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Effects of speed, agility, and quickness training on athletic performance: a systematic review and meta-analysis

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Abstract

Background Previous studies have demonstrated the effects of SAQ training on sprint, change-of-direction, and jump performance in soccer players. However, further research is needed to assess its broader impact on different athletic populations and performance metrics. This study aims to expand the existing evidence by incorporating a wider range of outcomes and providing a more comprehensive analysis of SAQ training effects.

Methods A thorough search of databases, including Web of Science Core, SPORTDiscus, PubMed, and SCOPUS, was conducted, with data up to July 2024. The PEDro scale assessed study quality and RevMan 5.3 evaluated bias risk. Effect sizes (ES) were calculated from means and standard deviations, with heterogeneity assessed using the I^2 statistic. Publication bias was evaluated using an extended Egger test.

Results Eleven RCTs involving 499 healthy athletes from sports such as soccer, basketball, tennis, and handball met the inclusion criteria. The SAQ interventions lasted between 4 and 12 weeks, with a frequency of two to three sessions per week. The analysis revealed significant improvements in 5-meter sprint (ES = 0.63, $p < 0.01$), 20-meter sprint (ES = 0.49, $p < 0.01$), 30-meter sprint (ES = 0.55, $p = 0.015$), change of direction (COD) performance (ES = 0.39, $p < 0.01$), reaction time (ES = 0.52, $p = 0.01$), lower limb power (ES = 0.96, $p < 0.01$), and flexibility (ES = 0.57, $p < 0.01$), with effect sizes ranging from small to moderate. Subgroup analysis indicated that only session duration had a near-significant effect on COD performance (≤ 60 min: ES = 0.58; >60 min: ES = 0.24; $p = 0.059$).

Conclusions SAQ training effectively enhances sprint performance, COD ability, reaction time, lower limb strength, and flexibility, with effect sizes ranging from small to moderate. The findings suggest that shorter training durations (≤ 60 min) may be more beneficial for improving COD performance, although this effect did not reach statistical significance. Further trials are recommended to determine the optimal training dosage, along with high-quality studies covering a broader range of sports, particularly in athletes aged 14 to 18.

Keywords Speed, Agility, And quickness (SAQ) training, Athletic performance, Systematic review, Meta-analysis

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Introduction

Speed, Agility, and Quickness (SAQ) training is considered a key factor in enhancing athletic performance. This training focuses on improving an athlete's speed, agility, and reaction time, which are critical for excelling in numerous sports [1–4]. Previous research has identified key determinants of agility, including neuromuscular control, technique, and reactive ability [5]. Recent advancements in sports science have heightened interest in how SAQ training contributes to athletic development. Effective SAQ training can lead to significant performance gains, thereby boosting an athlete's competitiveness in their sport. Typically, SAQ training involves a range of exercises, including sprints, agility drills, and quick reaction activities, all aimed at increasing muscular power, reaction speed, and coordination [6–8]. A systematic SAQ training regimen can improve athletic performance rapidly and enhance overall competitiveness in sports.

The ability to execute high-speed movements, such as sprinting, agility, and rapid reactions, is considered a critical factor in determining outcomes across various sports [4, 9]. For instance, in soccer, while high-speed actions account for only 5-15% of a player's total distance covered, these movements can significantly influence the game's result [10]. Moreover, in actual competitions such as basketball or soccer, athletes do not always sprint in straight lines during high-speed running. Instead, they frequently perform actions involving changes in direction and acceleration [11, 12]. These movements rely on athletes' ability to respond to specific stimuli encountered during high-speed motion [13, 14]. The brain's motor nervous system governs and controls the muscles, enabling a series of coordinated actions, including deceleration, directional changes, initiation, acceleration [15]. This process requires precise neuromuscular coordination to execute effectively [16]. Consequently, a variety of training methods have been developed to enhance these skills, including resistance training [17], core training [18], and plyometric training [19]. Importantly, SAQ training necessitates that athletes perform movement tasks at high speeds within short time frames, with or without cognitive stimuli [20]. This training method incorporates both linear sprints (for speed) and multi-directional sprints (for change of direction, or COD) across different distances [21]. The actions involved in SAQ training, such as jumping, changing direction, and sprinting, utilize the muscle stretch-shortening cycle (SSC) [22]. Contractions associated with SSC are generated by activities arising from feedforward (pre-programmed) and feedback (reflexive) pathways, facilitated through complex interactions at various levels of the human central nervous system (CNS) [23]. Through training in the SAQ continuum, athletes exhibit improved adaptability of their nervous systems, particularly in terms of reaction time (detecting and distinguishing stimuli and making decisions) [21, 24]. This suggests that the benefits of SAQ training are largely derived from adaptations in neuromuscular performance [24], as significant improvements in reaction time have not been observed with plyometric training [25].

Although SAQ training is widely used across various sports, research findings on its specific effects are inconsistent. Some studies demonstrate that SAQ training can significantly enhance athletes' speed, agility, and reaction time [6, 8, 9, 26], thereby improving overall performance [24, 27]. Conversely, other research has not substantiated a significant impact of SAQ training on athletic performance. This variability in results underscores the need for a thorough systematic review to fully understand the true effects of SAQ training. Existing studies often involve small sample sizes or limited research designs, which hampers a complete evaluation of SAQ training's effectiveness [2, 24, 28]. Previous meta-analyses [29], such as Uysal et al. (2022), have investigated the effects of SAQ training but were limited to soccer players and focused primarily on sprint speed, jump performance, and change-of-direction (COD) speed. Additionally, many prior reviews included heterogeneous study designs, limiting the strength of their conclusions. To address these gaps, the present study aims to provide a broader and more rigorous evaluation of SAQ training by (1) including athletes from multiple sports to improve the generalizability of findings, (2) analyzing a wider range of performance outcomes such as reaction agility, flexibility, (3) applying stricter inclusion criteria by selecting only randomized controlled trials (RCTs), and (4) incorporating more recent studies beyond those included in previous meta-analyses. These improvements offer a more comprehensive and updated perspective on the effectiveness of SAQ training.

