Archives of Rehabilitation Research and Clinical Translation (2024) 6, 100365

ACRM
AMERICAN CONGRESS OF REHABILITATION MEDICINE

Archives of Rehabilitation Research and Clinical Translation

Archives of Rehabilitation Research and Clinical Translation 2024;6:100365

Available online at www.sciencedirect.com

Review Article

Exploratory Analysis of Unstable Surface Training: A Systematic Review and Meta-Analysis for Chronic Ankle Instability

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KEYWORDS
Ankle;
Exercise therapy;
Postural balance;
Rehabilitation

Abstract *Objective:* To conduct an exploratory systematic review and meta-analysis to evaluate the effect of unstable surface training on balance and hop function in individuals with chronic ankle instability (CAI).
Data Sources: Four major electronic databases were searched, including Cochrane Library, PubMed, Embase, and Web of Science, from January 1, 2000 to June 20, 2024.
Study Selection: Randomized controlled trials that compare unstable surface training with either general intervention or no intervention in individuals with CAI were included.
Data Extraction: The physical therapy evidence database scale was used to assess the risk of bias and methodological quality of included studies. The mean differences (MDs) with 95% confidence intervals (CIs) were calculated using Review Manager 5.4 software.
Data Synthesis: The review ultimately included 9 studies involving 308 participants. Compared with the other exercises or no exercise, unstable surface training could improve the significant effects of the star excursion balance test (SEBT) in the direction of posterolateral (MD=5.80; 95% CI, 1.60-9.99; P=.007), posteromedial (MD=6.24; 95% CI, 2.32-10.16; P=.002), medial (MD=9.11; 95% CI, 6.42-11.80; P<.00001), anteromedial (MD=7.25; 95% CI, 2.33-12.17; P=.004), the time-in-balance test (MD=8.45; 95% CI, 1.50-15.40; P=.02), the foot-lift test (MD=-1.39; 95% CI, -2.49 to -0.28; P=.01). However, there was no significant difference in the anterior direction of the SEBT (MD=3.22; 95% CI, -0.66 to 7.10; P=.10), the side-hop test (MD=-1.94; 95% CI, -4.82 to 0.95; P=.19), and the figure-of-8 hop test (MD=-0.97; 95% CI, -2.39 to 0.46; P=.18) between groups.
Conclusions: Compared with the other exercises or no exercise, unstable surface training has potential benefits in improving balance in people with CAI but has no significant effect on hop function. However, the exploratory nature of this study highlights the need for further research to confirm these findings.

List of abbreviations: AM, anteromedial; CAI, chronic ankle instability; CI, confidence interval; MD, mean difference; PEDro, physical therapy evidence database; PL, posterolateral; PM, posteromedial; SEBT, star excursion balance test.
Clinical Trial Registration No.: PROSPERO: CDR42023389226
Cite this article as: Arch Rehabil Res Clin Transl. 2024;6:100365

https://doi.org/10.1016/j.arrct.2024.100365

Acute ankle sprains rank among the most common musculoskeletal injuries,[1] with over 2 million incidents reported annually in the United States, and approximately half occurring during daily physical activities.[2] Lateral ankle sprains, in particular, are prevalent, boasting a recurrence rate of up to 73%.[3] Furthermore, more than 70% of individuals suffering from acute lateral ankle sprains may eventually develop chronic ankle instability (CAI), which can significantly disrupt daily activities and lead to subsequent disability.[1]

The CAI manifests as a disorder characterized by recurrent ankle sprains and/or the sensation of the ankle giving way, accompanied by pain, weakness, reduced range of motion, and self-reported functional decline persisting for at least 1 year after the initial ankle sprain.[4] Restoration of balance and hop function has been a key focus in managing this condition. With the continuous development in sports medicine, unstable surface training has emerged as a promising therapeutic approach.

Unstable surface training typically utilizes unstable equipment like wobble boards, bosu balls, foam cushions, and others to disrupt the body's center of gravity and induce postural instability. Common exercise modalities performed on unstable surfaces include single-leg standing, squats, lunges, weight shifting, and more. Compared with training on a stable surface, training on an unstable surface enhances participants' motor control strategies and somatosensory feedback according to their weight distribution.[5] Moreover, it can lead to rapid improvements in balance ability[5] and increased muscle activation around the ankle.[6,7] A previous meta-analysis has demonstrated the effectiveness of training on an unstable surface for enhancing muscle strength, power, and balance across various age groups.[8] Furthermore, a meta-analysis performed by Van Criekinge et al[9] found that unstable surface training was superior to stable surface training in improving both dynamic and static balance among patients with stroke.

In summary, although unstable surface training shows potential benefits for patients with CAI, its efficacy and safety in individuals with CAI remain subject to controversy. Therefore, the aim of this exploratory review and meta-analysis was to evaluate whether unstable surface training positively affects the balance and hop function in patients with CAI. Provide clinical guidance to enhance exercise rehabilitation for these individuals by identifying and summarizing existing evidence.

Methods

Protocol and registration

This systematic review and meta-analysis adhered to the reporting guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[10] Furthermore, the study was registered with the International Prospective Register of Systematic Reviews (http://www.crd.york.ac.uk/PROSPERO) under the registration number CRD42023389226.

Search strategy

Electronic databases were systematically searched to identify relevant studies using a combination of keywords and medical subject headings. Two independent reviewers (S.L. and B.G.) performed searches in PubMed, Cochrane, Web of Science, and Embase databases from January 1, 2000, to June 20, 2024. The search terms included "ankle instability," "unstable surface," "balance training," "exercise therapy," and "randomized control trial," and synonyms and abbreviations of these terms. Tailored search strategies were employed for each database. The detailed search strategy is shown in supplemental appendix S1 (available online only at http://www.archives-pmr.org/).

