Ability of Functional Performance Tests to Identify Individuals With Chronic Ankle Instability: A Systematic Review With Meta-Analysis

Adam B. Rosen, PhD, ATC,* Alan R. Needle, PhD, ATC,† and Jupil Ko, PhD, ATC‡

Abstract

Objective: The purpose of this systematic review with meta-analysis was to determine the effectiveness of functional performance tests (FPTs) in differentiating between individuals with chronic ankle instability (CAI) and healthy controls. **Data Sources:** The National Library of Medicine Catalog (PubMed), the Cumulative Index for Nursing and Allied Health Literature (CINAHL), and the SPORTDiscus, from inception to June 2017 were searched. Search terms consisted of: "Functional Performance Test*" OR "Dynamic Balance Test*" OR "Postural Stability Test*" OR "Star Excursion Balance Test*" OR "Hop Test*" AND "Ankle Instability" OR "Ankle Sprain." Included articles assessed differences in FPTs in patients with CAI compared with a control group. **Main Results:** Included studies were assessed for methodological quality and level of evidence. Individual and mean effect sizes were also calculated for FPTs from the included articles. Twenty-nine studies met the criteria and were analyzed. The most common FPTs were timed-hop tests, side-hop, multiple-hop test, single-hop for distance, foot-lift test, and the Star Excursion Balance Tests (SEBTs). The side-hop ($g = -1.056$, $P = 0.009$, n = 7), timed-hop tests ($g = -0.958$, $P = 0.002$, n = 9), multiple-hop test ($g = 1.399$, $P < 0.001$, n = 3), and foot-lift tests ($g = -0.761$, $P = 0.020$, n = 3) demonstrated the best utility with large mean effect sizes, whereas the SEBT anteromedial ($g = 0.326$, $P = 0.022$, n = 7), medial ($g = 0.369$, $P = 0.006$, n = 7), and posteromedial ($g = 0.374$, $P < 0.001$, n = 13) directions had moderate effects. **Conclusions:** The side-hop, timed-hopping, multiple-hop, and foot-lift seem the best FPTs to evaluate individuals with CAI. There was a large degree of heterogeneity and inconsistent reporting, potentially limiting the clinical implementation of these FPTs. These tests are cheap, effective, alternatives compared with instrumented measures.

Key Words: dynamic balance, postural stability, hop test, Star Excursion Balance Test

(*Clin J Sport Med* 2017;0:1–14)

INTRODUCTION

Lateral ankle sprains are consistently among the most common injuries observed in physically active populations, including high school and collegiate athletes, and the military.[1–4] Although once considered a benign injury causing only a small loss of time from activity, the past several decades have established this injury as the first in a cascade that has the potential to contribute to decreased health-related quality of life.[5,6] Most commonly described following ankle injury is the development of chronic ankle instability (CAI)—repeated sensations of "giving way" or "rolling" of the ankle, often associated with recurrent injury.[7,8] Chronic ankle instability has been associated with several detrimental consequences that include decreased physical activity[9] and the early onset of posttraumatic ankle osteoarthritis.[10,11] Furthermore, the combination of recurrent injury and degenerative changes to the joint associated with CAI represents a significant financial burden on the health care system, estimated to cost 6.2 billion USD per year.[5,12]

The current standards of clinical practice rely on self-reported questionnaires in order for clinicians and researchers to determine whether patients or participants meet the criteria of having CAI.[13] A wide variety of questionnaires are implemented, with questions ranging from asking individuals to estimate the number of giving-way episodes they experience, to rating any pain or difficulty in performing varying functional task related to sports or activities of daily living.[14–17] Although these tools have proven useful, they have limitations related to their subjectivity and patient interpretation of questions (eg, individual understandings of giving way).[16] The reliance on solely subjective measures of ankle function to diagnose individuals as having CAI is in stark contrast to similar models of knee instability that rely not only on subjective questionnaires, but also on a combination of special and functional tests to characterize sensations of giving way.[18] For instance, various hop tests, including a triple-hop for distance, have been used to discriminate functional status for patients who have experienced a rupture of the knee's anterior cruciate ligament.[19] However, a similar set of standardized tests have not been documented with regard to their efficacy in discriminating individuals with CAI.

An abundance of research has been conducted to determine functional deficits, such as strength,[20] proprioception,[21]

Submitted for publication October 7, 2016; accepted September 7, 2017.

*From the *School of Health and Kinesiology, University of Nebraska at Omaha, Omaha, Nebraska; †Department of Health & Exercise Science, Appalachian State University, Boone, North Carolina; and ‡Department of Physical Therapy & Athletic Training, Northern Arizona University, Flagstaff, Arizona.*

The authors report no conflicts of interest.

