrow D. A review of agility: practical applications for strength and conditioning. *Strength Cond J* 2006; 28: 24.
9. Hrysomallis C. Injury incidence, risk factors and prevention in Australian rules football. *Sports Med* 2013; 43: 339–354.
10. Paul DJ, Gabbett TJ and Nassis GP. Agility in team sports: testing, training and factors affecting performance. *Sports Med* 2016; 46: 421–442.
11. Polman R, Walsh D, Bloomfield J, et al. Effective conditioning of female soccer players. *J Sports Sci* 2004; 22: 191–203.
12. Miller MG, Herniman JJ, Ricard MD, et al. The effects of a 6-week plyometric training program on agility. *J Sports Sci Med* 2006; 5: 459.
13. Myer GD, Faigenbaum AD, Ford KR, et al. When to initiate integrative neuromuscular training to reduce sports-related injuries in youth? *Curr Sports Med Rep* 2011; 10: 155.
14. Fort-Vanmeerhaeghe A, Romero-Rodriguez D, Lloyd RS, et al. Integrative neuromuscular training in youth athletes. Part II: strategies to prevent injuries and improve performance. *Strength Cond J* 2016; 38: 9–27.
15. Lauersen JB, Bertelsen DM and Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. *Br J Sports Med* 2014; 48: 871–877.
16. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009; 151: 264–269.

17. Huedo-Medina TB, Sánchez-Meca J, Marín-Martínez F, et al. Assessing heterogeneity in meta-analysis:  $q$  statistic or  $I^2$  index? *Psychol Med* 2006; 11: 193.
18. Egger M, Smith GD, Schneider M, et al. Bias in meta-analysis detected by a simple, graphical test. *Br Med J* 1997; 315: 629–634.
19. Hopkins W, Marshall S, Batterham A, et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41: 3.
20. NIH, National, Heart, Lung, and Blood Institute. Quality assessment tool for before-after (pre-post) studies with no control group. 2014. <https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools>.
21. Menezes GB, Alexandre DR, Pinto JCL, et al. Effects of integrative neuromuscular training on motor performance in prepubertal soccer players. *J Strength Cond Res* 2022; 36: 1667–1674.
22. Ling DI, Janosky J, Schneider B, et al. A controlled trial of the effects of neuromuscular training on physical performance in male and female high school athletes. *Sports Health* 2023; 15: 386–396.
23. Kooroshfard N and Rahimi Z. The effect of the neuromuscular, strength, and combined training on balance and performance in female basketball players. *Phys Treatments-Specific Phys Therapy J* 2022; 12: 41–50.
24. Gidu DV, Badau D, Stoica M, et al. The effects of proprioceptive training on balance, strength, agility and dribbling in adolescent male soccer players. *Int J Environ Res Public Health* 2022; 19: 1–15.
25. Zhao W, Wang C, Bi Y, et al. Effect of integrative neuromuscular training for injury prevention and sports performance of female badminton players. *BioMed Res Int* 2021; 5555853:1–12.
26. Puzi MHB and Choo LA. The effect of six weeks CoBAgi training on coordination, dynamic balance & agility of adolescent handball players. *Peda Phys Cult Sport* 2021; 25: 31–38.
27. Hovsepian A, Esfarjani F, Bambaiechi E, et al. The effect of high intensity functional training on the oxidative status, muscle damage and performance of basketball players. *J Sports Med Phys Fit* 2021; 61: 188–198.
28. González-Fernández FT, Sarmiento H, Castillo-Rodríguez A, et al. Effects of a 10-week combined coordination and agility training program on young male soccer players. *Int J Environ Res Public Health* 2021; 18: 1–12.
29. Boraczyński M, Boraczyński T, Gajewski J, et al. Effects of intensity modulated total-body circuit training combined with soccer training on physical fitness in prepubertal boys after a 6-month intervention. *J Hum Kinet* 2021; 80: 207–222.
30. Aloui G, Hermassi S, Khemiri A, et al. An 8-week program of plyometrics and sprints with changes of direction improved anaerobic fitness in young male soccer players. *Int J Environ Res Public Health* 2021; 18: 1–13.
31. Trajković N and Bogataj Š. Effects of neuromuscular training on motor competence and physical performance in young female volleyball players. *Int J Environ Res Public Health* 2020; 17: 1–12.
32. Panagoulis C, Chatzinikolaou A, Avloniti A, et al. In-season integrative neuromuscular strength training improves performance of early-adolescent soccer athletes. *J Strength Cond Res* 2020; 34: 516–526.
33. Gee TI, Morrow RA, Stone MR, et al. A neuromuscular training program enhances dynamic neuromuscular control and physical performance in court-sport athletes. *Transl Sports Med* 2020; 3: 9–15.
