Non-instrumented Clinical Assessment of Static Postural Stability in Chronic Ankle Instability: A Systematic Review and Meta-analysis

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Highlights

- The single-leg and tandem stance in the Balance Error Scoring System can detect decreased static postural stability in chronic ankle instability.
- The use of foam surfaces in the Balance Error Scoring System could potentially detect greater static postural stability deficits in chronic ankle instability than firm surfaces.
- Foot-lift and time-in-balance tests may also be useful for detecting static postural stability deficits in chronic ankle instability.

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Abstract

Context: Several clinical tests are available to assess static postural stability in individuals with chronic ankle instability (CAI); however, it is unclear which test should be used.

Objective: To determine which non-instrumented clinical tests should be used to detect static postural stability deficits in individuals with CAI.

Evidence Acquisition: We searched four databases from their inception to February 2023, and included studies comparing static postural stability in individuals with CAI and healthy controls using non-instrumented assessments. Two reviewers independently extracted study characteristics, participant information, static postural stability assessment methods, and results. We calculated the pooled standardized mean difference (SMD) and 95% confidence interval (CI) using a random-effects meta-analysis and assessed the certainty of the evidence.

Evidence Synthesis: Fourteen cross-sectional studies (293 participants with CAI and 284 healthy controls) were included. The meta-analysis showed no significant differences between the CAI and healthy groups in the double-leg stance condition of the Balance Error Scoring System (BESS) (SMD, −0.03; low-certainty evidence). Significant group differences were found in the BESS single-leg stance (SLS) on firm and foam surfaces (SLS firm: SMD, 0.47, very low-certainty evidence; SLS foam: SMD, 0.80, very low-certainty evidence), the tandem stance (TS) on firm and foam surfaces (TS firm: SMD, 0.39, low-certainty evidence; TS foam: SMD, 0.76, low-certainty evidence), and the total BESS in the foam conditions (SMD, 1.12, very low certainty evidence). Significant differences were also found between the CAI and healthy groups in the foot-lift (SMD, 1.24; very low certainty evidence) and time-in-balance tests (SMD, −0.94; very low certainty evidence).

Conclusions: Due to the large magnitude of the differences, the SLS foam, TS foam, and the total BESS in the foam conditions, as well as the foot-lift test or time-in-balance test, may be the most appropriate to clinically identify static postural stability impairment in individuals with CAI.

Key words: ankle sprain; ankle ligament injury; balance; postural control; rehabilitation

CONTEXT

Lateral ankle sprains (LASs) are one of the most common sports injuries and have a high recurrence rate.[1] The proportion of recurrent ankle sprains in the sports population ranges from 12% to 47%.[2] Of those who sustain an LAS, 40% develop chronic ankle instability (CAI),[3] which can lead to perceived instability, giving way, and reinjury of the ankle.[4] Up to 10% to 20% of athletes who continue to participate in sports activities have CAI.[5] Furthermore, CAI is associated with ankle osteoarthritis and reduced health-related quality of life.[1,6,7]

Several types of impairments are associated with CAI, including pathomechanical, motor-behavioral, and sensory-perceptual impairments.[8] Among these, many studies have been conducted on postural stability deficits, which are classified as motor-behavioral impairments.[9,10] A recent meta-analysis found that individuals with CAI have static postural stability deficits during single-leg standing.[10] Static postural stability is the most commonly assessed outcome in intervention studies,[9] and its assessment in clinical practice guidelines for post-LAS and CAI is recommended.[11] Thus, the importance of assessing static postural stability in individuals with CAI is widely recognized.

A number of methods have been used to assess static postural stability in CAI.[9,10,12] A systematic review of instrument-based assessment of static postural stability in CAI reported that assessment by the center of pressure trajectory using a force plate can identify static postural stability impairment in CAI.[10] However, force plates may not always be available in clinical practice because of their high cost. There are several non- instrumented methods to assess static postural stability, such as the Balance Error Scoring System (BESS), foot-lift test, time-in-balance test, etc.[13] The BESS consists of a total of six conditions, including three standing conditions and two floor conditions. The BESS conditions used varied among the studies; additionally, only single-leg standing on a firm or foam surface was used.[14-16]

However, it remains unclear which specific BESS conditions or other tests (i.e., foot-lift test, time-in-balance test, etc.) should be used to detect differences in static postural stability between individuals with and without CAI. Evidence-based clarification of this issue will provide helpful insights for clinical decision making when selecting an assessment method. Therefore, this study aimed to identify appropriate non-instrumented assessment methods to detect differences in static postural stability between individuals with and without CAI through a systematic review and meta-analysis.

METHODS

Design

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement.[17] The protocol for this review was pre-registered with PROSPERO (registration number: blind).

Evidence acquisition

Search strategy

Four databases (PubMed, CINAHL, Cochrane Library, and Web of Sciences) were searched from their inceptions until February 1, 2023. A search strategy was created for each database (Supplemental Content 1), and the search results were exported to Endnote X9 (Thomson Reuters, New York, NY, USA). Duplicate papers were removed using software. Two independent reviewers screened the titles and abstracts of the studies according to eligibility criteria described below. Two reviewers screened the full text of the remaining studies. At each screening stage, disagreements between the reviewers were resolved by consensus.

Study selection

The inclusion criteria for the studies included in this systematic review were as follows: (1) they compared static postural stability between individuals with CAI and healthy controls, (2) static postural stability was assessed using non-instrumented methods, and (3) the criteria for CAI included a history of at least one ankle sprain, and a history of giving way, recurrent sprains, and/or a feeling of instability.[4] The exclusion criteria were as follows (1) studies that did not include healthy participants as a control group, and (2) non-English articles. Static postural stability was defined as the measure of postural stability when the body is stationary.[18]

Data extraction

Two reviewers independently extracted the following data: study characteristics (author name and year of publication), participant information (sample size and definitions of the injured group), static postural stability assessment methods (type of test and conditions), and the mean and standard deviation (SD) of the static postural stability assessment results (injured and healthy control groups). When the median and quartiles were reported, the mean and SD were estimated using the Box-Cox method.[19] If static postural stability data were not reported in the paper, we requested the data from the corresponding author by e-mail. Studies with unavailable data were excluded from the meta-analysis.

