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Effectiveness of core strength training for racket sport athletes' performance: a systematic review and meta-analysis

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This meta-analysis examined the effects of core strength training (CST) on physical fitness and technical performance in racket sport athletes. Eighteen studies involving tennis, badminton, and table tennis were included. Compared with control conditions, CST was associated with significant improvements in several physical performance outcomes, including balance, agility, core endurance, and muscular strength. In addition, CST demonstrated beneficial effects on technical performance indicators such as ball velocity, spin control, and shot accuracy. Given the shared biomechanical demands of racket sports, including trunk rotation, kinetic chain efficiency, and coordinated whole-body movement, these findings support the role of CST as a targeted, sport-specific training strategy. This study provides the first quantitative synthesis focusing exclusively on racket sport athletes, offering practical insights for coaches and practitioners seeking to enhance performance within high-speed, multidirectional racket sport contexts.

Keywords Racket sport, Core strength training, Physical fitness, Performance

Racket sports, including tennis, badminton, squash, and table tennis, require athletes to execute rapid and coordinated full-body movements. Core strength, which involves the muscles of the abdomen, pelvis, lower back, and hips, is fundamentally important for these athletes as it facilitates efficient force transfer, trunk stability, and dynamic balance during explosive strokes and agile movements on court[1]. Effective stroke production—such as a tennis serve, badminton smash, or squash forehand—heavily depends on the core's ability to efficiently channel energy generated by the lower limbs upward through the kinetic chain, ultimately enhancing racket velocity and precision[2]. Inadequate core strength can disrupt this energy transfer, reducing stroke effectiveness and potentially elevating injury risk, particularly in the shoulders, elbows, and spine[2,3]. Thus, developing core stability is crucial not only for optimizing performance but also for injury prevention across racket sports.

Given the shared demands across racket sports, it is reasonable to examine them collectively when studying core training effects. Because the biomechanical similarities across racket disciplines justify a combined analysis. Despite differences in equipment and court dynamics, racket sports share critical movement patterns: trunk rotations, rapid directional changes, lateral lunges, and explosive overhead actions, all reliant upon core musculature[4–7]. Researchers frequently employ similar core training protocols—such as medicine ball throws, planks, and rotational exercises—across racket sports due to their shared physical demands and kinetic chain utilization[8,9]. Furthermore, research evidence within any individual racket sport remains limited, making it difficult to draw broad conclusions. Combining these sports provides a larger and richer dataset, enabling more reliable conclusions about the overall impact of core strength training (CST) in this specific athletic population.

Previous studies have provided initial evidence supporting CST's benefits. For instance, badminton and tennis studies have shown enhanced stroke velocity, improved agility, and better balance following CST interventions[10–12]. However, results across studies have been mixed. Some research found only minimal or non-significant improvements in sport-specific outcomes such as stroke speed and agility after isolated CST programs[13]. These inconsistencies may reflect differences in study designs, participant levels, training durations, or exercise specificity, highlighting the need for a systematic synthesis of existing evidence.

To date, reviews of core training in sports have been limited in scope. Notably, Ahmed conducted a narrative review, which qualitatively summarized the literature on tennis, badminton, and similar sports[2].

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That review concluded that most studies observed improvements in upper-limb performance following CST, and it emphasized the core's importance for athletic enhancement. However, the authors also highlighted the paucity of high-quality evidence and called for more rigorous research, noting that their conclusions were based on only five studies and lacked any quantitative effect size synthesis. In addition, their focus was narrowly on upper extremity outcomes, without examining lower-body or whole-performance metrics like agility, speed, or competitive success. Thus, while the narrative review underscored a likely benefit of core training in racket sports, it left open questions about the magnitude of these effects and their generalizability beyond arm function.

More broadly, several systematic reviews and meta-analyses have evaluated CST across various athletic populations. However, most of these syntheses group together a wide range of sports and are not specific to racket disciplines. For example, Rodríguez-Perea reported that CST improves general physical attributes such as balance and jump height, highlighting its role in overall athleticism[3]. Yet, when it comes to sport-specific performance, the evidence is less consistent. Dong found that although CST significantly enhanced core endurance and stability, its effects on specific performance indicators—such as speed and maximal strength—were negligible[14]. Agility showed moderate improvement but failed to reach statistical significance. These findings suggest that generic CST programs may not directly translate into competitive performance benefits unless they are tailored to the movement demands of the sport. Importantly, none of these systematic reviews or meta-analyses have focused exclusively on racket sports. By including sports with very different biomechanical profiles (e.g., soccer, volleyball, field sports), prior reviews[3,14,15] may have underestimated CST's impact in sports like tennis or badminton, where trunk rotation and postural control are central to performance. This underscores the need for a sport-specific synthesis focused on racket athletes.

This study addresses a critical gap by providing the first quantitative evaluation of CST effects specifically in racket sport athletes. By synthesizing data across tennis, badminton, squash, table tennis, and related disciplines, this study examines whether CST consistently improves physical fitness and sport-specific outcomes in these populations. Unlike prior narrative reviews that lacked statistical aggregation, this meta-analysis produces pooled effect sizes, offering clearer estimates of CST's impact on key outcomes. By limiting the scope to racket sports, we reduce confounding from unrelated athletic contexts and target the domain where CST may be most relevant. If CST is shown to be effective, it would provide evidence-based support for prioritizing core training in conditioning programs and offer practical insights for coaches and practitioners.

Methods

This study followed the PRISMA guidelines to conduct and was registered with the PROSPERO (CRD420251031236).

Search strategy

This study conducted a literature search through the Web of Science, Scopus, SportDiscus, and PubMed databases, with the search date cutoff in April 2025. The following search terms were used: ("core training" OR "core strength training" OR "core stability training" OR "core muscle training" OR "core muscle" OR "core exercise" OR "core strength exercise" OR "core stability exercise" OR "core muscle exercise") AND ("table tennis" OR "ping-pong" OR "badminton" OR "tennis" OR "pickleball" OR "squash" OR "racquetball" OR "racket" OR "racquet").