Eligibility criteria

The inclusion criteria for studies assessing the effects of unstable surface exercise training on CAI involved several key aspects. First, studies were considered if their primary aim was to evaluate the effect of such training. Second, only studies employing a randomized controlled design were included. Third, participants included in these studies had to be diagnosed with CAI, indicated by a score of <27 on the Cumberland ankle instability tool or experiencing symptoms such as ankle giving way. Finally, it was necessary for the studies to include at least one outcome assessment related to balance or function for patients with CAI. These assessments could be measured through different tests. For static balance, the foot-lift test and time-in-balance test were used. The star excursion balance test (SEBT) was employed for dynamic balance assessment. For hop function evaluation, the side-hop test and the figure-of-8 hop test were used.

On contrary, studies were excluded based on specific criteria. First, studies were not considered if they did not involve participants with reported acute sprain symptoms or a history of lower extremity surgery or fracture. Second, studies including participants diagnosed with other lower extremity conditions, such as knee arthritis, plantar fasciitis, meniscus injury, or knee ligament injury, were also excluded. Finally, studies not published in English were not included in the review.

Study selection

Two independent reviewers (S.L. and B.G.) screened the titles and abstracts of all studies. The full texts of potentially relevant studies were then reviewed to determine their eligibility for inclusion. In the event of any disagreement between the 2 initial reviewers, a senior reviewer (Q.W.) was consulted to make the final decision regarding inclusion or exclusion.

Assessing the quality of studies

The methodological quality of included studies was assessed using the physical therapy evidence database (PEDro) scale, which assesses the methodological quality of clinical trials. Studies with the PEDro score of less than 4 were considered poor in methodological quality; 4 to 5 were considered fair; 6 to 8 were considered "good"; and 9 to 10 were considered excellent.[11] Points were awarded only when the scoring criteria were clearly met. If a criterion was not met or was unclear from the written content of the research report, no credit was given for that item.

The selected studies were initially scored independently by 2 reviewers (S.L. and B.G.). Subsequently, the reviewers reviewed the scoring results together, and any discrepancies in scores were discussed. If the reviewers were unable to reach a consensus after the discussion, a senior reviewer (Q.W.) made the final decision.

Data extraction

The researchers (S.L. and B.G.) collected and organized relevant information about the study, including authors, publication year, study design, participant characteristics, sample size, interventions, training dose, outcome measures, and risk of bias. Any disagreements were resolved through discussion or a third independent reviewer (Q.W.) if required.

In one article,[12] data were presented in the form of a line chart. Although line charts are a great way to visualize data, we need precise numerical data for a deeper review. To overcome this challenge, we used the web plot digitizer tool. The application allows us to extract data from a line chart by aligning the chart's axes with the application's axes and then marking points on the line. The application then converts the visual data back into numerical data by giving us the corresponding numerical values for these points based on the alignment. However, when performing data extraction, we noticed that data on the posteromedial (PM) direction of SEBT were missing from the article. To fill this gap in the data, we attempted to contact the authors to request the missing information. Unfortunately, despite our efforts, we have yet to hear back from them.

After extraction, the data were classified according to different outcome metrics. The main outcome measures for this review included the results of SEBT, foot-lift test, time-in-balance test, side-hop test, and figure-of-8 hop test. The mean, SD, and the number of participants in both the experimental and control groups for relevant outcome measures across different studies were extracted separately.

Data analysis and synthesis

Pooled meta-analyses were separately performed for each outcome measure using Review Manager 5.4 to evaluate the effects of various interventions on clinical outcomes. Because the outcome data were continuous, they were presented as mean differences (MDs), with effect sizes and 95% confidence intervals (CIs) calculated accordingly. Statistical significance was defined as a *P* value of less than 0.05.[13,14] Statistical heterogeneity of the included studies was assessed using the I^2 statistic. Considerable heterogeneity was indicated by an I^2 value greater than 50% or a P value less than 0.10. A random-effects model was employed if heterogeneity was significant (I^2>50% or P<.10).[13,14] Otherwise, a fixed-effects model was used. Sensitivity analyses were performed by deleting each study one by one to assess the consistency of the meta-analysis results. This study did not employ the funnel plot asymmetry test to assess publication bias. It should not be used when there are fewer than 10 studies in the meta-analysis because test power is usually too low to distinguish chance from real asymmetry.[15]

Results

Search results

The original search strategy yielded 766 articles. After excluding 196 duplicate studies using the reference manager, reviewers excluded 544 additional studies based on title and abstract screening. Subsequently, the remaining 26 articles underwent full-text review, resulting in the inclusion of 9 studies. The article screening process and results are shown in figure 1.

Basic characteristics of included studies

Nine studies,[12,16–23] published between May 10, 2013, and June 3, 2021, were included. These studies involved a total of 308 patients with CAI, aged between 15 and 50 years old. The participants primarily consisted of college students, athletes, and recreationally active individuals. However, one study[19] did not specify the characteristics of the participants.

Three studies[12,20,23] used the wobble board, while 2 studies[17,18] employed the biomechanical ankle platform system board. The remaining 4 studies used the balance ball,[21] bosu ball,[22] shoes with an unstable surface (a semispherical structure with 100-degree curvature connected to the sole),[19] or various other unstable surfaces.[16] Of the 9 included studies, five[17–20,23] implemented interventions lasting 4 weeks, while four[12,16,21,22] implemented interventions lasting 6 weeks. One study[12] performed training sessions twice a week, whereas the rest trained 3 times a week. Control groups across the studies received either no intervention, resistance training, or vibration training. Specifically, one study[23] involved resistance training, another study[19] used vibration training, and the remaining 7 studies received no intervention (table 1).[12,16-23] Throughout the trial period, all studies reported no adverse events.