Risk of bias

Two reviewers independently assessed the risk of bias of the included studies. There is no gold standard for assessing the risk of bias in cross-sectional studies,[20] but the Newcastle-Ottawa Scale (NOS)[21] is often used with modifications. Therefore, we adapted the

NOS for use in a cross-sectional study based on previous studies.[20,22-24] For sample selection, we assessed four items: (1) The representativeness of the sample (was the sample truly or somewhat representative of the target population?), (2) Sample size (justified or satisfactory?), (3) definition of injured population (was a validated measurement tool used?), and (4) non-included participants (was comparability established and was the inclusion rate satisfactory?). In addition, we assessed the comparability of cases and controls based on design or analysis. For outcomes, the following two items were assessed: (1) Outcome assessment (was an independent blind assessment conducted using an objectively validated method?) (2) Statistical tests (is an appropriate test used and clearly described?). Scores were assigned for each item assessment and interpreted as follows: 8–10 points, low risk of bias; 6–7 points, medium risk of bias; 5 points or less, high risk of bias.[23]

Data analysis

Meta-analysis (random effects) was conducted using Review Manager 5.4 (RevMan).[25] Data for similar postural stability assessment methods from each study were pooled, and standardized mean differences (SMDs) and 95% confidence intervals (CIs) were calculated using RevMan. The SMD, rather than the mean difference, was calculated to examine the magnitude of the differences between the CAI and healthy groups based on the method of assessment. A positive SMD, except for the time-in-balance test, indicated that the CAI group had decreased postural stability compared to the healthy control group. Differences were considered statistically significant if the 95% CI of the SMD did not include a 0. The SMD was interpreted as small if less than 0.40, moderate if 0.40 to 0.70, and large if greater than 0.70.[26] Statistical heterogeneity of 0% was interpreted as possibly unimportant, 30% as moderate, 50% as substantial, and 75% as considerable, based on the I^2 statistic.[26] Publication bias was assessed using a funnel plot when more than 10 studies were available in the meta-analysis.[27]

Finally, two reviewers independently assessed the certainty of the evidence for each meta-analysis using the Grading of Recommendations Assessment, Development, and Evaluation methodology.[28] The certainty of the evidence, based on previous studies,[29,30] was downgraded if the following five criteria were met: more than 75% of the studies were not considered to be at low risk of bias; I^2 statistic greater than 50%; wide 95% CI (upper or lower 95% CI >0.5 of the effect size in either direction) and a sample size of fewer than 400 in the meta-analysis for each variable; studies with indirect comparisons; asymmetric funnel plots. The certainty of evidence was downgraded from high to moderate, low, or very low when each of the above criteria was met.

Evidence synthesis

Study selection and characteristics

Fourteen studies (293 patients with CAI and 284 healthy controls) were included after screening (Figure 1). Table 1 summarizes the characteristics of the included studies. All the included studies examined static postural stability in individuals with CAI using a cross-sectional design. Non-instrumented assessments included the BESS (n=8),[31-38] foot-lift test (n=4),[36,39-41] time-in-balance test (n=4),[36,40-42] Clinical Test of Sensory Integration in Balance (n=1),[43] and Romberg test (n=1).[44] Table 2 describes each assessment method.

Risk of bias

Table 3 presents the results of the risk of bias assessment. Eight studies (57.1%) were considered high risk, six (42.9%) were considered medium risk, and none were considered low risk. Most studies had a high risk of sample representativeness (92.9%), non-included participants (100.0%), and sample size justification (64.3%). In addition, only 1.4% and 0.7%

of the studies scored 2 points for comparability and outcome assessment, respectively.

Meta-analysis of non-instrumented static postural stability

<u>Balance Error Scoring System</u>

Eight studies used the BESS, of which four studies examined double-leg stance (DLS) conditions on firm (DLS firm) and foam (DLS foam) surfaces.[31,32,34,36] The SMD of the DLS firm could not be estimated because the mean and SD were zero in most studies. The pooled data for DLS foam showed no significant difference between the CAI and control groups (SMD, −0.03; 95% CI, −0.34-0.28; I^2=7%; low-certainty evidence) (Figure 2 and Table 4). In the single-leg stance condition of the BESS, six and four studies examined firm (SLS firm) and foam (SLS foam) surfaces, respectively.[31,32,34-36,38] In the SLS firm condition, the CAI group showed significantly more errors than the control group (SMD: 0.47; 95% CI, 0.07-0.86; I^2=57%; very low certainty evidence) (Figure 2 and Table 4). The CAI group also had significantly more errors than the control group in the SLS foam condition (SMD, 0.80; 95% CI, 0.24-1.35; I^2=67%; very low certainty evidence) (Figure 2 and Table 4). The tandem stance (TS) on firm (TS firm) and foam (TS foam) surfaces was examined in four studies.[31,32,34,36] The CAI group had significantly more errors than the control group in both the TS firm (SMD, 0.39; 95% CI, 0.09-0.69; I^2=0%; low certainty evidence) and TS foam (SMD, 0.76; 95% CI, 0.45-1.07; I^2=0%; low certainty evidence) conditions.

Four studies were used for the total scores for all BESS conditions.[32-34,36] The pooled SMD showed no significant difference between the CAI and control groups (SMD, 0.40; 95% CI, −0.25-1.05; I^2=76%; very low certainty evidence) (Figure 3 and Table 4). This statistical heterogeneity was considerable, and the result was significant when the study with the highest heterogeneity was excluded (SMD, 0.70; 95% CI, 0.24-1.15, I^2=34%). In addition, 2 studies reported the total scores for the firm (firm total) and foam (foam total) surface conditions, respectively.[34,37] The meta-analysis showed no significant group differences in the firm total (SMD, 0.61; 95% CI, −1.52-2.73; I^2=91%; very low certainty evidence) (Figure 3 and Table 4), whereas the foam total had a significantly higher number of errors in the CAI group (SMD, 1.12; 95% CI, 0.23-2.02; I^2=51%; very low certainty evidence) (Figure 3 and Table 4). Statistical heterogeneity was considerable for total firm scores; however, there were only two studies.