Eligibility criteria

The inclusion criteria for this study were based on the PICOS framework, which encompasses Population, Intervention, Comparators, Outcomes, and Study Design (Table 1). As detailed below: (1) Population should be racket sport athletes, including but not limited to table tennis, badminton, and tennis, who were free from injury or known clinical conditions at the time of participation. No restrictions were applied based on gender, age, years of training, or skill level. (2) The intervention had to consist solely of core strength training. Studies that combined core training with other interventions (e.g., nutritional programs or additional training modalities) were excluded. To ensure sufficient training exposure and physiological adaptation, only interventions with a minimum duration of four weeks were considered eligible[3]. (3) The study must include a comparison between core strength training and control conditions, including no additional training, regular sport-specific training, or alternative training programs (e.g., traditional strength training). (4) At least one outcome measure had to be related to physical or sport-specific performance. (5) Only studies designed as randomized controlled trials (RCTs) were eligible. (6) Only studies published in English and peer-reviewed journals were included.

Items	Information
Population	Healthy racket sport athletes
Intervention	Core training for at least 4 weeks
Comparison	Core training vs. Other training
Outcomes	Athletes' physical fitness and performance
Study designs	RCT

Table 1. PICOS framework.

Study selection
After removing duplicate files using the reference management software Zotero, XW. Y and H.Y independently reviewed the titles and abstracts of the studies. Subsequently, full-text reviews were conducted for articles that potentially met the inclusion criteria to make a final determination. Any disagreements during the screening process were resolved by a third author J.Z. Additionally, while reviewing the literature, the authors also examined the reference lists of the studies included to identify any relevant articles that might have been overlooked.

Data extraction
After identifying the studies that met the final inclusion criteria, we extracted the necessary data from the literature. The extracted data included the following details: (a) author, (b) year of publication, (c) study country, (d) study design, (e) sample size, (f) type of athletes, (g) population characteristics, (h) intervention methods, (i) intervention duration, (j) frequency of intervention, (k) length of each intervention session.

Quality assessment
To assess the methodological quality of the included studies, we utilized the PEDro scale, a widely recognized tool for evaluating the internal validity and methodological quality of randomized controlled trials (RCTs)[16]. The PEDro scale consists of 11 criteria that assess key aspects such as random allocation, blinding, and statistical analysis. It is important to note that the first Eligibility Criterion is not included in the total score, so the maximum possible score on the PEDro scale is 10 points. Higher scores indicate better methodological quality, with a study scoring 6 or above considered to have adequate quality[17]. Studies that scored 3 or below were categorized as low-quality and excluded from this study.

Risk of bias
We assessed the risk of bias in the included studies using the Cochrane Risk of Bias (RoB). This tool evaluates potential biases across seven domains: selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), reporting bias (selective reporting), and other potential biases. Each domain was rated as "low," "high," or "unclear" risk of bias, based on the information provided in the studies. The Cochrane Risk of Bias Tool is considered the gold standard for assessing the internal validity of studies, ensuring that the results of the meta-analysis are based on reliable evidence[18].

Data analysis
Given that each study may use different methods to assess the same outcome, which can introduce variability in the results, we chose to calculate the effect size using Cohen's d for the meta-analysis. Effect size magnitudes were interpreted according to Cohen's conventions, where values of 0.2, 0.5, and 0.8 represent small, medium, and large effects, respectively[19]. To enhance the robustness and reliability of the findings, only studies that reported data on the same outcome measure and where at least four studies were available with usable data were included in the meta-analysis. Outcomes for which fewer than four studies were available, or for which studies did not report sufficient quantitative data (e.g., means and standard deviations), were synthesized qualitatively rather than included in the meta-analysis. We employed a random-effects model for the meta-analysis to account for potential variations between studies. The degree of heterogeneity among studies was assessed using the I^2 statistic. An I^2 value of 0% suggests no observed heterogeneity, while values of 25%, 50%, and 75% represent low, moderate, and high levels of heterogeneity, respectively[20]. Higher I^2 values indicate greater variability between studies, which may suggest the presence of other factors influencing the results.

Results
Study selection
Through the search process, a total of 514 articles were initially identified across the databases. After removing duplicate records, 316 articles remained for title and abstract screening. Following this stage, 31 articles proceeded to full-text review. During the full-text assessment, 2 articles were excluded because they were not written in English, 3 articles were excluded due to inappropriate study populations, and 4 articles were excluded because their interventions combined CST with other measures (e.g., nutritional interventions or sleep management) rather than focusing solely on CST. Additionally, 4 articles were excluded because their study designs were not RCT, and 1 article was excluded due to low methodological quality. Moreover, during the reference-checking process of the included studies, one additional article that met the inclusion criteria was identified. Ultimately, 18 articles were included in this study (as shown in Fig. 1).

Quality assessment
The overall quality of the studies included, as assessed using the PEDro scale, varied, with scores ranging from 4 to 7 (as shown in Table 2). Studies with higher scores (6 or above) generally demonstrated better methodological quality, including random allocation, follow-up, and intention-to-treat analysis. However, most studies exhibited limitations in critical areas such as the blinding of participants, therapists, and assessors, as well as the lack of detailed between-group comparisons. These factors contributed to lower methodological quality in studies scoring 3 or below, which were excluded from this study due to concerns about potential bias and reliability.

Risk of bias
The risk of bias assessment, conducted using the Cochrane Risk of Bias Tool, revealed varying levels of methodological quality across studies (as shown in Fig. 2). Most studies showed a low risk of bias in domains such as incomplete outcome data, selective reporting, and random sequence generation. However, a high risk

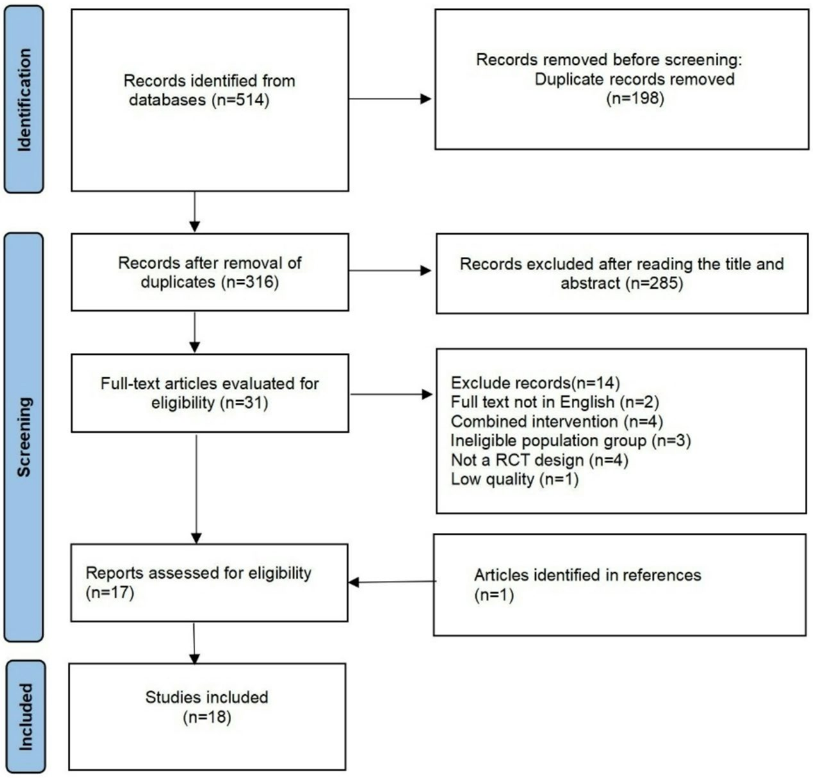

Fig. 1. Flow chart.

