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SYSTEMATIC REVIEW

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Meta-analysis of the dosage of balance training on ankle function and dynamic balance ability in patients with chronic ankle instability

Fang Tang[1†], Meng Xiang[2†], Shanshan Yin[3†], Xiang Li[1] and Pincao Gao[1,2*]

Abstract

Objective To explore and compare the dosage of balance training on ankle function and dynamic balance ability in patients with chronic ankle instability (CAI).

Methods The PubMed, Embase, Web of Science, Medline, and Cochrane databases were searched up to December 2023. Quality assessment was carried out using the risk-of-bias guidelines of the Cochrane Collaboration, and the standardized mean differences (SMD) or mean differences (MD) for each outcome were compute.

Results Among 20 eligible studies, including 682 participants were analyzed in this meta-analysis. The results of the meta-analysis demonstrated that balance training was effective in enhancing ankle function with self-functional scores (SMD = 1.02; 95% CI, 0.61 to 1.43; $p < 0.00001$; $I^2 = 72\%$) and variables associated with the ability of dynamic balance such as SEBT-A (MD = 5.88; 95% CI, 3.37 to 8.40; $p < 0.00001$; $I^2 = 84\%$), SEBT-PM (MD = 5.47; 95% CI, 3.40 to 7.54; $p < 0.00001$; $I^2 = 61\%$), and SEBT-PL (MD = 6.04; 95% CI, 3.30 to 8.79; $p < 0.0001$; $I^2 = 79\%$) of CAI patients. Meta-regression indicated that the intervention time might be the principal cause of heterogeneity ($p = 0.046$) in self-functional scores. In subgroup analyses of self-functional score across intervention types, among the intervention time, more than 20 min and less than 30 min had the most favorable effect (MD = 1.21, 95% CI: 0.96 to 1.46, $p < 0.00001$, $I^2 = 55\%$); among the intervention period, 4 weeks (MD = 0.84, 95% CI: 0.50 to 1.19, $p < 0.00001$, $I^2 = 78\%$) and 6 weeks (MD = 1.21, 95% CI: 0.91 to 1.51, $p < 0.00001$, $I^2 = 71\%$) had significant effects; among the intervention frequency, 3 times (MD = 1.14, 95% CI: 0.89 to 1.38), $p < 0.00001$, $I^2 = 57\%$) had significant effects. Secondly, in subgroup analyses of SEBT across intervention types, a 4-week and 6-week intervention with balance training 3 times a week for 20–30 min is the optimal combination of interventions to improve SEBT (dynamic balance) in patients with chronic ankle instability.

Conclusion Balance training proves beneficial for ankle function in patients with CAI. Intervention time constitutes a major factor influencing self-function in patients with CAI. It is recommended that the optimal dosage of balance training for CAI involves intervention three times a week, lasting for 20 to 30 min over a period of 4 to 6 weeks for superior rehabilitation.

Keywords Balance training, Chronic ankle instability, Meta-analysis, Dosage of balance training, Self-functional, SEBT

†Fang Tang, Meng Xiang and Shanshan Yin contributed equally to this work and share co-first author.

*Correspondence:
Pincao Gao
112312@aqnu.edu.cn
Full list of author information is available at the end of the article

Introduction

Lateral ankle sprains (LASs) are the most common musculoskeletal injuries in young and active individuals [1]. The incidence rates of LASs are between 75 and 85% in all ankle injuries [2], meanwhile 40% of the general population experience LASs during their lifetime [3, 4]. Despite initial treatment (taping/bracing) and physical rehabilitation for LAS, 30%-40% of LAS patients develop chronic ankle instability (CAI) [5]. CAI is characterized by repeated episodes or sensations of ankle loosening; persistent symptoms such as pain, weakness, or decreased ankle range of motion (ROM), diminished self-reported function, recurrence of ankle sprains more than 1 year after initial injury [6]. These potential long-term consequences highlight the need for suitable treatments for these conditions.

In current treatment methods, traditional conservative interventions is the most common choice for CAI, such as resistance training, joint mobilization, soft tissue mobilization, passive calf stretching and orthotics [7].Impaired balance ability is one of the main causes of recurrent ankle sprains, postural stability training provides a great boost in the rehabilitation of patients with CAI [8].

Rehabilitation researchers have recently paid increasing attention to the efficacy of balance training as an alternative treatment for CAI patients, in particular, dynamic and unstable balance training have been reported to be an effective modality for improve the symptoms of ankle instability and promote proprioceptive recovery in clinical practice [9]. A review concluded that balance training effectively reduces the risk of ankle sprain in sports participants [10]. Previous studies also showed that their self-reported function and neuromuscular control ability were improved both by dynamic balance training and single leg balance training for CAI [11, 12]. The possible mechanism is that balance training on stable ground may correspond with enhanced static postural control, whereas instability balance training may improve dynamic postural control [13, 14].

There also have been previous systematic reviews and meta-analyses on the impact of balance training on CAI [15–17], and the systematic reviews of Mollà-Casanova, et al. have explored the effects of balance training combined with strength training on CAI and Jiang, Huang et al. have elaborated of the effect of balance training on dynamic posture in CAI while the studies of Wang, Zhang et al. was a protocol for a systematic review and meta-analysis. However, in the previous meta-analysis, there was no uniformly recommended exercise prescription (such as exercise frequency and duration of a single exercise), which led to the existing exercise forging can improve the efficiency of exercise, reduce the ineffective exercise, and strengthen the clarity and operability of exercise guidance by refining the exercise dose. In previous studies, balance training methods with different intervention period [e.g., 4 weeks of intervention [12, 18, 19], 6 weeks of intervention [20–22], and more than 6 weeks of intervention [23]] have used for patients with chronic ankle instability as same as the different intervention frequencies, and different intervention durations, however, what is this optimal intervention dose? Therefore, through meta-analysis, the purpose of this article is to explore the efficacy of the optimal intervention dosage of balance training on chronic ankle instability, and to provide a reliable theoretical basis for the scientific development of exercise prescription for CAI patients.

Materials and methods

The review follows the Cochrane Handbook for the Preferred Reporting Items for Systematic Reviews (PRISMA) statement [24] and as it was registered(Identifier: CRD42024502230) in the International Prospective Register of Systematic Reviews (PROSPERO).

Study search and selection

The references on PubMed, Embase, Web of Science, Medline, Cochrane Central Register of Controlled Trials up to December 2023 without any date restrictions were searched. Search terms were (training OR exercise OR rehabilitation) AND balance AND (chronic ankle instability OR mechanical ankle instability OR functional ankle instability OR Joint Instability OR Joint Instability OR Ankle Joint).The inclusion criteria of this meta-analysis included: (a) the study was conducted on patients diagnosed with CAI, (b) reporting quantitative data related to ankle functional or balance ability such as Foot and Ankle Ability Measure, Star Excursion Balance Test and Cumberland Ankle Instability Tool, (c) interventions were only balance training, such as Progressive Jump Stable Balance (PHSB) training method or the balance training based on the unstable surface or Biomechanical Ankle Platform System (BAPS) plate or swing boards, (d) the control group was non-balance training program, including conventional physical therapy, strength training and so on, and(e) using randomized control trial design. The exclusion criteria of this meta-analysis included: (a)studies excluded patients with CAI plus other ankle disorders, (b) the origin of the subject population is repeated, (c) literature other than English, (d) the trial was not conducted with a comparison group, or data on baseline score or end-point outcome were not provided sufficiently, (e) Review articles, case reports, editorials, and conferences were also excluded. Additionally, the diagnostic criteria for CAI by International Ankle Consortium include the following [20]: (a) at least1 acute ankle-inversion sprain that resulted in swelling, pain, and dysfunction that occurred at least 12 months before the study; (b)at least 2 episodes of the ankle "giving way" within the past 6 months; (c)answered 4 or more questions with yes on the Ankle Instability Instrument; (d) a disability score of $\leq$ 90% on the Foot and Ankle Ability Measure (FAAM),and (e) a disability score $\leq$ 80% on the FAAM–Sport(FAAM-S). Additionally, CAI participants were required to score < 75% in 3 or more categories on the Foot and Ankle Outcome Score, score < 24 on the Cumberland Ankle Instability Tool, and have clinically negative anterior drawer and talar tilt tests. The duplicates article from the search was removed by the EndNote X9 software, and then the titles and abstracts of articles to establish eligibility for inclusion was read independently by two reviewers. Studies that failed to meet the inclusion criteria were not reviewed further. Articles that could not be excluded was searched and the full text was evaluated by two reviewers (FT and SY). The authors were contacted via email when data validation or more information was required. Disagreements or ambiguities were resolved through a third reviewer (PG) discussion.

Data extraction and quality assessment

The following data were extracted from included studies: first author, year of publication, simple size, age, sex, intervention method, intervention period/time/frequency, outcome measurements, and adverse effect of the study subjects. The quality of the included studies was evaluated using the Cochrane Collaboration's risk-of-bias guidelines [25]. We will evaluate the risk of bias (low, high and unclear risk) in seven areas, including: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessments, incomplete outcome data, selective reporting, and other biases. The final decisions will be made by a third reviewer (PG) if discrepancies appear.

Types of outcome measures

The primary outcome parameters were self-functional score of ankle instability, which comprises Cumberland Ankle Instability Tool (CAIT) and Foot and Ankle Ability Measure-Sport (FAAM-S). Furthermore, the secondary outcome parameter was Star Excursion Balance Test (SEBT), which it mainly reflects the dynamic balance ability of the ankle joint and it consists of a star-shaped offset balancing test in 3 directions: anterior (SEBT-A), posterior medial a(SEBT-PM) and posterior lateral (SEBT-PL).