Foot-lift test

Four studies used the foot-lift test,[36,39-41] but only three were included in the meta-analysis.[36,39,41] This was because the mean and SD could not be extracted from one study.[40] The pooled data showed that the CAI group had a significantly greater number of foot lifts than the control group (SMD, 1.24; 95% CI, 0.82-1.66; I^2=90%; very low certainty evidence) (Figure 4 and Table 4). Statistical heterogeneity was significant. When the study that contributed most to the heterogeneity was excluded,[39] the I^2 statistic was 0%, and the statistical result was similar (SMD, 0.72; 95% CI, 0.24-1.20; I^2, 0%).

Time-in-balance test

Four studies used the time-in-balance test,[36,40-42] but only three were included in the meta-analysis.[36,41,42] This was because the mean and SD could not be extracted from one study.[40] A meta-analysis showed that the CAI group maintained postural stability for a significantly shorter time than the control group (SMD, –0.94; 95% CI, –1.29 to –0.59; I^2=50%; very low certainty evidence) (Figure 5 and Table 4).

Other tests

One study used the Clinical Test of Sensory Integration in Balance (CTSIB) to compare a CAI group with a control group.[43] A meta-analysis could not be performed because only one study was available for the CTSIB. The CAI group had significantly worse scores for conditions 2 and 6 of the CTSIB, CTSIB composite score, and CTSIB somatosensory ratio than the control group.[43] The Romberg test was used in one study, and no significant group differences were found.[44]

DISCUSSION

This systematic review and meta-analysis aimed to determine which non-instrumented static postural stability assessment methods are useful for individuals with CAI. The present meta-analysis suggests that the SLS firm, SLS foam, TS firm, TS foam, and foam total in the BESS as well as the foot-lift and time-in-balance tests can detect static postural stability deficits in the CAI group. In particular, the pooled SMD showed that the SLS foam, TS foam, and foam total in the BESS, foot-lift test, and time-in-balance test had large effects (SMD >0.7). Therefore, the present study suggests that these assessments can be used in clinical practice to detect static postural stability deficits associated with CAI. However, it should be noted that most of the certainty of the evidence was very low to low.

The BESS is the most commonly used non-instrumented static postural stability assessment tool for individuals with CAI. This is also the clinical assessment recommended in the consensus statement of the International Ankle Consortium.[45] The present study suggests that the SLS and TS conditions can detect static postural stability impairment in the CAI group but not in the DLS condition. No significant group differences were observed in DLS. The DLS conditions of the BESS are easy and may not be necessary for static postural stability assessment in the CAI group. The SLS and TS conditions detected significant group differences for each surface condition; however, these SMDs were larger when using the foam surface than when using the firm condition. The total number of errors for the foam condition also exhibited a high SMD. These findings suggest that assessing errors in SLS or TS on a foam surface is useful for detecting static postural stability impairments caused by CAI.

A meta-analysis of the foot-lift test showed a large pooled SMD, suggesting that it is useful for assessing static postural stability in the CAI group. As this statistical heterogeneity was substantial, we confirmed that excluding the study with high heterogeneity resulted in a large SMD (0.72).[39] A previous meta-analysis also showed that the foot-lift test can discriminate between the CAI and healthy groups.[13] This test is performed on a firm surface, and unlike the BESS, the stance is maintained for 30 seconds and the number of times any part of the foot lifts from the floor is counted.[36,39,41] A cross-sectional study by Linens et al also reported a larger effect size for the difference between the CAI and healthy groups in the foot-lift test than in the SLS firm of the BESS.[36] In the single-leg standing on a firm surface, the assessment of foot-focused errors for 30 seconds may be useful to detect static postural stability impairments in CAI.

For the time-in-balance test, the CAI and healthy groups were significantly different, with a large pooled SMD. The synthesized effect size for the time-in-balance test has not been reported in a previous meta-analysis,[13] whereas a cross-sectional study reported that the time-in-balance test had an effect size as large as that of the foot-lift test for the difference between the CAI and healthy groups.[36] The present meta-analysis suggests that the time-in-balance test would be useful for detecting static postural stability impairment in CAI. It is noteworthy that the mean value of the time-in-balance test for the CAI group was less than 10 seconds in two studies,[41,42] while it was 28.99 seconds in one study.[36] As a possible explanation for this, Wikstrom et al. discussed the potential variation in the definition of balance loss in this test among different studies.[41] In the time-in-balance test, loss of balance is defined as the movement of the tested foot or the touching of the ground by the contralateral foot during single-leg standing. However, the definition of a moving test foot was not specific. In the future, it will be necessary to define this as any part of the foot moving off the floor (e.g., medial foot elevation, heel lateral shift, etc.), similar to the study by Wikstrom et al.[41]

In clinical practice, the SLS foam, TS foam, or the total score of the BESS foam surface condition, as well as either the foot-lift test or the time-in-balance test, can be used to detect static postural stability impairments in individuals with CAI because these conditions or tests have large SMDs. For example, in patients who have difficulty standing on a single leg, static postural stability may be adequately assessed by assessing them in the TS condition, preferably using a foam surface. Additionally, if clinicians do not have access to a foam pad, a foot-lift test or time-in-balance test may be a better option. Furthermore, unlike the BESS, which necessitates the observation of errors throughout the body (from checking eye openings to hip and foot movements), these two tests only require observation of the test foot. This may enable the examiner to observe small foot movements without overlooking them, and may facilitate the detection of reduced postural stability due to CAI. Additionally, clinical postural stability assessment in the DLS condition may be unnecessary because of the difficulty in detecting postural stability impairments associated with CAI. Assessment of the total score of the BESS foam surface condition requires three conditions for a 20-second postural stability test: DLS, SLS, and TS foam conditions. This is not more time-efficient than other tests, such as SLS foam only, TS foam only, foot-lift test, and time-in-balance test. This information may also be useful in time-constrained settings.