Corresponding Author: Adam B. Rosen, PhD, ATC, The University of Nebraska, 6001 Dodge St, HPER 207Y, Omaha, NE 68132 (arosen@unomaha.edu).

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.cjsportmed.com).

http://dx.doi.org/10.1097/JSM.0000000000000535

balance,[22] and functional kinematics[23] between patients with CAI and healthy participants, as well as those who have successfully "coped" after injury.[24] However, the majority of these tests require the use of advanced equipment including isokinetic dynamometers, force plates, and motion capture systems to differentiate these individuals. Clinical practitioners would benefit from noninstrumented clinical tests, such as functional performance tests (FPTs), to determine the functional ability of patients with suspected CAI. These FPTs have the advantage of being inexpensive, quick to administer, and accessible in clinical and field settings, with examples including single-leg heel and toe raises, noninstrumented balance tests, and hopping tasks. A simple outcome measurement that could include time in position or to completion of a task, distance moved, or number of repetitions in a given time allow for standardized measures that can be compared across patients and at numerous time points throughout a patient's rehabilitation.

To date, investigations into FPTs in chronically unstable ankles have largely consisted of hopping tests that require large degrees of lateral movement, as well as noninstrumented tests of balance, such as the Star Excursion Balance Test (SEBT). However, a large degree of differences in methodology, outcome measures, and results have served as a clear barrier toward the implementation of these potentially useful tests in clinical practice.[25] A comprehensive summary of the findings in this area will allow health care providers to make evidence-based informed decisions related to functional performance testing to aid the diagnosis of—and track the rehabilitation for—patients with CAI. Therefore, the purpose of this systematic review with meta-analysis was to search the available literature to identify studies that implemented FPTs to differentiate patients with CAI from healthy controls and to perform a quantitative and qualitative appraisal of the methodology and findings reported throughout these investigations. These findings may, therefore, provide estimates regarding the effect sizes for varying FPTs for discriminating CAI, providing guidance to clinicians regarding which tests may best be implemented in practice.

METHODS

This systematic review and meta-analysis was completed in a manner in accordance with recommendations made in the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (see **Supplemental Digital Content 1**, http://links.lww.com/JSM/A161).[26]

Data Acquisition

An electronic database search was initially conducted by 2 of the coauthors (J.K. and A.R.N.) on National Library of Medicine Catalog (MEDLINE/PubMed), the Cumulative Index for Nursing and Allied Health Literature (CINAHL), and the SPORTDiscus, from inception to June 2017. The initial key terms search consisted of exactly "Functional Performance Test*" OR "Dynamic Balance Test*" OR "Postural Stability Test*" OR "Star Excursion Balance Test*" OR "Hop Test*" AND "Ankle Instability" OR "Ankle Sprain." Key terms searched were determined from our purpose and research question and confirmed by all investigators before conducting the search.

Inclusion and Exclusion Criteria

All articles included in the systematic review and meta-analysis met the following inclusion criteria: (1) written in the English language; (2) research conducted on human participants; (3) studies must use a FPT that involves hopping, landing, agility, and/or noninstrumented balance assessment; and (4) studies must include a group comparison between patients with CAI and healthy controls. Although studies would preferably adhere to identifying CAI individuals in accordance with standards put forward by the International Ankle Consortium,[13] many articles were published before this criteria. Therefore, participants in the experimental group must have enrolled those with a history of at least 1 ankle sprain with subsequent complaints of rolling or giving way identified through self-reporting or use of a patient-reported outcomes, consistent with criteria related to functional or CAI.[27] Research studies were excluded if they used the uninjured limb as a comparison, or if functional testing required instrumentation such as force platforms, electromyography, and other biomechanical data as primary outcome measures.

Data Extraction and Analysis

After the initial search was conducted using the aforementioned key terms, duplicates from across the databases were removed. The titles and abstracts were then inspected for relevance to the inclusion and exclusion criteria, followed by obtaining full-text manuscripts for those identified. Post–full-text retrieval manuscripts were further scrutinized for inclusion and exclusion criteria, and the reference lists of each were cross-checked for additional manuscripts. A consensus among all the authors was then sought for the final inclusion of manuscripts.

Manuscripts were then evaluated separately by 2 authors (A.B.R. and A.R.N.) for their methodological quality via the 22-item checklist for observational studies put forth by the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement.[27] STROBE scores were averaged across all studies and assessed as a percentage. Studies were also assessed for their level of evidence based on the Oxford Centre for Evidence-Based Medicine's 2011 guidelines.[28] Disagreements in scoring were resolved with a consensus between the 2 authors; if a situation arose where a consensus was not able to be achieved, the third author was consulted.