of bias was commonly observed in the blinding of participants and personnel, as well as in the blinding of outcome assessment. Allocation concealment also showed a considerable proportion of high or unclear risk. These results indicate that while some methodological safeguards were present, issues related to blinding and allocation concealment were prevalent among the included studies.

Study characteristics

Eighteen RCTs were included in this study (as shown in Table 3). Of these studies by country or region, nine were conducted in China[11,12,21,25,26,28,29,32,34], five in Turkey[24,27,30,31,33], two in India[10,22], one in Taiwan[23], and one in the United States[13]. In terms of sports disciplines, two studies involved table tennis players[25,26], four studies focused on badminton athletes[10,12,21,31], and the remaining eleven examined tennis athletes[11,13,22–24,27–30,32–34]. Participants were predominantly adolescent or young adult athletes, with reported mean ages ranging from 12[30] to 35[13] years old. Gender distribution varied across studies: four studies included only male participants[12,21,29,33,34], 1 included only female participants[11], six studies included mixed-gender sample[13,24–26,31,32], and the remaining six studies did not mention sample gender. Most participants were identified as competitive, collegiate, or national-level athletes, suggesting a moderately to highly trained population. The sample sizes ranged from 12[29] to 40[24,31] participants, with a median and mean of 26 and 31.65, respectively.

Most of the included studies adopted a combination of dynamic and static core strength training methods. In all studies, participants were divided into two groups for comparison. Specifically, sixteen studies employed CCST protocols[10,12,13,21,22,24–34], while two studies adopted DCST[11,23] approaches. Regarding the control conditions, seven studies used an NT group[13,24,27,28,30,31,33] as the comparator, four studies used RT approaches[22,23,25,26], six studies employed TST as the control group[11,12,21,29,32,34], and one study used the PT[10] program. The intervention durations and session times varied across studies. Nine studies implemented CST sessions lasting 30 min or less[11,13,21,25,27–31], while five studies used sessions longer than 30 minutes[12,23,24,32,34], and four studies did not report the session duration[10,22,26,33]. In terms of training frequency, ten studies applied a regimen of 3 sessions per week[11,12,21–23,27,28,30,31,33,34], one study conducted training 4 times per week[32], three studies scheduled training 2 times per week[10,13,24], and three studies did not report the training frequency[25,26,29]. Regarding intervention duration, ten studies had interventions lasting 8 weeks or fewer[10,13,22–24,27,29,30,33,34], while seven studies lasted more than 8 weeks[11,12,21,25,26,28,32], and one study did not report the intervention duration[31]. The outcome measures assessed across studies were diverse, reflecting multiple aspects of athletic performance. Commonly evaluated outcomes included core stability, core endurance, balance, agility, strength, flexibility, and sport-specific technique.

Study	Eligibility criteria	Random allocation	Allocation concealment	Baseline comparability	Blind participants	Blind therapist	Blind assessor	FollowUp	Intention to Treat Analysis	Between-Group Comparisons	Point Measure and Variability	Total PEDro Score
Sun[21]	1	1	0	1	0	0	0	1	0	1	1	5
Zhou[12]	1	1	0	1	0	0	0	1	1	1	1	6
Khatoon[10]	1	1	0	1	0	0	0	1	0	0	1	4
Wang[11]	1	1	0	1	0	0	0	1	0	1	1	5
Bashir[22]	1	1	0	0	0	0	0	1	0	1	1	4
Huang[23]	1	1	0	1	0	0	0	1	1	1	1	6
Gergüz[24]	1	1	0	1	0	0	0	1	1	1	1	6
Meng[25]	1	1	0	0	0	0	0	1	0	1	1	4
Guo[26]	0	1	0	0	0	0	0	1	0	1	1	4
Esen[27]	0	1	0	0	0	0	0	1	0	1	1	4
Liu[28]	0	1	0	0	0	0	0	1	0	1	1	4
Ma[29]	1	1	0	1	0	0	0	1	0	0	1	4
Arslan[30]	1	1	0	1	0	0	0	1	1	1	1	6
McCurdy[13]	1	1	0	1	0	0	0	1	1	1	1	6
Yüksel[31]	1	1	0	0	0	0	0	1	1	1	0	4
Chen[32]	1	1	0	1	1	1	0	1	0	1	1	7
Türkmen[33]	1	1	0	1	0	0	0	1	0	1	1	5
Cui[34]	1	1	0	1	0	0	0	0	1	1	1	5

Table 2. PEDro scale.

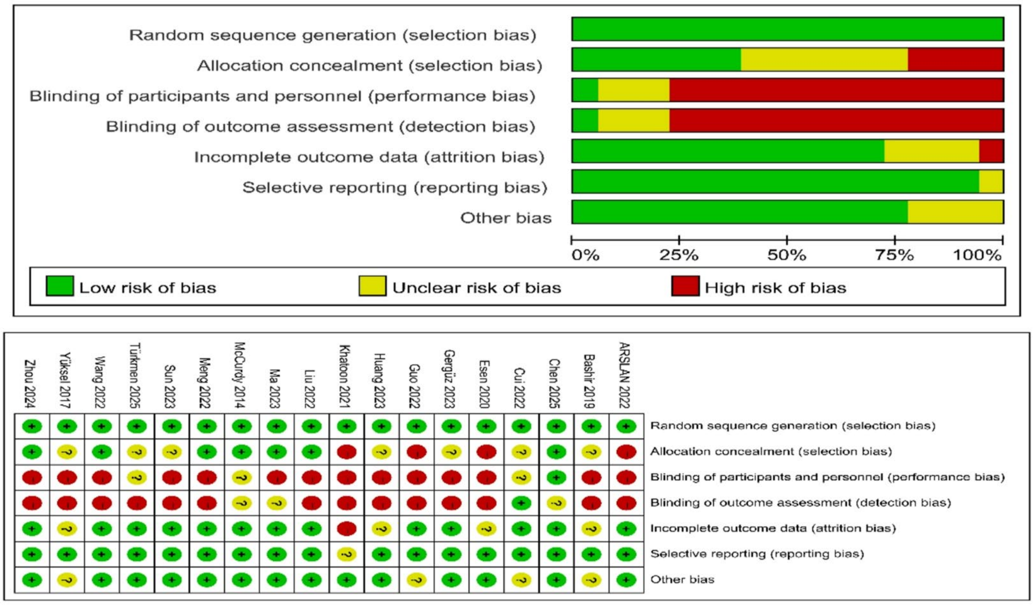

Fig. 2. Risk of bias graph and summary.