Study limitations

This study had several limitations. First, there were no low risk of bias studies in the present review. Therefore, the results should be interpreted with caution. Second, the statistical heterogeneity of most of the meta-analyses in this review ranged from substantial to considerable. This indicates that the effect sizes varied between the studies included in the meta-analysis and that the results should be interpreted with caution. Third, the definition of CAI varied among included studies. Finally, although we were unable to perform a meta-analysis, a cross-sectional study found significant differences between CAI and healthy participants on several scores of the CTSIB scores.[43] This test differs from the other tests in that it has a visual conflict dome condition to produce a visual sway referencing effect.[43] The significant group difference was found in the visual-conflict dome condition.[43] Static postural stability was also assessed using a stroboscopic glass that disrupts visual information,[46] which is cost-effective and easy to use in clinical practice. Future studies that use such tools to manipulate visual information are likely to contribute to the development of clinical assessment methods for postural stability in individuals with CAI.

CONCLUSIONS

Our systematic review and meta-analysis showed that SLS firm, SLS foam, TS firm, TS foam, and foam total in the BESS as well as the foot-lift and time-in-balance tests could detect static postural stability impairment in the CAI group. In particular, the pooled SMD showed that the SLS foam, TS foam, and foam total in the BESS, foot-lift test, and time-in-balance test had a large effect (SMD >0.7), and therefore can be used to detect static postural stability impairment in individuals with CAI. However, the certainty of the evidence was very low to low, and therefore the present results should be interpreted with caution.

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Figure legends

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

Figure 2. Meta-analyses on each condition of the Balance Error Scoring System. This forest plot was generated by RevMan 5.4.[25] CAI, chronic ankle instability; DLS foam, double leg stance on the foam surface; SLS firm, single leg stance on the firm surface; SLS foam, single leg stance on the foam surface; TS firm, tandem stance on the firm surface; TS firm, tandem stance on the firm surface.

Figure 3. Meta-analyses on the total scores of the Balance Error Scoring System. This forest plot was generated by RevMan 5.4.[25] CAI, chronic ankle instability.

Figure 4. Meta-analyses on the foot lift test. This forest plot was generated by RevMan 5.4.[25] CAI, chronic ankle instability.

Figure 5. Meta-analyses on the time-in-balance test. This forest plot was generated by RevMan 5.4.[25] CAI, chronic ankle instability.

Table 1. Study characteristics

Author	N	Key definitions of CAI	Clinical balance assessment	Findings
Chrintz[42]	CAI: 29 CON: 41	1) a history of recurrent ASs and GW incidents resistant to training; 2) prior to operative exploration of the lateral ligaments of the ankle.	· **Time in Balance test in EC** and EO	· Significantly less time in the CAI group than in the CON group. **Mean and SD were estimated based on reported medians and quartiles for meta-analysis.*
Dobo[31]	CAI: 32 CON: 19	1) at least one significant AS; 2) self-reported sensations of ankle GW during activity.	· BESS 6 conditions: **(1) DLS firm, (2) DLS foam, (3) SLS firm, (4) SLS foam, (5) TS firm, (6) TS foam**	· No results of group comparisons were reported. · Significant cutoffs were found in the SLS firm, SLS foam, and TS foam conditions that could identify individuals with CAI.
Docherty[32]	CAI: 30 CON: 30	1) at least one AS; 2) repeated feeling of GW or instability in the ankle	· BESS 6 conditions: **(1) DLS firm, (2) DLS foam, (3) SLS firm, (4) SLS foam, (5) TS firm, (6) TS foam** · **BESS total errors**	· Significantly more errors in the SLS firm, SLS foam, and TS foam conditions in the CAI group than in the CON group. · Significantly more total BESS errors in the CAI group than in the CON group.
Hiller[39]	CAI: 31 CON: 15	1) at least one AS; 2) CAIT score ≤ 24.	· **Foot lift test**	· Significantly more foot lifts in the CAI group than in the CON group. **Data from the unilateral and bilateral instability groups were combined for meta-analysis.*
John[33]	CAI: 20 CON: 20	1) a history of at least one AS, GW and/or RAS and/or feelings of instability; 2) CAIT score ≤ 24; 3) FAAM score < 90%; 4) FAAM Sports < 80%	· **BESS total errors**	· No significant group effect on the total BESS errors.
Ko[40]	CAI: 25 CON: 33	1) a history of moderate–severe AS that required at least 3 days of partial or non-weight bearing; 2) a history of GW with activity; 3) CAIT score ≤ 25	· Foot lift test · Time in Balance test	· No results of group comparisons were reported.
Koshino[34]	CAI: 16 CON: 16	1) at least one AS; 2) the initial sprain over 1 year ago; 3) at least two GW within 6 months and/or recurrent AS; 4) CAIT score ≤ 25.	· BESS 6 conditions: **(1) DLS firm, (2) DLS foam, (3) SLS firm, (4) SLS foam, (5) TS firm, (6) TS foam** · BESS scores: **(1) total errors, (2) firm total errors, (3) foam total errors**	· Significantly more total foam errors in the CAI group than in the CON group.