Assessment of methodologic quality

The included studies had PEDro scores ranging from 4 to 7, with a mean score of 5.56, indicating a fair quality overall. Five studies were categorized as good, whereas the remaining 4 studies were classified as fair (table 2).[12,16-23]

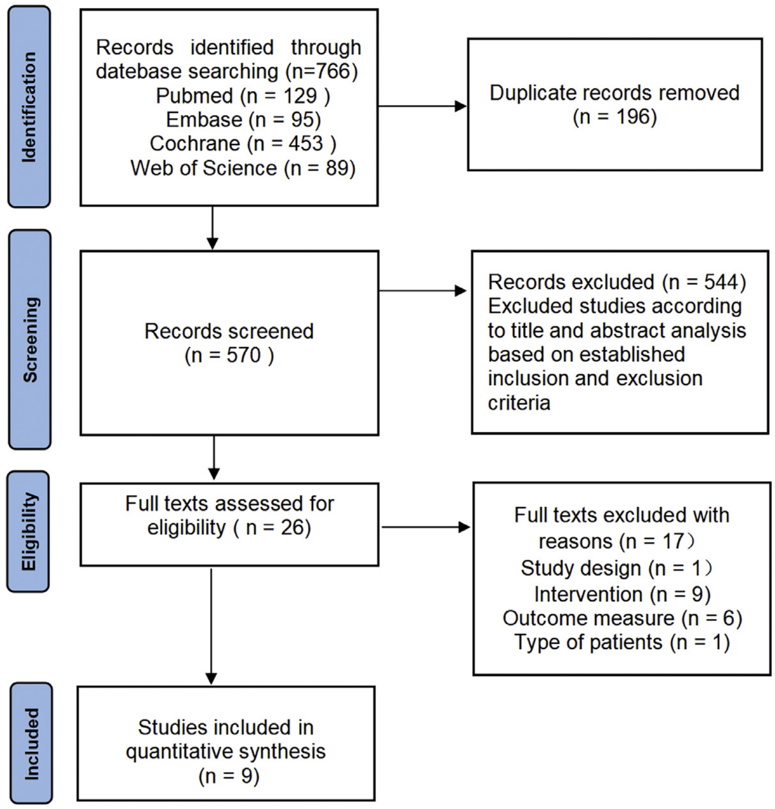

Fig 1 Flow diagram of literature selection. This flow diagram illustrates the process of literature selection for the meta-analysis. It outlines the steps taken from the initial identification of articles through various phases of screening, eligibility assessment, and final inclusion. The initial number of articles identified through database searches is shown, followed by the number of articles remaining after duplicates were removed. Subsequent steps include the number of articles screened, full-text articles assessed for eligibility, and studies included in the final quantitative synthesis. Excluded articles are annotated with reasons for exclusion at each stage.

Meta-analysis results

Six studies[12,16,18,19,21,22] reported the effect of unstable surface training on the posterolateral (PL) reach of the SEBT in 212 patients with CAI. Meta-analysis revealed that unstable surface training significantly outperformed the control group in enhancing balance ability in the PL direction of the SEBT (MD=5.80; 95% CI, 1.60-9.99; *P*=.007). This finding was analyzed using a random-effects model, given the considerable heterogeneity among the studies (I^2=88%; *P*<.0001) (fig 2).[12,16,18,19,21,22] Sensitivity analysis, performed by removing studies one by one, revealed that the significance of the results changed when 2 studies[12,16] were removed separately, which offered inferior evidence for the effect of unstable surface training on the PL reach of the SEBT.

Five studies[12,18,19,21,22] reported the effect of unstable surface training on the anterior reach of the SEBT in 142 patients with CAI. The meta-analysis showed that unstable surface training did not significantly affect balance ability in the anterior direction of the SEBT compared to the control group (MD=3.22; 95% CI, -0.66 to 7.10; *P*=.10). This finding was analyzed using a random-effects model, given the considerable heterogeneity among the studies (I^2=66%; *P*=.02) (fig 3).[12,18,19,21,22] A sensitivity analysis was performed, and it was demonstrated that the significance of the results changed when one study[21] was excluded. Therefore, more evidence is required to guarantee the influence of unstable surface training on the anterior reach of the SEBT.

Eight studies[16-23] reported the effect of unstable surface training on the PM reach of the SEBT in 286 patients with CAI. The meta-analysis demonstrated that unstable surface training significantly enhanced balance ability in the PM direction of the SEBT compared to the control group (MD=6.24; 95% CI, 2.32-10.16; *P*=.002). This finding was analyzed using a random-effects model, given the considerable heterogeneity among the studies (I^2=70%; P=.001) (fig 4).[16-23] Sensitivity analysis showed that pooled results were stable even when studies were excluded one by one.

Five studies[17,18,20–22] reported the effect of unstable surface training on the medial reach of the SEBT in 152 patients with CAI. The meta-analysis revealed that unstable surface training significantly improved balance ability in the medial direction of the SEBT compared to the control group (MD=9.11; 95% CI, 6.42-11.80; *P*<.00001). This finding was analyzed using a fixed-effects model, given the heterogeneity among the studies (I^2=37%; *P*=.18) (fig 5).[17,18,20-22] Sensitivity analysis found that the pooled results remained unaffected by individual trials.

Six studies[16–18,20–22] reported the effect of unstable surface training on the anteromedial (AM) reach of the SEBT in 222 patients with CAI. The meta-analysis demonstrated that unstable surface training significantly improved balance ability in the AM direction of the SEBT when compared with

Table 1 Characteristics of subjects and unstable surface intervention protocols of included studies.