Effect of core strength training on physical fitness

Among the eighteen studies included in this study, fifteen studies examined the impact of CST on physical fitness. These studies assessed a range of physical fitness components, with varying outcomes across the trials. Specifically, seven studies measured balance[10,12,22,24,27,31,33], five studies evaluated strength[12,21,29,30,33], six studies focused on agility[10,22,29,30,33,34], seven studies evaluated stability[11,21,24–26,31,34] three studies measured endurance[10,11,29], and two studies evaluated flexibility[21,24].

Balance

Seven studies evaluated the effects of CST on balance performance. Among these, four studies employed the Star Excursion Balance Test (SEBT)[10,22,27,31], two studies utilized the Flamingo Balance Test[24,33], and one study used the Eyes-Closed Balance Test as the assessment method[12]. Although all seven studies assessed balance-related outcomes, only four studies provided sufficiently homogeneous and extractable quantitative data to be included in the meta-analysis. Despite the variation in balance measurement tools, the meta-analysis revealed a significant positive effect of CST on balance (Fig. 3). The pooled effect size was large, with a Cohen's d of 1.16 (95% CI: 0.40 to 1.92, $p = 0.003$), indicating that CST substantially improved balance ability among racket athletes compared to control conditions. Given the substantial heterogeneity among studies ($I^2 = 91\%$), we performed a sensitivity analysis. The pooled effect size remained statistically significant after the exclusion of outliers, indicating the robustness of the findings (as shown in Fig. 4). In addition to the studies included in the meta-analysis, three studies assessed balance outcomes but could not be quantitatively pooled due to insufficient data reporting or the use of non-comparable balance assessment tools. All three studies reported significant improvements in balance performance following CST compared with control conditions ($P < 0.05$), indicating a consistent direction of effect that supports the findings of the meta-analysis.

Strength

Five studies assessed the effects of CST on strength-related outcomes. Among these, two studies specifically evaluated core strength[12,33], with both reporting significant improvements favoring the CST group. One study examined upper-body strength and found a significant positive effect[29]. Three studies assessed lower-body strength; two of them reported significant improvements following CST interventions[30,33], while one study, which used a squat test as the primary outcome measure, did not find a statistically significant difference between the intervention and control groups[21]. Due to heterogeneity in strength domains assessed and outcome measurement methods, as well as the limited number of studies within each strength category, a quantitative meta-analysis was not performed. Overall, qualitative synthesis indicates that CST is generally effective in enhancing core and upper-body strength, while its effects on lower-body strength appear to be inconsistent across studies.

Endurance

As fewer than four studies were available, findings were synthesized qualitatively. Three studies investigated the effect of CST on core muscle endurance. Two of these studies were conducted among tennis athletes[11,29], and one focused on badminton players[10]. Although the studies employed different assessment methods to evaluate endurance performance, all three consistently reported significant improvements in core muscle endurance following CST interventions.