Kwon[35]	CAI: 20 CON: 20	1) at least one AS; 2) multiple episodes of GW in the 6 months and/or 'feeling of instability'; 3) CAIT score < 24; 4) FAAM score < 90%.	· **<u>BESS SLS firm condition in EC</u>** and EO	· No significant group differences in errors for the SLS firm condition in EC and EO.
Linens[36]	CAI: 17 CON: 17	1) at least one significant AS; 2) self-reported sensations of GW at least twice; 3) CAIT score < 27; 4) no signs or symptoms of an acute injury.	· BESS 6 conditions: **<u>(1) DLS firm, (2) DLS foam, (3) SLS firm, (4) SLS foam, (5) TS firm, (6) TS foam</u>** · **<u>BESS total errors</u>** · **<u>Foot lift test</u>** · **<u>Time in Balance test</u>**	· No results of group comparisons were reported. · Significant cutoffs were found in the BESS SLS firm, total BESS, foot lift test, time-in balance test and that could identify individuals with CAI.
Powell[37]	CAI: 10 CON: 10	1) at least one AS; 2) at least 2 episodes of GW in the past 3 months; 3) AII score ≥ 4.	· BESS scores: **<u>(1) firm total errors, (2) foam total errors</u>**	· Significantly more total firm and total foam errors in the CAI group than in the CON group. **Mean and SD were estimated based on reported medians and quartiles for meta-analysis.*
Ross[38]	CAI: 17 CON: 17	1) self-reported history of AS; 2) least two episodes of GW sensations within the year prior to enrolling.	· **<u>BESS SLS firm condition</u>**	· Although not compared between groups, regression analysis indicated more errors in the SLS firm in the CAI group than in the CON group.
Song[43]	CAI: 15 CON: 15	1) at least one AS; 2) at least two episodes of GW within the past 6 months; 3) IdFAI score > 11; 4) FAAM score ≤ 90%; 4) FAAM Sports ≤ 80%.	· Ten parameters of the CTSIB in single leg standing.	· Significantly more scores of the condition 2 and 6 in CTSIB, CTSIB composite score, and CTSIB somatosensory ratio in the CAI group than in the CON group.
Wikstrom[41]	CAI: 19 CON: 19	1) at least one AS; 2) a minimum of two GW episodes within the past 12 months.	· **<u>Foot lift test</u>** · **<u>Time in Balance test</u>**	· No significant group differences in foot lift test and time-in balance test.
Yalfani[44]	CAI: 12 CON: 12	1) history of ankle injury which caused limping or pain for at least 24 hours; 2) at least two episodes of GW within the past 6 months; 3) FADI score ≤ 89%; 4) FADI Sports ≤ 84%.	· Romberg test in EO and EC	· No significant group differences in Romberg test in EO and EC.

Bold and underlined text indicate data used in the meta-analysis. AII, Ankle Instability Instrument; AS, lateral ankle sprain; BESS, Balance Error Scoring System; CAIT, Cumberland Ankle Instability Tool; CTSIB, Clinical Test of Sensory Integration in Balance; DLS firm, double leg stance on the firm surface; DLS foam, double leg stance on the foam surface; EC, eyes closed; EO, eyes open; FAAM, Foot and Ankle Ability Measure; FADI, Foot and Ankle Disability Index; GW, giving way; IdFAI, Identification of Functional Ankle Instability; SD, standard deviation; SLS firm, single leg stance on the firm surface; SLS foam, single leg stance on the foam surface; TS firm, tandem stance on the firm surface; TS firm, tandem stance on the firm surface.

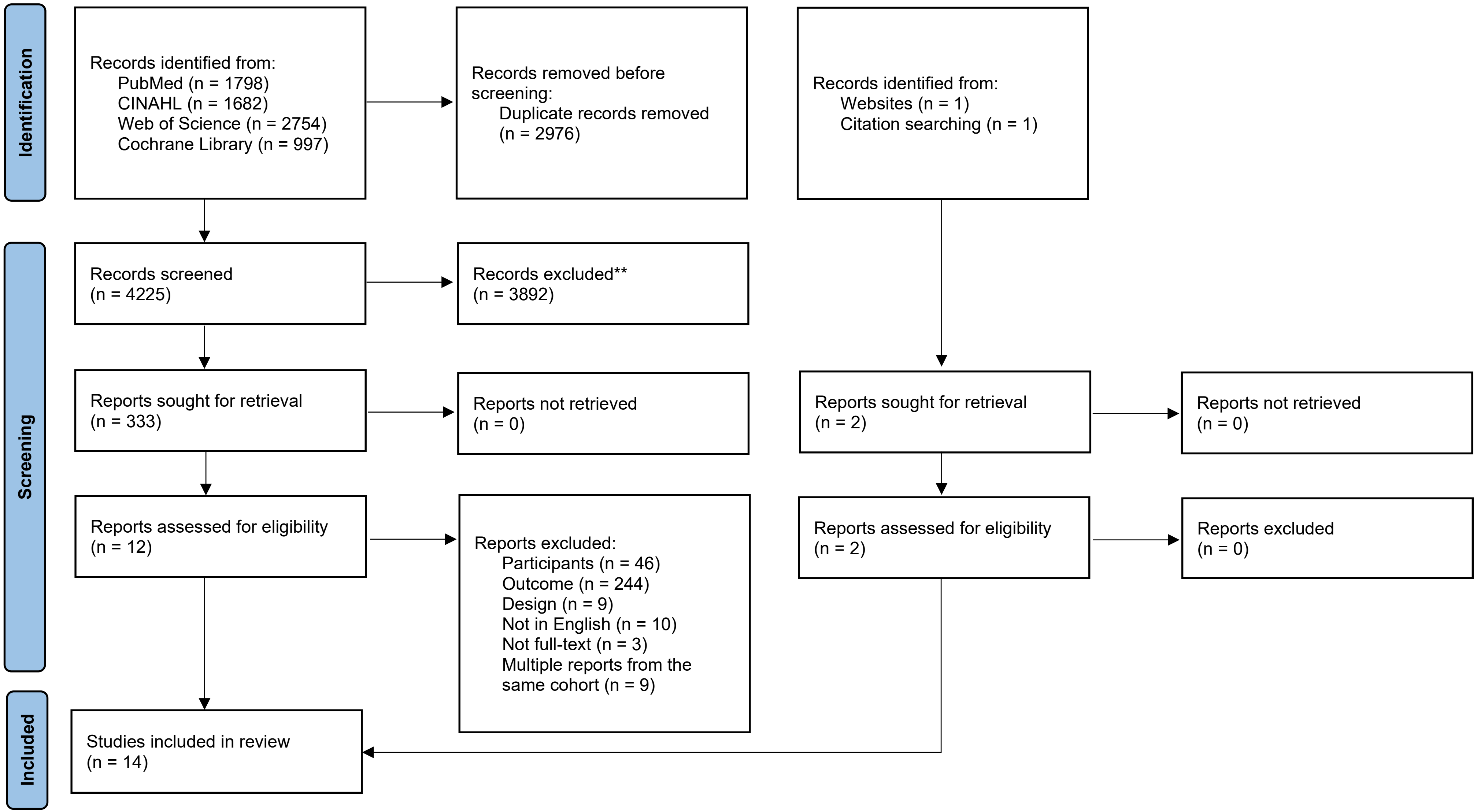
Table 2. Non-instrumented static postural stability assessment methods