Numerical data extracted included the sample sizes and outcome measures for each FPT by group. A single investigator (A.B.R.) conducted all effect size calculations through Comprehensive Meta-Analysis (V3.3.070; Biostat, Inc, Englewood, New Jersey). Effect sizes were calculated using the standardized mean difference for each of the outcome measures adjusting for small sample bias (Hedges g).[29] Because of the uncertainty of evaluating a homogenous population, a mean effect size (Δ) was determined using a random effects model, if 3 or more studies evaluated a similar FPT.[30] Further tests were calculated to determine whether heterogeneity existed by assessing the I^2 and the Q-statistics. Finally, fail safe N was determined to evaluate the potential number of unpublished studies that would bring the value to a level of insignificance for each of the mean effect sizes.[30]

RESULTS

Figure 1 provides a flow chart of the article retrieval. Nine hundred ninety-six manuscripts were identified by the initial search terms across the databases and after duplicate removal, 479 remained. After title and abstract screening, 433 articles were excluded whereas 46 remained and their full texts were retrieved. Seven additional manuscripts were then identified by cross-checking the reference lists of the full-text manuscripts. Twenty-four of these articles were then excluded: 14 for assessing only instrumented or biomechanical data, 6 not comparing against a control group, 3 not having an experimental CAI group, and 1 being repetitive data from a previous study. Ultimately, 29 manuscripts were assessed, 7 were cross-sectional studies, 21 were case-control, and 1 was a randomized-control trial (Table 1). Correspondingly, the studies were deemed levels 2, 3, and 4 evidence, respectively. Only 4 disagreements in the STROBE scoring were needed to be resolved via a consensus and most often, disagreements occurred regarding whether the experimental design, participant demographics, or results were stated with enough detail. The average STROBE score across the evaluated studies was 17.3 ± 1.6 of a possible 22 (see **Table, Supplemental Digital Content 2**, http://links.lww.com/JSM/A162). In total, 97 individual effect sizes for FPTs' were calculated, as well as 11 overall mean effect sizes. Altogether, across the 29 studies, 1317 participants were surveyed, with 680 participants having CAI and 637 control participants.

Pooled effect sizes were calculated for the most common FPTs that included the single-limb timed-hopping tests (n = 9),[31–39] the single-limb side-hop test (n = 7),[32,34,36–40] all directions of the star-excursion balance test (n = 15),[36,40–53] the single-limb hop test for distance (n = 3),[34,37,39] the multiple-hop test (n = 3),[54–56] and the foot-lift test (n = 3).[36,40,57] Although