Study	Population		Interventions		Measurement Index	Outcomes
	Type of athletes	Sample/Age/Gender	Method	Time/Frequency/Duration		
Sun[21]/China/RCT	Collegiate badminton athletes	20/18.0 ± 1.04/100%male	EG: CCST CG: TST	25 min/3 times weekly/10 weeks	FMS Technique	FMS: squat ↔; hurdle↔; straight squat ($P<0.05$)↑; shoulder flexibility↔; lower waist flexibility ↔; body control push up ↔; swivel stability ($P<0.05$)↑; Skill: back toss medicine ball ↔; badminton throw ($P<0.01$)↑; backhand draw ($P<0.05$)↑; forehand kick ($P<0.05$)↑; backhand kick ($P<0.05$)↑
Zhou[12]/China/RCT	Collegiate badminton athletes	20/22.15 ± 0.17/100%male	EG: CCST CG: TST	120 min/3 times weekly/12 weeks	Physical fitness technique	Core strength: badminton throw($P<0.05$)↑; sit-up ($P<0.05$)↑; 8-stage abdominal bridge ↔ Balance: eyes-closed single leg standing ($P<0.05$)↑; eyes-closed straight-line walking ($P<0.05$)↑ Smash: stroke speed ($P<0.01$)↑; placement stability ($P<0.01$)↑
Khatoon[10]/India/RCT	Collegiate badminton athletes	34/19–23/NR	EG: CCST CG: PT	NR/2 times weekly/6 weeks	Physical fitness	Star excursion balance test ($P<0.05$)↑; Agility ($P<0.05$)↑; core endurance ($P<0.05$)↑
Wang[11]/China/RCT	Collegiate tennis athletes	23/18.04 ± 2.07/100% female	EG: DCST CG: TST	30 min/3 times weekly/9 weeks	Physical fitness technique	Core stability: supine leg lift ($P<0.05$)↑; core endurance: abdominal fatigue test ($P<0.05$)↑; supine back extension ($P<0.05$)↑ Technique: serve accuracy ($P<0.05$)↑; serve speed ($P<0.05$)↑; volley ($P<0.05$) ↓
Bashir[22]/India/RCT	Adolescent junior tennis players	30/15.3 ± 0.8/NR	EG: CCST CG: RT	NR/3 times weekly/5 weeks	Physical fitness	Star excursion balance test ($P<0.01$)↑; Agility ($P<0.01$)↑
Huang[23]/Taiwan/RCT	Collegiate tennis athletes	30/21.9 ± 1.9/NR	EG: DCST CG: RT	60 min/3 times weekly/8 weeks	Technique	Accuracy: BC($P<0.05$)↑RFC ($P<0.05$)↑;RFD($P<0.05$)↑; RBC ($P<0.05$)↑; RBD ($P<0.05$)↑; FC ↔; FD ↔; BD ↔Ball Speed: FC ($P<0.05$)↑, FD ($P<0.05$)↑; BC ($P<0.05$)↑; BD ($P<0.05$)↑; RFC↔; RFD ($P<0.05$)↑; RBC ($P<0.05$)↑, RBD↔
Gergüz[24]/Turkey/RCT	Junior tennis players	40/12.03 ± 3.54/50% male	EG: CCST CG: NT	50 min/2 times weekly/8 weeks	Physical fitnessQuality of life	Core stability ($P<0.01$)↑; lower waist flexibility ($P<0.01$)↑; shoulder flexibility ($P<0.01$)↑; static balance ($P<0.01$)↑; dynamic balance ($P<0.01$)↑; stability ($P<0.01$)↑ Physical functioning ↔; bodily pain ($P<0.01$)↑; vitality ($P<0.01$)↑; mental health ($P<0.01$)↑; general health ($P<0.01$)↑
Meng[25]/China/RCT	National table tennis athletes	24/NR/71% male	EG: CCST CG: RT	25 min/NR/9 weeks	Physical fitness Technique	Core stability ($P<0.01$)↑ spin control ($P<0.05$)↑
Guo[26]/China/RCT	Adolescent table tennis athletes	27/9–17/63% male	EG: CCST CG: RT	NR/NR/12 weeks	Grade VIII abdominal bridge	Core stability ($P<0.01$)↑
Esen[27]/Turkey/RCT	Collegiate tennis players	26/NR/NR	EG: CCST CG: NT	30 min 3 times weekly/8 weeks	Star excursion balance test	Balance ($P<0.05$)↑
Liu[28]/China/RCT	Collegiate tennis players	20/NR/NR	EG: CCST CG: NT	30 min/3 times weekly/14 weeks	Technique	Serve speed ($P<0.05$)↑
Ma[29]/China/RCT	Adolescent tennis athletes	12/15.0 ± 3.8/100% male	EG: CCST CG: TST	20 min/NR/8 weeks	Physical fitness	Agility ($P<0.05$)↑; upper strength ($P<0.05$)↑, core endurance ($P<0.01$)↑;
Arslan[30]/Turkey/RCT	Adolescent tennis athletes	25/12.38 ± 1.21/NR	EG: CCST CG: NT	20 min/3 times weekly/8 weeks	Physical fitness Technique	Lower-body strength ($P<0.01$)↑; agility ($P<0.05$)↑; Comprehensive performance ($P<0.01$)↑
McCurdy[13] USA/RCT	Collegiate intermediate tennis players	35/26.14 ± 6.69/60% male	EG: CCST CG: NT	30 min/2 times weekly/8 weeks	Physical fitness Technique	Core stability ($P<0.05$)↑ Serve speed ↔
Yüksel[31]/Turkey/RCT	National Badminton players	40/18.98 ± 1.92/55% male	EG: CCST CG: NT	25 min/3 times weekly/8 weeks	Star excursion balance test	Balance ($P<0.05$)↑
Chen[32]/China/RCT	Collegiate tennis players	22/NR/64%male	EG: CCST CG: TST	45 min 4 times weekly/16 weeks	Technique	Stroke accuracy ($P<0.05$)↑; spin control ($P<0.01$)↑
Continued						

Study	Population		Interventions		Measurement Index	Outcomes
	Type of athletes	Sample/Age/Gender	Method	Time/Frequency/Duration		
Türkmen[33]/Turkey/RCT	Collegiate tennis players	30/20.47 ± 2.04/100% male	EG: CCST CG: NT	NR 3 times weekly/6 weeks	Physical fitness	Core strength ($P<0.01$)↑; balance ($P<0.05$)↑; lower-body strength ($P<0.05$)↑; agility ($P<0.05$)↑
Cui[34]/China/RCT	Adolescent tennis athletes	30/16/18/100% male	EG: CCST CG: TST	60 min/3 times weekly/8 weeks	Physical fitness	Agility ($P<0.05$)↑; core stability ($P<0.01$)↑

Table 3. Study characteristics. *RCT* randomized controlled trial, *EG* experimental group, *CG* comparison group, *CCST* combined core strength training, *DCST* dynamic core strength training, *TST* traditional strength training, *PT* plyometric training, *RT* regular training, *NT* no training, *NR* no report, FC forehand cross-court, *FD* forehand down-the-line, *BC* backhand cross-court, *BD* backhand down-the-line, *RFC* running forehand cross-court, *RFD* running forehand down-the-line, *RBD* running backhand down-the-line.

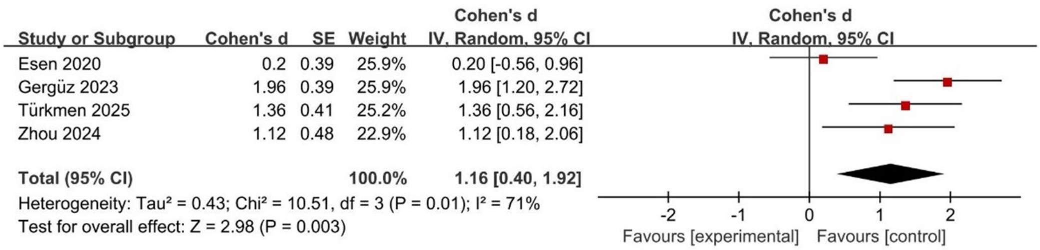

Fig. 3. Forest plot of the effect of CST on balance.

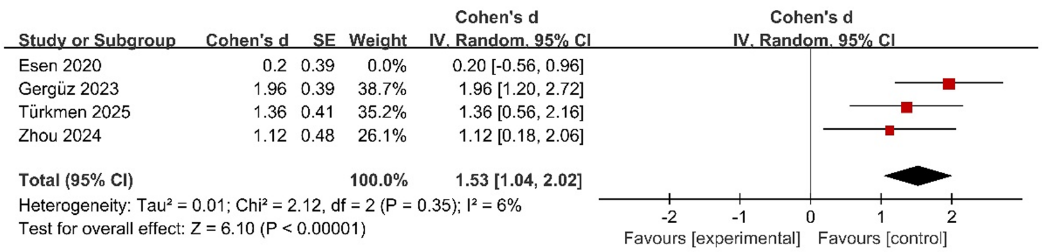

Fig. 4. Sensitivity analysis forest plot of the effect of CST on stability after excluding outlier studies.