34. Fernandez-Fernandez J, García-Tormo V, Santos-Rosa FJ, et al. The effect of a neuromuscular vs. dynamic warm-up on physical performance in young tennis players. *J Strength Cond Res* 2020; 34: 2776–2784.
35. Zouhal H, Abderrahman AB, Dupont G, et al. Effects of neuromuscular training on agility performance in elite soccer players. *Front Physiol* 2019; 10: 1–9.
36. Muniraju S and Santhosha C. Effect of circuit training on selected physical variables among school football players. *Online Int Interdisciplinary Res J* 2020; 8: 2480–2486.
37. Hermassi S, Wollny R, Schwesig R, et al. Effects of in-season circuit training on physical abilities in male handball players. *J Strength Cond Res* 2019; 33: 944–957.
38. Hammami M, Gaamouri N, Aloui G, et al. Effects of a complex strength-training program on athletic performance of junior female handball players. *Int J Sports Physiol Perf* 2019; 14: 163–169.
39. Gopianathan P. Effect of circuit training on speed, agility and explosive power among inter collegiate handball players. *J Yogic Human Movement Sports Sci* 2019; 4: 1294–1296.
40. Canlı U. Effects of neuromuscular training on motoric and selected basketball skills in pre-pubescent basketball players. *Universal J Edu Res* 2019; 7: 16–23.
41. Moreira NB, Alves RC, Ferandes DYB, et al. Effect of proprioceptive training and central stabilization in physical fitness in young soccer players. *J Phys Edu Sport* 2017; 17: 810–814.
42. Ahmed TAE. Improving musculoskeletal fitness and the performance enhancement of basketball skills through neuromuscular training program. *J Hum Sport Exerc* 2015; 10: 795–804.
43. Lindblom H, Walden M and Hagglund M. No effect on performance tests from a neuromuscular warm-up programme in youth female football: a randomised controlled trial. *Knee Surg Sports Traumatol Arthrosc* 2012; 20: 2112–2119.
44. Chaabene H, Prieske O, Negra Y, et al. Change of direction speed: toward a strength training approach with accentuated eccentric muscle actions. *Sports Med* 2018; 48: 1773–1779.
45. Kibler WB, Press J and Sciascia A. The role of core stability in athletic function. *Sports Med* 2006; 36: 189–198.
46. Zemková E and Hamar D. Sport-specific assessment of the effectiveness of neuromuscular training in young athletes. *Front Physiol* 2018; 9: 264.
47. Manolopoulos K, Gissis I, Galazoulas C, et al. Effect of combined sensorimotor-resistance training on strength, balance, and jumping performance of soccer players. *J Strength Cond Res* 2016; 30: 53–59.
48. de Villarreal ES, Requena B, Cronin JB, et al. The effects of plyometric training on sprint performance: a meta-analysis. *J Strength Cond Res* 2012; 26: 575–584.
49. Miller AEJ, MacDougall J, Tarnopolsky M, et al. Gender differences in strength and muscle fiber characteristics. *Eur J Appl Physiol Occup Physiol* 1993; 66: 254–262.
50. Nagano Y, Ida H, Akai M, et al. Relationship between three-dimensional kinematics of knee and trunk motion during shuttle run cutting. *J Sports Sci* 2011; 29: 1525–1534.

51. De Luca CJ and Mambrito B. Voluntary control of motor units in human antagonist muscles: coactivation and reciprocal activation. *J Neurophysiol* 1987; 58: 525–542.
52. Sigward SM and Powers CM. The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. *Clin Biomech* 2006; 21: 41–48.
53. McLean SG, Huang X and Van Den Bogert AJ. Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: implications for ACL injury. *J Sci Med Sport* 2005; 20: 863–870.
54. Malinzak RA, Colby SM, Kirkendall DT, et al. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech* 2001; 16: 438–445.
55. McLEAN SG, Neal RJ, Myers PT, et al. Knee joint kinematics during the sidestep cutting maneuver: potential for injury in women. *Med Sci Sports Exerc* 1999; 31: 959–968.
56. Asadi A, Arazi H, Young WB, et al. The effects of plyometric training on change-of-direction ability: a meta-analysis. *Int J Sports Physiol Perform* 2016; 11: 563–573.
57. Arazi H, Coetzee B and Asadi A. Comparative effect of land-and aquatic-based plyometric training on jumping ability and agility of young basketball players. *S Afr J Res Sport Phys Edu Rec* 2012; 34: 1–14.
58. Nimphius S, Callaghan SJ, Bezodis NE, et al. Change of direction and agility tests: challenging our current measures of performance. *Strength Cond J* 2018; 40: 26–38.
59. DeWeese BH and Nimphius S. Program design and technique for speed and agility training. In: Haff GG and Triplett NT (eds) *Essentials of Strength Training and Conditioning*. 4th ed. Lower Mitcham: Human Kinetics, 2016, pp. 521–558.