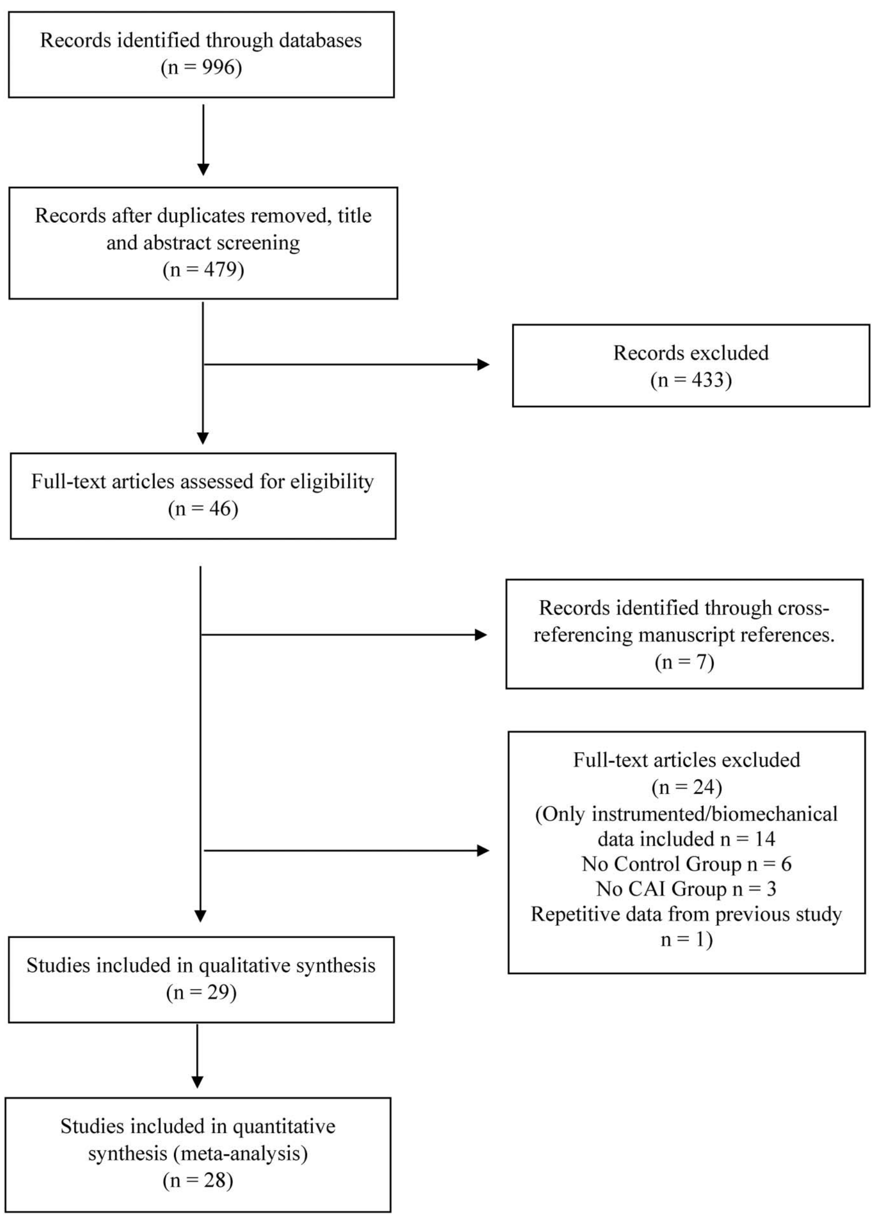

Figure 1. Flow chart of articles included in the systematic review and meta-analysis.

TABLE 1. Summary of Evidence for Each Individual Study Included Resulting From Systematic Search of the Literature

Author (Year)	Buchanan, Docherty, Schrader (2008)	Caffrey, Docherty, Schrader, Klossner (2009)	de La Motte, Arnold, Ross (2015)	De Noronha, Refshauge, Kibreath, Crosbie (2007)
Study design (level of evidence)	Case-control (4)	Cross-sectional (3)	Case-control (4)	Cross-sectional (3)
Participants				
CAI (n, female/male)	20 (NR)	30 (15F, 15M)	20 (13F, 7M)	20 (16F, 4M)
Control (n, female/male)	20 (NR)	30 (15F, 15M)	20 (13F, 7M)	20 (9F, 11M)
CAI group inclusion criteria	History of moderate to severe ankle sprains and residual episodes of giving way or instability	Unilateral functional ankle instability determined using ankle instability instrument	History of ankle sprain not in the past 30 d; multiple reports of giving way in the month before data collection	History of ankle sprain; score ≤23 on the Cumberland Ankle Instability Tool
FPT/outcome measure (unit)	(1) Single-limb hopping test (time, s) (2) Single-limb hurdle test (time, s)	(1) Figure-of-8 hopping test (time, s) (2) Side-hop test (time, s) (3) 6-m crossover hop test (time, s) (4) Square hop test (time, s)	Anteromedial, medial, and posteromedial SEBT	8–square hopping test (time, s)
Results	No significant differences between the control and CAI groups	CAI group performed worse on the side-hop test, the 6-m crossover hop test and the square hop test compared with the control group. Significant. No significant differences between CAI and control groups in the figure-of-8 test	No differences between CAI and control groups	No significant differences between the control and CAI groups
STROBE score	16	17	16	19

Author (Year)	Demerritt, Shultz, Gansneder, Perrin (2002)	Docherty, Arnold, Gansneder, Hurwitz, Gileck (2005)	Docherty, Valovich McLeod, Shultz (2006)	Eechaute, Bautmans, De Hertogh, Vaes (2009)
Study design (level of evidence)	Case–control (4)	Case–control (4)	Case–control (4)	Case–control (4)
Participants				
CAI (n, female/male)	20 (20M)	42 (NR)	30 (21F, 9M)	29 (12F, 17M)
Control (n, female/male)	20 (20M)	18 (NR)	30 (21F 9M)	21 (8F, 21M)
CAI group definition	History of at least 1 significant ankle sprain where subject could not bear weight; at least 1 episode of repeated injury or feelings of instability; no participation in rehabilitation	Six dichotomous questions pertaining to instability during activities of daily living including "Have you ever sprained your ankle?" and a minimum of 2 "yes" answers	History of at least 1 inversion ankle sprain and repeated feelings of giving way	History of traumatic lateral ankle sprain requiring 2 or more medical consultations; complaints of repetitive ankle sprains for ≥6 mo; fear of ankle giving way; and reporting decrease performance level of activities
FPT/outcome measure (unit)	(1) Co-contraction (time, s) (2) Shuttle run (time, s) (3) Agility hop test (errors, n)	(1) Figure-of-8 hop test (time, s) (2) Side hop test (time, s) (3) Up-down hop test (time, s) (4) Single-hop test (distance, m)	BESS (errors, n)	Multiple hop test, (errors, n)
Results	No significant differences between the control and CAI groups	The authors did not report statistical comparisons between the control and CAI groups	FAI participants had significantly more total errors (worse balance) compared with the control group. Specifically, the FAI had more errors on the single-limb firm, tandem foam, and single foam conditions compared with the controls	ICC coefficients of the CAI group were higher than the healthy group. The multiple hop test demonstrated the greatest diagnostic accuracy because of a high positive likelihood ratio and low negative likelihood ratio
STROBE score	17	17	16	18