Flexibility

Two studies examined the effects of CST on flexibility. One study reported significant improvements in both shoulder flexibility and low-waist flexibility following the CST intervention[24]. In contrast, the other study found no statistically significant changes in either of these flexibility domains[21]. Given the limited number of studies and inconsistent findings, a qualitative synthesis was conducted.

Agility

Six studies assessed the impact of CST on agility performance[10,22,29,30,33,34]. Most of these studies employed the Pro-Agility Test as the primary assessment tool, which is commonly used to evaluate rapid direction changes and reactive movement capacity in athletes. The meta-analysis revealed a significant positive effect of CST on agility (Fig. 5), with a pooled Cohen's d of 1.22 (95% CI: 0.78 to 1.66, p < 0.0001, Tau^2=0.00, I^2 = 0%). In addition to the studies included in the meta-analysis, two studies assessed agility but could not be quantitatively pooled due to insufficient data reporting. Both studies reported significant improvements in agility performance following CST compared with control conditions (P < 0.05), indicating a consistent direction of effect that supports the findings of the meta-analysis.

Stability

Six studies examined the effects of CST on stability[11,13,21,24–26]. The meta-analysis demonstrated a significant positive effect (Fig. 6), with a large pooled effect size of Cohen's d = 1.87 (95% CI: 0.73 to 3.02, p = 0.001, Tau^2=2.13, I^2 = 91%), indicating that CST substantially improves stability among athletes. Given the substantial heterogeneity among studies (I^2 = 91%), we performed a sensitivity analysis. The pooled effect size remained

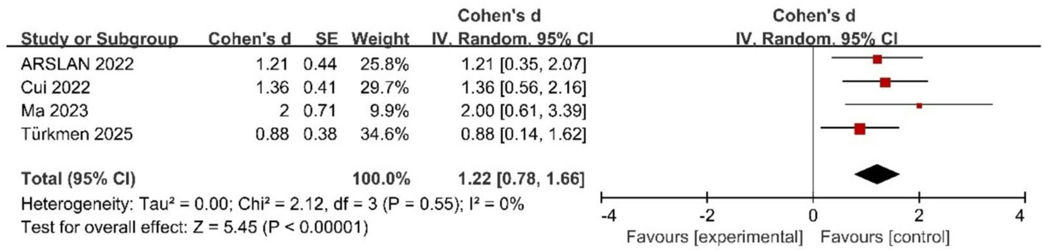

Fig. 5. Forest plot of the effect of CST on agility.

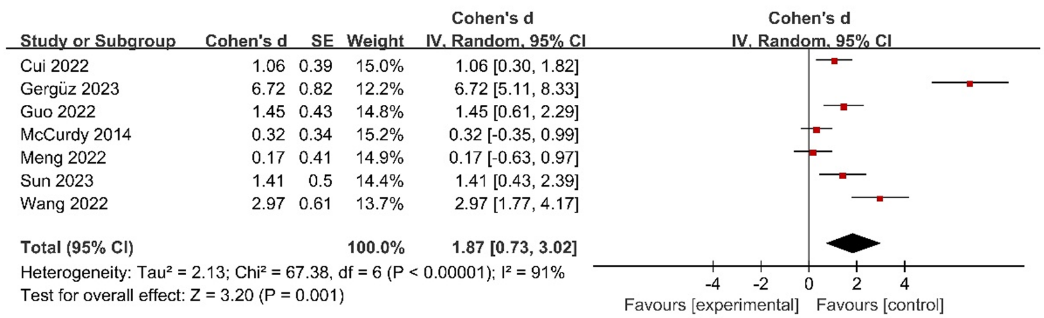

Fig. 6. Forest plot of the effect of CST on stability.

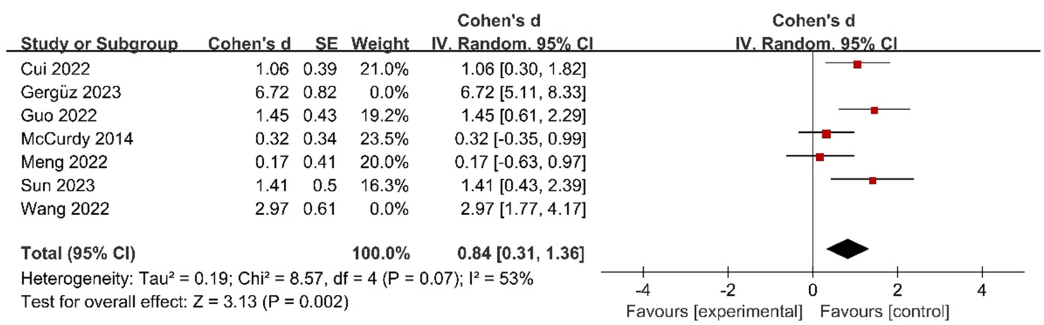

Fig. 7. Sensitivity analysis forest plot of the effect of CST on stability after excluding two outlier studies.

statistically significant after the exclusion of outliers, indicating the robustness of the findings (as shown in Fig. 7).

Effect of core strength training on technical performance

Eight studies evaluated the effects of CST on technical performance in racket sports. Among these, six studies assessed ball velocity[11–13,21,23,28], four studies measured ball accuracy[11,12,23,32], two studies evaluated spin control[25,32], and one study examined overall technical ability through a composite performance score[30].

Spin control

Two studies assessed the effects of CST on spin control in racket sports. Both studies consistently reported significant improvements in spin control following CST interventions. As only two studies were available, the results were summarized qualitatively rather than pooled quantitatively.

Ball accuracy

Four studies evaluated the impact of CST on ball placement accuracy. Despite variations in measurement tools and task designs across studies, all consistently reported significant improvements in accuracy outcomes for athletes who underwent CST interventions. Due to substantial heterogeneity in measurement protocols and insufficient data, a quantitative meta-analysis was not performed, and findings were synthesized qualitatively.

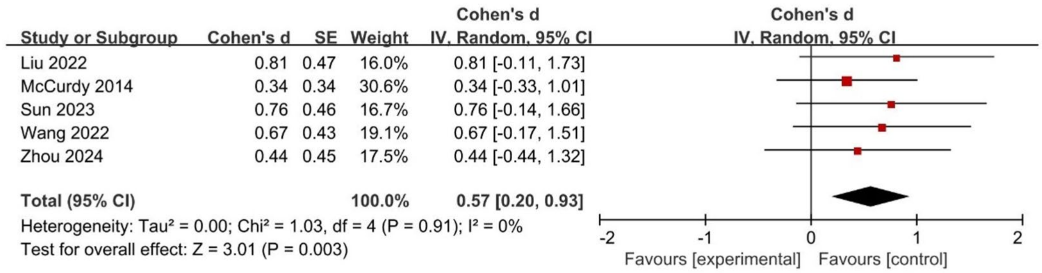

Fig. 8. Forest plot of the effect of CST on ball velocity.