Study	Subject Characteristics	Unstable Surface Device	Intervention Type	Dosage	Main Outcome Measure
Cain et al[17]	EG: n=11, age=16.45±0.93y CG: n=11, age=16.55±1.29y	BAPS board	EG: performed 5 trials of clockwise and counter clockwise rotations, changing direction every 10 s during each 40-s trial CG: no intervention	3 times/wk for 4 wk	SEBT, foot-lift test, side-hop test, figure-of-8 hop test
Cain et al[18]	EG: n=10, age=16.40±0.97y CG: n=11, age=16.45±1.04y	BAPS board	EG: performed 5 trials of clockwise and counter clockwise rotations, changing direction every 10 s during each 40-s trial. CG: no intervention	3 times/wk for 4 wk	SEBT, time-in-balance test, foot-lift test, side-hop test
Chang et al[21]	EG: n=21, age=20.43±1.25y CG: n=21, age=20.43±1.25y	Balance ball	EG: maintain balance on either leg or an affected leg while having eyes closed on the balance ball. CG: continue their normal daily activity	3 times/wk for 6 wk	SEBT
Cloak et al[12]	EG: n=11, age=22.7±1.2y CG: n=11, age=23.1±1.1y	Wobble board	EG: progressive balance training on wobble board CG: no intervention	2 times/wk for 6 wk	SEBT
Cruz-Díaz et al[16]	EG: n=35, age=31.89±10.52y CG: n=35, age=28.83±7.91y	Exercise mats, dynair, bosu, mini tramp, foam roller, ankle disc	EG: exercise comprised 7 tasks performed with different training materials. exercise was progressive, and the intensity was increased with some modifications being added every 2 wk CG: performed their usual activity	3 times/wk for 6 wk	SEBT
Linens et al[20]	EG: n=17, age=22.94±2.77y CG: n=17, age=23.18±3.64y	Wobble board	EG: performed 5 trials of clockwise and counter clockwise rotations, changing direction every 10 s during each 40-s trial. CG: no intervention	3 times/wk for 4 wk	SEBT, time-in-balance test, foot-lift test, side-hop test, figure-of-8 hop test
Shamseddini Sofla et al[19]	EG: n=12, age=40.58±8.76y CG: n=12, age=35.83±12.08y	The shoe with an unstable surface	EG: received progressive WBV training with shoes with an unstable surface CG: received 4 wk progressive WBV training	3 times/wk for 4 wk	SEBT
Sierra-Guzmán et al[22]	EG: n=16, age=21.8±2.1y CG: n=17, age=23.6±3.4y	Bosu	EG: performed barefoot on a Bosu balance trainer CG: continue their normal daily activity	3 times/wk for 6 wk	SEBT
Wright et al[23]	EG: n=20, age=22.60±5.89y CG: n=20, age=21.45±3.24y	Wobble board	EG: completed five 40-s sets of clockwise and counterclockwise rotations (alternating direction every 10 s), with 60 s of rest between sets CG: received resistance training exercise	3 times/wk for 4 wk	SEBT, time-in-balance test, foot-lift test, side-hop test, figure-of-8 hop test

Abbreviations: BAPS, biomechanical ankle platform system; CG, control group; EG, experimental group; WBV, whole body vibration.

Table 2 Internal validity: PEDro scale scoring.

Articles	0	1	2	3	4	5	6	7	8	9	10	Total
Cain et al[17]	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4
Cain et al[18]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	7
Chang et al[21]	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5
Cloak et al[12]	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	5
Cruz-Díaz et al[16]	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	7
Linens et al[20]	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4
Shamseddini Sofla et al[19]	No	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	6
Sierra-Guzmán et al[22]	No	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	6
Wright et al[23]	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	6

NOTE. 0: eligibility criteria were specified; 1: subjects were randomly allocated to groups; 2: allocation was concealed; 3: the groups were similar at baseline regarding the most important prognostic indicators; 4: there was blinding of all subjects; 5: there was blinding of all therapists who administered the therapy; 6: there was blinding of all assessors who measured at least one key outcome; 7: measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; 8: all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by intention to treat; 9: the results of between-group statistical comparisons are reported for at least one key outcome; 10: the study provides both point measures and measures of variability for at least one key outcome.

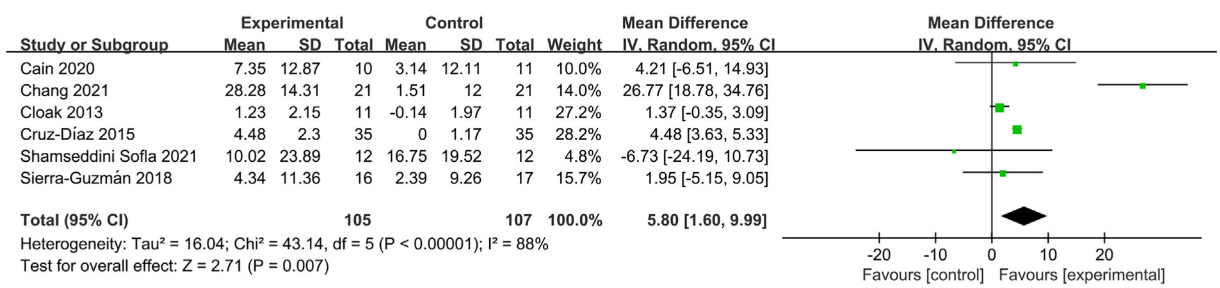

Fig 2 Meta-analysis of the effect of unstable surface exercise training on dynamic balance assessed with the PL direction of the SEBT. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on dynamic balance as measured by the PL direction of the SEBT. The x-axis represents the MD in the reach distance in the PL direction between the experimental group (trained with an unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results indicate that unstable surface training significantly outperformed the control group in enhancing dynamic balance in the PL direction of the SEBT.