TABLE 1. Summary of Evidence for Each Individual Study Included Resulting From Systematic Search of the Literature *(Continued)*

Author (Year)	Eechaute, Vaes, Duqet (2008)	Gribble, Hertel, Denegar, Buckley (2004)	Groters, Groen, van Cingel, Duysens (2013)	Hadadi, Mousavi, Fardipour, Vameghi, Mazaheri (2014)
Study design (level of evidence)	Cross-sectional (3)	Case-control (4)	Case-control (4)	Case-control (4)
Participants				
CAI (n, female/male)	29 (12F, 17M)	14 (7F, 7M)	16 (12F, 4M)	16 (6F, 10M)
Control (n, female/male)	29 (8F, 21M)	16 (8F, 8M)	16 (12F, 4M)	16 (6F, 10M)
CAI group definition	History of traumatic lateral ankle sprain requiring 2 or more medical consultations; complaints of repetitive ankle sprains for ≥6 mo; fear of ankle giving way; and reporting decrease performance level of activities	History of at least 1 acute ankle sprain resulting in pain, swelling, and loss of function ≥3 mo, and history of multiple episodes of ankle giving way within 6 mo	History of lateral ankle sprain, without mechanical instability; giving way at least 3 times per year over the last 2 yrs	History of at least 1 unilateral inversion sprain >1 yr before testing; at least 1 recurrent sprain or feeling of instability within last 6 mo; no presence of mechanical instability
FPT/outcome measure (unit)	Multiple hop test, (errors, n)	Anterior, medial, posterior SEBT (normalized reach distance)	Multiple hop test (errors)	Medial, anteromedial, and posteromedial (PM) SEBT (normalized reach distance)
Results	The CAI group had more errors compared with healthy subjects	CAI group had significantly larger reach distance compared with the healthy group	CAI group had more balance errors than the healthy control	No significant differences between the control and CAI groups
STROBE score	17	17	18	17

Author (Year)	Hale, Hertel, Olmstead (2007)	Hertel, Braham, Olmsted-Kramer (2006)	Hiller, Refshauge, Herbert, Kilbreath (2007)	Hoch, Staton, Medina McKeon, Mattacola, McKeon (2012)
Study design (level of evidence)	Randomized control trial (2)	Case–control (4)	Cross-sectional (3)	Case–control (4)
Participants				
CAI (n, female/male)	16 (10F, 6M)	48 (26F, 22M)	19 (NR)	30 (17F, 13M)
Control (n, female/male)	19 (9F, 10M)	39 (16F, 23M)	20 (NR)	30 (17F, 13M)
CAI group definition	History of at least 1 ankle sprain; chronic symptoms associated with the initial injury; self-report giving way episodes in the 6 mo before testing	History of at least a single ankle sprain on the involved ankle which required medical interventions and 3 or more episodes of the giving way in the past 12 mo	History of ankle sprain with instability that resulted in change of weight bearing status or use of ankle support; self-reported instability or ≤24 Cumberland Ankle Instability Tool (CAIT)	History of an ankle sprain; minimum of 2 episodes of giving way; yes to question 1 and 3 other questions or more on the ankle instability instrument
FPT/outcome measure (unit)	All 8 directions of the SEBT (normalized reach distance)	All 8 directions of the SEBT (normalized reach distance)	Foot-lift test	Anterior, posteromedial, and posterolateral SEBT
Results	No significant differences at baseline between control and CAI groups	Significantly less SEBT distance in all directions in the CAI group compared with controls	Significantly more foot-lifts in CAI group compared with controls	Significantly less reach distance (worse) in CAI group compared with control group in the anterior direction only
STROBE score	18	17	17	18

Author (Year)	Jerosch (1997)	Ko, Rosen, Brown (2015)	Linens, Ross, Arnold, Gayle and Pidcoe (2014)	Martinez-Ramirez, Lecumberri, Gómez, Izquierdo (2010)
Study design (level of evidence)	Case–control (4)	Cross-sectional	Case–control (4)	Case–control (4)
Participants				
CAI (n, female/male)	23 (4F, 19M)	25 (15F, 10M)	17 (13F, 4M)	13 (7F, 6M)
Control (n, female/male)	18 (14F, 6M)	33 (17F, 16M)	17 (13F, 4M)	12 (5F, 7M)
CAI group definition	Athletes with self-reported functional instability and no ankle sprains within past 3 mo	History of at least 1 moderate to severe ankle sprain; ≤25 Cumberland Ankle Instability Tool (CAIT); a history of giving way	History of at least 1 ankle sprain; a minimum of 2 episodes of giving way and Cumberland Ankle Instability Tool (CAIT) score ≤27	History of ankle sprain that required medical care and the ankle giving away during activity
FPT/outcome measure (unit)	(1) Single-leg jump landing test (time, s) (2) Japan test (time, s)	(1) Foot lift test (2) Side-hop test (3) Time in balance (4) Posteromedial SEBT	(1) Anteromedial, medial, and posteromedial SEBT (normalized reach distance) (2) Side-hop test (time, s) (3) Figure-of-8 hop test (time, s)	Anterior, posteromedial, and posterolateral SEBT (normalized reach distance)