Ball velocity
Six studies examined the effect of CST on ball velocity in racket sports. Despite variations in measurement protocols (e.g., smash speed, serve speed), the meta-analysis revealed a statistically significant positive effect of CST on ball velocity (as shown in Fig. 8). The pooled effect size was moderate, with a Cohen's d of 0.57 (95% CI: 0.20 to 0.93, $p = 0.0003$), and no heterogeneity was observed among the studies ($I^2 = 0\%$).

Discussion
This study examined the effects of CST on physical fitness and technical performance among racket sports athletes. Across the 18 included randomized controlled trials, CST was found to produce a range of significant benefits. Specifically, CST demonstrated a large and statistically significant effect on balance, and especially core stability, indicating significant improvements in neuromuscular control and postural coordination. Similarly, significant enhancements were observed in core endurance, strength (including core, upper, and lower body), and flexibility, although the latter showed inconsistent findings across studies. In terms of technical performance, CST was shown to be effective in improving ball velocity, accuracy, and spin control, with all relevant studies reporting favorable outcomes.

The overall methodological quality of the studies included was moderate. According to the PEDro scale, the total quality scores ranged from 4 to 7 out of a maximum of 10 points. While all studies reported random allocation and baseline comparability, only one study implemented blinding of participants or therapists, and no studies blinded outcome assessors. These limitations are common in exercise intervention studies due to the practical challenges of implementing blinding procedures[35]. The Cochrane Risk of Bias assessment further revealed similar concerns. Although most studies showed low risk in domains such as random sequence generation and incomplete outcome data, high or unclear risks were frequently identified in allocation concealment, performance bias (blinding of participants and personnel), and detection bias (blinding of outcome assessors). These methodological shortcomings may increase the potential for bias and should be taken into account when interpreting the overall findings. Despite these limitations, the consistency of positive outcomes across studies of varying quality suggests that the observed effects of CST are robust.

Effect of core strength training on physical fitness
CST was found to significantly improve balance performance, which aligns with previous findings. For instance, Rodríguez-Perea et al.[3] systematically reviewed multiple studies and similarly reported a strong positive effect of CST on balance among athletes, indicating consistent benefits across various sports contexts. However, the magnitude of the improvement observed in this study is higher compared to some prior studies. For example, one study observed only moderate improvements in dynamic balance among adolescent badminton players after CST[36]. This difference in outcomes could be attributed to variations in participant characteristics such as age, baseline balance proficiency, and training status, as well as discrepancies in intervention specifics, such as training duration, intensity, and exercise selection. The effectiveness of CST in enhancing balance can be explained through improved neuromuscular control and proprioception[37]. CST exercises typically involve maintaining or controlling challenging postures and positions, which require athletes to actively engage their core musculature. This continuous engagement enhances sensory feedback and neuromuscular coordination, crucial for maintaining balance during rapid, multidirectional movements inherent in racket sports. Consequently, athletes undergoing CST are better equipped to adjust their body positions in response to dynamic demands, leading to notable improvements in balance performance.

Agility also emerged as a domain positively influenced by CST, with multiple studies reporting meaningful improvements. However, discrepancies exist in broader contexts. Another recent meta-analysis[14], which included randomized controlled trials across various sports disciplines (without restricting to racket sports), found improvements in agility following CST interventions, but these improvements did not reach statistical significance. The difference between our findings and those may primarily result from variations in sports-specific movement demands. Racket sports inherently involve rapid and frequent changes in direction, short-distance movements, and high demands on lateral agility. Consequently, racket-sport athletes may exhibit greater sensitivity to CST interventions specifically tailored to enhance agility-related motor patterns, compared to athletes from sports with less agility-specific demands.

The effect of CST on strength-related outcomes was generally positive, though with some variation across studies, particularly in improving core and upper-body strength. These improvements may be attributed to the targeted activation of core musculature, which enhances force transmission and stability during upper-body movements[38]. However, the effects of CST on lower-body strength were less consistent throughout studies. Among three studies evaluating lower-body strength, two reported significant improvements[30,33], while another study that employed a squat test as the primary measure found no statistically significant difference[21]. This discrepancy may stem from several factors. First, CST primarily targets the lumbar-pelvic-hip complex rather than directly loading the lower limbs[37]. Thus, improvements in lower-body strength following CST may be indirect and dependent on the degree of neuromuscular integration or transfer effects from core musculature to lower extremities. Second, variations in exercise selection and specificity might explain these inconsistent results. Studies reporting significant improvements possibly utilized exercises more closely linked to lower-body movements involving hip extension or stabilization, facilitating better transfer to lower-body strength assessments[30,33]. In contrast, tests like squats may demand more direct leg-muscle activation, thus limiting the observable transfer from CST interventions alone[39,40]. Future research should focus on delineating specific exercise selections and protocols that optimize CST's effects on lower-body strength.

The findings regarding the effects of CST on flexibility were notably mixed, highlighting important discrepancies within the existing literature. The variability observed across studies can be attributed to several factors. Firstly, flexibility outcomes may depend heavily on the specific types of core exercises utilized. CST programs emphasizing predominantly static or strength-focused exercises may lack the adequate stimulus to induce meaningful changes in muscle length or joint range of motion[41,42]. Secondly, the duration and intensity of the interventions could also play a pivotal role; shorter interventions might be insufficient to elicit significant flexibility adaptations. Thirdly, baseline flexibility levels among participants could influence responsiveness to CST interventions. To maximize the potential flexibility benefits of CST, future training programs could consider integrating specific flexibility-enhancing exercises, such as dynamic stretches or yoga-inspired movements, into the existing core training regimen[43].

Among all physical parameters assessed, stability improvements were among the most substantial, suggesting that CST directly targets key neuromuscular systems underpinning this capacity. The underlying mechanisms responsible for CST-induced improvements in stability likely involve multiple physiological adaptations. Enhanced core stability is predominantly achieved through targeted training that increases the strength and endurance of deep core stabilizers, such as the transverse abdominis, multifidus, and pelvic floor muscles[44]. The improved strength and coordination of deep core stabilizing muscles enhances athletes' control over their center of gravity during dynamic movements, thereby minimizing trunk sway, increasing postural stability, and facilitating rapid and precise adjustments—essential during complex athletic tasks characteristic of racket sports.