Test	Posture	Conditions	Test time	Outcome measure
Balance Error Scoring System	Maintaining posture in each condition with EC and hands on hips	Six conditions: 1) DLS firm, 2) DLS foam, 3) SLS firm, 4) SLS foam, 5) TS firm, 6) TS foam.	Each condition for 20 sec	Count the number of errors. The maximum number of errors for each condition is 10. The following outcomes were reported: number of errors in each condition, total number of errors in all conditions, firm surface conditions, and foam surface conditions, respectively.
Foot-lift test	Single leg standing on a firm surface with EC	None.	For 30 sec	Count as an error if part of the foot is lifted, the contralateral foot touches the floor, and the contralateral foot remains on the floor (every second).
Time-in-Balance test	Single leg standing on a firm surface with EC	None.	Maximum 60 sec	Measure the time (seconds) until a part of the test foot moves off on the floor or the contralateral foot touches the floor.
Clinical Test of Sensory Integration in Balance	Single leg standing	Six sensory conditions: 1) firm and EO, 2) firm and EC, 3) firm and visual-conflict dome, 4) foam and EO, 5) foam and EC, 6) foam and visual-conflict dome.	Maximum 30 sec	Measure the time (in seconds) that the participant maintains postural stability.
Romberg test	Standing with both feet together	EO and EC.	N/A	Measure the time that the participant maintains postural stability.

DLS firm, double leg stance on the firm surface; DLS foam, double leg stance on the foam surface; EC, eyes closed; EO, eyes open; N/A, not applicable; SLS firm, single leg stance on the firm surface; SLS foam, single leg stance on the foam surface; TS firm, tandem stance on the firm surface; TS firm, tandem stance on the firm surface.

Table 3. Risk of bias assessment of each study using the modified Newcastle-Ottawa Scale

	Selection				Comparability	Outcome		
Author	Representative ness of the sample	Definition of injured population	Non-included participants	Sample size justification	Comparability of cases and controls on the basis of the design or analysis	Assessment of outcome	Statistical test	Total scores
Chrintz[42]	1	1	0	0	0	1	1	4
Dobo[31]	0	1	0	0	2	1	1	5
Docherty[32]	0	1	0	0	2	1	1	5
Hiller[39]	0	2	0	0	1	1	1	5
John[33]	0	2	0	0	1	1	1	5
Ko[40]	0	2	0	1	1	2	1	7
Koshino[34]	0	2	0	1	1	1	1	6
Kwon[35]	0	2	0	1	1	1	1	6
Linens[36]	0	2	0	0	1	1	1	5
Powell[37]	0	2	0	0	1	1	1	5
Ross[38]	0	1	0	1	1	1	1	5
Song[43]	0	2	0	1	1	1	1	6
Wikstrom[41]	0	1	0	0	1	1	1	4
Yalfani[44]	0	2	0	0	1	1	1	5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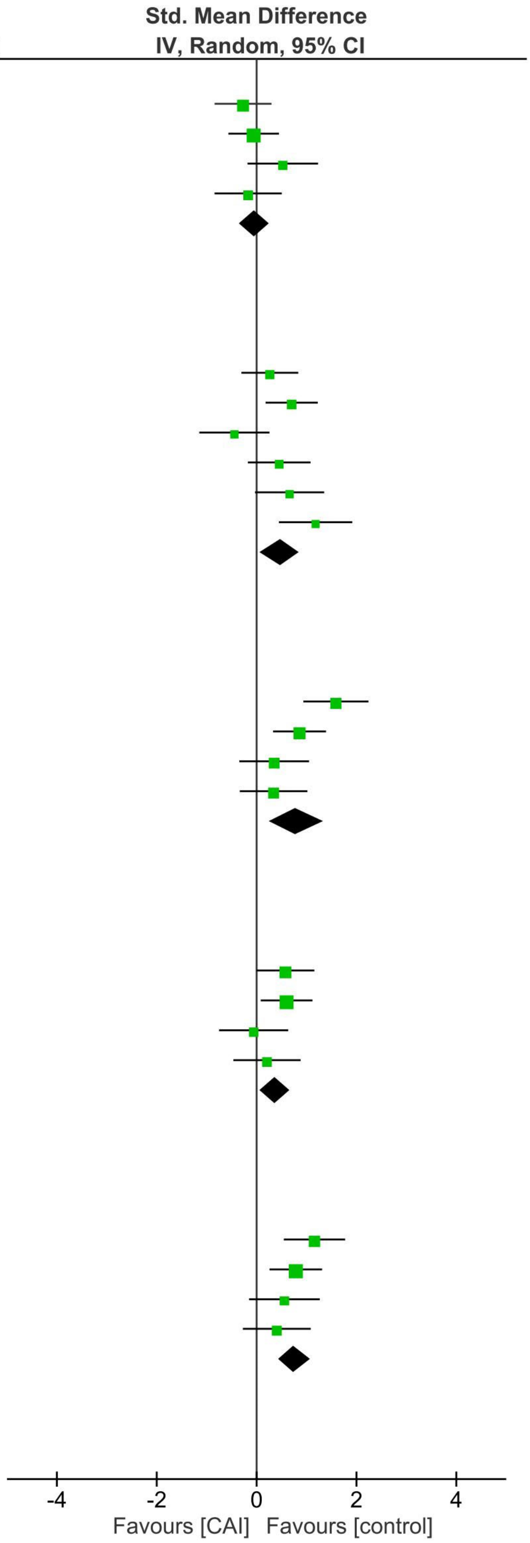
CINAHL (n = 1682)
Web of Science (n = 2754)
Cochrane Library (n = 997)
Records removed before screening:
Duplicate records removed (n = 2976)
Records identified from:
Websites (n = 1)
Citation searching (n = 1)
Screening
Records screened (n = 4225)
Records excluded** (n = 3892)
Reports sought for retrieval (n = 333)
Reports not retrieved (n = 0)
Reports sought for retrieval (n = 2)
Reports not retrieved (n = 0)
Reports assessed for eligibility (n = 12)
Reports excluded:
Participants (n = 46)
Outcome (n = 244)
Design (n = 9)
Not in English (n = 10)
Not full-text (n = 3)
Multiple reports from the same cohort (n = 9)
Reports assessed for eligibility (n = 2)
Reports excluded (n = 0)
Included
Studies included in review (n = 14)