This systematic review and meta-analysis are designed to thoroughly summarize and assess the current evidence on the effects of SAQ training on athletic performance. By synthesizing relevant studies, this research aims to clarify the true impact of SAQ training, examine its effects on different performance indicators, and explore factors that may affect its outcomes. Furthermore, due to the broad usage of the term "agility," this study classifies tests involving predetermined task stimuli—such as the 90-degree turn test, 180-degree turn test, Arrowhead agility test, and SEMO agility test—as measures of change-of-direction (COD) performance, which aligns with the prevailing consensus among most scholars [29, 30]. The results will offer valuable guidance for coaches and athletes, and contribute to advancing research and practical application of SAQ training.

Materials and methods

Search strategy

This comprehensive review and meta-analysis was performed following the Cochrane Collaboration's protocols and adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards. The protocol for this study has been recorded on Inplasy.com with the identifier INPLASY202480062.

Eligibility criteria

The PICOS framework was used to evaluate the eligibility of the studies. Two independent reviewers (CD and SDC) conducted a comprehensive evaluation of potentially relevant studies based on the predetermined inclusion and exclusion criteria (Table 1). This process involved screening the titles, abstracts, and full texts of the studies to determine their eligibility for inclusion in the meta-analysis. In cases where the two reviewers (CD and SDC) disagreed on the inclusion or exclusion of a study, a third reviewer (KGS) was consulted to resolve the discrepancy.

Search strategy and selection process

We conducted a comprehensive search of electronic databases, including Web of Science, SPORTDiscus, PubMed, and SCOPUS, for articles published up to July 2024. The search utilized the following keywords and Boolean operators: ((((Speed, Agility, Quickness training) OR (SAQ training)) OR (SAQ exercises)) OR (Speed, Agility, Quickness exercises)) AND (((((((((((((performance) OR (physical performance)) OR (sport performance)) OR (athletic performance)) OR (skill)) OR (speed)) OR (agilit*)) OR (flexibility)) OR (explosiveness)) OR (reaction time)) OR (strength)) OR (endurance)) OR (power)). In addition, we manually searched Google Scholar for supplementary materials and reviewed the reference lists of identified articles to find additional relevant publications. An experienced librarian also assisted in ensuring the accuracy and completeness of the data collection process. For details, please refer to Appendix File 1.

The study selection process commenced with the removal of duplicate records. During the title and abstract review, non-English articles were excluded, along with conference abstracts, books, book chapters, pilot studies, and non-peer-reviewed papers. The remaining articles underwent full-text screening based on predefined eligibility criteria. Articles with unavailable full texts from databases or authors were also excluded. This selection process was carried out by two independent reviewers (SZM and CD), with disagreements resolved through discussion, and a third reviewer (KGS) involved if necessary to achieve consensus.

Data extraction

Two reviewers (SDC and SZM) extracted data from each study, with a third reviewer [31] verifying the accuracy. The following data were considered:

1. The name of the first author, the year of publication;
2. Participant characteristics: age, gender, sample size, competitive level, and sports experience;
3. Training intervention details: duration, frequency, timing, and type of exercise;
4. Assessment of performance and skill metrics.

Quality assessment

Bias risk for the included studies was assessed using RevMan 5.3, and study quality was independently evaluated with the PEDro scale, a validated tool. The PEDro scale scores range from 1 to 10: scores of 3 or below indicate poor quality, 4–5 reflect moderate quality, and 6–10 denote high quality. It includes 11 criteria for methodological assessment, with each criterion met adding one point to the total score (0–10 points). Standard 1, related to external validity, was not included in this assessment. To mitigate bias risk, studies scoring 3 or below were excluded. Two reviewers (MS and SDC) conducted independent evaluations, resolving discrepancies through discussion with a third reviewer (KGS).

Statistical analysis

Due to the typically small sample sizes in the field of exercise interventions [32], meta-analysis was conducted only when three or more studies reported technical skill outcomes. Missing data or data presented only in graphical form were supplemented by contacting the corresponding authors. For graphical data, values were

Table 1 Eligibility criteria according to the PICOS conditions

Category	Inclusion criteria	Exclusion criteria
Population	Athletes from various sports, with no restrictions on age or gender	Non-healthy athletes with injuries and medical conditions
Intervention	A clearly defined SAQ training program, typically consists of ladder drills, cone drills, plyometric exercises, change-of-direction drills, and reaction-based movement tasks.	Interventions that do not involve a complete SAQ training program, such as isolated change-of-direction sprint drills.
Comparator	Active control group	No control or passive control group
Outcome	Performance outcomes include speed, agility, strength, flexibility, balance, and endurance, as well as sport-specific skill assessments.	Failure to report mean and standard deviation data for the intervention and control groups at pre and post-test.
Study design	RCT	Non-RCT study designs

extracted using WebPlotDigitizer 5.0 (Automeris.io/wpd/), with verification results showing $r = 0.99$, $p < 0.001$ [33]. The effect size (ES), represented by Hedges' g, for the performance outcomes of the SAQ group compared to the control group was calculated using the mean and standard deviation values from pre- and post-intervention measurements. The standard deviation from the post-intervention data was used for standardization, and a random-effects model was applied to account for potential variability among studies that might influence the effectiveness of the SAQ intervention. The computed ES and its 95% confidence interval (CI) were used to assess the magnitude of the effect, categorized as follows: ES < 0.2 was considered trivial, 0.2–0.6 as small, 0.6–1.2 as moderate, 1.2–2.0 as large, 2.0–4.0 as very large, and ES > 4.0 as extremely large [34]. Heterogeneity was evaluated using the I^2 statistic, with values of < 25% indicating low, 25–75% moderate, and > 75% high heterogeneity [35]. The extended Egger's test was used to examine publication bias, and sensitivity analyses were conducted for significant findings [36]. All statistical analyses were carried out using Comprehensive Meta-Analysis software (Version 3; Biostat, Englewood, NJ, USA), with a significance threshold set at $p < 0.05$.