Effect of core strength training on technical performance

In this study, CST was associated with a significant improvement in ball velocity among racket sport athletes, which was inconsistent with previous[45]. The biomechanical explanation for CST's contribution to ball velocity centers on the kinetic chain concept[46,47]. In racket sports, high-velocity movements—such as serves, smashes, and groundstrokes—require efficient force transmission through a sequential activation of body segments, typically from the ground up: beginning with the legs, progressing through the hips and trunk, and culminating in the upper limbs and racket. This energy flow is known as the proximal-to-distal sequencing of the kinetic chain. The core acts as a critical "force bridge" in this chain. A well-conditioned core enables efficient transfer of ground reaction forces from the lower extremities to the upper body, minimizing energy leaks and maximizing power output at the end-effector (i.e., the racket). Poor core stability or strength may interrupt this chain, reducing racket speed and, consequently, ball velocity. Studies such as Reid et al.[48] have emphasized that trunk rotation velocity is strongly correlated with racket head speed in tennis players, reinforcing the relevance of trunk conditioning in improving ball striking.

The analysis indicated that CST significantly improves ball accuracy, which aligns with previous research[15]. A strong core provides a stable base for the upper and lower body, facilitating efficient force transfer and precise movements[49]. This stability allows athletes to maintain proper posture and control during dynamic actions, leading to more accurate ball placement. Furthermore, CST may enhance the kinetic chain's efficiency, allowing for better synchronization between the upper and lower body during stroke execution[47]. This synchronization is essential for accurate ball placement, as it ensures that the force generated by the lower body is effectively transferred through the core to the upper body and ultimately to the racket. Combining CST with sport-specific skill training may yield more substantial improvements in ball accuracy. Future research should explore the optimal combination of CST and skill training to maximize performance outcomes in racket sports.

Spin control is a critical component of technical performance in racket sports, contributing to shot variation, precision, and tactical advantage. The findings from this study indicate that CST has a significant positive effect on athletes' ability to generate and regulate spin. CST enhances neuromuscular control and proprioception—key components in managing fine motor control during wrist and forearm manipulation, both of which are critical for adjusting spin angles and stroke mechanics[50,51]. However, the literature on CST's direct effect on spin control remains scarce. While preliminary findings are promising, existing studies are often limited by small sample sizes, lack of long-term follow-up, or sport-specific variability in how spin is measured and defined. Some researchers argue that CST alone may not be sufficient to elicit meaningful improvements in spin control unless it is integrated with technical skill practice targeting spin mechanics[2]. This suggests that the effectiveness of CST may be amplified when combined with sport-specific drills that emphasize racket face control, timing, and stroke variability.

Implication

The results of this study highlight the practical value of incorporating CST into racket sports training programs. CST was shown to improve both physical fitness and technical performance. Given the core's essential role in force transfer and postural control, CST should be considered a foundational component of athletic development across all levels. A combined approach using both static and dynamic exercises, performed 2–3 times per week for at least 4–8 weeks, appears effective. Integrating CST with sport-specific skill training may yield even greater improvements, particularly in technical outcomes. For younger athletes, CST supports motor coordination and movement quality, while in elite settings, it may enhance stroke efficiency and injury prevention[52]. To maximize effectiveness, practitioners should apply progressive overload principles and tailor CST programs to individual athlete needs, using standardized assessments to track performance gains.

Limitations

Despite the encouraging findings, several limitations should be acknowledged. First, the overall methodological quality of the studies included was moderate. Many studies lacked blinding procedures, and reporting of key intervention characteristics was often insufficient. These issues may have introduced bias and limited the precision of the pooled estimates. Second, substantial heterogeneity was observed for several outcomes, which is not uncommon in training intervention meta-analyses involving diverse athlete populations, intervention protocols, and outcome assessment methods. Although sensitivity analyses supported the robustness of the main findings, the presence of heterogeneity suggests that results should be interpreted with caution. Third, the included studies employed a variety of control conditions, including usual training and alternative training programs. As a result, the present meta-analysis primarily reflects the relative effectiveness of core strength training compared with commonly used training approaches, rather than its absolute effects compared with no training. The inclusion of active comparator groups may have reduced the contrast between intervention and control conditions and, consequently, attenuated observed effect sizes. Finally, the number of available studies for most outcomes was limited, and sample sizes were generally small. This constrained the feasibility of conducting subgroup analyses or meta-regression to explore potential moderators such as sport type, age, intervention duration, or training characteristics. In addition, most studies were conducted within specific geographic regions, which may limit the generalizability of the findings to broader racket sport athlete populations.

Future directions

Future research should address several key gaps identified in this review. First, there is a need for high-quality randomized controlled trials with rigorous methodological designs, including adequate sample sizes, assessor blinding, and transparent reporting of intervention protocols. Detailed descriptions of training intensity, progression, and supervision are essential to enhance reproducibility and facilitate meaningful synthesis across studies. Second, future studies should adopt standardized and sport-specific outcome measures, particularly for technical performance variables, to improve comparability and reduce methodological heterogeneity. Consistent reporting of quantitative data is also critical to enable inclusion in meta-analytic synthesis. Third, as the current evidence base expands, future meta-analyses would be well positioned to apply stricter control group classifications or conduct subgroup analyses based on control type, intervention duration, training frequency, or athlete characteristics. Such approaches would allow for cleaner causal contrasts and a more nuanced understanding of the conditions under which core strength training is most effective. Finally, future research should explore potential moderating factors, including age, sex, sport discipline, and training experience, as well as examine the long-term sustainability of CST-induced performance improvements. Longitudinal studies may also clarify the role of core strength training in injury prevention and long-term athlete development.

Conclusion

This study provides strong evidence that CST is an effective intervention for improving both physical fitness and technical performance in racket sports athletes. Importantly, this study helps to reconcile inconsistencies in previous findings and addresses a critical gap in the literature by synthesizing evidence across multiple racket sports and performance outcomes. Despite some methodological limitations, the overall results support the systematic integration of CST into athlete training programs. Future research should refine CST protocols and explore long-term effects using standardized methods to optimize application in sport-specific contexts.

Data availability

All data generated or analysed during this study are included in this published article.

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XW.Y wrote the main manuscript text, XW.Y, H.Y and J.Z collect the data. H.Y prepared the figures. J.Z supervised the manucript.

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Declarations

Competing interests
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