Data synthesis and statistical analysis

All outcome parameters of this studies included in this meta-analysis were continuous variables, and the mean difference (MD) with 95% CI will be used for the continuous variables, and standardized mean difference (SMD) and 95%CI will be used for the continuous variables if the units are different. Data processing was conducted by the RevMan5.3 and Stata14.0 software for this meta-analysis. Stata14.0 software was used to perform Z tests to compare differences in the subgroup's overall effect sizes based on the intervention period/frequency/time. Heterogeneity test was performed using the Q statistic, and if $p > 0.05$, and $I^2 \leq 50\%$, indicating that the studies are homogeneous, then a fixed-effect model was used for analysis. Otherwise, a random-effect model was used for analysis. Subgroup analysis and sensitivity analysis were performed if there was large heterogeneity in the pooled study results. A subgroup analysis according to intervention period/frequency/time was performed. A sensitivity analysis was conducted to prove the reliability of our meta-analysis results by removing each study to evaluate the consistency and quality of the results [26].When there were more than 10 studies with outcome indicators, funnel plots, and Egger asymmetry tests were used to detect publication bias. It was hard to find the cause of asymmetry when there were fewer than ten studies [27]. Statistically significant differences were set at a = 0.05.

Results

Search results

A total of 672 records were retrieved after initial database search, and 446 records were included in the initial screening after removing duplicates with EndNote. The abstract and text for each study was reviewed by two reviewers based on the inclusion and exclusion criteria. 358 studies were excluded due to review articles, case report, unavailability of full text, and unrelated study design, interventions, and outcome parameters (e.g., protocol studies). Eighty-eight records were included in the full-text screening. After further screening, we find another 68 studies that did not fit the criteria and exclude them. Finally, 20 articles met the criteria and were included in our study, and all studies were published in English [11, 18–23, 28–38]. The flowchart is shown as Fig. 1.

Participant characteristics

Twenty studies were included in this meta-analysis including 682 patients with CAI (range of mean age = 15 ~ 41 years), and the mean age of CAI patients in one study [31]was not reported. The sex of CAI's patients in the study [22, 37] were not reported. The Hoehn and

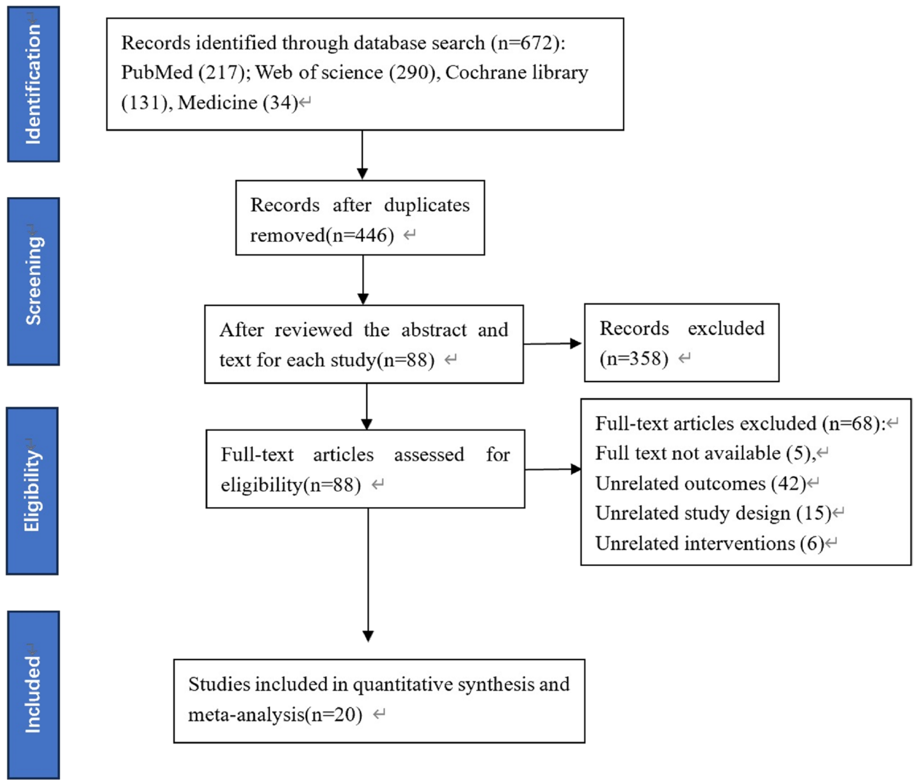

Fig. 1 The flow diagram of the selection process

Yahr scale ranged from 1 to 5. The adverse effect was not reported in all studies. Specific details regarding participant characteristics are shown in Table 1.

Methodological quality assessment

The methodological quality of all included studies was evaluated using the Cochrane Collaboration's techniques for assessing bias risk. In the domain of random sequence generation, all of the included trials described randomized allocation and were evaluated for low-risk. 10 studies [18–20, 22, 23, 29–31, 33, 39] were classified as having an unclear risk in the field of allocation concealment while one study [34] were classified as having a high risk. In the domain of blinding of participants and personnel, eight studies [11, 12, 18, 19, 22, 34, 35, 37]were assessed as having an unclear risk, while four study [21, 23, 30, 39] had a low risk. In their outcome assessment, four studies [19, 21, 22, 28] were deemed as an unclear risk, and the rest were classified as low risk. All studies were reported as low risk in the field of incomplete outcome data. Regarding to selective outcome reporting bias, 8 studies [18, 28, 30–32, 36, 38, 39] were deemed to be at unclear risk, while three study [11, 29, 34]was deemed to be at high risk. Fifteen studies [12, 18–23, 29–32, 34, 37–39]were evaluated as having an unclear risk, and two studies [33, 35]were assessed as having a high risk of other bias. These results are summarized in Fig. 2.

Meta-analysis results

Meta-analysis results of balance training on self-functional scores of patients with chronic ankle instability

Overall effect sizes of the intervention A total of 14 article [11, 12, 18, 20, 23, 28–32, 34, 35, 38], were included in the study of balance training on self-functional scores of patients with chronic ankle instability, including 460 patients with CAI. Test for overall effect using a random effects model showed that balance training had prominent significant effect on the self-functional scores of patients with CAI (SMD = 1.02, 95% CI: 0.61 to 1.43, $p < 0.00001$, $I^2 = 72\%$), as shown in Fig. 3.

Results of meta regression analysis and subgroup tests When the heterogeneity $I^2 \geq 50\%$, so it is necessary to explore the reasons for the heterogeneity and further subgroup testing by Meta regression [40]. Three moderating variables were set according to the literature: intervention period, intervention frequency and intervention time. Intervention period was categorized as 4 weeks, 6 weeks, and > 6 weeks; intervention frequency was

Table 1 Basic characteristics of the included studies

Author (Years)	Simple Size(E/C,n)	Age(E/C,year)	Sex (M/F)	Intervention method	Intervention period/time/frequency	Outcome	adverse effect
Anguish 2018 [12]	9/9	18.33 ± 1.87/ 18.44 ± 1.87	2/16	E: Progressive dynamic balance training: Jump on one leg from different distances to a stable, 9-marked grid in 4 different difficulty levels, Jump to a stable, open and closed eye jump on a dangerous plane C: Maintain daily routines	4Weeks/5Times,15 min	SEBT-A, SEBT-PM, SEBT-PL, FAAM-ADL, FAAM-S	NR
Ardakani 2019 [20]	14/14	22.78 ± 3.09/22.57 ± 2.76	28/	E: Different forms of jump stability training, complete 80 landings in the first week, then increase 20 times per week (150 times in the sixth week), the movement requires increasing difficulty C: Maintain daily routines	6 weeks /3 times, 30 min	CAIT	NR
Cain 2020 [18]	10/11	age range from 15 to18	12/9	E: Balance training using resistance bands and BAPS boards C: No intervention	3 times a week for 4 weeks, 15 min	CAIT, SEBT-A, SEBT-PM, SEBT-PL	NR
Cain2017 [19]	11/11	16.45 ± 0.93/ 16.55 ± 1.29	11/11	E: Five sets of 40 s clockwise and counterclockwise rotations (10 s intervals) were completed on a Biomechanical Ankle Platform System (BAPS) plate. 5 sets of 40 s of clockwise and counterclockwise rotation (1 change of direction every 10 s) with 1 min rest in between; difficulty level (1 change in direction every 10 s), the difficulty level of the exercises was increased from 1–5 C: No intervention	3 times a week for 4 weeks,10-15 min	SEBT-A, SEBT-PM, SEBT-PL,	NR

Table 1 (continued)

Author (Years)	Simple Size(E/C,n)	Age(E/C,year)	Sex (M/F)	Intervention method	Intervention period/time/frequency	Outcome	adverse effect
Chang 2021 [22]	21/21/21	20.31 ± 1.28/20.43 ± 1.25 /21.23 ± 1.47	NR	E1: performed the exercises while standing on the vibration platform, which operated at a frequency and amplitude of 5 Hz and 3 mm, respectively E2: performed the exercises on the balance ball C: continue their normal daily activity and avoid exercise	3 times per week for 6 weeks, 30 min	SEBT-A, SEBT-PM, SEBT-PL	NR
Cloak2010 [21]	11/22	19 ± 0.8/19 ± 1.3	33/0	E: Using the swing board and vibrating ball, complete the actions of single leg standing, single leg heel raising, single foot stepping, single leg straight leg hard pulling, etc. The difficulty increases with the weeks C: Maintain daily routines	6 weeks /2 times, 15 min	SEBT-A, SEBT-PM, SEBT-PL	NR
Cruz-Diaz D2015 [28]	35/35	31.89 ± 10.52/28.83 ± 7.91	35/35	E: Add balance training on the basis of strength training, use BUSO ball, foam roller and other tools to stand on one leg, jump on one leg, one leg standing throwing and catching exercises C: Conventional strength training	6 weeks /3 times, 20–25 min	CAIT, SEBT-A, SEBT-PM, SEBT-PL	NR
Deussen 2018 [29]	6/14	30.0 ± 6.83/29.833 ± 8.18/26 .67 ± 6.22	6/14	E: Standing on one and two legs on different unstable devices. The number of practice sets increases over time C: Maintain daily physical activity	6 weeks /2 times, 20–30 min	CAIT	NR
Donovan2016 [30]	13/13	21.31 ± 3.35/ 21.46 ± 2.88	7/19	E: Ankle-destabilization devices C: Lower limb strength training	60 min, 3 days/week for 4 weeks	FAAM-ADL, FAAM-S	NR