Figure 1

Figure 2

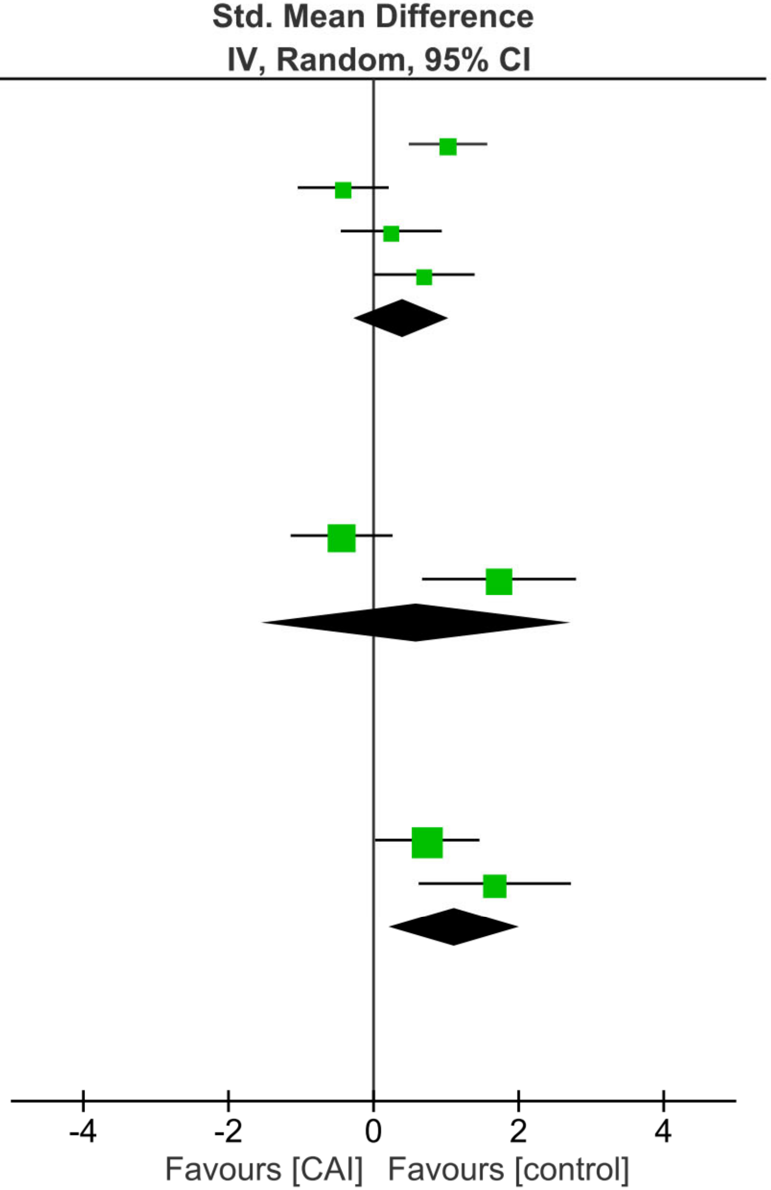
Study or Subgroup	CAI Mean	CAI SD	CAI Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 DLS foam								
Dobo 2015	0.06	0.25	32	0.16	0.5	19	27.4%	-0.27 [-0.84, 0.30]
Docherty 2006	0.17	0.53	30	0.2	0.48	30	34.1%	-0.06 [-0.56, 0.45]
Koshino 2023	0.75	1.18	16	0.25	0.58	16	18.4%	0.52 [-0.18, 1.23]
Linens 2014	0.06	0.24	17	0.11	0.33	17	20.1%	-0.17 [-0.84, 0.50]
Subtotal (95% CI)			**95**			**82**	**100.0%**	**-0.03 [-0.34, 0.28]**
Heterogeneity: Tau² = 0.01; Chi² = 3.23, df = 3 (P = 0.36); I² = 7%								
Test for overall effect: Z = 0.20 (P = 0.84)								
1.1.2 SLS firm								
Dobo 2015	2.28	1.8	32	1.84	1.3	19	18.3%	0.27 [-0.31, 0.84]
Docherty 2006	2.9	2.19	30	1.63	1.25	30	19.5%	0.70 [0.18, 1.23]
Koshino 2023	1.38	1.54	16	2.31	2.44	16	15.3%	-0.44 [-1.15, 0.26]
Kwon 2018	2.7	1.87	20	1.81	1.98	20	16.9%	0.45 [-0.18, 1.08]
Linens 2014	2.53	2.37	17	1.29	1.05	17	15.5%	0.66 [-0.03, 1.35]
Ross 2011	2.1	1.4	17	0.8	0.59	17	14.6%	1.18 [0.45, 1.92]
Subtotal (95% CI)			**132**			**119**	**100.0%**	**0.47 [0.07, 0.86]**
Heterogeneity: Tau² = 0.14; Chi² = 11.65, df = 5 (P = 0.04); I² = 57%								
Test for overall effect: Z = 2.32 (P = 0.02)								
1.1.3 SLS foam								
Dobo 2015	5.84	1.37	32	3.95	0.71	19	24.7%	1.59 [0.94, 2.24]
Docherty 2006	7.07	1.6	30	5.6	1.77	30	27.9%	0.86 [0.33, 1.39]
Koshino 2023	7.13	1.89	16	6.38	2.25	16	23.4%	0.35 [-0.35, 1.05]
Linens 2014	6	1	17	5.59	1.33	17	24.0%	0.34 [-0.34, 1.02]
Subtotal (95% CI)			**95**			**82**	**100.0%**	**0.80 [0.24, 1.35]**
Heterogeneity: Tau² = 0.21; Chi² = 9.00, df = 3 (P = 0.03); I² = 67%								
Test for overall effect: Z = 2.83 (P = 0.005)								
1.1.4 TS firm								
Dobo 2015	1.22	1.24	32	0.58	0.77	19	27.1%	0.58 [-0.00, 1.16]
Docherty 2006	1.23	1.25	30	0.53	1.04	30	33.9%	0.60 [0.08, 1.12]
Koshino 2023	1.44	2.06	16	1.56	1.9	16	19.0%	-0.06 [-0.75, 0.63]
Linens 2014	1.29	1.53	17	1	1.17	17	20.0%	0.21 [-0.47, 0.88]
Subtotal (95% CI)			**95**			**82**	**100.0%**	**0.39 [0.09, 0.69]**
Heterogeneity: Tau² = 0.00; Chi² = 2.93, df = 3 (P = 0.40); I² = 0%								
Test for overall effect: Z = 2.54 (P = 0.01)								
1.1.5 TS foam								
Dobo 2015	3.81	1.28	32	2.47	0.84	19	25.5%	1.16 [0.55, 1.77]
Docherty 2006	4.33	2.35	30	2.73	1.6	30	34.6%	0.79 [0.26, 1.31]
Koshino 2023	6.5	2.73	16	5.06	2.29	16	19.1%	0.56 [-0.15, 1.27]
Linens 2014	3.71	1.65	17	3.06	1.48	17	20.8%	0.40 [-0.28, 1.08]
Subtotal (95% CI)			**95**			**82**	**100.0%**	**0.76 [0.45, 1.07]**
Heterogeneity: Tau² = 0.00; Chi² = 2.99, df = 3 (P = 0.39); I² = 0%								
Test for overall effect: Z = 4.79 (P < 0.00001)								