TABLE 1. Summary of Evidence for Each Individual Study Included Resulting From Systematic Search of the Literature *(Continued)*

Results	The authors did not report statistical comparisons between the control and CAI groups	The authors did not report statistical comparisons between the control and CAI groups	The authors did not report statistical comparisons between the control and CAI groups	No significant differences between the control and CAI groups
STROBE score	13	17	18	16

Author (Year)	McCann, Crossett, Terada, Kosik, Bolding, Gribble (2017)	Nakagawa and Hoffman (2004)	Olmsted, Garcia, Hertel, Shultz (2002)	Plante and Wikstrom (2013)
Study design (level of evidence)	Case–control (4)	Case–control (4)	Case–control (4)	Case–control (4)
Participants				
CAI (n, female/male)	30 (26F, 4M)	19 (NR)	20 (10F, 10M)	25 (NR)
Control (n, female/male)	26 (15F, 11M)	19 (NR)	20 (10F, 10M)	20 (NR)
CAI group definition	History of ankle sprain; inclusion criteria endorsed by the International Ankle Consortium; Ankle Instability Instrument; Identification of Functional Ankle Instability (IdFAI), Cumberland Ankle Instability Tool (CAIT)	History of recurrent ankle sprain that required immobilization and ≥2 ankle sprains in the past 5 yrs	Unilateral injury with at least 1 previous ankle sprain and multiple episodes of giving way in the preceding 12 mo	1 giving way episode in the past year; 1 recurrent sprain 3-6 mo previous study; ≤22 on the Ankle Joint Functional Assessment Tool (AJFAT); perceived disability including pain, instability or weakness
FPT/outcome measure (unit)	Anterior, posteromedial, and posterolateral SEBT	All 8 directions of SEBT (average reach of each direction)	All 8 directions of SEBT (reach distance, cm)	Anterior, posteromedial, and posterolateral SEBT (normalized reach distance)
Results	Significantly less reach distance (worse) in CAI group compared with control group in the anterior direction only	No significant differences between the control and CAI groups	Significantly less reach distance (worse) in CAI compared with control group	Significantly less reach distance posteromedial in CAI compared with control group
STROBE score	22	17	17	19

Author (Year)	Pozzi, Moffat, and Gutierrez (2015)	Sefton, Hicks-Little, Hubbard, Clemens, Yengo, Koceja, Cordova (2009)	Sharma, Sharma, Sandhu (2011)	Someeh, Norasteh, Daneshmandi, Asadi (2015)
Study design (level of evidence)	Cross-sectional (3)	Case–control (4)	Case–control (4)	Cross-sectional (3)
Participants				
CAI (n, female/male)	9 (6F, 6M)	22 (17F, 5M)	31 (NR)	16 (6F, 10M)
Control (n, female/male)	12 (5F, 4M)	21 (16F, 5M)	31 (NR)	16 (6F, 10M)
CAI group definition	A history of at least 1 previous ankle sprain; ≤24 on the Cumberland Ankle Instability Tool (CAIT) indicating perceived instability	History of ankle sprain, recurrent instability and ≥2 on the functional ankle instability index section	Athletes with a score ≥2 on the ankle instability instrument	Professional athletes with a score <90% on the foot and ankle disability index and <75% on the sport subscale
FPT/outcome measure (unit)	Posteromedial SEBT	Anteromedial, medial, and posteromedial SEBT (normalized reach distance)	(1) Single-limb hopping test (time, s) (2) Figure-of-8 hopping test (time, s) (3) Side-hop test (time, s) (4) Single-limb hurdle test (time, s) (5) Square hop test (time, s) (6) Single-hop test (distance, m)	(1) Single-limb hopping test (time, s) (2) Figure-of-8 hopping test (time, s) (3) Side-hop test (time, s)
Results	No significant differences between the control and CAI groups	No significant differences between the control and CAI groups	CAI group took significantly longer (worse) compared with control group for all timed tests. No difference in distance in the single hop test for distance	The CAI group had significantly longer (worse) time to completion of hopping test times compared with the uninjured group
STROBE score	16	18	18	16

TABLE 1. Summary of Evidence for Each Individual Study Included Resulting From Systematic Search of the Literature *(Continued)*