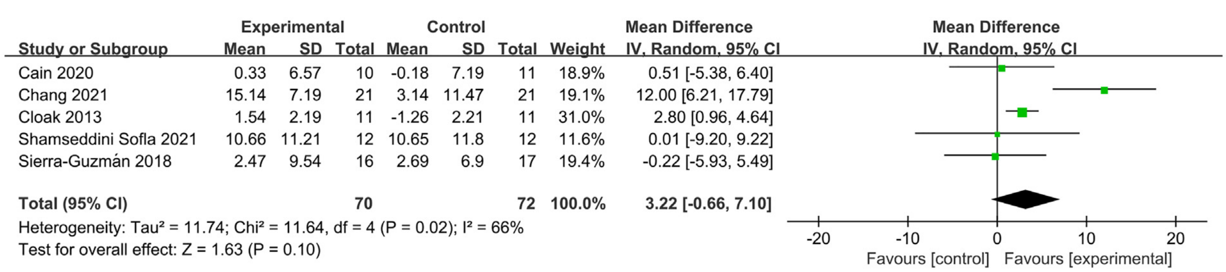

Fig 3 Meta-analysis of the effect of unstable surface exercise training on dynamic balance assessed with the anterior direction of the SEBT. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on dynamic balance, as measured by the anterior direction of the SEBT. The x-axis represents the MD in the reach distance in the anterior direction between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results indicate that unstable surface training did not significantly affect dynamic balance in the anterior direction of the SEBT when compared with the control group.

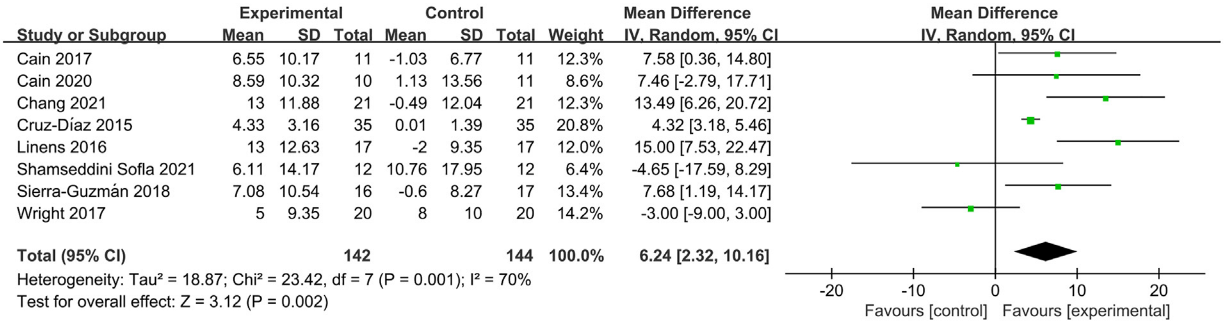

Fig 4 Meta-analysis of the effect of unstable surface exercise training on dynamic balance assessed with the PM direction of the SEBT. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on dynamic balance, as measured by the PM direction of the SEBT. The x-axis represents the MD in the reach distance in the PM direction between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results indicate that unstable surface training significantly enhanced dynamic balance in the PM direction of the SEBT compared to the control group.

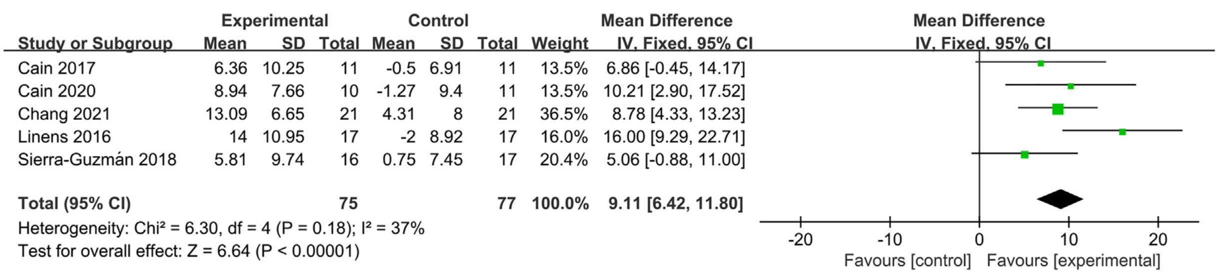

Fig 5 Meta-analysis of the effect of unstable surface exercise training on dynamic balance assessed with the medial direction of the SEBT. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on dynamic balance, as measured by the medial direction of the SEBT. The x-axis represents the MD in the reach distance in the medial direction between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results indicate that unstable surface training significantly improved dynamic balance in the medial direction of the SEBT compared to the control group.

the control group (MD=7.25; 95% CI, 2.33-12.17; *P*=.004). This finding was analyzed using a random-effects model, given the considerable heterogeneity among the studies (I^2=84%; *P*<.00001) (fig 6).[16−18,20−22] Sensitivity analysis found that the pooled results were not affected by individual trials.

Four studies[17,18,20,23] analyzed the effect of unstable surface training on the time-in-balance test, involving a total of 117 patients with CAI. The meta-analysis showed that unstable surface training significantly improved the score of the time-in-balance test in patients with CAI (MD=8.45; 95% CI, 1.50-15.40; *P*=.02). This finding was analyzed using a fixed-effects model, given the heterogeneity among the studies (I^2=0%; *P*=.47) (fig 7).[17,18,20,23] Sensitivity analysis found that the pooled results were affected by 2 studies,[17,20] which provided weaker evidence for the effect of unstable surface training on the time-in-balance test. Therefore, further evidence is required to confirm the influence of unstable surface training on the time-in-balance test.