Additional analysis

We conducted a subgroup analysis to examine the potential influence of moderating factors. Based on the authors' discussions and study characteristics, we identified relevant sources of heterogeneity that could impact training effectiveness, including intervention duration (weeks), total number of intervention sessions, and session duration. Using the median-split method [37], participants were categorized by training duration (≤ 7 weeks vs. > 7 weeks), total number of SAQ sessions (< 24 vs. ≥ 24 sessions), and session length for the main training component (≤ 60 min vs. > 60 min). For each moderate factor, the median was calculated if data were available from at least three studies. Additionally, we analyzed athlete age (< 18 years vs. ≥ 18 years) as a potential moderator.

Results

Study selection

Initially, 415 articles were identified through database searches. Through Google Scholar and reference list reviews, 38 more studies were identified. Following the removal of duplicates, 327 unique records were retained. Title and abstract screening yielded 81 papers deemed potentially eligible for full-text review. Following full-text evaluation, 68 publications were excluded. Ultimately, 13 studies met the inclusion criteria. The literature screening process and exclusions are detailed in Fig. 1.

Characteristics and quality assessment of the included studies

Table 2 presents the participant characteristics, intervention details, and primary outcomes of the randomized controlled trials included in this review. The studies involved 619 athletes: 346 males, 97 females, and 176 with unspecified gender. Among the studies, 8 focused on soccer players [4, 6, 8, 9, 20, 21, 38, 39], 1 on basketball players [27], 1 on handball [28], 1 on athletes from various sports [26], and 2 on physical education students without specifying a sport [24, 40]. The intervention durations ranged from 4 to 12 weeks: 1 study for 4 weeks [21], 3 for 6 weeks [24, 26, 38], 3 for 8 weeks [4, 9, 28], 1 for 10 weeks [40], and 5 for 12 weeks [6, 8, 20, 27, 39]. Control group training included conventional training [4, 8, 9, 20, 27, 28, 38–40], small-sided games [21, 24], and physical conditioning [6, 26].

Risk of bias and quality assessment results

Each study's quality was assessed using the PEDro checklist, revealing that 9 studies scored above 5, indicating high quality, while three study scored 5, reflecting moderate quality. One study, scoring below 3, was excluded from the meta-analysis (Table 3). The risk of bias in the included studies was evaluated using the RevMan 5.3 bias table (Fig. 2).

Meta-analysis results

This meta-analysis consolidated 11 studies examining athletes' physical fitness, specifically measuring sprint speed, agility, lower limb explosiveness, flexibility, reaction time, and dribbling agility. The data utilized in the meta-analysis can be found in Table S2.

Sprint performance data were collected from nine studies ($n = 331$), with the initial Egger test indicating potential bias ($p = 0.022$). A sensitivity analysis excluded one study [28], resulting in a non-significant Egger test ($p \geq 0.05$). Thus, eight studies were analyzed. The results showed that SAQ training had a moderate, significant effect on 5 m sprint performance (ES = 0.94; 95% CI = 0.173–1.715; $p = 0.016$; I^2 = 86.82%; Egger test $p = 0.022$). After excluding one study [8], the effect size (ES) decreased, accompanied by a substantial reduction in heterogeneity (ES = 0.63; 95% CI = 0.30–0.97; $p < 0.001$; I^2 = 0.00%; Egger test $p = 0.67$) (Fig. 3). It had a small but significant effect on 20 m sprint performance (ES = 0.49; 95% CI = 0.14–0.84; $p = 0.006$; I^2 = 27.89%; Egger test $p = 0.74$) (Fig. 4) and a minor effect on 30 m sprint performance (ES = 0.55; 95% CI = 0.11–0.99; $p = 0.015$; I^2 = 2.16%; Egger test $p = 0.62$) (Fig. 5).

Seven studies contributed data on agility (total $n = 331$), indicating that SAQ training had a modest but significant impact on COD performance (ES = 0.39; 95% CI = 0.201–0.577; $p < 0.001$; I^2 = 6.85%, Egger test $p = 0.169$) (Fig. 6).