Author (Year)	Wikstrom, Tillman, Chmielewski, Cauraugh, Naugle, Borsa (2009)
Study design (level of evidence)	Case-control (4)
Participants	
CAI (n, female/male)	24 (NR)
Control (n, female/male)	24 (NR)
CAI group definition	Minimum 1 episode of giving way in the previous year; 1 recurrent sprain in the prior 3-6 mo; ≤22 on the Ankle Joint Functional Assessment Tool (AJFAT); perceived pain/ instability/weakness in the ankle due to the initial injury; and failure to resume all preinjury level activities
FPT/outcome measure (unit)	(1) Figure-of-8 hopping test (time, s) (2) Side–side-hop test (time, s) (3) Triple crossover hop test (distance, m) (4) Single-limb hop test (distance, m)
Results	No differences between CAI and control groups
STROBE score	20

NR, not reported.

some studies reported several different timed-hop tests, a single timed-hop test was chosen from each available study based on a similarity to limit the influence of individual studies on the mean effect. The figure-of-8 hopping test was the most common test (n = 6)[32,34,36–39] included in the single timed-hopping tests mean effect, whereas the other 3 studies reported FPTs described as the single-limb hopping test,[31] hopping test,[33] and single-leg jump landing test,[35] respectively.

The distribution for all unweighted effects calculated are shown in Figures 2–4 and see **Figure, Supplemental Digital Content 3**, http://links.lww.com/JSM/A163. Mean effect and their 95% confidence intervals, tests for homogeneity, and fail safe N calculations are shown in Table 2. The single-limb side-hop ($g = -2.314$, $P = 0.001$), timed single-limb hop tests ($g = -1.056$, $P = 0.009$), multiple-hop test ($g = 1.399$, $P = 0.001$), and foot-lift test ($g = -0.761$, $P = 0.020$) had large, significant mean effects across the included studies; whereas the SEBT-AM ($g = 0.326$, $P = 0.022$), SEBT-M ($g = 0.369$, $P < 0.006$), and SEBT-PM ($g = 0.406$, $P < 0.001$) directions demonstrated small to moderate, significant main effects. The single-hop ($g = 0.033$, $P = 0.859$), SEBT-A ($g = 0.264$, $P = 0.051$), SEBT-PL ($g = 0.056$, $P = 0.599$), SEBT-AL ($g = 0.246$, $P = 0.116$), SEBT-P ($g = 0.232$, $P = 0.137$), and SEBT-L ($g = 0.253$, $P = 0.105$) were not significant between groups. The timed hop and side-hop tests had relatively high Q, I^2, and fail safe N values. Funnel plots for the single-limb hop, SEBT and foot-lifts tests are located in Supplemental Digital Content 4, 5, and 6 (Figures 5 and 6, see **Figures, Supplemental Digital Content 4–6**, http://links.lww.com/JSM/A164; http://links.lww.com/JSM/A165; http://links.lww.com/JSM/A166).

Other FPTs reported in the literature included the agility hop test ($g = -0.039$),[58] Balance Error Scoring System (BESS) ($g = -1.026$; -0.696),[36,59] co-contraction test ($g = -0.235$), Japan test ($g = 0.670$),[35] shuttle run test ($g = -0.114$),[58] single-limb hurdle test ($g = -3.748$; -0.168),[31,37] 6-m crossover hop test ($g = -3.484$),[32] square hop test ($g = -13.256$; -3.416),[32,37] time-in-balance test ($g = 0.898$; -0.362),[36,40] triple-crossover hop ($g = -0.256$),[39] and the up-down hop test ($g = -0.609$).[34] Descriptions of individual FPTs are shown in Table 3.

DISCUSSION

The purpose of this systematic review with meta-analysis was to synthesize the literature to determine the relative effectiveness of various FPTs in differentiating between those with CAI and healthy individuals. The most effective FPTs to discriminate those with CAI, in descending order based on the magnitude of the pooled effect size, are the side-hop test, the multiple-hop test, timed-hop tests, foot-lift test, and the 3 directions of the SEBT, respectively. The single-hop test for distance seems to be an ineffective FPT in CAI populations, whereas a multitude of other FPTs lacked sufficient evidence to determine effectiveness although presented promising initial findings.