Four studies[17,18,20,23] investigated the effect of unstable surface training on the foot-lift test, involving a total of 117 patients. The meta-analysis showed that unstable surface training had a significant effect on the foot-lift test compared with the control group (MD=-1.39; 95% CI, - 2.49 to -0.28; *P*=.01). This finding was analyzed using a fixed-effects model, given the heterogeneity among the studies (I^2=25%; P=.26) (fig 8).[17,18,20,23] A sensitivity analysis was performed, revealing that the significance of the results changed when 2 studies[17,20] were removed. Therefore, more evidence is required to guarantee the influence of unstable surface training on the foot-lift test.

Four studies[17,18,20,23] assessed the effect of unstable surface training on the side-hop test, involving a total of 77 patients. The meta-analysis showed that unstable surface training had no significant effect on the side-hop test when compared with the control group (MD=-1.94; 95% CI, -4.82 to 0.95; *P*=.19). This finding was analyzed using a random-effects model, given the considerable heterogeneity among the studies (I^2=53%; *P*=.09) (fig 9).[17,18,20,23] Sensitivity analysis found that the significance of the results changed when one study[23] was removed.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Cain 2017	6.21	7.26	11	-0.01	5.24	11	16.7%	6.22 [0.93, 11.51]
Cain 2020	3.81	6.8	10	0.39	7.27	11	15.8%	3.42 [-2.60, 9.44]
Chang 2021	13.07	7.28	21	-7.36	12.64	21	15.5%	20.43 [14.19, 26.67]
Cruz-Díaz 2015	3.66	5.88	35	0.04	1.53	35	20.0%	3.62 [1.61, 5.63]
Linens 2016	9	10.71	17	-2	7.67	17	15.5%	11.00 [4.74, 17.26]
Sierra-Guzmán 2018	3.46	8.35	16	3	7.3	17	16.6%	0.46 [-4.90, 5.82]
Total (95% CI)			**110**			**112**	**100.0%**	**7.25 [2.33, 12.17]**

Heterogeneity: Tau² = 30.48; Chi² = 32.03, df = 5 (P < 0.00001); I² = 84%
Test for overall effect: Z = 2.89 (P = 0.004)

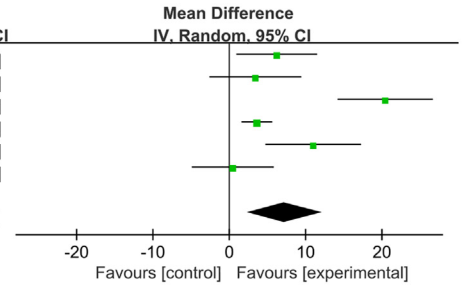

Fig 6 Meta-analysis of the effect of unstable surface exercise training on dynamic balance assessed with the anteromedial direction of the SEBT. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on dynamic balance, as measured by the AM direction of the SEBT. The x-axis represents the MD in the reach distance in the AM direction between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results indicate that unstable surface training significantly improved dynamic balance in the AM direction of the SEBT compared to the control group.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Cain 2017	10.62	15.94	11	-0.11	11.31	11	36.2%	10.73 [-0.82, 22.28]
Cain 2020	-1.53	25.33	10	-15.21	19.38	11	12.8%	13.68 [-5.75, 33.11]
Linens 2016	16.21	20.8	17	4.18	20.01	17	25.7%	12.03 [-1.69, 25.75]
Wright 2017	7.5	24.39	20	8.59	20	20	25.3%	-1.09 [-14.91, 12.73]
Total (95% CI)			**58**			**59**	**100.0%**	**8.45 [1.50, 15.40]**

Heterogeneity: Chi² = 2.52, df = 3 (P = 0.47); I² = 0%
Test for overall effect: Z = 2.38 (P = 0.02)

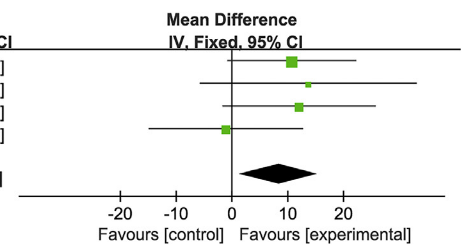

Fig 7 Meta-analysis of the effect of unstable surface exercise training on static balance assessed with a time-in-balance test. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on static balance, as measured by the time-in-balance test. The x-axis represents the MD in the duration of maintaining balance during the time-in-balance test between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results suggest that unstable surface exercise training had a significant positive effect on static balance as assessed by the time-in-balance test.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Cain 2017	-2.81	2.83	11	0.67	3.44	11	17.6%	-3.48 [-6.11, -0.85]
Cain 2020	-0.43	5.24	10	0	3.36	11	8.4%	-0.43 [-4.24, 3.38]
Linens 2016	-1.79	2.58	17	-0.39	1.86	17	53.3%	-1.40 [-2.91, 0.11]
Wright 2017	-1.92	3.6	20	-1.96	4.22	20	20.6%	0.04 [-2.39, 2.47]
Total (95% CI)			**58**			**59**	**100.0%**	**-1.39 [-2.49, -0.28]**

Heterogeneity: Chi² = 4.00, df = 3 (P = 0.26); I² = 25%
Test for overall effect: Z = 2.46 (P = 0.01)

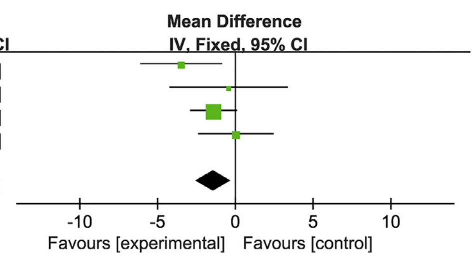

Fig 8 Meta-analysis of the effect of unstable surface exercise training on static balance assessed with a foot-lift test. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on static balance, as measured by the foot-lift test. The x-axis represents the MD in the number of times the lift supports the leg during the foot-raising test between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results suggest that unstable surface training had a significant positive effect on static balance as assessed by the foot-lift test compared with the control group.