Table 1 (continued)

Author (Years)	Simple Size(E/C,n)	Age(E/C,year)	Sex (M/F)	Intervention method	Intervention period/time/frequency	Outcome	adverse effect
Hale 2014 [31]	12/9	NR	8/26	E: A unilateral balance training program: Single-legged stance, Wobble board, Steamboats, ball catch, Toe touch downs, Hop ups and downs, etc C: continue their normal activities	twice weekly for 4 weeks, 30 min	SEBT-A, SEBT-PM, SEBT-PL, FAAM-ADL, FAAM-S	NR
Hall2018 [39]	26/13	23.5 ± 6.5/24.8 ± 9.0	21/18	E: Dynamic balance training: including jumping to stability, jumping to stability and stretching, jumping to stability box, standing on one leg with eyes open and eyes closed, Stand on one leg for 5 moves and include 7 difficulty levels C: Keep up normal activities	6 weeks /3 times, 20 min	FAAM-ADL, FAAM-S	NR
Kim 2021 [32]	25/24	29.76 ± 10.009/29.67 ± 9.407	25/24	E: The mixed balance training of single leg standing, single leg standing throwing and catching, single leg hard pulling, single leg jumping to stability, etc., has different difficulty progress C: Keep up normal activities	6 weeks /3 times, 20 min	CAIT, SEBT-A, SEBT-PM, SEBT-PL	NR
Lee 2019 [23]	15/15	21.53 ± 2.47/22.00 ± 2.70	15/15	E: Perform instability training on the stability trainer C: Receive routine physiotherapy	8 weeks/3times, 20–25 min	CAIT	NR
Linens 2016 [33]	17/17	22.94 ± 2.77/ 23.18 ± 3.64	6/28	E: Balance training using swing boards C: maintain daily physical activity levels	4 weeks/3times, 15 min	SEBT-A, SEBT-PM, SEBT-PL	NR

Table 1 (continued)

Author (Years)	Simple Size(E/C,n)	Age(E/C,year)	Sex (M/F)	Intervention method	Intervention period/time/frequency	Outcome	adverse effect
McKeon 2008 [34]	16/15	22.2 ± 4.5/19.5 ± 1.2	12/19	E: Dynamic balance training: including jumping to stability, jumping to stability and stretching, jumping to stability box, standing on one leg with eyes open and eyes closed Stand on one leg for 5 times, include 7 difficulty levels C: Keep up normal activities	4 weeks/3times, 20 min	SEBT-A, SEBT-PM, SEBT-PL, FAAM-ADL, FAAM-S	NR
Minoonejad 2019 [11]	14/14	22.78 ± 3.09/22.57 ± 2.76	28/0	E: Complete the jump training combination on different planes, the first week needs to complete 80 landings, and the subsequent week increases by 20; intergroup interval 30 s, different exercises interval 1 min C: Keep up normal activities	6 weeks /3 times, 15–20 min in the first week, 30–40 min in the second week	CAIT	NR
Schaefer2012 [35]	13/11	18.4 ± 5.9/17.1 ±0.3	16/8	E: Consisted of 4 exercises for single-limb hops to stabilization, 5-repetition hop to stabilization and reach, unanticipated hop to stabilization, and single-limb-stance activities with 7 levels of difficulty C: Conventional physical therapy	8 weeks/2times, 45 min	SEBT-A, SEBT-PM, SEBT-PL,FAAM-ADL, FAAM-S,	NR

Table 1 (continued)

Author (Years)	Simple Size(E/C,n)	Age(E/C,year)	Sex (M/F)	Intervention method	Intervention period/time/frequency	Outcome	adverse effect
Shamseddini Sofla 2021 [36]	12/12/10	40.58 ± 8.76/35.83 ± 12.08/38.40 ± 10.49	13/21	E1: received the vertical type WBV machine, The progressive program consisted of increasing duration and frequency of vibration E2: received WBV with the same parameter and duration as the E1 group while they wore the shoe with an unstable surface C: Receive routine physiotherapy	4 weeks/3times, 30 min	SEBT-A, SEBT-PM, SEBT-PL	NR
Sierra-Guzmán 2018 [37]	17/17/17	22.4 ± 2.6/23.6 ± 3.4	NR	E1: Training with BUSO ball, the training plan consists of 3 series of 4 45 s exercises, with 45 s intervals; Increase the difficulty of the exercise after 3 weeks E2: trained on an Excel Pro vibration platform C: Maintain physical activity	6 weeks/3times, 15 min	SEBT-A, SEBT-PM, SEBT-PL	NR
Wright 2017 [38]	20/20	22.60 ± 5.89/21.45 ± 3.24	11/29	E: Balance swing board training: 5 sets of 40 s clockwise and counter-clockwise rotation (alternating directions every 10 s), 60 s interval for each set. The swing level increased with the intervention progress from 1 to 5 C: The ankle joint resistance training was performed with elastic bands in 4 directions for 3 sets of 10 repetitions. The strength of elastic band increased with the progress of intervention	4 weeks/3times, 5 min	CAIT	NR

E Experimental group, *C* Control group, *FAAM-S* Foot and Ankle Ability Measure-Sport, *SEBT* Star Excursion Balance Test, *A* Anterior, *PM* Posterior Medial, *PL* Posterior Lateral, *CAIT* Cumberland Ankle Instability Tool, *NR* not reported