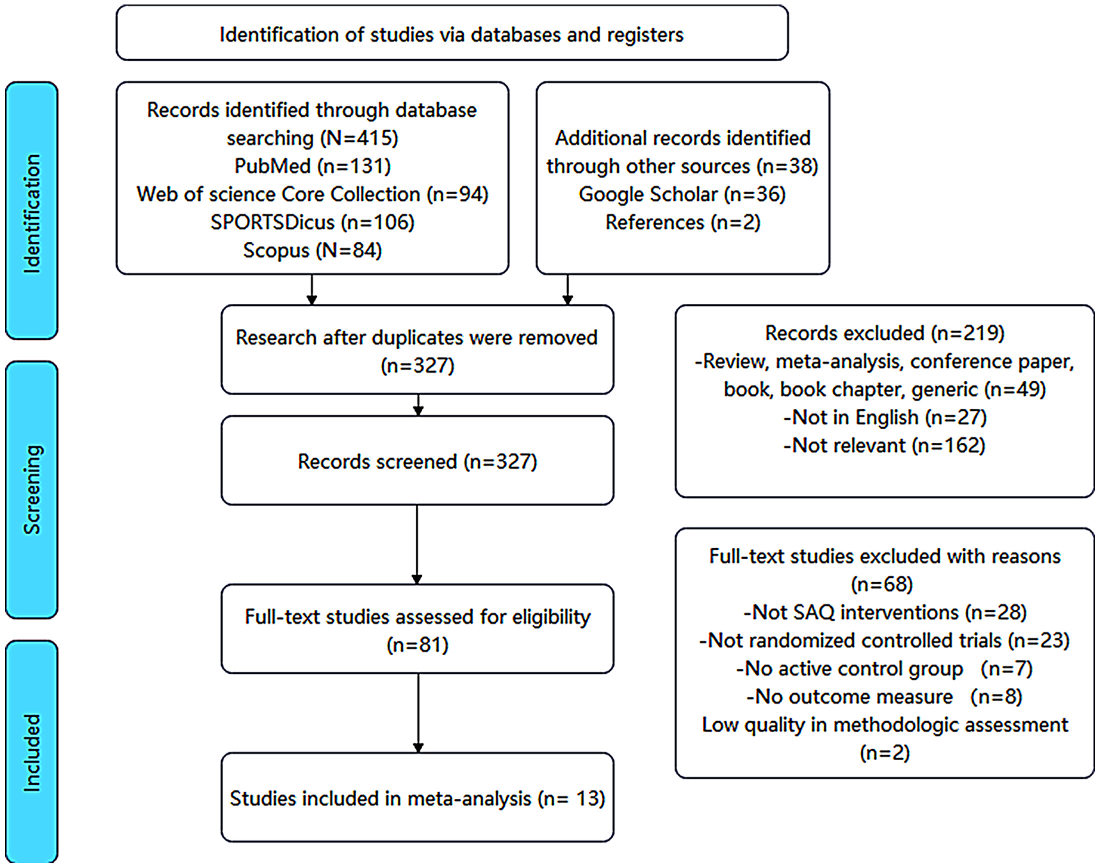


Fig. 1 PRISMA flow diagram

Reaction time was assessed in four studies ($n = 96$), with the Egger test initially indicating potential bias ($p = 0.04$). Following a sensitivity analysis and the exclusion of one study [4], SAQ training was found to have a moderate effect on reaction time (ES = 0.52; 95% CI = 0.12–0.91; $p = 0.01$; I^2 = 0.00%; Egger test $p = 0.09$) (Fig. 7).

Three studies provided data on lower limb power (total $n = 74$). The analysis revealed that SAQ training had a significant moderate effect on lower limb power (ES = 0.757; 95% CI = 0.201–1.313; $p = 0.008$; I^2 = 52.79%, Egger test $p = 0.03$). After excluding one study [39], the intervention demonstrated a significant moderate effect, while heterogeneity decreased (ES = 0.96; 95% CI = 0.29–1.64; $p = 0.005$; I^2 = 49.75%, Egger test $p = 0.13$) (Fig. 8).

Four studies provided data on lower limb flexibility (total $n = 218$). The analysis indicated that SAQ training had a small but significant effect on lower limb flexibility (ES = 0.57; 95% CI = 0.20–0.94; $p = 0.003$; I^2 = 37.43%, Egger test $p = 0.15$)(Fig. 9).

Additional analysis

Due to the limited number of studies, we conducted moderator analyses only for selected outcomes. Regarding the moderating effect of participant age, no significant improvements were observed in 5-meter sprint performance (< 18 years, ES = 0.42; ≥18 years, ES = 0.90; $p = 0.162$) or COD performance (< 18 years, ES = 0.17; ≥18 years, ES = 0.48; $p = 0.233$) following SAQ training in older athletes compared to younger athletes.

For training-related moderators, no significant differences were observed between SAQ programs lasting more than 7 weeks and those lasting 7 weeks or less in terms of 5-meter sprint performance (≤ 7 weeks, ES = 0.63; >7 weeks, ES = 0.63; $p = 0.994$) or COD performance (≤ 7 weeks, ES = 0.62; >7 weeks, ES = 0.34; $p = 0.245$). Similarly, athletes who completed more than 24 SAQ sessions did not exhibit significant improvements in 5-meter sprint (< 24 sessions, ES = 0.64; ≥24 sessions, ES = 0.63; $p = 0.994$) or COD performance (< 24 sessions, ES = 0.62; ≥24 sessions, ES = 0.34; $p = 0.245$) compared to those with fewer than 24 sessions. For COD performance, SAQ sessions lasting ≤ 60 min showed a trend toward significance compared to those exceeding 60 min (≤ 60 min, ES = 0.58; >60 min, ES = 0.24; $p = 0.059$), whereas no significant difference was found for 5-meter sprint performance (≤ 60 min, ES = 0.74; >60 min, ES = 0.39; $p = 0.339$). Additionally, increasing training frequency from twice per week to three or more sessions per week did not result in significant improvements in either 5-meter sprint performance (2 sessions/

Table 2 Participant and SAQ intervention characteristics

Study	N	Sex	Age	Level	Sport	Comparison	W/F/T	Outcome
Polman, R et al. 2004 [6]	EG1 = 12 EG2 = 12 CG = 12	F	21.2 ± 3.1	national club	Soccer	EG1 = SAQ EG2 = SAQ(EQ) CG = activity	12/2/60	Aerobic and anaerobic capacity↑25 m sprint↑ Agility↑ Vertical and horizontal power↑ Flexibility↑
Jonathan et al. 2007 [26]	EG = 14 CG = 16	F = 14 M = 16	20.5 ± 3.1	NR	Soccer, Basketball, etc.	EG = SAQ CG = Random conditioning	6/2/60	5 m,↑15 m↑ T agility↑Flexibility→ CMJ→SLJ
Polman et al. 2009 [24]	EG = 7 CG = 7	F = 8 M = 6	21.1 ± 4.0	NR	NR	EG = SAQ CG = SSG	6/2/60	5 m↑15 m↑ Reaction time→
Jovanovic et al. 2011 [9]	EG = 50 CG = 50	NR	19	national club	Soccer	EG = SAQ CG = RT	8/3/90	5 m↑10 m↑ CMJ↑ CJS↑ SJ→
Kanniyan et al. 2011 [38]	EG1 = 10 CG = 10	M	18–26	College Athletes	Soccer	EG1 = SAQ CG = RT	6/2/60	Shuttle run↑sit-ups↑,30↑
Milanović et al. 2013 [39]	EG = 66 CG = 66	M	U19	College Athletes	Soccer	EG = SAQ CG = RT	12/4/90	Sprint 4 × 5 m↑ Sprint with 180° turns↑ Slalom test with ball↑ Sprint with 90° turns↑ Sprint with backward and forward running→
Emeish, Mohamed Kamal. 2015 [28]	EG = 10 CG = 10	NR	13.1 ± 1.2	NR	Handball	EG = SAQ CG = RT	8/3/90	Coordination↑ reactive agility↑ Shoulders Flexibility→ backbone Flexibility↑30 m↑ throwing medical ball→ broad jump↑
Milanović et al. 2015 [8]	EG = 66 CG = 66	M	EG = 18.5 ± 0.4 CG = 18.6 ± 0.6	national club	Soccer	EG = SAQ CG = RT	12/4/90	5 m↑10 m↑20 m→ Flexibility→
Trecroci et al. 2016 [20]	EG = 20 CG = 15	NR	10.57 ± 0.26	sub-elite	Soccer	EG = SAQ CG = RT	12/2/25	5 m↑ RAT↑ MICODT→EG and CG 20 m↑
Amany et al.2017 [40]	EG = 20 CG = 20	M	EG = 18.1 ± 0.4 CG = 18.1 ± 0.6	Sports Institute	NR	EG = SAQ CG = RT	10/2/60	SLJ↑30 m↑ Reaction time↑
Moselhy. 2020 [27]	EG = 10 CG = 10	FM	U10	Local Clubs	Basketball	EG = SAQ CG = RT	12/3/90	5 m→ 20 m→ Illinois Agility→ Illinois agility dribbling EG > CG↑
Trecroci et al. 2022 [21]	EG = 11 CG = 10	NR	9–11	Soccer Academy	Soccer	EG = SAQ CG = SSG	4/3/120	5 m↑ 20 m↑ Flanker task perceptual speed↑ CODS→
Lee et al.2024 [4]	EG = 9 CG = 10	FM	U20	College Athletes	Soccer	EG = SAQ CG = RT	8/3/40	5 m↑10 m↑30 m↑ 20-m sprints with dribbling and 30 m EG > CG↑ arrowhead agility (left) → Reactive agility↑

Note N, Number; FM, Female; M, Male; U, Under; EG, Experimental group; CG. Control group; NR, Not Reported; SAQ, speed agility, quickness; SAQ(EQ), speed agility, quickness equipment; SSG, Small-Sided Games; RT, Regular training; W, week; F, Frequency; T, Time; 5 m, 5-meter sprint; 10 m, 10-meter sprint; CODS; SJ, test values in squat jump; SLJ, standing long jump; CMJ, countermovement jump; CJS, continuous jumps; RAT, Reaction agility test; MICODT, Modified Illinois change of direction test

week, ES = 0.58; ≥3 sessions/week, ES = 0.78; $p = 0.580$) or COD performance (2 sessions/week, ES = 0.47; ≥3 sessions/week, ES = 0.41; $p = 0.806$).

Discussion

This study is the first meta-analysis to investigate the impact of SAQ training on athletic performance. The results indicate that SAQ training has a significant moderate effect on 5 m sprints (ES = 0.63) and lower limb power (ES = 0.96). However, its effects on 20 m and 30 m sprints, agility, reaction time, and lower limb flexibility are relatively small (ES = 0.39–0.57). The Heterogeneity increased from low to moderate (I^2 = 0.00–49.75%).

Although reports emphasize that SAQ training plays a crucial role in developing essential athletic skills such as speed, agility, power, reaction time, and quickness [9, 41], this meta-analysis only moderately supports the effects of SAQ training on 5 m sprints and lower limb power. This finding is consistent with most randomized controlled trials [4, 8, 9, 20, 21, 24, 26]. However, the effects on 20 m and 30 m sprints, agility, and reaction time were less pronounced than some reports suggest [4, 6, 21, 26, 39, 40], but do not align with others that observed no significant improvements [8, 20, 24, 26, 27]. These discrepancies may be attributed to variations in training protocols. For example, a six-week intervention with sessions twice a week for 60 min each did not result in improved reaction time [24], while a ten-week intervention with the same session frequency and duration showed significant improvements [40]. Additionally, differences in participant age could contribute to varying outcomes. In three interventions involving pre-adolescent athletes, no significant improvements in agility were observed, regardless of whether the intervention lasted 4 weeks [21] or

Table 3 Physiotherapy evidence database (PEDro) scale ratings

Stuty	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	Total	Study quality
Polman, R et al. 2004 [6]	1	1	0	1	0	0	0	1	1	1	1	6	High
Jonathan et al. 2007 [26]	1	1	0	1	0	0	0	0	1	1	1	5	Moderate
Polman et al. 2009 [24]	1	1	0	1	0	0	0	1	1	1	1	6	High
Jovanovic et al. 2011 [9]	1	1	0	1	0	0	0	1	1	1	1	6	High
Kanniyan et al. 2011 [38]	0	0	0	0	0	0	0	1	0	1	1	3	Low
Milanović et al. 2013 [39]	1	1	0	1	0	0	0	1	1	1	1	6	High
Emeish 2015 [28]	0	0	0	1	0	0	0	1	1	1	1	5	Moderate
Milanović et al. 2015 [8]	1	1	0	1	0	0	0	1	1	1	1	6	High
Trecroci et al. 2016 [20]	1	1	1	1	1	0	0	1	1	1	1	8	High
Amany et al.2017 [40]	1	0	0	1	0	0	0	1	1	1	1	5	Moderate
Moselhy. 2020 [27]	1	1	0	1	0	0	0	1	1	1	1	6	High
Trecroci et al. 2022 [21]	1	1	0	1	0	0	0	1	1	1	1	6	High
Lee et al.2024 [4]	1	1	0	1	0	0	0	1	1	1	1	6	High

Note A detailed explanation for each PEDro scale item can be accessed at https://www.pedro.org.au/english/downloads/pedro-scale

*From a possible maximal punctuation of 10

12 weeks [20, 27]. Research indicates that the ability to train COD reaches its maximum around ages 13–14 [42]. As a result, the neuromuscular adaptations gained from SAQ training might not be adequate to notably improve COD performance in soccer players younger than 10 years old [21]. Furthermore, gender differences may have influenced the outcomes; in two 12-week interventions, flexibility did not significantly improve in male groups [8], whereas significant improvements were reported in female groups, although similar improvements were also observed in the control groups [6]. Notably, subgroup analysis suggested that session duration had a near-significant effect on COD performance ($p=0.059$), with training sessions of ≤60 min appearing more beneficial. This advantage may stem from better maintenance of training quality and athlete focus over shorter durations [43]. However, as statistical significance was not reached, further research is needed to validate these findings.

The effectiveness of Speed, Agility, and Quickness (SAQ) training on specific physical performance indicators can be elucidated through a comprehensive biomechanical and physiological framework.

Firstly, SAQ training is known to substantially enhance the recruitment and activation of fast-twitch muscle fibers [31, 44]. These fibers are critical for high-intensity activities due to their rapid contraction and ability to generate significant force output [45]. High-intensity, short-duration exercises typical of SAQ training—such as sprints and plyometrics—promote adaptations that increase the efficiency and quantity of fast-twitch muscle fiber recruitment [9, 46]. This increased recruitment is essential for improving performance in short-distance sprints and explosive power, which are vital for many athletic activities [9].

In addition to enhancing muscle fiber recruitment, SAQ training improves neuromuscular coordination. This training enhances the synchronization between the nervous system and the muscles [47], leading to faster reaction times and improved motor control. Studies have demonstrated that such improvements in neuromuscular coordination can significantly enhance performance in agility and quickness tests [48, 49]. For example, research indicates that SAQ training leads to more efficient movement patterns and faster decision-making processes, which are crucial for athletic success in sports requiring rapid changes in direction [1, 21].

Furthermore, SAQ training contributes to increased joint flexibility and stability. By incorporating dynamic movements and functional exercises, SAQ training strengthens the muscles around the joints and improves their stability, thereby reducing the risk of injuries [26]. This enhanced joint stability also translates into greater exercise efficiency and overall performance improvements [50–52]. For instance, improved flexibility and

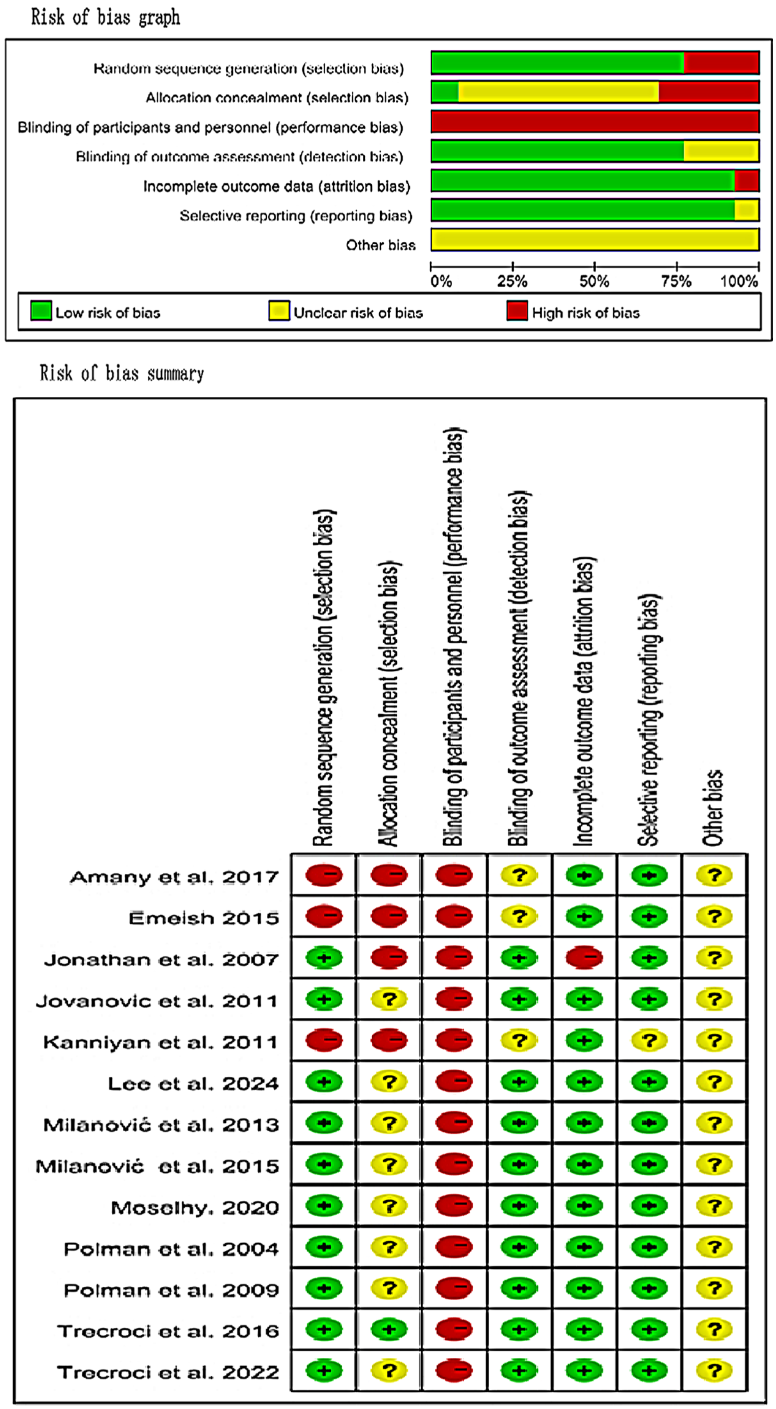


Fig. 2 Risk of bias assessment using Rob for included studies

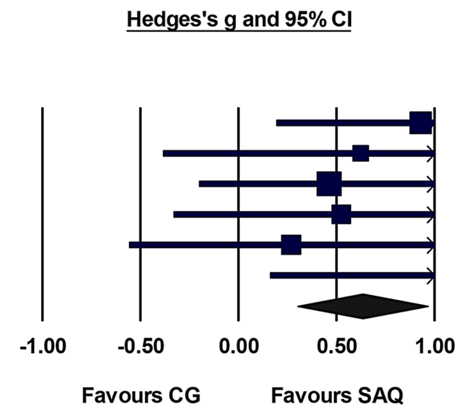
joint stability have been associated with better performance in sports that require a high degree of mobility and rapid changes in direction [53, 54].

Overall, the synergistic effects of these biomechanical and physiological mechanisms provide a robust explanation for the observed improvements in athletes' physical performance indicators due to SAQ training. The enhancements in muscle fiber recruitment, neuromuscular coordination, and joint stability collectively contribute to superior athletic performance across a range of physical tasks.

Limitations

This study has several limitations. Firstly, the number of studies included was relatively small ($n = 11$), and the majority of participants were soccer players ($n = 9$),

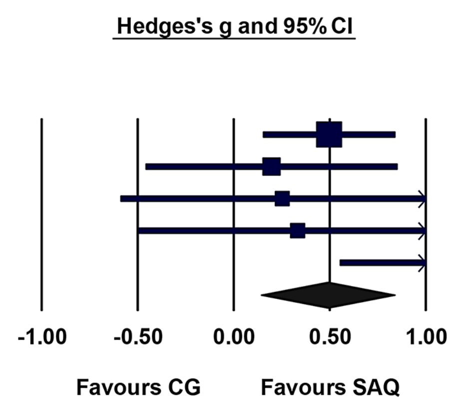
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Jonathan et al. 2007	0.931	0.376	0.141	0.194	1.667	2.476	0.013
Polman et al. 2009	0.624	0.514	0.264	-0.384	1.631	1.213	0.225
Trecroci et al. 2016	0.463	0.338	0.114	-0.200	1.126	1.369	0.171
Moselhy. 2020	0.525	0.436	0.190	-0.330	1.380	1.203	0.229
Trecroci et al. 2022	0.270	0.422	0.178	-0.557	1.096	0.639	0.523
Lee et al. 2024	1.089	0.473	0.224	0.162	2.016	2.302	0.021
	0.633	0.169	0.029	0.302	0.965	3.744	0.000



Meta Analysis of 5m Sprint

Fig. 3 Forest plot of the overall effect of SAQ training on 5 m sprint

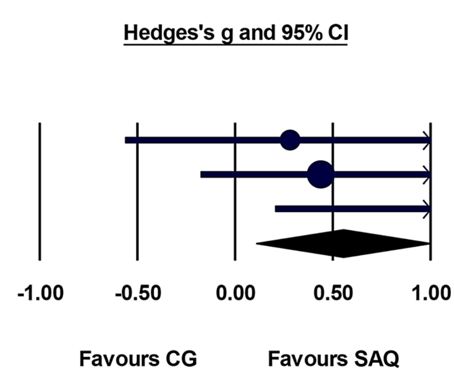
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Milanovi et al. 2015	0.497	0.176	0.031	0.153	0.842	2.828	0.005
Trecroci et al. 2016	0.197	0.335	0.112	-0.459	0.853	0.589	0.556
Moselhy. 2020	0.253	0.430	0.185	-0.590	1.097	0.589	0.556
Trecroci et al. 2022	0.333	0.423	0.179	-0.495	1.162	0.789	0.430
Lee et al. 2024	1.543	0.505	0.255	0.553	2.533	3.054	0.002
	0.490	0.177	0.031	0.143	0.837	2.766	0.006



Meta Analysis of 20m Sprint

Fig. 4 Forest plot of the overall effect of SAQ training on 20 m sprint

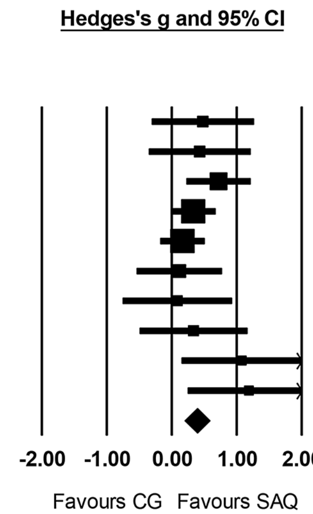
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Emeish 2015	0.282	0.431	0.185	-0.562	1.126	0.654	0.513
Amany et al. 2017	0.439	0.314	0.098	-0.176	1.054	1.400	0.162
Lee et al. 2024	1.139	0.476	0.227	0.206	2.073	2.392	0.017
	0.553	0.227	0.051	0.108	0.997	2.436	0.015



Meta Analysis of 30m Sprint

Fig. 5 Forest plot of the overall effect of SAQ training on 30 m sprint

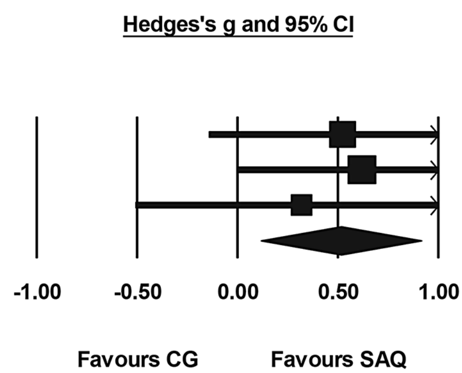
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Polman et al. 2004(EG1)	0.479	0.400	0.160	-0.305	1.263	1.197	0.231
Polman et al. 2004(EG2)	0.430	0.399	0.159	-0.352	1.213	1.079	0.281
Jonathan et al. 2007	0.720	0.251	0.063	0.228	1.213	2.866	0.004
Milanovi et al. (CODS)2013	0.331	0.174	0.030	-0.011	0.672	1.897	0.058
Milanovi et al. 2013(ST)	0.165	0.173	0.030	-0.175	0.505	0.953	0.341
Trecroci et al. 2016	0.115	0.334	0.112	-0.539	0.770	0.345	0.730
Moselhy. 2020	0.086	0.429	0.184	-0.754	0.926	0.200	0.842
Trecroci et al. 2022	0.335	0.423	0.179	-0.493	1.164	0.793	0.428
Lee et al. 2024(L)	1.078	0.472	0.223	0.152	2.004	2.282	0.022
Lee et al. 2024(R)	1.188	0.479	0.230	0.248	2.127	2.478	0.013
	0.389	0.096	0.009	0.201	0.577	4.055	0.000



Meta Analysis of COD

Fig. 6 Forest plot of the overall effect of SAQ training on COD

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Trecroci et al. 2016	0.523	0.340	0.115	-0.142	1.189	1.540	0.123
Amany et al. 2017	0.620	0.318	0.101	-0.003	1.242	1.952	0.051
Trecroci et al. 2022	0.320	0.422	0.178	-0.508	1.148	0.758	0.449
	0.516	0.203	0.041	0.117	0.914	2.536	0.011

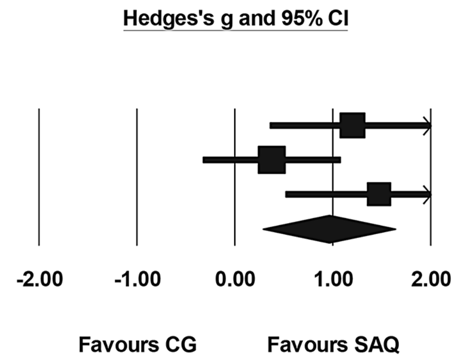


Meta Analysis of Reaction time

Fig. 7 Forest plot of the overall effect of SAQ training on reaction time

resulting in high sample homogeneity, which somewhat limits our understanding of the generalizability of SAQ training to other sports. Secondly, although this study conducted subgroup analyses on sprint and change-of-direction (COD) performance, the limited number of included studies restricted further detailed analysis. As a result, more definitive evidence on the optimal SAQ intervention could not be provided. Additionally, although some studies reported other outcomes (e.g., aerobic endurance [6], balance [26], and motor skills [4, 27]), these outcomes were not included in this meta-analysis due to the insufficient number of studies (less than three). Restricting the literature search to English-language studies may also have limited the representativeness of our findings. Lastly, although we assessed the risk of bias, some studies exhibited a high risk of selection and reporting biases, which may have impacted the internal validity of the results. Future studies should delve deeper into the impact of SAQ training across various genders, age groups, and sports disciplines. We found no high-quality studies focusing on athletes aged 14 to 18. Moreover, long-term follow-up research is essential to evaluate the lasting effects of SAQ training, which would enhance our understanding of its underlying mechanisms and overall effectiveness.

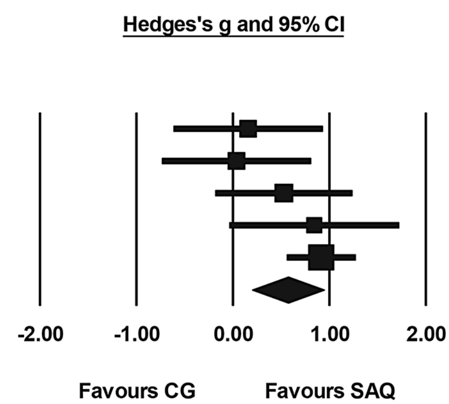
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Polman et al. 2004	1.203	0.431	0.185	0.358	2.047	2.792	0.005
Jonathan et al. 2007	0.378	0.359	0.129	-0.326	1.083	1.053	0.292
Emeish 2015	1.473	0.488	0.238	0.517	2.428	3.021	0.003
	0.961	0.344	0.119	0.286	1.635	2.790	0.005



Meta Analysis of Lower limb power

Fig. 8 Forest plot of the overall effect of SAQ training on lower limb power

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Polman et al. 2004(EG1)	0.158	0.395	0.156	-0.616	0.932	0.400	0.689
Polman et al. 2004(EG2)	0.037	0.394	0.155	-0.735	0.810	0.095	0.925
Jonathan et al. 2007	0.529	0.363	0.131	-0.182	1.239	1.458	0.145
Emeish 2015	0.844	0.449	0.201	-0.036	1.723	1.880	0.060
Milanovi et al. 2015	0.917	0.182	0.033	0.560	1.273	5.035	0.000
	0.572	0.189	0.036	0.201	0.943	3.021	0.003



Meta Analysis of Flexibility

Fig. 9 Forest plot of the overall effect of SAQ training on flexibility

Conclusion

SAQ training effectively enhances sprint performance, COD ability, reaction time, lower limb strength, and flexibility, with effect sizes ranging from small to moderate. The findings suggest that shorter training durations (≤60 min) may be more beneficial for improving COD performance, although this effect did not reach statistical significance. Further trials are recommended to determine the optimal training dosage, along with high-quality studies covering a broader range of sports, particularly in athletes aged 14 to 18.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

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Author contributions

MS conceptualized the study and wrote the main manuscript. KGS and ABY contributed to conceptualization, methodology, and supervision. Investigation was conducted by CD, SZM, and SDC. KGS, ABY, SZM, SDC, and CD contributed to the review and editing of the manuscript. All authors reviewed and approved the final manuscript.

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Data availability

The data supporting the findings of this study are included within the manuscript and/or its supplementary information files.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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