Three studies[17,18,23] examined the effect of unstable surface training on the figure-of-8 hop test, involving a total of 95 patients. The forest plot revealed that unstable surface training had no significant effect on the figure-of-8 hop test compared with the control group (MD=-0.97; 95% CI, -2.39 to 0.46; *P*=.18). This finding was analyzed using a fixed-effects model, given the heterogeneity among the studies (I^2=41%; *P*=.18) (fig 10).[18,20,23] Sensitivity analysis found that pooled results were not affected by individual trials.

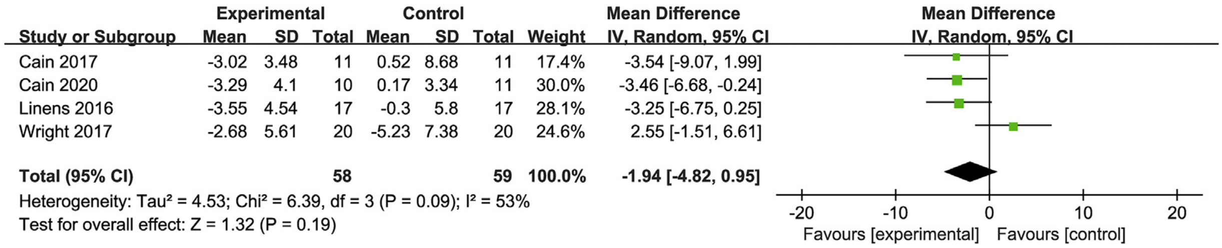

Fig 9 Meta-analysis of the effect of unstable surface exercise training on hop function assessed with side-hop test. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on function, as measured by the side-hop test. The x-axis represents the MD in the number of times the participant could hop sideways between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results suggest that unstable surface training had no significant positive effect on hop function as assessed by the side-hop test compared with the control group.

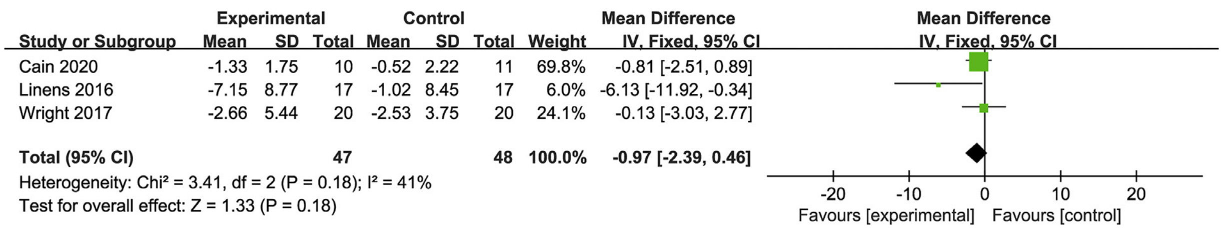

Fig 10 Meta-analysis of the effect of unstable surface exercise training on function assessed with a figure-of-8 hop test. This figure presents a meta-analysis of studies examining the effect of unstable surface exercise training on function, as measured by the figure-of-8 hop test. The x-axis represents the MD in the time taken to complete the figure-of-8 hop test between the experimental group (trained with unstable surface) and the control group. The y-axis lists the included studies, which are represented by individual squares. The size of each square is proportional to the weight of the study in the meta-analysis, and the horizontal line passing through each square represents the 95% CI for the MD. The diamond at the bottom represents the pooled MD and its 95% CI. The results suggest that unstable surface training had no significant positive effect on hop function as assessed by the figure-of-8 hop test compared with the control group.

Publication bias

Because there were fewer than 10 studies for each outcome indicator, funnel plots were not generated to assess publication bias.

Discussion

To our knowledge, this is the first exploratory systematic review and meta-analysis to assess the effects of unstable surface training on balance and function in patients with CAI, compared with other treatments or no intervention. Our analysis revealed statistically significant differences in the unstable surface training group for 6 outcomes, including the PL, PM, and AM, and medial directions of the SEBT, and the time-in-balance test and the foot-lift test. These improvements in outcomes hold significant clinical value for patients with CAI. Conversely, 3 outcomes, including the anterior direction of the SEBT, the side-hop test, and the figure-of-8 hop test, did not show significant benefits when comparing unstable surface training with the control group. However, the exploratory nature of our study underscores the preliminary nature of these findings and suggests that more rigorous studies are needed to validate these results.

Effect on static balance

Both the time-in-balance test and the foot-lift test are used to evaluate patients' static balance and their ability to maintain their center of gravity on a stable surface.[18] Meta-analyses indicate that unstable surface training yields superior results when compared with control groups in both these tests. Research has demonstrated that unstable surface training significantly decreases the number of touches on the opposite leg during single-legged standing in children without CAI.[24,25] Adding an unstable surface may enhance muscle activation and force output, thereby improving stability.[26] In individuals without CAI, the ankle strategy is the predominant control mechanism during both disturbed and undisturbed balance while standing, accounting for more than 90% of the time.[27] However, patients with CAI because of ankle joint instability, may exhibit a preference for a hip strategy over an ankle strategy to maintain balance.[28]

In both the time-in-balance test and the foot-lift test, participants are tasked with maintaining single-leg balance for as long as possible, predominantly relying on the ankle strategy for stability maintenance. Hence, the enhancement in the time-in-balance test results could potentially be attributed to interventions that prompted a favorable shift in the patient's balance-strategy pattern. However, because of the instability of pooled results, further research is imperative to determine the effect of unstable surface training on static balance in patients with CAI.