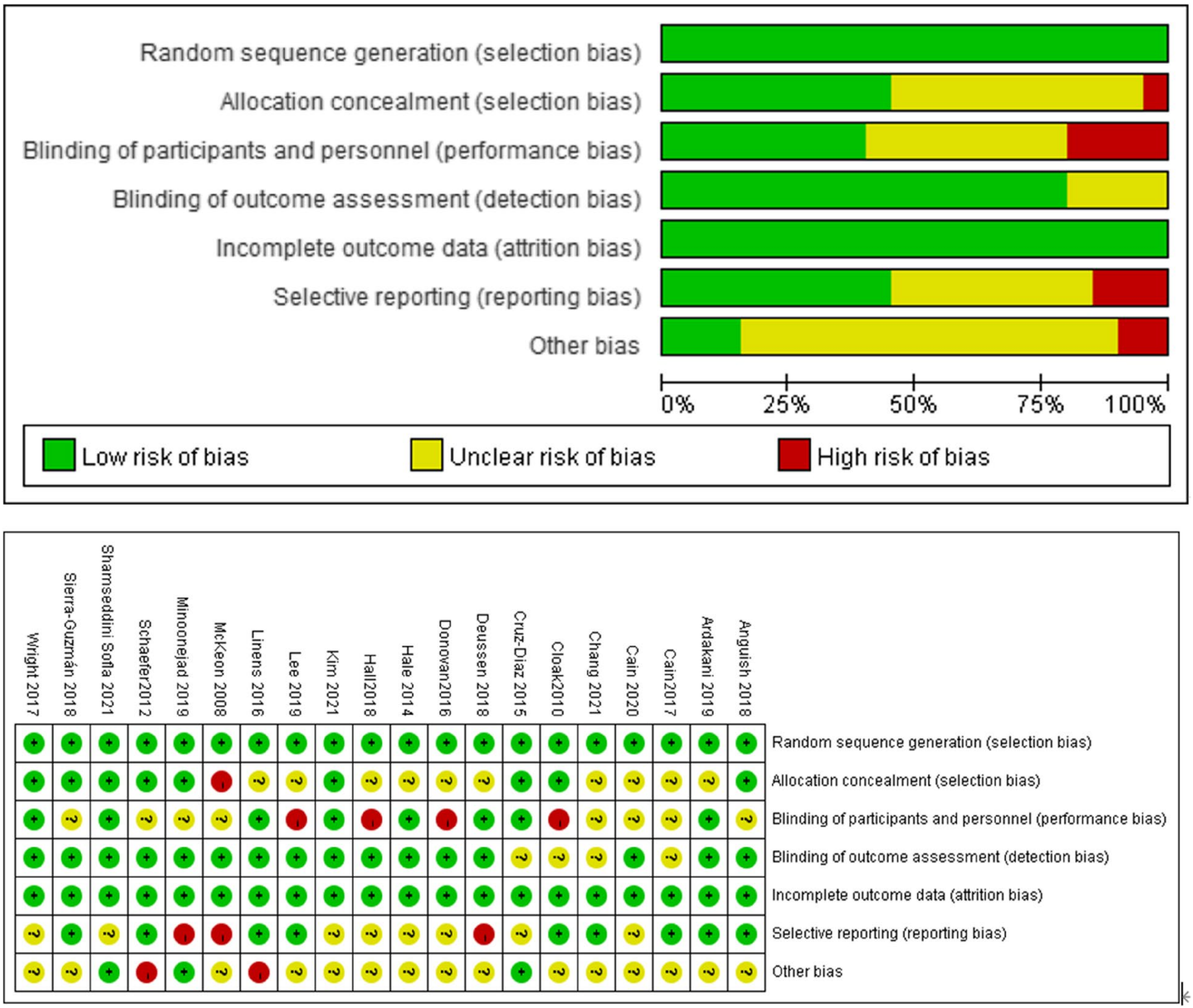

Fig. 2 Risk of bias summary

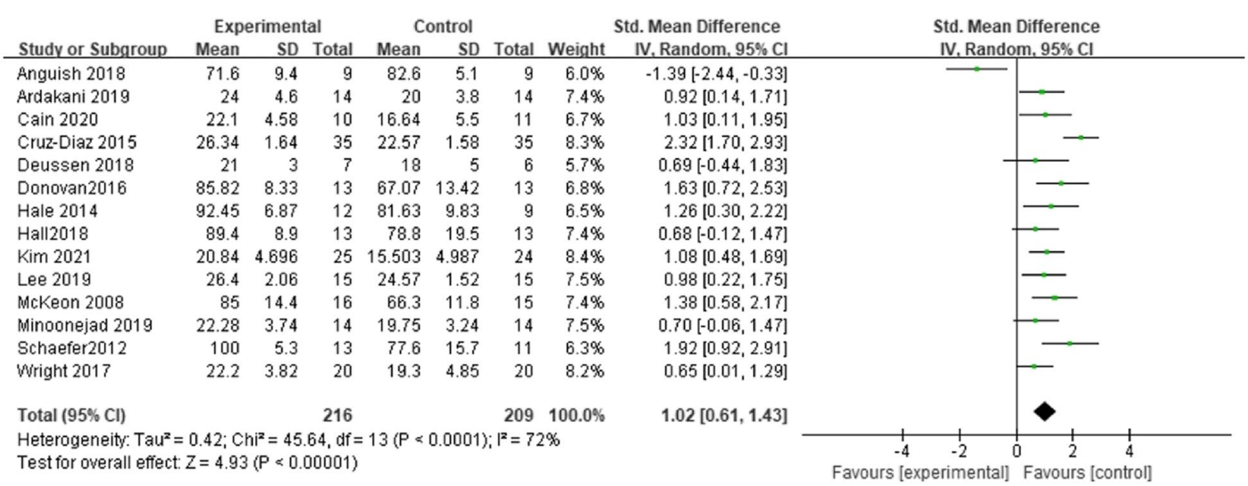

Fig. 3 Meta-analyses of the effect of balance training on self-functional scores compared with the control group

categorized as 2 times, 3 times, and > 3 times; and intervention time was categorized as > 30 min,20 min < t ≤ 30 min, and t ≤ 20 min. The result of meta regression analytic showed that only the P value of intervention time ($p = 0.046$) was less than 0.05, and the P values of intervention period ($p = 0.347$) and intervention frequency ($p = 0.305$) were greater than 0.05, as shown in Table 2. Thus, the intervention time indicator may be the main reason for heterogeneity.

The result of subgroup analysis revealed that among the intervention time, interventions of More than 20 min and less than 30 min had the better effect(MD = 1.21, 95% CI: 0.96 to 1.46, $p < 0.00001$, $I^2 = 55\%$), in addition, the p-value for the more than 30 min subgroup, despite its significance, was not supported by sufficient research evidence as it included only 2 articles; among the intervention period, 4 weeks (MD = 0.84, 95% CI:0.50 to 1.19, $p < 0.00001$, $I^2 = 78\%$)and 6 weeks (MD = 1.21, 95% CI: 0.91 to1.51, $p < 0.00001$, $I^2 = 71\%$) had significant effects; among the intervention frequency, 2 times (MD = 1.34, 95% CI:0.74 to 1.93, $p = 0.01$, $I^2 = 22\%$) and 3 times (MD = 1.14, 95% CI:0.89 to 1.38), $p < 0.00001$, $I^2 = 57\%$) had significant effects, however, in the subgroup of 2 interventions times, there was also a lack of evidence for the significance of the findings, as only 3 studies were included in the literature. Therefore 3 times having the best effect; and as shown in Table 3. In summary, interventions of 4 weeks and 6 weeks, interventions of 3 times per week, and intervention time of 20 to 30 min could be the effective ways to improve the functional health of patients with chronic ankle instability, as shown in Table 3.

Results of sensitivity analysis The heterogeneity of the article I^2 was 76% (Fig. 3), so it is necessary to explore whether one study will have a greater impact on the whole study by eliminating the study one by one. Through the sensitivity analysis, the exclusion of a study has little effect on the overall heterogeneity, indicating that the results of meta-analysis are stable and reliable, see Fig. 4.

Results of the literature publication bias test The funnel plot and Egger's method test were used to test the publication bias of the self-functional score in the study. The results of the Egger's method test shown that the P-value of the self-functional score ($p = 0.261$) is greater than 0.05, as shown in Table 4, and the left and right distributions of the funnel plot are more balanced, as shown in Fig. 5, which indicates that there is no obvious publication bias in the literature included in the self-functional score, the results of the included literature are stable.

Table 2 Meta-regression analysis results of different covariates on self-functional score of chronic ankle instability patients

Regulatory variables	β Regression coefficient	standard error	t	P > |t|	95%CI
intervention time	0.8471	0.3763	2.25	0.046	0.1876
intervention period	0.3184	0.3251	0.98	0.347	-0.3900
intervention Frequency	-0.5649	0.5226	-1.08	0.305	-1.7294

Results of meta-analysis of balance training on dynamic balance ability

Results of the overall effect size test of the SEBT SEBT is an evaluation method to detect the dynamic stability of the affected ankle joint, which consists of the evaluation of the distance of maximal extension in three directions: anterolateral (SEBT-A), posterolateral (SEBT-PL) and posteromedial (SEBT-PM). A total of 13 articles were included in the study of balance training on SEBT with

Table 3 Result of subgroup analysis on different covariates on self-functional score of patients with CAI

Regulatory variables	subgroup	Number of effectors	SMD(95%CI)	P	I^2
intervention time	t < 20 min	3	0.35(-0.12,0.82)	0.15	85%
	20 min < t ≤ 30 min	9	1.21(0.96,1.46)	< 0.00001	55%
	> 30 min	2	1.76(1.09,2.43)	< 0.00001	0%
intervention period	4 weeks	6	0.84(0.50,1.19)	< 0.00001	78%
	6 weeks	6	1.21(0.91,1.51)	< 0.00001	71%
	> 6 weeks	2	1.33(0.92,1.93)	< 0.0001	53%
intervention Frequency	2	3	1.34(0.74,1.93)	0.01	22%
	3	10	1.14(0.89,1.38)	< 0.00001	57%
	> 3	1	-1.39(-2.44, -0.33)	0.01	Not useful

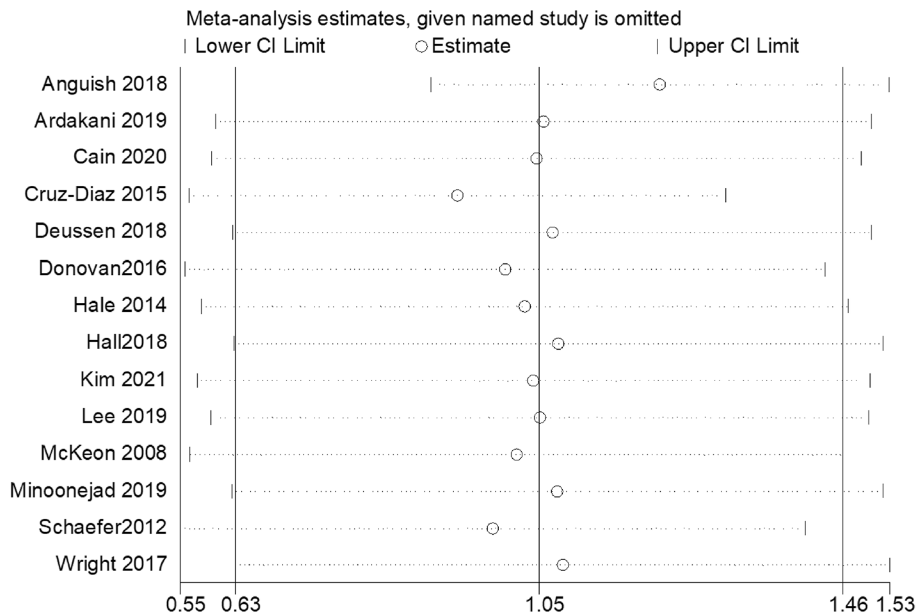

Fig. 4 Sensitivity analysis results of exercise intervention on self-functional score

Table 4 Meta-analysis of Egger test result of self-functional score

Std_Eff	Coef	Std.Err	t	P	95%CI
slope	2.367	1.083	2.19	0.049	0.008
bias	-3.16	2.676	-1.18	0.261	-8.989

CAI patients. The heterogeneity test (I^2 = 84%, 61% and 79%, $p < 0.00001$) showed a high degree of heterogeneity, so a random effects model were used for testing of overall effect. The overall effect found that the balance training had significant improving effect on SEBT-A (MD = 5.88; 95% CI, 3.37 to 8.40; $p < 0.00001$; Fig. 6), SEBT-PM (MD = 5.47; 95% CI, 3.40 to 7.54; $p < 0.00001$; Fig. 6), SEBT-PL (MD = 6.04; 95% CI, 3.30 to 8.79; $p < 0.0001$; Fig. 6) compared with the control group. The above data suggest that balance training can improve the dynamic balance ability of with CAI patients.

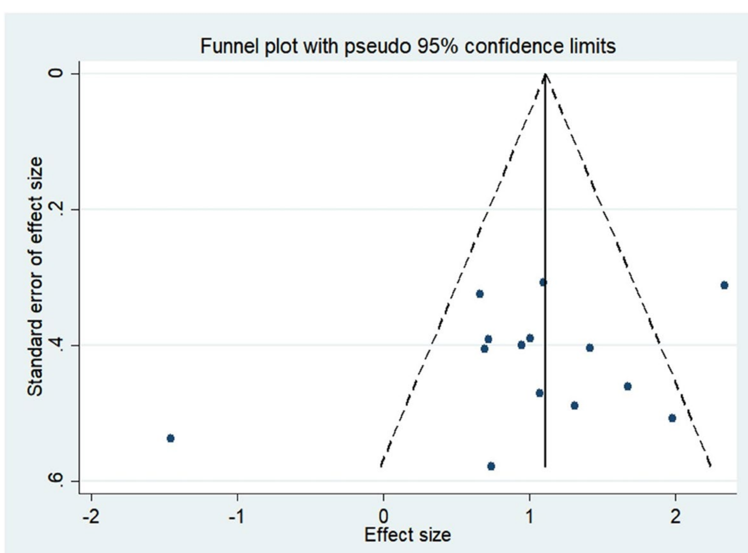

Fig. 5 Funnel plot of exercise intervention on self-functional score

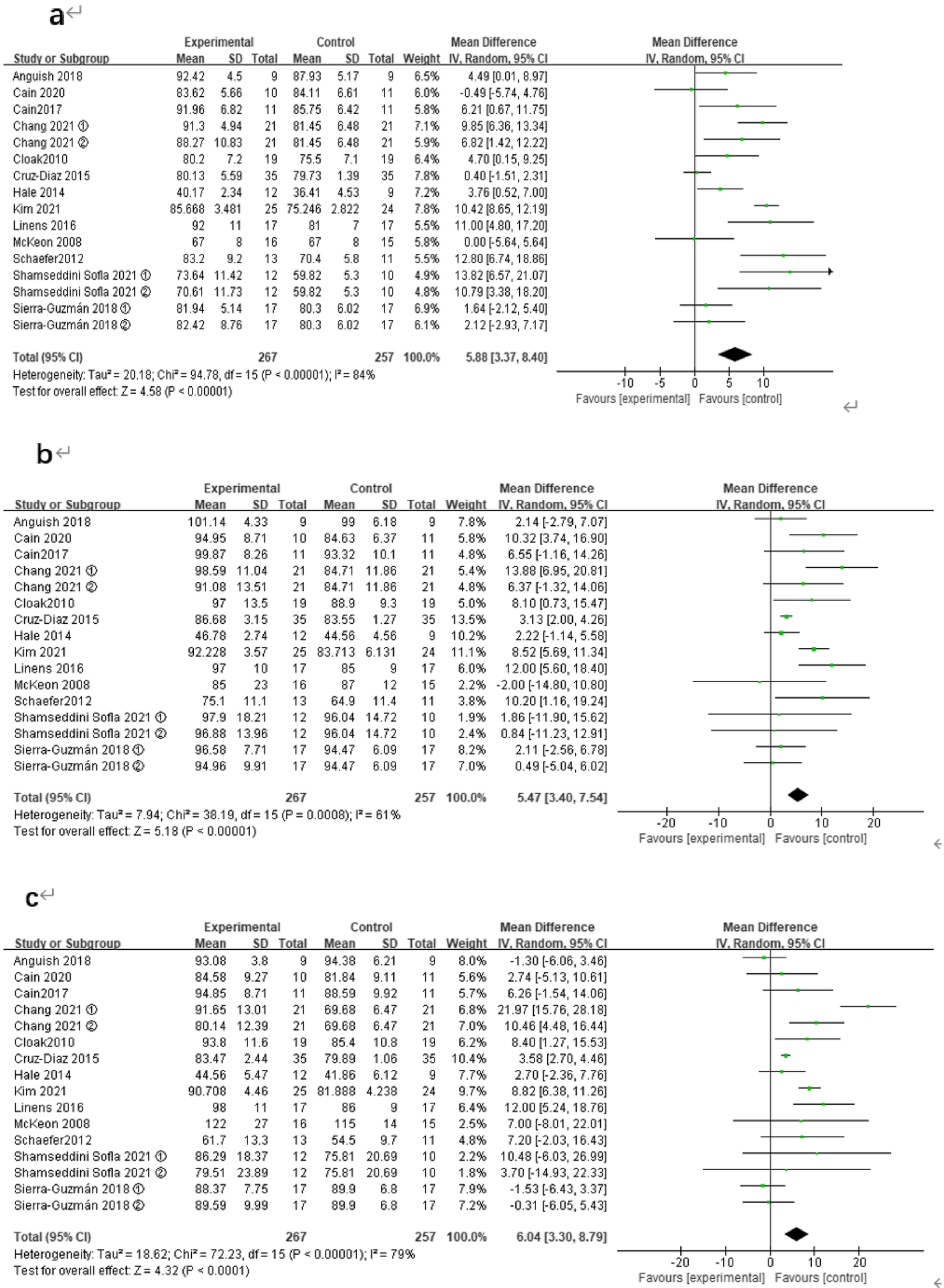

Fig. 6 Meta-analyses of the effect of balance training on SEBT compared with the control group, **a**: SEBT-A; **b**: SEBT-PM; **c**: SEBT-PL

Subgroup test results of SEBT Subgroup analyses results of the effects of the SEBT on the three directions are shown in Table 5. In terms of intervention time, interventions of less than 20 min had an improvement in the SEBT-A(MD = 3.91, 95% CI:1.48 to 6.33, $p = 0.002$, $I^2 = 42\%$) and SEBT-PM (MD = 4.42, 95% CI:1.29 to 7.55, $p = 0.003$, $I^2 = 41\%$) but not in the SEBT-PL, and interventions of 20–30 min had an improvement and a large effect size in all SEBT directions[SEBT-A(MD = 6.71, 95% CI:2.75 to 10.66, $p = 0.0009$, $I^2 = 91\%$);SEBT-PM(MD = 5.18, 95% CI:2.27 to 8.18, $p = 0.0007$, $I^2 = 69\%$);SEBT-PL(MD = 8.68, 95%CI:4.32 to 13.04, $p < 0.0001$,$I^2 = 86\%$)]; In terms of the intervention period, the 4-week and 6-week intervention showed significant improvements in all SEBT directions [4-week:SEBT-A(MD = 4.90, 95% CI:3.10 to 6.70, $p < 0.00001$,$I^2 = 64\%$); SEBT-PM(MD = 3.82, 95%CI:0.93 to 6.70, $P = 0.009$,$I^2 = 25\%$); SEBT-PL(MD = 4.40, 95% CI:0.72 to 8.08, $p = 0.02$,I2 = 39%)]; [6-week:SEBT-A(MD = 5.65, 95% CI:4.57 to 6.72, $p < 0.0001$, $I^2 = 91\%$); SEBT-PM(MD = 5.61, 95% CI:2.54 to 8.67, $p = 0.0003$,$I^2 = 75\%$);SEBT-PL(MD = 7.04, 95% CI:2.84 to 11.24, $p = 0.001$,$I^2 = 90\%$)]and large effects in the SEBT-PM and SEBT-PL. Regarding the frequency of interventions, there were significant improvement on all SEBT directions by the 2 and 3 interventions per week[2-times:SEBT-A(MD = 6.53, 95% CI:1.73 to 11.33, $p = 0.008$,$I^2 = 71\%$);SEBT-PM(MD = 5.28 95% CI:2.68 to 7.87, $p < 0.0001$,$I^2 = 64\%$);SEBT-PL(MD = 5.04, 95% CI:1.28 to 8.80, $p = 0.009$, $I^2 = 0\%$)];[3-times:SEBT-A(MD = 5.73, 95% CI:2.76 to 8.70, $p = 0.0002$, $I^2 = 86\%$);SEBT-PM(MD = 3.82, 95% CI:0.93 to 6.70, $p = 0.009$, $I^2 = 25\%$); SEBT-PL(MD = 6.96, 95% CI:3.53 to 10.38, $p < 0.0001$,$I^2 = 83\%$)]. In conclusion, a 4-week and 6-week intervention with balance training two and three times a week for 20–30 min are the better combination of interventions to improve SEBT (dynamic balance) in patients with chronic ankle instability.

Results of sensitivity analysis of SEBT Since the heterogeneity of the combined effect sizes of SEBT-A, SEBT-PM, and SEBT-PL were all greater than 50%,so sensitivity analyses were performed, see Fig. 7, the results showed that the exclusion of one study had little effect on the overall heterogeneity of the above indicators, which indicating that the results of the meta-analysis were stable and reliable.

Results of the literature publication bias test Funnel plots and Egger asymmetry tests were performed for testing the publication bias on SEBT parameters (SEBT-A, SEBT-PM, SEBT-PL). The results of the Egger's method test indicated that SEBT-PM ($p = 0.104$) and SEBT-PL($p = 0.108$) were greater than 0.05 while the P-value of SEBT-A($p = 0.032$) less than 0.05, as shown in Table 6, and the left and right distributions of the funnel plot of SEBT-PM and SEBT-PL parameters are more balanced, as shown in Fig. 8. The above results indicate that SEBT-A has some publication bias whereas SEBT-PM and SEBT-PL didn't, and therefore the results for SEBT-PM and SEBT-PL from the included literature are stable.

Discussion

The main purpose of this study was to analyze the effectiveness of different intervention dosages of balanced exercise on chronic ankle instability. In this meta-analysis, we reviewed 20 articles, including 682 patients with CAI. Our results found that balance training improved ankle function by self-functional score.

Chronic ankle instability is predominantly classified into two types: functional and mechanical. Mechanical factors primarily encompass joint capsule laxity, bursitis, cartilage damage, and joint degeneration, among others. Functional factors consist of weakened muscle strength, proprioceptive impairment, inadequate postural control, and a reduced ability to adjust subsequent to instability.

Table 5 Result of subgroup analysis on SEBT of patients with CAI

Regulatory variables	subgroup	Number of effectors	SEBT-A MD(95%CI)	SEBT-PM MD(95%CI)	SEBT-PL MD(95%CI)
intervention time	t < 20 min	7	3.91(1.48,6.33)*	6.14(2.12,10.17)*	3.29(-0.68,7.27)
	20 min < t ≤ 30 min	8	6.71(2.75,10.66)*	5.18(2.17,8.18)*	8.68(4.32,13.04)*
	> 30 min	1	12.80(6.74,18.86)	10.20(1.16,19.24)	7.20(-2.03,16.43)
intervention period	4 weeks	8	4.90(3.10,6.70)*	3.82(0.93,6.70)*	4.40(0.72,8.08)*
	6 weeks	7	5.65(4.57,6.72)*	5.61(2.54,8.67)*	7.20(-2.03,16.43)*
	> 6 weeks	1	12.80(6.74,18.86)	10.20(1.16,19.24)	10.20(1.16,19.24)
intervention Frequency	2	3	6.53(1.73,11.33)*	5.59(0.41,10.77)*	5.04(1.28,8.80)*
	3	12	5.73(2.76,8.70)*	5.28(2.68,7.87)*	6.96(3.53,10.38)*
	> 3	1	4.49 (0.01, 8.97)	2.14 (-2.79,7.07)	-1.30 (-6.06, 3.46)

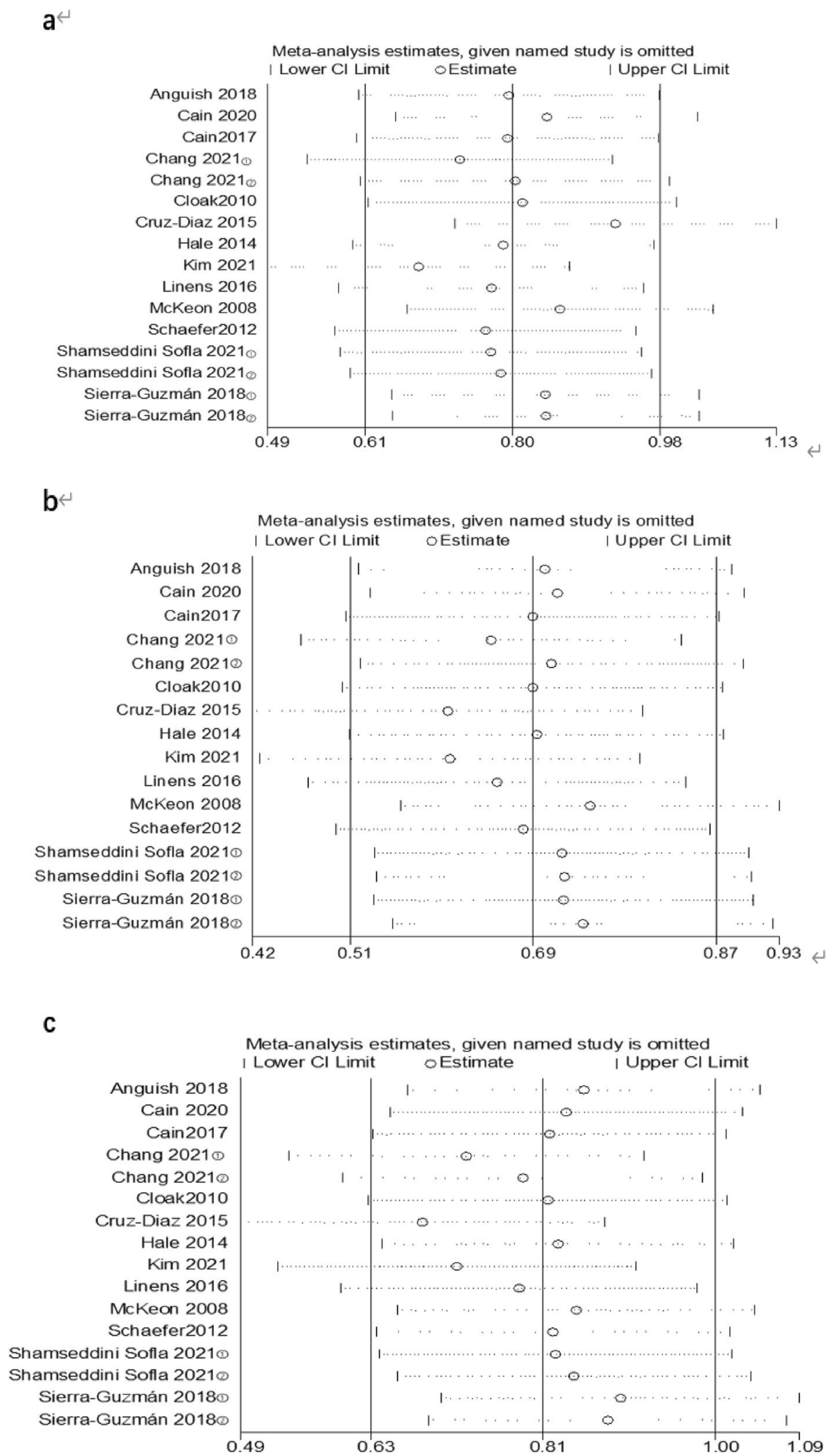

Fig. 7 Sensitivity analysis results of exercise intervention on SEBT, **a**: SEBT-A; **b**: SEBT-PM; **c**: SEBT-PL

Table 6 Meta-analysis of Egger test result of SEBT parameter

variables	Std_Eff	Coef	Std.Err	t	P	95%CI
SEBT-A	slope	-1.148	0.834	-1.38	0.190	-2.936
	bias	5.271	2.210	2.39	0.032	0.531
SEBT-PM	slope	2.088	0.813	2.57	0.022	0.344
	bias	-3.853	2.214	-1.74	0.104	-8.602
SEBT-PL	slope	3.117	1.356	2.30	0.037	0.210
	bias	-6.161	3.592	-1.71	0.108	-13.866

The subjects included in the literature for this study were individuals with functional chronic ankle instability. Dynamic balance training was employed to stimulate the deep sensory receptors of the foot and ankle joints, such as kinesthesia, positional sensation, muscle group muscle plexus, and tendons, with the aim of improving the function of the ankle sensory-motor system and reducing the incidence of re-sprains. The self-functional score is a reliable and valid measure that correlates the degree of motor function and quality of life with the rehabilitation outcome parameter in patients with CAI. The CAIT Scale [41] and the FAAM Scale [42] were included as self-functional scoring indicators in this study. The meta-analysis results of this study demonstrated that, compared with the control group undergoing non-equilibrium training, including strength training and physical therapy, dynamic equilibrium training could effectively enhance the patients' self-functional scores and improve their ankle joint function after treatment. This is consistent with the findings of previous clinical studies [28, 34, 43, 44]. and systematic reviews [45].

Although balance training holds more advantages over physical therapy or strength training in enhancing self-functional scores in patients with chronic ankle instability, nevertheless, there exists a considerable degree of heterogeneity in their studies. For instance, MCKEON et al. prescribed 20 min per day, 3 times per week, for 4 weeks [34]; Hall et al. recommended 30 min per day, 3 times per week, for 4 weeks [39]; Anguish et al. proposed 20 min per day, 3 times per week, with a program lasting 6 weeks [12]. This might have resulted in greater heterogeneity between groups. Thus, the question arises: what is the most appropriate dosage of exercise intervention? In this respect, we conducted a regression analysis, and the regression analysis indicated that the intervention time was the main factor influencing the improvement of self-functional scores in patients with chronic ankle instability through balance training. Moreover, we discovered again through subgroup analysis that an intervention time of 20 to 30 min for balance training would yield the best efficacy. Ankle rehabilitation training ensures that the muscles are in a highly excited state, as balance training demands fine neuromuscular control and recruits more muscles to participate in the movement. Additionally, a certain amount of exercise is necessary to effectively stimulate the function of the ankle muscles. Therefore, we believe that if the body exercises for too short a period, it leads to insufficient activation time for the muscles and the brain's nervous system. Conversely, too long a period can also cause nerve and muscle fatigue, at which point the efficiency of the exercise will be reduced. Hence, maintaining balance and postural control exercises at approximately 20 to 30 min is the optimal time for the human body and the nervous system to be in the best state of excitability. Consequently, keeping balance and postural control exercises at around 20 to 30 min represents the optimal excitability of the human body, which further suggests that we can control the duration of each exercise and increase the frequency of weekly exercises to enhance the effect of rehabilitation training.

The SEBT is a reliable dynamic balance evaluation method incorporating anterolateral (SEBT-A), posterolateral (SEBT-PL) and posteromedial (SEBT-PM). It has significant correlation with lower limb postural control and dynamic balance ability with high testing efficiency. In our study of meta-analysis, balance training was found to improve dynamic stability in SEBT-A, SEBT-PM and SEBT-PL.

As far as we know, action and control in human locomotion are dependent on the sensorimotor system, and when the ankle joint is damaged the sensitivity of the musculoskeletal receptors decreases, resulting in impaired afferent information pathways, prolonged peroneal reaction time, and reduced neuromuscular conduction velocity [46], and since the control of postural stability is affected by afferent information from vision, vestibular sensation, positional sense, and proprioception, postural control deficits are most likely secondary to the combination of impaired neuromuscular control and proprioceptive impairments in combination. Studies have shown that balance training using either stable or unstable surfaces can improve SEBT scores in patients with chronic ankle instability [33, 44]. Moreover, One

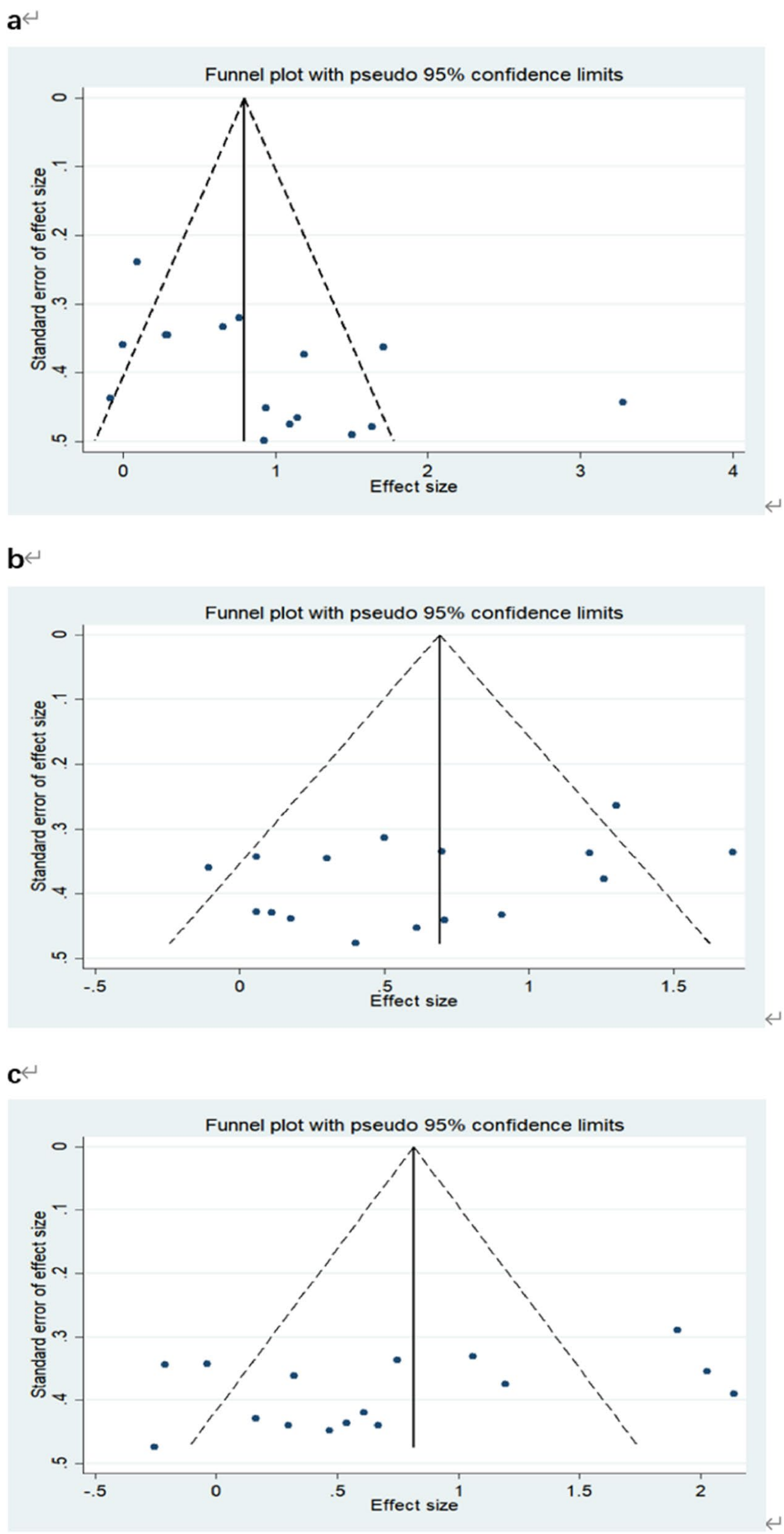

Fig. 8 Funnel plot of exercise intervention on SEBT, **a**: SEBT-A; **b**: SEBT-PM; **c**: SEBT-PL

study analyzed moderate effect size evidence to support the improvement of dynamic postural stability through balance training and neuromuscular control in patients with CAI [47]. Balance training improves postural control deficits and enhances neuromuscular control thereby improving dynamic stability. In subgroup analyses of this study, a 4-week and 6-week intervention with balance training three times a week for 20–30 min is the best combination of interventions to improve all SEBT (dynamic balance)-directions in patients with chronic ankle instability.

Although we conducted a thorough and comprehensive analysis of this meta-analysis study, it still has some limitations. First, several studies showed only randomized trials but no specific methods of random sequence generation, RCTs of allocation concealment, or blinding of outcome assessment. Many of the included RCTs were generally of low methodological quality and may have a high risk of bias; Secondly, the diversity of the protocols used in each study may have led to variability in the results, such as the balance training program included single-leg balance training, unstable balance training and other balance interventions. Although our results demonstrate the effect of balance training on patients with CAI, the quality of the individual studies and the heterogeneity of stimulation protocols should be considered when interpreting the results. Finally, the study included different load parameters and self-assessment scales for the interventions, which may have biased the results.

In the future, we should focus on different forms of balance training such as dynamic and static balance training to determine the optimal stimulation regimen on CAI patients, including stimulation intensity, duration, and sites.

Conclusion

In summary, the current of systematic review and meta-analysis provided evidence that balance training benefits ankle function with CAI patients. Intervention time is a major factor influencing self-function in patients with CAI, the optimal dosage of balance training for CAI is recommended to obtain the best rehabilitation effect by intervening 3 times a week, each intervention time of 20 min to 30 min, and consecutively intervening for 4 weeks to 6 weeks. These findings and could provide a theoretical reference for the design of future balanced exercise training intervention doses.

Abbreviations

LASs	Lateral ankle sprains
CAI	Chronic ankle instability
CAIT	Cumberland Ankle Instability Tool
FAAM-S	Foot and Ankle Ability Measure-Sport
SEBT	Star Excursion Balance Test
SEBT-A	Star Excursion Balance Test-anterior
SEBT-PM	Star Excursion Balance Test-posterior medial a
SEBT-PL	Star Excursion Balance Test-posterior lateral

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Authors' contributions
F.T and P.G did the study conception, design, data collection, statistics, and writing. M.X, S.Y, and X.L did the data collection and participated in writing. All authors read and approved the final version of the manuscript.

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Availability of data and materials
All data generated or analyzed during this study are included in this published article or are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was a systematic review and meta-analysis and followed the PRISMA guidelines. It primarily included data from previously published studies and did not collect new data from human participants. As a result, the ethical approval was not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]College of Physical Education, Anqing Normal University, Anqing, China. [2]Hunan University of Medicine, Huaihua, China. [3]Department of Public Athletics, Taizhou University, Taizhou, China.

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References
1. Miklovic TM, Donovan L, Protzuk OA, Kang MS, Feger MA. Acute lateral ankle sprain to chronic ankle instability: a pathway of dysfunction. Phys Sportsmed. 2018;46:116–22. https://doi.org/10.1080/00913847.2018.1409604.
2. Braun BL. Effects of ankle sprain in a general clinic population 6 to 18 months after medical evaluation. Arch Fam Med. 1999;8:143–8. https://doi.org/10.1001/archfami.8.2.143.
3. Hiller CE, et al. Prevalence and impact of chronic musculoskeletal ankle disorders in the community. Arch Phys Med Rehabil. 2012;93:1801–7. https://doi.org/10.1016/j.apmr.2012.04.023.
4. Shah S, Thomas AC, Noone JM, Blanchette CM, Wikstrom EA. Incidence and Cost of Ankle Sprains in United States Emergency Departments. Sports health. 2016;8:547–52. https://doi.org/10.1177/1941738116659639.
5. Delahunt E, et al. Clinical assessment of acute lateral ankle sprain injuries (ROAST): 2019 consensus statement and recommendations of the International Ankle Consortium. Br J Sports Med. 2018;52:1304–10. https://doi.org/10.1136/bjsports-2017-098885.
6. Hertel J, Corbett RO. An Updated Model of Chronic Ankle Instability. J Athl Train. 2019;54:572–88. https://doi.org/10.4085/1062-6050-344-18.
7. Kosik KB, McCann RS, Terada M, Gribble PA. Therapeutic interventions for improving self-reported function in patients with chronic ankle

instability: a systematic review. Br J Sports Med. 2017;51:105–12. https://doi.org/10.1136/bjsports-2016-096534.
8. Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. Acta Physiol (Oxf). 2008;193:101–16. https://doi.org/10.1111/j.1748-1716.2008.01850.x.
9. Yoshida K, Kuramochi R, Shinohara J. Effect of a Balance Adjustment System on Postural Control in Patients with Chronic Ankle Instability. Int J Sports Phys Ther. 2023;18:636–44. https://doi.org/10.26603/001c.74722.
10. Schiftan GS, Ross LA, Hahne AJ. The effectiveness of proprioceptive training in preventing ankle sprains in sporting populations: a systematic review and meta-analysis. J Sci Med Sport. 2015;18:238–44. https://doi.org/10.1016/j.jsams.2014.04.005.
11. Minoonejad H, Karimizadeh Ardakani M, Rajabi R, Wikstrom EA, Sharifnezhad A. Hop Stabilization Training Improves Neuromuscular Control in College Basketball Players With Chronic Ankle Instability: A Randomized Controlled Trial. J Sport Rehabil. 2019;28:576–83. https://doi.org/10.1123/jsr.2018-0103.
12. Anguish B, Sandrey MA. Two 4-Week Balance-Training Programs for Chronic Ankle Instability. J Athl Train. 2018;53:662–71. https://doi.org/10.4085/1062-6050-555-16.
13. Kibele A, Behm DG. Seven weeks of instability and traditional resistance training effects on strength, balance and functional performance. J Strength Cond Res. 2009;23:2443–50. https://doi.org/10.1519/JSC.0b013e3181bf0489.
14. Kibele A, Classen C, Muehlbauer T, Granacher U, Behm DG. Metastability in plyometric training on unstable surfaces: a pilot study. BMC Sports Sci Med Rehabil. 2014;6:30. https://doi.org/10.1186/2052-1847-6-30.
15. Mollà-Casanova S, Inglés M, Serra-Añó P. Effects of balance training on functionality, ankle instability, and dynamic balance outcomes in people with chronic ankle instability: Systematic review and meta-analysis. Clin Rehabil. 2021;35:1694–709. https://doi.org/10.1177/02692155211022009.
16. Jiang C, et al. Effects of balance training on dynamic postural stability in patients with chronic ankle instability: systematic review and meta-analysis of randomized controlled trials. J Sports Med Phys Fitness. 2022;62:1707–15. https://doi.org/10.23736/s0022-4707.22.13566-8.
17. Wang J, Zhang D, Zhao T, Ma J, Jin S. Effectiveness of balance training in patients with chronic ankle instability: protocol for a systematic review and meta-analysis. BMJ Open. 2021;11: e053755. https://doi.org/10.1136/bmjopen-2021-053755.
18. Cain MS, et al. Four-Week Ankle-Rehabilitation Programs in Adolescent Athletes With Chronic Ankle Instability. J Athl Train. 2020;55:801–10. https://doi.org/10.4085/1062-6050-41-19.
19. Cain MS, Garceau SW, Linens SW. Effects of a 4-week biomechanical ankle platform system protocol on balance in high school athletes with chronic ankle instability. J Sport Rehabil. 2017;26(1):1–7. https://doi.org/10.1123/jsr.2015-0045.
20. Ardakani MK, Wikstrom EA, Minoonejad H, Rajabi R, Sharifnezhad A. Hop-Stabilization Training and Landing Biomechanics in Athletes With Chronic Ankle Instability: A Randomized Controlled Trial. J Athl Train. 2019;54:1296–303. https://doi.org/10.4085/1062-6050-550-17.
21. Cloak R, Nevill AM, Clarke F, Day S, Wyon MA. Vibration training improves balance in unstable ankles. Int J Sports Med. 2010;31:894–900. https://doi.org/10.1055/s-0030-1265151.
22. Chang WD, Chen S, Tsou YA. Effects of whole-body vibration and balance training on female athletes with chronic ankle instability. J Clin Med. 2021;10(11):2380. https://doi.org/10.3390/jcm10112380.
23. Lee E, Cho J, Lee S. Short-Foot Exercise Promotes Quantitative Somatosensory Function in Ankle Instability: A Randomized Controlled Trial. Medical science monitor : international medical journal of experimental and clinical research. 2019;25:618–26. https://doi.org/10.12659/msm.912785.
24. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6: e1000097. https://doi.org/10.1371/journal.pmed.1000097.
25. Higgins JP, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ (Clinical research ed). 2011;343:d5928. https://doi.org/10.1136/bmj.d5928.
26. Gao P, Tang F, Liu W, He K, Mo Y. Effect of liuzijue qigong on patients with stable chronic obstructive pulmonary disease: A systematic review and meta-analysis. Medicine. 2021;100: e27344. https://doi.org/10.1097/md.0000000000027344.
27. Sterne JA, et al. Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. BMJ (Clinical research ed). 2011;343:d4002. https://doi.org/10.1136/bmj.d4002.
28. Cruz-Diaz D, Lomas-Vega R, Osuna-Pérez MC, Contreras FH, Martínez-Amat A. Effects of 6 Weeks of Balance Training on Chronic Ankle Instability in Athletes: A Randomized Controlled Trial. Int J Sports Med. 2015;36:754–60. https://doi.org/10.1055/s-0034-1398645.
29. Deussen S, Alfuth M. The influemce of Sensorimotor training modalities on balance, strength, joint function, and plantar foot sensitivity in recreational athletes with a history of ankle sprain: a randomize controlled pilot study. Int J Sports Phys Ther. 2018;13:993–1007.
30. Donovan L, et al. Rehabilitation for Chronic Ankle Instability With or Without Destabilization Devices: A Randomized Controlled Trial. J Athl Train. 2016;51:233–51. https://doi.org/10.4085/1062-6050-51.3.09.
31. Hale SA, Fergus A, Axmacher R, Kiser K. Bilateral improvements in lower extremity function after unilateral balance training in individuals with chronic ankle instability. J Athl Train. 2014;49:181–91. https://doi.org/10.4085/1062-6050-49.2.06.
32. Kim KM, Estudillo-Martínez MD, Castellote-Caballero Y, Estepa-Gallego A, Cruz-Díaz D. Short-term effects of balance training with stroboscopic vision for patients with chronic ankle instability: A single-blinded randomized controlled trial. Int J Environ Res Public Health. 2021;18(10):5364. https://doi.org/10.3390/ijerph18105364.
33. Linens SW, Ross SE, Arnold BL. Wobble Board Rehabilitation for Improving Balance in Ankles With Chronic Instability. Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine. 2016;26:76–82. https://doi.org/10.1097/jsm.0000000000000191.
34. McKeon PO, et al. Balance training improves function and postural control in those with chronic ankle instability. Med Sci Sports Exerc. 2008;40:1810–9. https://doi.org/10.1249/MSS.0b013e31817e0f92.
35. Schaefer JL, Sandrey MA. Effects of a 4-week dynamic-balance-training program supplemented with Graston instrument-assisted soft-tissue mobilization for chronic ankle instability. J Sport Rehabil. 2012;21:313–26. https://doi.org/10.1123/jsr.21.4.313.
36. Shamseddini Sofla F, Hadadi M, Rezaei I, Azhdari N, Sobhani S. 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 Rehabil. 2021;13:28. https://doi.org/10.1186/s13102-021-00256-6.
37. Sierra-Guzmán R, Jiménez-Diaz F, Ramírez C, Esteban P, Abián-Vicén J. Whole-Body-Vibration Training and Balance in Recreational Athletes With Chronic Ankle Instability. J Athl Train. 2018;53:355–63. https://doi.org/10.4085/1062-6050-547-16.
38. Wright CJ, Linens SW, Cain MS. A Randomized Controlled Trial Comparing Rehabilitation Efficacy in Chronic Ankle Instability. J Sport Rehabil. 2017;26:238–49. https://doi.org/10.1123/jsr.2015-0189.
39. Hall EA, Chomistek AK, Kingma JJ, Docherty CL. Balance- and Strength-Training Protocols to Improve Chronic Ankle Instability Deficits, Part I: Assessing Clinical Outcome Measures. J Athl Train. 2018;53:568–77. https://doi.org/10.4085/1062-6050-385-16.
40. Westmacott A, Sanal-Hayes NEM, McLaughlin M, Mair JL, Hayes LD. High-Intensity Interval Training (HIIT) in Hypoxia Improves Maximal Aerobic Capacity More Than HIIT in normoxia: a systematic review, meta-analysis, and meta-regression. Int J Environ Res Public Health. 2022;19(21):14261. https://doi.org/10.3390/ijerph192114261.
41. Hiller CE, Refshauge KM, Bundy AC, Herbert RD, Kilbreath SL. The Cumberland ankle instability tool: a report of validity and reliability testing. Arch Phys Med Rehabil. 2006;87:1235–41. https://doi.org/10.1016/j.apmr.2006.05.022.
42. Martin RL, Irrgang JJ, Burdett RG, Conti SF, Van Swearingen JM. Evidence of validity for the Foot and Ankle Ability Measure (FAAM). Foot Ankle Int. 2005;26:968–83. https://doi.org/10.1177/107110070502601113.
43. Burcal CJ, Sandrey MA, Hubbard-Turner T, McKeon PO, Wikstrom EA. Predicting dynamic balance improvements following 4-weeks of balance training in chronic ankle instability patients. J Sci Med Sport. 2019;22:538–43. https://doi.org/10.1016/j.jsams.2018.11.001.
44. Youssef NM, Abdelmohsen AM, Ashour AA, Elhafez NM, Elhafez SM. Effect of different balance training programs on postural control in chronic ankle instability: a randomized controlled trial. Acta Bioeng Biomech. 2018;20:159–69.

45. Loudon JK, Santos MJ, Franks L, Liu W. The effectiveness of active exercise as an intervention for functional ankle instability: a systematic review. Sports Med. 2008;38:553–63. https://doi.org/10.2165/00007256-200838070-00003.
46. YIN Yan LD, LIU Hu, et al. Research progress on the mechanism and self-assessment scale of functional ankle instability. Chin Rehabil Theory Pract. 2018;24:671–7.
47. O'Driscoll J, Delahunt E. Neuromuscular training to enhance sensorimotor and functional deficits in subjects with chronic ankle instability: A systematic review and best evidence synthesis. Sports Med Arthrosc Rehabil Ther Technol. 2011;3:19. https://doi.org/10.1186/1758-2555-3-19.