Single-Limb Hop Tests

The single-limb side-hop and timed-hop tests provided the best clinical utility to identify those with CAI demonstrating large effect sizes. Although both tests are timed, the side-hop demonstrated greater utility than other single-limb timed-hopping tests such as the figure-of-8. It may be hypothesized that hopping tests that challenge an individual directly in the frontal plane would provide an additional challenge for patients with CAI, than challenging individuals directly in the sagittal plane The side-hop test is performed by completing 10 medial–lateral single-limb hops for a total of 20 jumps as quickly as possible, a movement occurring directly in the frontal plane. By comparison, the timed-hop tests are typically through a course such as the figure-of-8 that incorporates both sagittal and frontal plane aspects. Perhaps, the medial–lateral stress placed on the joint is more effective to disrupt those with CAI compared with frontal plane tasks. Although no studies have quantified the direct stress on the lateral ligament complex during these tasks, it has been revealed that the side hop requires a significant amount of peroneus longus activation, of which patients with CAI may be deficient. Nonetheless, both seem to be effective at discriminating those with CAI.[60,61]

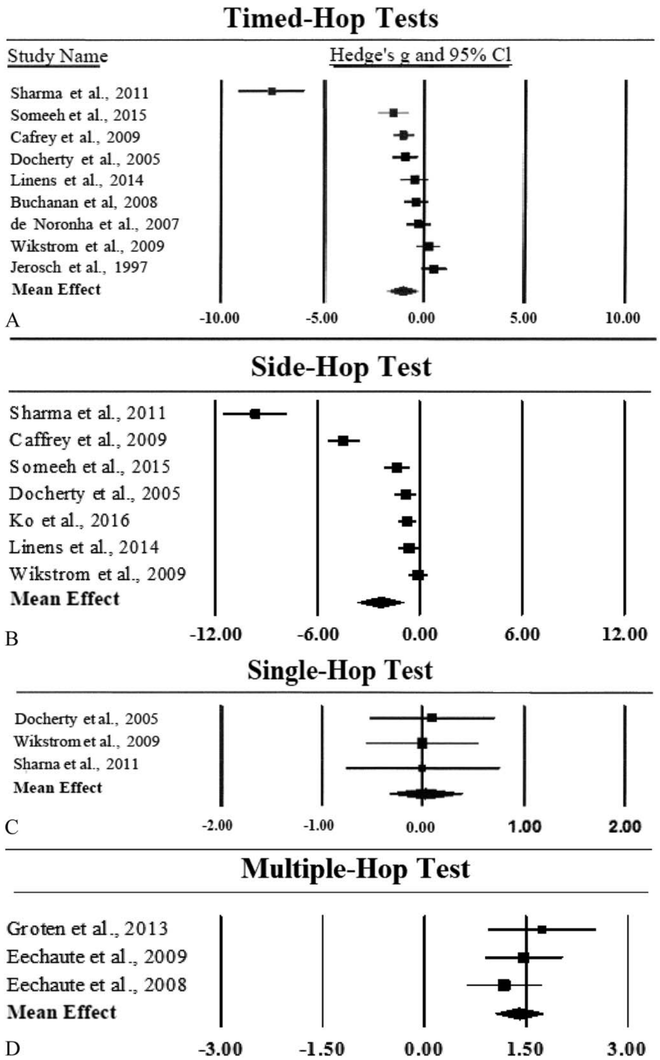

Figure 2. Forest plots of individual study effect sizes (Hedges *g*) and their 95% confidence intervals plotted in order of magnitude for the (A) Timed-Hopping Tests, (B) Side-Hop Test, (C) single-hop test, and (D) multiple-hop test. For the timed-hop and side-hop test effect sizes to the left of zero indicates worse times in the CAI group. For the Single-Hop Test, effect sizes to the left of zero indicates worse or lower jump distances in the CAI group. For the Multiple-Hop test, effect sizes to the right of zero indicates greater amount of errors in the CAI group. (■ = individual study; ♦ = mean overall effect).

However, of some concern pertaining to the side-hop and timed-hop tests is the funnel plots (Figures 5 and 6, see **Figures, Supplemental Digital Content 4–6**, http://links.lww.com/JSM/A164; http://links.lww.com/JSM/A165; http://links.lww.com/JSM/A166), and the heterogeneity statistics analyses indicate there may be some variations among the included studies. Driving these values was a study by Sharma et al,[37] which had a significant influence on the mean effect size. Although this study substantially influenced the effect sizes, when removing this particular outlier, the mean effect sizes for both tests remain moderate-large and significant (side-hop: $g = -1.444$, $P = 0.022$; timed-hop: $g = -0.446$, $P = 0.027$). It is difficult to ascertain why this study in particular had such a massive individual effect size; however, one possible explanation is that the authors dichotomized their instability group by those with CAI who reported giving way during the test and those who did not.[37] The group reporting giving way was used for the meta-analysis, and perhaps this drove the large effect sizes. Thus, using FPTs in those with CAI with those who report feeling unstable during their performance may be much more likely to identify those with CAI compared with their healthy counterparts or those who self-report CAI yet fail to report instability during the FPT.

Several other hopping tests may also provide adequate discriminative ability yet have only been reported by 1 or 2 studies. The single-limb hurdle test, 6-m crossover hop test, square hop test, and up-down hop test also demonstrated moderate-large individual effect sizes. