Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Comparative Effects of Exercise Interventions for Chronic Ankle Instability: A Systematic Review and Network Meta-analysis

Meng Tao
Shanghai University of Sport
Chengyu Zhou
School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, B152TT, United Kingdom
Zhuo Zeng
Strength and conditioning training college, Beijing Sports University, Beijing, China
Deborah Falla
falla@bham.ac.uk

School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham

Systematic Review

Keywords: chronic ankle instability, exercise therapy, systematic review, network meta-analysis, rehabilitation

Posted Date: October 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11409598/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: The authors declare no competing interests.

Abstract

Objective

This review compared exercise-based rehabilitation approaches for chronic ankle instability (CAI) using network meta-analysis and explored variation in outcomes across exercise dosage parameters.

Methods

The Cochrane Library, PubMed, Web of Science, Embase, and China National Knowledge Infrastructure databases were searched from inception, with the last search update completed in April 2026. Randomized controlled trials of exercise interventions in people with CAI or functional ankle instability were included. Analyses were performed using Review Manager 5.4 and Stata 18.

Results

Twenty-two randomized controlled trials were included. Treatment rankings differed across the Star Excursion Balance Test (SEBT), Cumberland Ankle Instability Tool (CAIT), and Foot and Ankle Ability Measure (FAAM). Surface under the cumulative ranking curve (SUCRA) values described relative treatment rankings, but sparse networks and uncertainty in the evidence limited conclusions about the superiority of individual approaches. Exploratory subgroup analyses described differences across session duration, weekly training frequency, and intervention period; they did not establish an optimal exercise dose.

Conclusion

Exercise-based rehabilitation may improve dynamic balance and self-reported ankle outcomes in people with CAI. However, uncertainty in comparative effect estimates limits firm conclusions about the superiority of individual exercise approaches. The exploratory subgroup findings do not establish an optimal exercise dose.

INTRODUCTION

Ankle sprains are among the most prevalent sports-related injuries globally, with a high incidence in sports involving frequent agility maneuvers, such as in basketball and football. Epidemiological studies indicate that approximately 800,000 ankle sprains of varying severity occur worldwide each day [1]. These injuries constitute roughly 25% of all sports injuries, with acute lateral ankle sprains accounting for approximately 85% of all ankle injury cases [2]. Although clinically classified as minor soft tissue injuries and managed with conventional conservative treatment, long-term follow-up studies reveal that up to 70% of people report persistent subjective ankle instability and recurrent sprains [3]. More notably, inadequate initial assessment or rehabilitation leads to the development of chronic ankle instability (CAI) in an estimated 20% to 40% of acute sprain cases, underscoring the significant risk of progression from an acute injury to a chronic functional impairment [4].

The condition of CAI is characterized by persistent joint instability resulting from structural abnormalities or functional control deficits. Its primary clinical manifestations include recurrent sprains, diminished joint control, and limited range of ankle motion. Based on its underlying pathology and clinical presentation, CAI is classified into two distinct types: functional ankle instability and mechanical ankle instability [5]. Functional ankle instability involves sensorimotor control deficits without objective structural laxity, often attributable to impaired proprioception following ligamentous injury and the consequent damage to mechanoreceptors. Clinically, functional ankle instability presents as muscle weakness, poor dynamic stability during landing, and recurrent sprains [6]. In contrast, mechanical ankle instability arises from tangible structural damage, such as ligamentous laxity, typically manifesting as range of motion of the ankle that exceeds physiological limits and may be accompanied by secondary pathologies like cartilage lesions or synovitis [7].

The persistent pain, joint instability, fear of re-injury, and functional limitations associated with CAI adversely affect daily activities of people with CAI and athletic performance while substantially diminishing their quality of life [8]. Analysis of national injury registry data reveals that among 120,000 patients with ankle injuries, approximately 36% required surgery following unsuccessful conservative management, incurring annual direct medical costs of nearly $40 million USD in the USA alone [6]. This figure underscores the considerable economic burden CAI places on public healthcare systems. Given the potential of exercise interventions to enhance joint stability, neuromuscular control, and functional performance, a systematic evaluation of the efficacy of exercise for the rehabilitation of CAI is of significant clinical relevance.

Yang et al. conducted a network meta-analysis of nonsurgical physical therapy approaches for CAI, including exercise and combinations of exercise with other treatments [9]. Their review provides an important context for the present work. The present review focuses on exercise-based rehabilitation and its comparative effects on dynamic balance and self-reported ankle outcomes.

This systematic review and network meta-analysis aimed to compare the effects of exercise-based rehabilitation approaches on dynamic balance and self-reported ankle outcomes in people with CAI. Session duration, weekly training frequency, and intervention period were examined in exploratory

subgroup analyses to describe variation across exercise dosage parameters, rather than to establish a definitive optimal exercise dose.

METHODS

This review was prospectively registered in PROSPERO (CRD420251179343). No deviations from the registered protocol occurred. Following registration, the literature search was updated to April 2026 and additional eligible study data were incorporated, without changing the registered eligibility criteria, outcomes, or analytical methods. Reporting followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [10].

Search strategy

The literature search was restricted to English-language publications. The Cochrane Library, PubMed, Web of Science, Embase, and China National Knowledge Infrastructure (CNKI) were initially searched from database inception to November 2025, and the literature search was updated in April 2026. The update used the same registered eligibility criteria and methods. The search strategy combined keywords and Medical Subject Headings for "Chronic Ankle Instability," "Functional Ankle Instability," "Exercise Intervention," "Strength Training," "Balance Training," "Vibration Training," "Proprioception Training," "Neuromuscular Control Training," and "Randomized Controlled Trial."

Inclusion and exclusion criteria

Eligibility criteria were structured using the population, intervention, comparator, outcomes, and study design (PICOS) framework.

Population (P): Adolescents and adults aged ≥ 14 years with a confirmed diagnosis of CAI or functional ankle instability (FAI), without severe comorbidities. Healthy participants and those without a confirmed CAI/FAI diagnosis were excluded. Intervention (I): Structured, professionally supervised exercise rehabilitation interventions targeting CAI/FAI prevention or treatment. Comparator (C): Alternative conventional rehabilitation, placebo interventions, or control conditions without a standardized exercise intervention. Outcomes (O): At least one of the following outcomes: SEBT, CAIT, or FAAM. Study design (S): Original randomized controlled trials (RCTs). Non-randomized studies, self-controlled trials, systematic reviews, narrative reviews, and case reports were excluded.

Additional exclusion criteria were non-English-language publications; duplicate reports; conference abstracts; unavailable extractable quantitative data; and studies enrolling participants without confirmed CAI/FAI.

Literature screening

Records were deduplicated and managed in NoteExpress. Two reviewers (CZ and MT) independently screened titles and abstracts and assessed full texts against the eligibility criteria. Disagreements were resolved through discussion, with arbitration by a third reviewer (ZZ).

The initial search across the five databases (from database inception to November 2025), supplemented by a manual review of reference lists from retrieved articles, yielded 827 records. After removing 323 duplicate records, 504 unique records remained for title and abstract screening; 446 irrelevant records were excluded at this stage, leaving 58 preliminarily eligible articles for full-text evaluation. A further 36 articles were excluded after full-text review for three reasons: (1) missing primary outcome data or absence of a control group; (2) low methodological quality; (3) incomplete reporting of predefined outcome indicators. Subsequent screening involved the evaluation of titles, abstracts, and finally, full-text articles against the PICOS-based inclusion criteria. This multi-step screening process culminated in the selection of 22 randomized controlled trials for the final network meta-analysis. The PRISMA flowchart outlining the complete literature retrieval and screening process is shown in Fig. 1.

Data extraction

Data were extracted independently and in duplicate by the same two reviewers (CZ and ZZ). Extracted information included the first author, publication year, participant characteristics, study design, intervention parameters (session duration, weekly frequency, and intervention period), and outcome data. Dynamic balance was assessed using the SEBT, whereas self-reported ankle instability and function were assessed using the CAIT and FAAM, respectively. Post-intervention scores from the intervention and comparator groups were selected for analysis. When relevant data were unavailable in the publication, the corresponding author was contacted. Studies were excluded if the required data could not be obtained. Disagreements were resolved through discussion, with arbitration by a third reviewer (ZZ).

Risk of bias assessment

The same two reviewers independently assessed the risk of bias of all included RCTs using the original Cochrane Risk of Bias tool. Each reviewer completed all bias domain judgements without access to the other's evaluation results. Any disagreements between the two reviewers were resolved through group discussion; a third reviewer (ZZ) served as an adjudicator if consensus could not be reached. All final risk judgements were collated and summarized in Review Manager 5.4. The evaluation covered six standard domains: (1) Selection bias (random sequence generation and allocation concealment); (2) Performance bias (blinding of participants and personnel delivering interventions); (3) Detection bias (blinding of outcome assessors);

(4) Attrition bias (completeness of outcome data and intention-to-treat analysis implementation); (5) Reporting bias (selective reporting of pre-specified primary and secondary outcomes); (6) Other potential sources of bias.

For performance bias judgements, we did not automatically classify trials as high risk solely due to the impossibility of participant/instructor blinding in exercise interventions. Instead, we evaluated whether lack of blinding introduced meaningful deviations to exercise implementation and participants' movement behaviours that could alter functional outcome measurements. Additionally, the Physiotherapy Evidence Database (PEDro) scale was used to assess the overall methodological quality of each trial, with scoring thresholds defined as: high quality (score > 6), moderate quality (score 4–5), low quality (score < 3).

Certainty of evidence

Certainty of evidence was assessed using the Confidence in Network Meta-Analysis (CINeMA) framework [11], which considers within-study bias, reporting bias, indirectness, imprecision, heterogeneity, and incoherence. Two reviewers independently completed the assessments, with disagreements resolved through discussion.

1. 1. Within-study bias: Judgements were based on the original Cochrane Risk of Bias tool. Physiotherapy Evidence Database (PEDro) scores were used descriptively and were not counted again when assessing evidence certainty.
2. 2. Reporting bias: Funnel plots were examined for small-study effects. Formal Egger regression tests were restricted to outcomes with at least 10 independent studies. Risk of bias due to missing evidence was assessed using the Risk Of Bias due to Missing Evidence in Network meta-analysis (ROB-MEN) tool. Non-significant asymmetry tests were not interpreted as excluding reporting bias.
3. 3. Indirectness: Assessments considered participant populations, ankle instability diagnoses, intervention characteristics, and the relevance of the outcome measures.
4. 4. Heterogeneity: Between-study heterogeneity was considered when judging certainty in the estimated intervention effects.
5. 5. Incoherence: Agreement between direct and indirect evidence was examined using node-splitting analyses where both sources of evidence were available.
6. 6. Imprecision: Sample sizes and the 95% confidence intervals for the estimated effects were considered in the precision assessment.

The certainty judgements and their domain-specific rationale are presented in the Results section and Table 6.

Statistical analysis

Statistical analysis was performed using Review Manager 5.4 software and Stata 18.0 software. A frequentist network meta-analysis (NMA) was conducted in Stata 18.0 via the network suite of commands, including network setup, network meta, network inconsistency, network nodesplit, network sucra, and network forest. A random-effects model was pre-specified a priori for all analyses to accommodate substantial clinical and methodological heterogeneity across CAI trials with diverse exercise modalities and mixed adolescent-adult populations; the choice of random-effects model was not solely reliant on I^2 statistics. Multi-arm RCTs were handled within the Stata network command framework to adjust for within-study correlation between multiple intervention arms from a single trial. Daily activity was defined as the unified reference comparator throughout all network comparisons.

Transitivity was evaluated by comparing key effect modifiers across direct comparisons, including participant age, baseline CAI/FAI severity, session duration, weekly training frequency, intervention period, and comparator type. Global inconsistency was assessed using the design-by-treatment interaction model. Local inconsistency was assessed using node splitting where direct and indirect evidence were available. Treatment rankings were summarized using SUCRA values, which summarize cumulative ranking probabilities across possible ranks rather than the probability of ranking first alone. Rankings were interpreted alongside effect estimates, 95% confidence intervals, network structure, and evidence certainty assessed using CINeMA [12].

For conventional pairwise analyses, continuous outcomes were summarized as mean differences (MDs) when the same measurement scale was used, or standardized mean differences (SMDs) when different scales were combined, with 95% confidence intervals. Heterogeneity was described using I^2 and Cochran's Q test ($\alpha = 0.10$). Leave-one-out sensitivity analyses examined the influence of individual studies on pooled estimates and treatment rankings. Funnel plots were used to examine small-study effects, with formal Egger regression tests restricted to outcomes with at least 10 independent studies. Heterogeneity statistics were not used as the sole criterion for selecting a fixed- or random-effects model.

RESULTS

Study characteristics

The initial search of five databases, from inception to November 2025, retrieved 827 records. After deduplication, title/abstract screening and full-text eligibility assessment managed via NoteExpress, 22 eligible RCTs were finally included in this network meta-analysis. The primary reasons for full-text exclusion were missing extractable primary data or absent control groups, low methodological quality, and incomplete reporting of predefined core outcome indicators (SEBT, CAIT, FAAM).

The 22 included studies investigated exercise rehabilitation in people with CAI or FAI. Eighteen studies were classified as CAI studies and four as FAI studies. Three trials enrolled adolescent athletes, with reported mean ages of 16.45 years in Cain (2017), 16.40 years in Cain (2020), and 14.10 years in

Park (2024). The other studies reported mean ages of at least 18 years. The intervention categories included WBVT, BAPS, GISTM, BAPS-CT, GISTM-CT, EBT, BT, RT, BOT, and other exercise approaches. Outcomes included SEBT, CAIT, and FAAM. Study characteristics are presented in Table 1.

Table 1
Characteristics of the included studies

Study	N trial/con	Sex m/f	Age (years)	Condition	Intervention	Comparator	Session duration	Sessions per week	Period (weeks)	Outcomes	PEDro
Anguish, 2018 [13]	9/9	16/2	18.38 ± 1.81	CAI	BT	Daily activity	30 min	3 t/w	4 w	SEBT; FAAM	8
Cain, 2017 [14]	11/11	11/11	16.45 ± 0.93	CAI	BAPS	Daily activity	10 min	3 t/w	4 w	SEBT	7
Cain, 2020 [15]	10/11	12/9	16.40 ± 0.97	CAI	BAPS	Daily activity	10 min	3 t/w	4 w	SEBT; FAAM; CAIT	8
	12/11	9/14			EBT	Daily activity	10 min	3 t/w	4 w		
	10/11	7/14			BAPS-CT	Daily activity	10 min	3 t/w	4 w		
Cloak, 2010 [16]	19/19	0/38	19.00 ± 0.80	FAI	WBVT	Daily activity	10–14 min	2 t/w	6 w	SEBT	5
Cloak, 2013 [17]	11/11	22/0	22.70 ± 1.20	FAI	BAPS	Daily activity	15 min	2 t/w	6 w	SEBT	6
	11/11	22/0			BAPS-CT	Daily activity	15 min	2 t/w	6 w		
Cruz-Díaz, 2020 [18]	24/21	23/22	27.63 ± 7.42	CAI	CrossFit	Daily activity	60–90 min	2 t/w	12 w	SEBT; CAIT	7
	25/21	19/27			GISTM-CT	Daily activity	60–90 min	2 t/w	12 w		
Deussen, 2018 [19]	6/6	2/10	29.83 ± 8.18	CAI	BT	Daily activity	20–30 min	2 t/w	6 w	CAIT	7
Hall, 2018 [20]	13/13	13/13	23.50 ± 6.50	CAI	BT	Daily activity	20 min	3 t/w	6 w	FAAM	5
	13/13	14/12			RT	Daily activity	20 min	3 t/w	6 w		
Kim, 2014 [21]	10/10	5/15	23.50 ± 2.70	FAI	RT	Daily activity	20 min	3 t/w	4 w	CAIT	5
	10/10	4/16			GISTM-CT	Daily activity	30 min	3 t/w	4 w		
Lee, 2012 [22]	9/9	18/0	21.00 ± 1.66	CAI	GISTM-CT	Daily activity	90–120 min	1 t/w	4 w	SEBT	6
Lee, 2019 [23]	15/15	15/15	21.53 ± 2.47	CAI	RT	Daily activity	20–25 min	3 t/w	8 w	CAIT	7
McKeon, 2008 [24]	16/15	12/19	22.20 ± 4.50	CAI	BT	Daily activity	20 min	3 t/w	4 w	SEBT	6
Minoonejad, 2019 [25]	14/14	28/0	22.78 ± 3.09	CAI	BOT	Daily activity	15–40 min	3 t/w	6 w	FAAM; CAIT	8
Nam, 2018 [26]	13/15	28/0	23.00 ± 2.90	CAI	GISTM-CT	RT	30 min	3 t/w	8 w	CAIT	6
Plaza-Manzano, 2016 [27]	28/28	39/17	24.40 ± 2.40	CAI	GISTM-CT	RT	40 min	2 t/w	4 w	CAIT	9
Schaefer, 2012 [28]	13/11	21/3	18.40 ± 5.90	CAI	GISTM-CT	BT	30 min	2 t/w	4 w	SEBT	7

Study	N trial/con	Sex m/f	Age (years)	Condition	Intervention	Comparator	Session duration	Sessions per week	Period (weeks)	Outcomes	PEDro
Shamseddini, 2021 [29]	12/10	13/9	35.83 ± 12.08	CAI	WBVT	Daily activity	15–20 min	3 t/w	4 w	SEBT	8
Shih, 2018 [30]	15/15	14/16	26.90 ± 5.80	CAI	RT	Daily activity	15–20 min	2 t/w	4 w	CAIT	5
	15/15	17/13			GISTM-CT	Daily activity	15–20 min	2 t/w	4 w		
Sierra-Guzmán, 2018 [31]	17/17	17/17	22.40 ± 2.60	CAI	WBVT	Daily activity	15 min	3 t/w	6 w	SEBT	7
Wright, 2017 [32]	20/20	11/29	22.60 ± 5.89	CAI	BT	EBT	5 min	3 t/w	4 w	FAAM; CAIT	7
Park, 2024 [33]	17/17	34/0	14.10 ± 0.70	FAI	RT	Daily activity	5 min	3 t/w	6 w	CAIT	8
	17/17	34/0			BT	Daily activity	8 min	3 t/w	6 w		
Yeum, 2024 [34]	14/16	14/16	27.86 ± 4.16	CAI	RT	Daily activity	40 min	2 t/w	4 w	FAAM	5

Risk of bias

Detailed results of the risk of bias evaluation are presented in Fig. 2. For random sequence generation, incomplete outcome data, selective reporting, and other bias domains, all included randomized controlled trials were judged to carry a low risk of bias. In terms of allocation concealment and blinding of outcome assessment, nearly half of the included studies lacked adequate reporting, leading to an unclear risk of bias across these two domains. Regarding performance bias, blinding of participants and intervention instructors was unachievable in all exercise rehabilitation trials. After evaluating whether lack of blinding would substantially alter exercise compliance and functional test performance, all trials were rated as high risk of performance bias. No trials presented severe attrition bias or evidence of selective outcome reporting.

Sensitivity analysis

Leave-one-out sensitivity analyses examined the influence of individual studies on the pooled effects. Sequential exclusion of individual studies did not materially change the reported direction or statistical significance of the pooled estimates. Although heterogeneity sometimes decreased after a study was removed, no single study was reported to account for the overall findings. These analyses address sensitivity to individual studies but do not resolve other sources of uncertainty.

Star Excursion Balance Test (SEBT)

Figure 3 presents the SEBT network and treatment rankings. Nodes represent intervention categories and connecting lines represent available direct comparisons. Table 2 presents the corresponding comparative estimates. The reported comparisons with the control node favoured WBVT and GISTM-CT, with confidence intervals excluding zero. The highest SUCRA values were reported for GISTM-CT (76.0%), followed by WBVT (73.2%) and CrossFit (58.7%). These values describe relative rankings and do not, by themselves, establish superiority over every alternative intervention.

Table 2
League table of SEBT for different exercise interventions

WBVT						
-0.40 (-8.16,7.36)	GISTM-CT					
1.67 (-8.02,11.37)	2.07 (-7.86,12.00)	EBT				
1.57 (-7.85,10.99)	1.97 (-5.82,9.75)	-0.11 (-11.37,11.15)	CrossFit			
6.48 (1.18,11.77)	6.88 (1.16,12.59)	4.80 (-3.31,12.92)	4.91 (-2.89,12.71)	CON		
5.02 (-2.87,12.92)	5.42 (-1.43,12.27)	3.35 (-6.66,13.36)	3.45 (-5.77,12.68)	-1.46 (-7.31,4.40)	BT	
3.68 (-3.82,11.18)	4.08 (-3.72,11.88)	2.01 (-6.09,10.11)	2.11 (-7.33,11.55)	-2.80 (-8.11,2.52)	-1.34 (-9.25,6.57)	BAPS

Cumberland Ankle Instability Tool (CAIT)

Figure 4 presents the CAIT network and treatment rankings, and Table 3 presents the comparative estimates. The reported comparisons with the control node favoured CrossFit, GISTM-CT, RT, and BOT, with confidence intervals excluding zero. The highest SUCRA value was reported for GISTM-CT (85.2%), followed by BOT (79.9%) and CrossFit (69.1%). Rankings should be interpreted alongside the comparative estimates and their uncertainty.

Table 3
League table of CAIT for different exercise interventions

CON							
-1.89 (-4.66,0.88)	BT						
-3.84 (-8.87,1.20)	-1.95 (-6.87,2.97)	BAPS					
1.01 (-4.69,6.71)	2.90 (-2.07,7.88)	4.85 (-2.15,11.85)	EBT				
-4.38 (-8.27,-0.49)	-2.49 (-7.16,2.18)	-0.54 (-6.82,5.74)	-5.39 (-12.21,1.43)	CrossFit			
-5.43 (-7.84,-3.03)	-3.54 (-6.93,-0.16)	-1.60 (-6.98,3.79)	-6.44 (-12.46,-0.43)	-1.05 (-4.93,2.82)	GISTM-CT		
-3.00 (-5.34,-0.65)	-1.11 (-4.23,2.01)	0.84 (-4.38,6.06)	-4.01 (-9.88,1.87)	1.38 (-2.78,5.55)	2.44 (0.23,4.64)	RT	
-5.50 (-10.23,-0.77)	-3.61 (-9.09,1.87)	-1.66 (-8.57,5.25)	-6.51 (-13.91,0.89)	-1.12 (-7.24,5.01)	-0.07 (-5.37,5.24)	-2.50 (-7.78,2.78)	BOT

Foot and Ankle Ability Measure (FAAM)

Figure 5 presents the FAAM network and treatment rankings. Table 4 presents the comparative estimates, several of which have confidence intervals that include zero. The highest reported SUCRA values were for BOT (82.8%) and BAPS (82.6%), followed by BT (48.5%) and EBT (44.9%). These rankings do not establish statistically significant or clinically important superiority over the control condition or other interventions.

Table 4
League table of FAAM for different exercise interventions

CON					
-1.80 (-4.85,1.25)	BT				
-5.11 (-13.80,3.58)	7.46 (-0.98,15.90)	BAPS			
5.66 (-2.21,13.53)	-0.04 (-7.63,7.55)	-7.50 (-15.21,0.21)	EBT		
-1.84 (-8.79,5.11)	2.95 (-1.82,7.72)	-4.51 (-13.20,4.18)	2.99 (-4.87,10.85)	RT	
-0.29 (-7.38,6.80)	-8.00 (-12.37,-3.63)	-15.46 (-23.94,-6.98)	-7.96 (-15.59,-0.33)	-10.95 (-15.78,-6.12)	BOT

Exploratory subgroup comparisons across exercise dosage parameters

Exploratory subgroup comparisons were stratified by session duration, weekly training frequency, and intervention period (Table 5). Figure 6 displays SMD estimates against total training volume. No formal dose–response meta-regression or restricted cubic spline analysis was performed. The scatter plots were interpreted descriptively and were not used to infer a linear or nonlinear dose–response relationship, a threshold effect, or an optimal exercise dose.

Publication bias

Funnel plots were generated for visual inspection of small-study effects across all three outcomes. Formal Egger's regression testing was only performed for SEBT and CAIT, as these two outcomes included ≥ 10 independent RCTs; the FAAM analysis contained fewer than 10 eligible studies, so quantitative asymmetry testing was omitted due to limited statistical power. For SEBT and CAIT, Egger's regression yielded $P > 0.05$, while visual inspection was used as a qualitative check for asymmetry. Importantly, non-significant funnel asymmetry does not definitively rule out risk of missing/unreported evidence, per ROB-MEN tool and Cochrane Handbook Chap. 13 guidance. We therefore accounted for potential reporting bias in the CINeMA certainty evaluations (Fig. 7).

Subgroup analysis results

Table 5 presents subgroup SMDs and 95% confidence intervals according to session duration, weekly training frequency, and intervention period, together with the reported heterogeneity statistics. Subgroup estimates were interpreted descriptively; differences in statistical significance between subgroups were not treated as formal evidence of between-subgroup differences.

For SEBT, the pooled SMDs were 0.66 (95% CI 0.22 to 1.10) for sessions shorter than 30 min, 1.04 (95% CI 0.39 to 1.69) for sessions of 30–60 min, and 1.58 (95% CI 1.14 to 2.01) for sessions longer than 60 min. Estimates stratified by weekly frequency and intervention period are also presented in Table 5. These subgroup estimates do not demonstrate a dose–response relationship.

For CAIT, subgroup estimates varied across session duration, weekly frequency, and intervention period (Table 5). The confidence intervals for several categories included zero. The available subgroup results do not establish that any particular frequency or intervention period is superior.

For FAAM, subgroup estimates by session duration, weekly training frequency, and intervention period are presented in Table 5. These exploratory analyses do not support a definitive recommendation for exercise dosage.

Table 5
Exploratory subgroup estimates by exercise dosage parameter

Variable	Subgroup	Category	N	SMD	95%CI	Heterogeneity	
						I^2	P
SEBT	Time	< 30 min	256	0.66	(0.22,1.10)	64.60%	0.103
		30–60 min	42	1.04	(0.39,1.69)	0.00%	0.002
		> 60 min	109	1.58	(1.14,2.01)	0.00%	0.638
	Frequency	1 t/w	18	1.63	(0.55,2.72)	35.00%	0.451
		2 t/w	197	1.23	(0.92,1.54)	3.00%	0.397
		3 t/w	192	0.60	(0.06,1.14)	28.90%	0.002
	Period	< 5 w	200	0.79	(0.24,1.34)	50.10%	0.541
		5–8 w	116	0.77	(0.39,1.15)	0.00%	0.042
		> 8 w	91	1.57	(1.09,2.04)	0.00%	0.346
CAIT	Time	< 30 min	283	0.73	(0.32,1.14)	63.00%	0.054
		30–60 min	144	0.25	(-1.44.1.95)	34.50%	0.001
		> 60 min	91	2.60	(2.04,3.17)	0.00%	0.663
	Frequency	2 t/w	219	0.84	(-0.75,2.42)	45.80%	0.001
		3 t/w	299	0.78	(0.22,1.33)	39.80%	0.001
	Period	< 5 w	261	0.79	(-0.08,1.66)	80.10%	0.064
		5–8 w	108	0.84	(0.11,1.56)	47.00%	0.028
		> 8 w	149	0.88	(-1.07,2.83)	66.00%	0.071
FAAM	Time	< 30min	157	0.07	(-0.38,0.52)	49.60%	0.078
		30-60min	76	1.06	(0.10,2.22)	30.90%	0.005
	Frequency	2t/w	30	0.39	(-0.33,1.12)	0.00%	0.071
		3t/w	203	0.36	(-0.21,0.92)	73.20%	0.001
	Period	< 5 w	153	0.29	(-0.14,0.72)	41.20%	0.155
		5–8 w	80	0.60	(-0.84,2.05)	88.90%	0.001

Certainty of the evidence

The outcome-level certainty judgements and domain-specific assessments are summarized in Table 6.

1. 1. Within-study bias: The reported unclear or high risk of bias across key domains led to a two-level downgrade for each outcome. PEDro scores were not counted as an additional source of downgrading.
2. 2. Reporting bias: Potential bias due to missing evidence led to a one-level downgrade for each outcome. Small-study effects were considered alongside the possibility of selectively unreported results.
3. 3. Indirectness: No downgrade was applied for indirectness.
4. 4. Heterogeneity: Between-study heterogeneity led to a one-level downgrade for each outcome.
5. 5. Incoherence: No downgrade was applied for incoherence.
6. 6. Imprecision: No downgrade was applied for imprecision.

After integrating all six domains, the overall certainty of evidence for SEBT, CAIT and FAAM was rated very low.

Table 6
Reported certainty of evidence by CINeMA domain

Outcome	Studies	Within-study bias	Heterogeneity	Reporting bias	Indirectness	Incoherence	Imprecision	Certainty
SEBT	11 RCTs	Serious	Moderate	Potential missing evidence bias	No concerns	None	Adequate precision	⨁●●● Very low
		Downgrade two levels	Downgrade one level	Downgrade one level	Do not rate down	Do not rate down	Do not rate down	
CAIT	11 RCTs	Serious	Serious	Potential missing evidence bias	No concerns	None	Adequate precision	⨁●●● Very low
		Downgrade two levels	Downgrade one level	Downgrade one level	Do not rate down	Do not rate down	Do not rate down	
FAAM	6 RCTs	Serious	Serious	Potential missing evidence bias	No concerns	None	Adequate precision	⨁●●● Very low
		Downgrade two levels	Downgrade one level	Downgrade one level	Do not rate down	Do not rate down	Do not rate down	

DISCUSSION

This review examined exercise-based rehabilitation for CAI, a condition associated with sensorimotor and strength deficits [7]. Exercise approaches addressing balance, neuromuscular control, and strength have been investigated in this population [35, 36, 37]. The present synthesis should be read alongside the broader physical therapy network meta-analysis by Yang et al. [9]; its intended contribution is a more focused examination of exercise-based rehabilitation, rather than a claim that exercise interventions have not previously been reviewed.

The outcomes represent related but distinct aspects of rehabilitation. The SEBT is a performance-based assessment of dynamic balance, whereas the CAIT and FAAM provide self-reported information on ankle instability and function, respectively. Performance-based and self-reported outcomes should therefore not be treated as interchangeable. An improvement in one domain does not necessarily imply an equivalent improvement in another. Considering the outcomes separately is important when interpreting both relative effects and treatment rankings.

The reported treatment rankings differed across SEBT, CAIT, and FAAM. A high SUCRA value indicates a favourable relative ranking within the analysed network, but it is not evidence that an intervention is definitively the best option. Comparative effect estimates and their confidence intervals are more informative for judging the magnitude and uncertainty of treatment differences [12]. Sparse networks and uncertainty in the evidence limit conclusions about the superiority of individual approaches. Accordingly, the findings should not be used to recommend a particular coded intervention, or multimodal training as a class, over every alternative.

Several mechanisms may help explain why different exercise approaches could influence rehabilitation outcomes, but the present synthesis did not directly test those mechanisms. Existing reviews have examined proprioception and balance-related exercise in CAI [38, 39, 40], and comparative work has considered resistance and proprioceptive training [41]. Studies of postural control and proximal muscle contributions also provide a rationale for considering the lower limb beyond the ankle [42, 43]. Hip-strengthening programmes have been investigated in CAI [34], but the current network does not establish that hip strengthening is superior to ankle-focused training. These findings provide context for future component-specific comparisons, rather than proof of a particular neuromuscular mechanism.

Exercise dosage also requires cautious interpretation. Although dosage-focused reviews have examined balance training in CAI [44], the present analyses were exploratory and did not include formal between-subgroup comparisons or continuous dose–response modelling. Numerical differences between subgroup estimates cannot establish that longer sessions, greater weekly frequency, or longer programmes cause larger benefits. These parameters may also vary with intervention type and participant characteristics. The subgroup results therefore identify questions for further study rather than a standardized exercise prescription.

Methodological considerations

Several limitations should be acknowledged. First, the English-language restriction may have excluded relevant studies. Second, reporting of allocation concealment and assessor blinding was incomplete, and participant and instructor blinding is challenging in exercise trials. Third, exercise intensity and comparator content were not consistently described, which limits comparisons across programmes. Combining heterogeneous exercise approaches within broad intervention categories may also obscure differences between their components. Fourth, the selected outcomes describe dynamic balance and self-reported ankle outcomes rather than physiological or structural adaptation. Finally, intervention periods were no longer than 12 weeks, and the analysed outcomes do not establish whether benefits are sustained or whether recurrent sprains are prevented.

The inclusion of adolescent and adult participants also introduces potential clinical heterogeneity. Study-level mean ages cannot define the age range of all participants. The limited number of adolescent trials restricted age-specific analyses, and separate evaluation of adolescents and adults remains an

important question for future research.

Conclusion

Exercise-based rehabilitation may improve dynamic balance and self-reported ankle outcomes in people with CAI. However, uncertainty in comparative effect estimates limits firm conclusions about the superiority of individual exercise approaches. The exploratory subgroup findings do not establish an optimal exercise dose. Better-reported, adequately powered trials with longer follow-up are needed to clarify comparative effects and the sustainability of rehabilitation outcomes.

Declarations

Authors' contributions

Conceptualization: C.Z., D.F.; Data curation: M.T., Z.Z.; Formal Analysis: Z.Z.; M.T.; Writing-original draft, Writing-review & editing:C.Z., Z.Z. All authors reviewed the results and approved the final version of the manuscript.

Funding Statement

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Clinical trial number

Not applicable.

References

1. Doherty CEA (2014) The incidence and prevalence of ankle sprain injury: a systematic review and meta-analysis of prospective epidemiological studies. Sports medicine (Auckland, N.Z). 44(1):123–140
2. Soboroff SH, Pappius EM, Komaroff AL Benefits, risks, and costs of alternative approaches to the evaluation and treatment of severe ankle sprain. Clin Orthop Relat Res, 1984(183): p. 160–168
3. Hupperets MDW, Verhagen EALM, van Mechelen W (2008) The 2BFit study: is an unsupervised proprioceptive balance board training programme, given in addition to usual care, effective in preventing ankle sprain recurrences? Design of a randomized controlled trial. BMC Musculoskelet Disord 9:71
4. Yeung MS et al (1994) An epidemiological survey on ankle sprain. Br J Sports Med 28(2):112–116
5. Valderrabano V et al (2006) [Chronic ankle instability in sports -- a review for sports physicians]. Sportverletz Sportschaden 20(4):177–183
6. de Vries JS et al Interventions for treating chronic ankle instability. Cochrane Database Syst Rev, 2006(4): p. CD004124
7. Thompson C et al (2018) Factors Contributing to Chronic Ankle Instability: A Systematic Review and Meta-Analysis of Systematic Reviews. Sports Med 48(1):189–205
8. Xue X et al (2023) Force sense deficits in chronic ankle instability: A systematic review and meta-analysis. PM R 15(6):780–789
9. Yang YS et al (2025) What Will Deliver the Best Bang-For-Your-Treatment-Buck? Treatment Effects of Physical Therapy Approaches to Managing Chronic Ankle Instability: A Network Meta-Analysis of Randomized Controlled Trials. J Orthop Sports Phys Ther 55(1):26–44.

10.2519/jospt.2024.12601
10. Page MJ et al (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71. 10.1136/bmj.n71
11. Nikolakopoulou A et al (2020) CINeMA: An approach for assessing confidence in the results of a network meta-analysis. PLoS Med 17(4):e1003082. 10.1371/journal.pmed.1003082
12. Chaimani A et al (2024) Chap. 11: Undertaking network meta-analyses. In: Higgins J.P., Thomas J., Chandler J., editors. Cochrane Handbook for Systematic Reviews of Interventions, version 6.5. Cochrane
13. Anguish B, Sandrey MA (2018) Two 4-Week Balance-Training Programs for Chronic Ankle Instability. J Athl Train 53(7):662–671
14. Cain MS, Garceau SW, Linens SW (2017) Effects of a 4-Week Biomechanical Ankle Platform System Protocol on Balance in High School Athletes With Chronic Ankle Instability. J Sport Rehabilitation 26(1):1–7
15. Cain MS et al (2020) Four-Week Ankle-Rehabilitation Programs in Adolescent Athletes With Chronic Ankle Instability. J Athl Train 55(8):801–810
16. Cloak R et al (2010) Vibration training improves balance in unstable ankles. Int J Sports Med 31(12):894–900
17. Cloak R et al (2013) Six-week combined vibration and wobble board training on balance and stability in footballers with functional ankle instability. Clin J Sport Med 23(5):384–391
18. Cruz-Díaz D et al (2020) Ankle-Joint Self-Mobilization and CrossFit Training in Patients With Chronic Ankle Instability: A Randomized Controlled Trial. J Athl Train 55(2):159–168
19. Deussen S, Alfuth M, THE INFLUENCE OF SENSORIMOTOR TRAINING MODALITIES ON BALANCE STRENGTH, JOINT FUNCTION, AND PLANTAR FOOT SENSITIVITY IN RECREATIONAL ATHLETES WITH A HISTORY OF ANKLE SPRAIN (2018) A RANDOMIZED CONTROLLED PILOT STUDY. Int J Sports Phys Therapy 13(6):993–1007
20. Hall EA et al (2018) Balance- and Strength-Training Protocols to Improve Chronic Ankle Instability Deficits, Part II: Assessing Patient-Reported Outcome Measures. J Athl Train 53(6):578–583
21. Kim K et al (2014) Which Treatment is More Effective for Functional Ankle Instability: Strengthening or Combined Muscle Strengthening and Proprioceptive Exercises? J Phys Therapy Sci 26(3):385–388
22. Lee K et al (2012) Short term rehabilitation and ankle instability. Int J Sports Med 33(6):485
23. Lee E, Cho J, Lee S (2019) Short-Foot Exercise Promotes Quantitative Somatosensory Function in Ankle Instability: A Randomized Controlled Trial. Med Sci Monit 25:618–626
24. MCKEON PO et al (2008) Balance Training Improves Function and Postural Control in Those with Chronic Ankle Instability. Med Sci Sports Exerc 40(10):1810–1819
25. Minoonejad H et al (2019) Hop Stabilization Training Improves Neuromuscular Control in College Basketball Players With Chronic Ankle Instability: A Randomized Controlled Trial. J Sport Rehabilitation 28(6):576–583
26. Nam S, Kim K, Lee DY (2018) Effects of visual feedback balance training on the balance and ankle instability in adult men with functional ankle instability. J Phys Ther Sci 30(1):113–115
27. Plaza-Manzano G et al (2016) Manual therapy in joint and nerve structures combined with exercises in the treatment of recurrent ankle sprains: A randomized, controlled trial. Man Therap 26:141–149
28. Schaefer JL, Sandrey MA (2012) Effects of a 4-week dynamic-balance-training program supplemented with Graston instrument-assisted soft-tissue mobilization for chronic ankle instability. J Sport Rehabil 21(4):313–326
29. Shamseddini Sofla F et al (2021) The effect of the combination of whole body vibration and shoe with an unstable surface in chronic ankle instability treatment: a randomized clinical trial. BMC Sports Sci Med Rehabilitation 13(1):28
30. Shih Y et al (2018) The effect of additional joint mobilization on neuromuscular performance in individuals with functional ankle instability. Phys Ther Sport 30:22–28
31. Sierra-Guzmán R et al (2018) Whole-Body–Vibration Training and Balance in Recreational Athletes With Chronic Ankle Instability. J Athl Train 53(4):355–363
32. Wright CJ, Linens SW, Cain MS (2017) A Randomized Controlled Trial Comparing Rehabilitation Efficacy in Chronic Ankle Instability. J Sport Rehabilitation 26(4):238–249
33. Park HS et al (2024) The Effect of Strength and Balance Training on Kinesiophobia, Ankle Instability, Function, and Performance in Elite Adolescent Soccer Players with Functional Ankle Instability: A Prospective Cluster Randomized Controlled Trial. J Sports Sci Med, : p. 593–602
34. Yeum W, Lee M, Lee B (2024) The Influence of Hip-Strengthening Program on Patients with Chronic Ankle Instability. Medicina 60(8):1199
35. Fitzgerald D et al (2010) Effects of a wobble board-based therapeutic exergaming system for balance training on dynamic postural stability and intrinsic motivation levels. J Orthop Sports Phys Ther 40(1):11–19
36. Yin Y et al (2025) Effect of proprioceptive neuromuscular facilitation on patients with chronic ankle instability: A systematic review and meta-analysis. PLoS ONE 20(1):e0311355
37. Zhang C et al (2025) Effectiveness of exercise therapy on chronic ankle instability: a meta-analysis. Sci Rep 15(1):11709
38. Xue X et al (2021) Chronic ankle instability is associated with proprioception deficits: A systematic review and meta-analysis. J Sport Health Sci 10(2):182–191

39. Han J et al (2022) Can Therapeutic Exercises Improve Proprioception in Chronic Ankle Instability? A Systematic Review and Network Meta-analysis. Arch Phys Med Rehabil 103(11):2232–2244
40. Guo Y et al (2024) A systematic review and meta-analysis of balance training in patients with chronic ankle instability. Syst Rev 13(1):64
41. Fakontis C et al (2023) Efficacy of resistance training with elastic bands compared to proprioceptive training on balance and self-report measures in patients with chronic ankle instability: A systematic review and meta-analysis. Phys Ther Sport 64:74–84
42. Pintsaar A, Brynhildsen J, Tropp H (1996) Postural corrections after standardised perturbations of single limb stance: effect of training and orthotic devices in patients with ankle instability. Br J Sports Med 30(2):151–155
43. Rios JL, Gorges AL, Dos Santos MJ (2015) Individuals with chronic ankle instability compensate for their ankle deficits using proximal musculature to maintain reduced postural sway while kicking a ball. Hum Mov Sci 43:33–44
44. Tang F et al (2024) Meta-analysis of the dosage of balance training on ankle function and dynamic balance ability in patients with chronic ankle instability. BMC Musculoskelet Disord 25(1):689

Figures

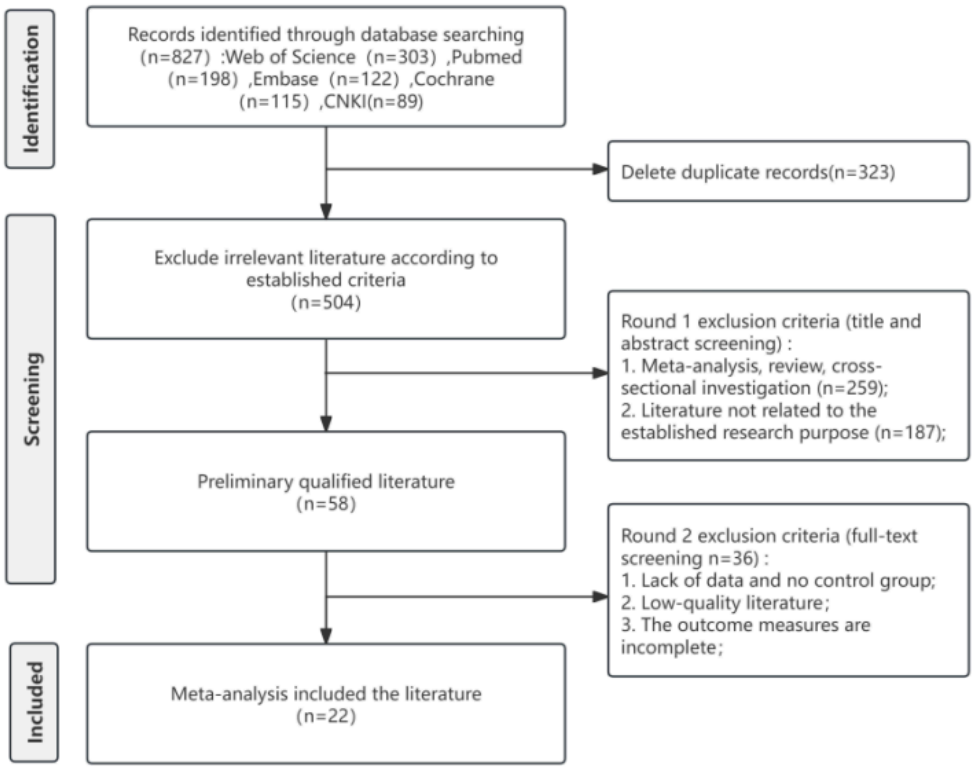

Figure 1

Study selection flow diagram

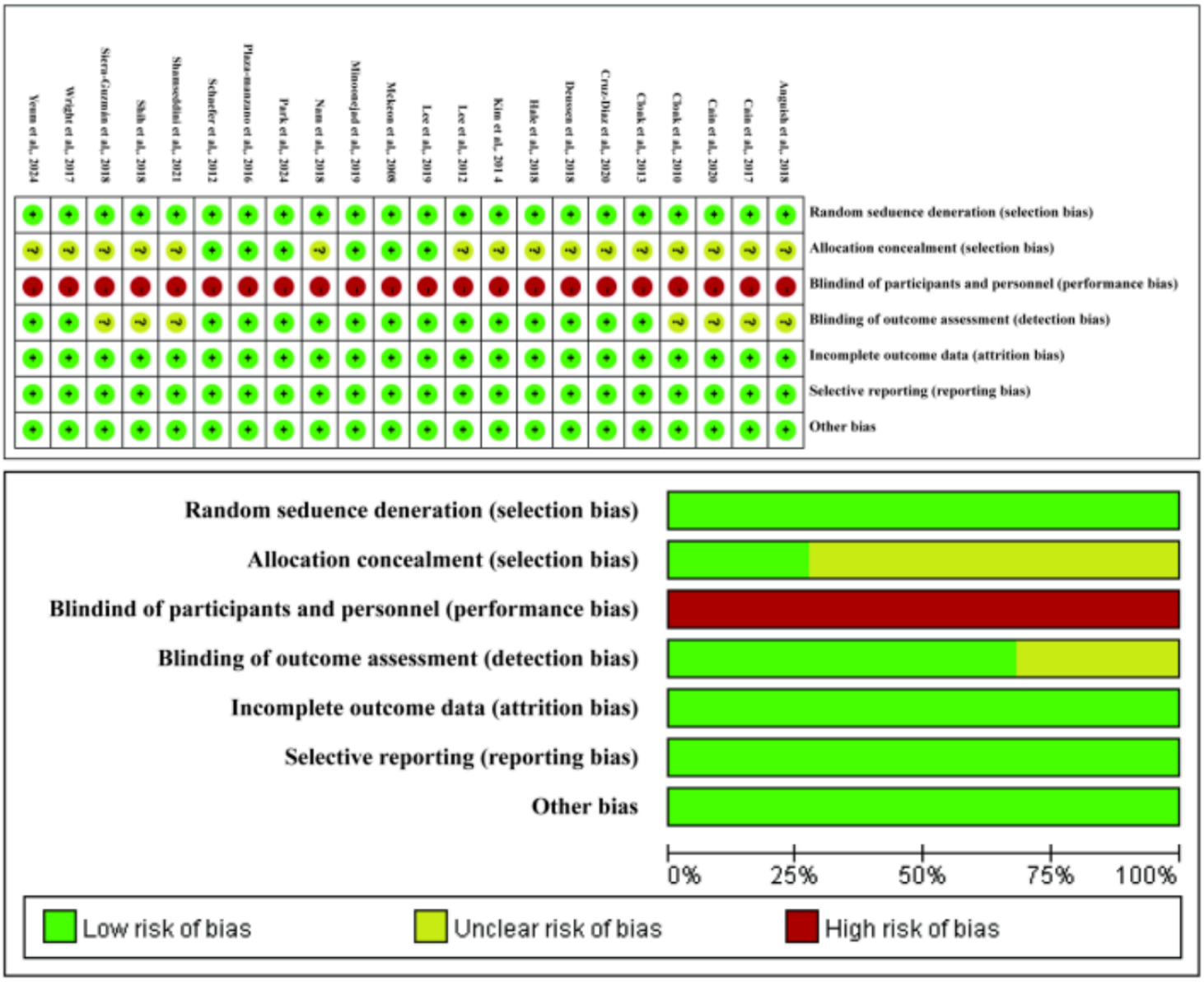

Figure 2

Risk of bias assessments for the included studies

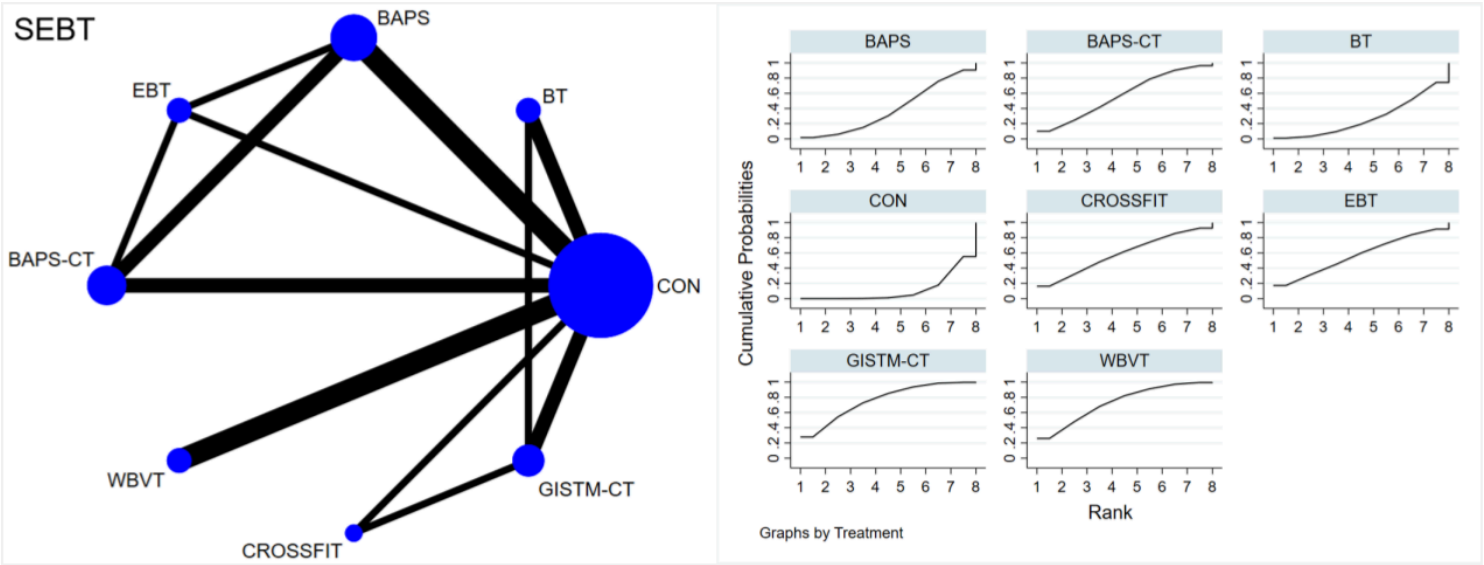

Figure 3

Network diagram and SUCRA rankings for SEBT

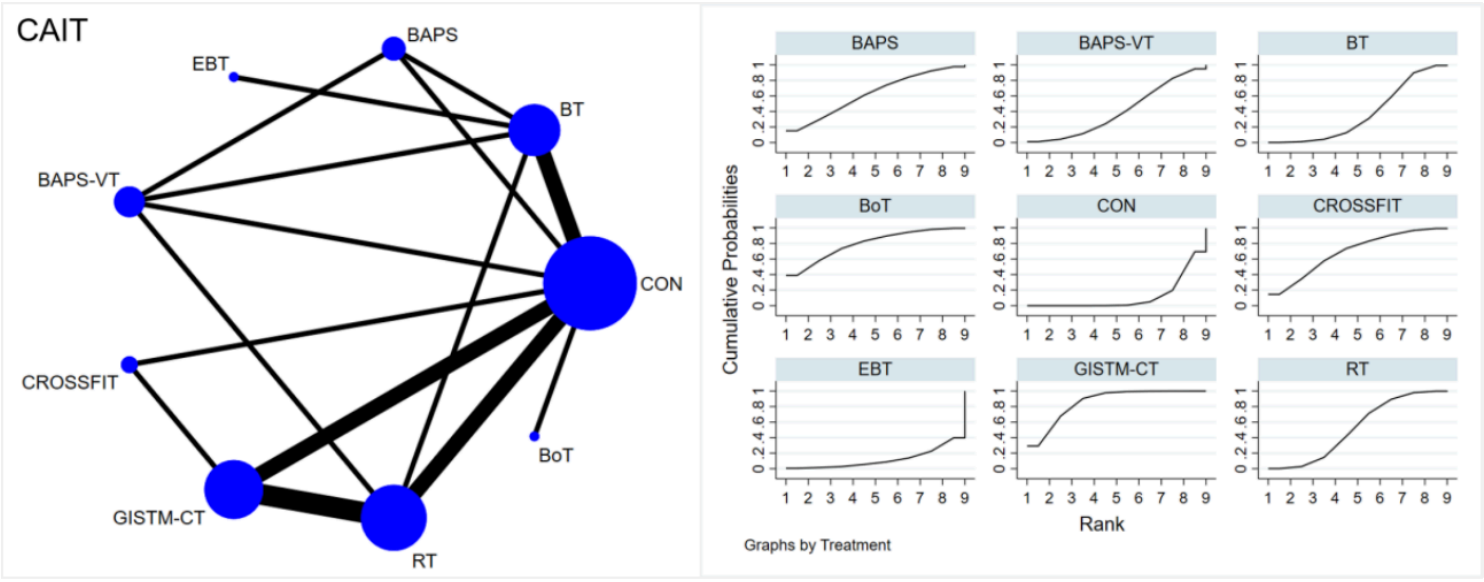

Figure 4

Network diagram and SUCRA rankings for CAIT

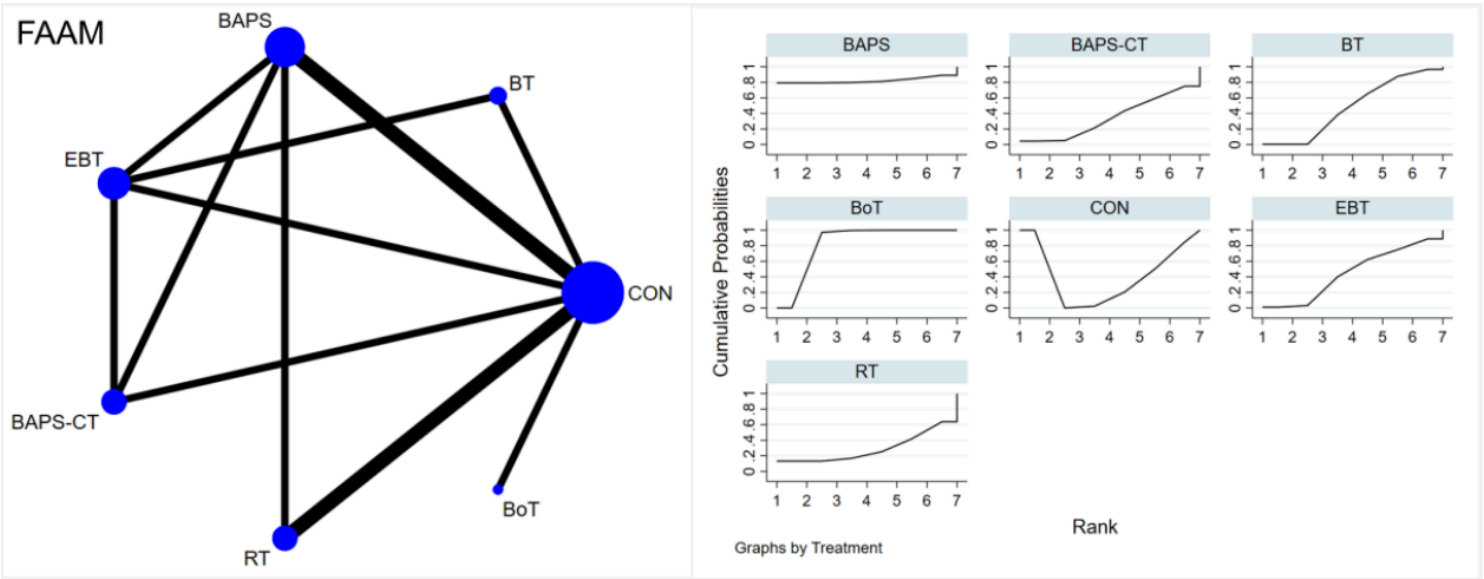

Figure 5

Network diagram and SUCRA rankings for FAAM

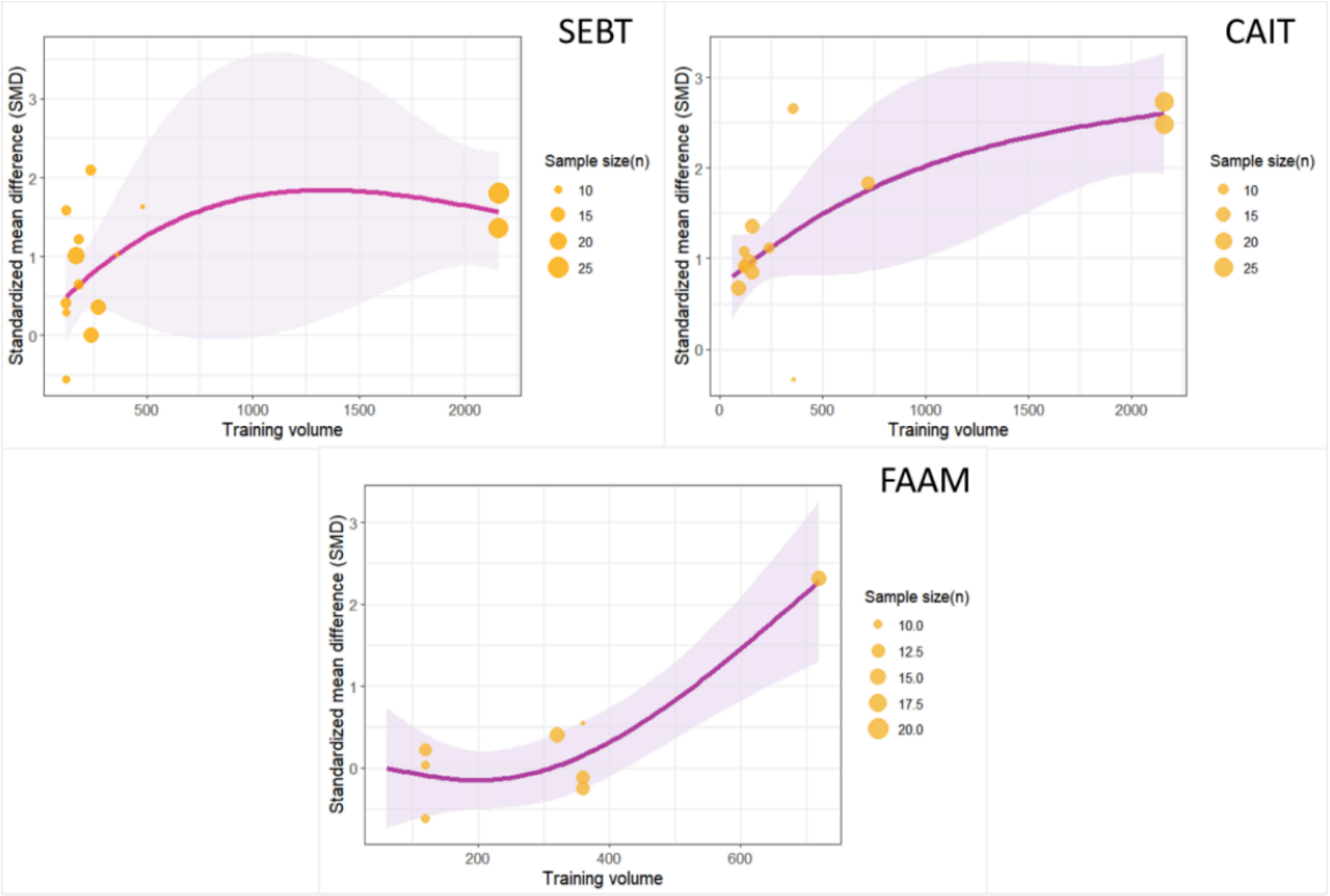

Figure 6

Scatter plots of SMD estimates against total training volume for SEBT, CAIT, and FAAM

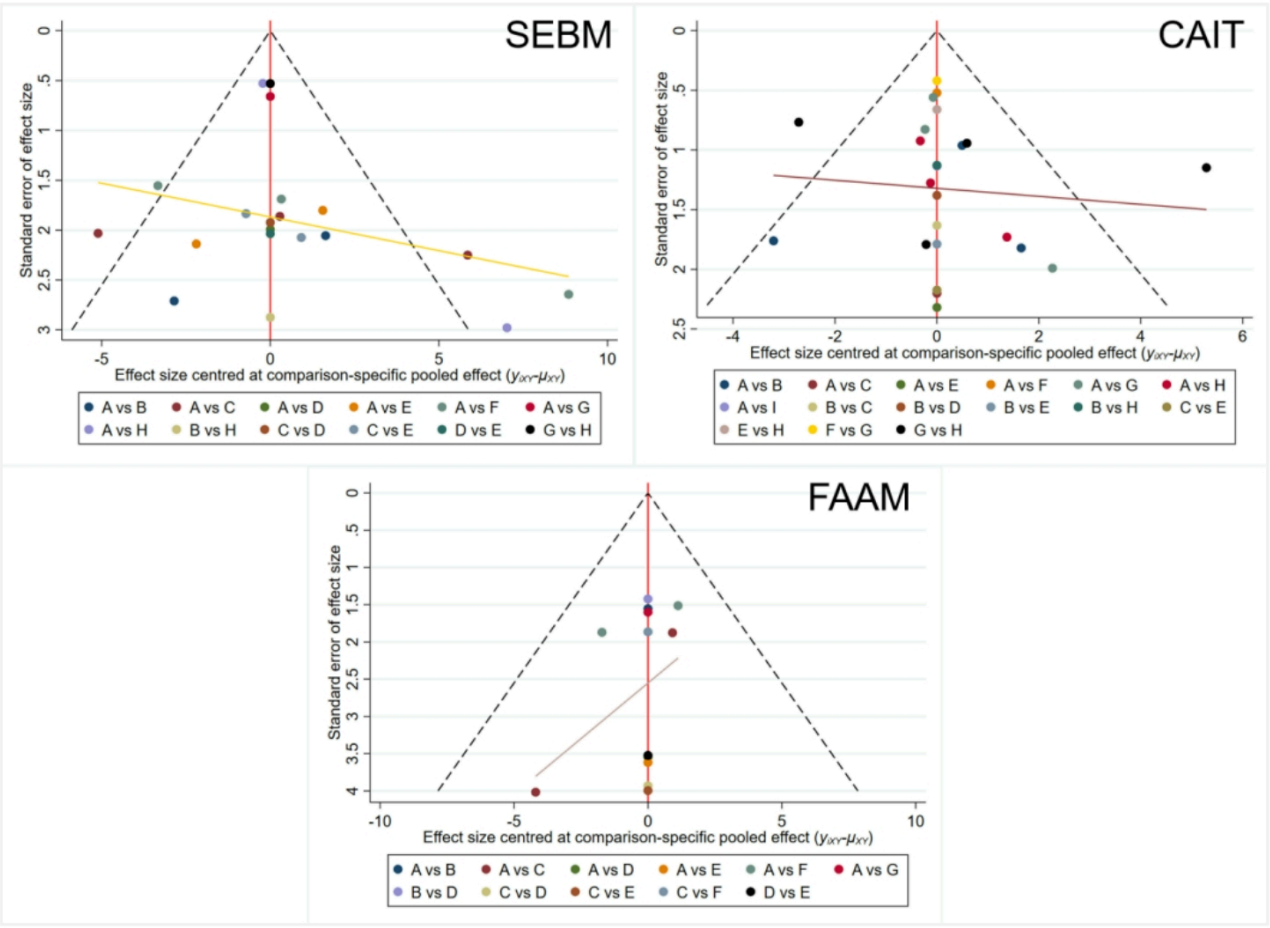

Figure 7

Funnel plots for SEBT, CAIT, and FAAM