Effect on dynamic balance

The SEBT has been established as a reliable measurement tool with validity for identifying dynamic balance deficits in patients with various lower extremity conditions.[29] The SEBT typically involves extension in 8 directions. However, in our meta-analysis, we only included 5 directions. Because data on anterolateral, posterior, and lateral directions were only available in 1 study, a meta-analysis of these 3 directions could not be performed. Meta-analysis showed that unstable surface training outperformed other treatments or no intervention in the PL, PM, AM, and medial reach of the SEBT in patients with CAI. An unstable training environment can improve neuromuscular adaptation and training specificity, offering a range of training methods and effective training stimulation.[8] The mechanism underlying balance maintenance in an unstable situation involves shifting the center of mass throughout the body to some extent through muscle action, thereby ensuring that the center of pressure remains within safe limits.[30] Mademli et al[31] exhibited that perturbations caused by surfaces increased local instability and encouraged muscle cooperation and activity during pose tracking. Training on a compliant surface may prompt the re-weighting of sensory modalities, as observed after some practice in balancing on unstable surfaces.[5] Therefore, the improvement in the 4 directions of the SEBT may be attributed to increased intrinsic muscle strength surrounding the ankle and anterior tibia, and improved function of mechanoreceptors in the lower extremities.

Meta-analysis showed no significant difference in the anterior direction of the SEBT between groups. Previous studies have shown that mechanical limitations in ankle dorsiflexion could restrict the anterior reach of the SEBT.[32–34] Consequently, it is plausible that unstable surface training might not significantly enhance ankle dorsiflexion range of motion in individuals with CAI. In addition, it is worth considering that not all SEBT orientations hold equal diagnostic value for CAI; among them, the anteromedial, medial, and posteromedial orientations appear to offer the most clinical utility.[35] The anterior direction of the SEBT may lack the necessary sensitivity to discern balance changes between experimental and control groups.[35]

Further research is required to ascertain the effect of unstable surface movement training on the PL and anterior directions in individuals with CAI, based on the combined findings of these directions.

Effect on hop function

The side-hop test and the figure-of-8 hop test are used to evaluate hop capability and patients' capability to efficiently hold their center of gravity while responding to disturbances during landing and takeoff tasks.[18] Meta-analysis showed no significant difference between the 2 groups in terms of performance on these tests. Nevertheless, unstable surface movement training has demonstrated effectiveness in enhancing dynamic postural control, ankle strength production, neuromuscular adaptation, and sensory weighting.[5,36,37] These enhancements facilitate improved coordination and increased muscle activation in the ankle during functional movements. Hopping tests require muscular speed, power, and agility,[35,38] and significant motor planning and sensory integration.[39] During jumping and landing, the active and passive stabilizers of the ankle joint are challenged by excessive ankle supination and pronation movement,[40] which require more muscle activation of the peroneal longus and tibial anterior muscles to complete the jump; however, these muscles have been proved weak after ankle sprains.[41]

Improvements in these 2 tests may require longer interventions to achieve significant results. Furthermore, a previous study has demonstrated that individuals with CAI may not fully regain all the physiological elements required to perform certain motor tasks.[42] Further research is warranted to investigate the effect of unstable surface exercise training on the side-hop test and the figure-of-8 hop test in patients with CAI.

Future research

Future research is needed to assess the effect of training on various unstable surfaces on rehabilitation outcomes for patients with CAI. The intervention programs included in this study were 4 or 6 weeks, 2 or 3 times per week. Moving forward, additional studies are required to determine the optimal duration for rehabilitation programs and whether factors such as sex and age influence outcomes. Moreover, how long can clinical improvements in balance and function be sustained is unknown. Finally, comparing the effectiveness of unstable surface treatment protocols with traditional rehabilitation approaches for CAI treatment could provide valuable insights into identifying the most effective treatment plan for CAI rehabilitation.

Study limitations

The meta-analysis is constrained by a limited number of included studies, most of which had small sample sizes. Variations existed in baseline levels, intervention methods, and duration among these studies, leading to considerable heterogeneity in several outcomes. Because of the small number of studies, no publication bias test was performed. Future studies should aim to account for patients' baseline levels and increase sample sizes to enhance the reliability of conclusions drawn. Furthermore, the methodological quality of the included studies varied, with some failing to clearly specify the random allocation method, concealment of allocation, or implementation of blinding, which could ultimately undermine result reliability. The exploratory nature of this systematic review and meta-analysis indicates that our findings are preliminary and should not be taken as conclusive. Future research with more robust methodologies is necessary to confirm the potential benefits observed in this exploratory analysis.

Conclusions

In summary, unstable surface training, when compared to conventional physiotherapy intervention or no intervention, has shown effective improvements in the PL, PM, AM, and medial directions of the SEBT, the time-in-balance test, and the foot-lift test in patients with CAI. However, it does not have a significant effect on the anterior direction of the SEBT, the side-hop test, or the figure-of-8 hop test. This suggests that unstable surface training may enhance balance but may not notably effect hop function. It is important to note that the exploratory nature of this systematic review and meta-analysis suggests that our findings are preliminary and should not be considered conclusive. Therefore, further exploration with more high-quality research articles is necessary to validate these findings.

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Disclosure

The investigators have no financial or nonfinancial disclosures to make in relation to this project.

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