Test for subgroup differences: Chi² = 14.55, df = 4 (P = 0.006), I² = 72.5%

Figure 3

Study or Subgroup	CAI Mean	CAI SD	CAI Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 Total score								
Docherty 2006	15.7	6	30	10.7	3.2	30	26.9%	1.03 [0.49, 1.57]
John 2020	9.8	3.8	20	11.4	3.7	20	25.2%	-0.42 [-1.05, 0.21]
Koshino 2023	16.9	4.5	16	15.6	5.8	16	23.9%	0.24 [-0.45, 0.94]
Linens 2014	13.59	4	17	11.06	3.01	17	24.0%	0.70 [0.00, 1.39]
Subtotal (95% CI)			**83**			**83**	**100.0%**	**0.40 [-0.25, 1.05]**
Heterogeneity: Tau² = 0.33; Chi² = 12.54, df = 3 (P = 0.006); I² = 76%								
Test for overall effect: Z = 1.19 (P = 0.23)								
1.2.2 Firm total score								
Koshino 2023	2.5	2	16	3.9	3.9	16	51.7%	-0.44 [-1.14, 0.26]
Powell 2014	4.55	2.45	10	1.18	0.98	10	48.3%	1.73 [0.67, 2.79]
Subtotal (95% CI)			**26**			**26**	**100.0%**	**0.61 [-1.52, 2.73]**
Heterogeneity: Tau² = 2.14; Chi² = 11.17, df = 1 (P = 0.0008); I² = 91%								
Test for overall effect: Z = 0.56 (P = 0.58)								
1.2.3 Foam total score								
Koshino 2023	14.4	3.7	16	11.7	3.4	16	58.8%	0.74 [0.02, 1.46]
Powell 2014	7.98	1.78	10	4.46	2.23	10	41.2%	1.67 [0.62, 2.72]
Subtotal (95% CI)			**26**			**26**	**100.0%**	**1.12 [0.23, 2.02]**
Heterogeneity: Tau² = 0.22; Chi² = 2.05, df = 1 (P = 0.15); I² = 51%								
Test for overall effect: Z = 2.46 (P = 0.01)								



Test for subgroup differences: Chi² = 1.66, df = 2 (P = 0.44), I² = 0%

Figure 4

	CAI			Control				Std. Mean Difference	Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**	**IV, Fixed, 95% CI**
Hiller 2007	22.6	3.29	31	13.3	2.3	15	22.3%	3.04 [2.14, 3.93]	
Linens 2014	5.57	2.38	17	3.2	2.68	17	35.4%	0.91 [0.20, 1.62]	
Wikstrom 2017	12.3	6.08	19	9.3	4.09	19	42.3%	0.57 [-0.08, 1.22]	
Total (95% CI)			**67**			**51**	**100.0%**	**1.24 [0.82, 1.66]**	

Heterogeneity: Chi² = 20.41, df = 2 (P < 0.0001); I² = 90%
Test for overall effect: Z = 5.75 (P < 0.00001)

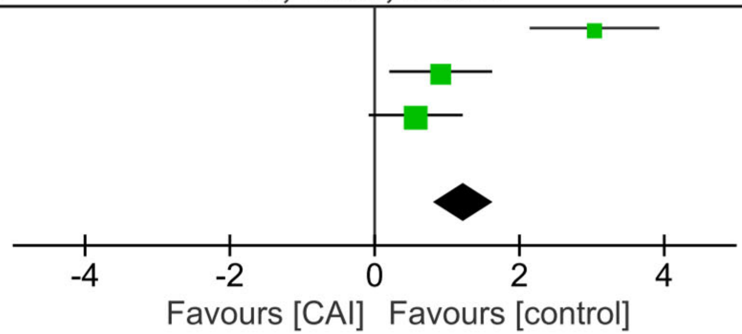


Figure 5

	CAI			Control				Std. Mean Difference	Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**	**IV, Fixed, 95% CI**
Chrints 1991	6.69	9.04	29	24.66	16.36	41	45.4%	-1.29 [-1.81, -0.76]	
Linens 2014	28.99	17.3	17	46.01	19.64	17	24.7%	-0.90 [-1.61, -0.19]	
Wikstrom 2017	9.83	7.02	19	14.55	12.94	19	29.9%	-0.44 [-1.09, 0.20]	
Total (95% CI)			**65**			**77**	**100.0%**	**-0.94 [-1.29, -0.59]**	

Heterogeneity: Chi² = 3.96, df = 2 (P = 0.14); I² = 50%
Test for overall effect: Z = 5.21 (P < 0.00001)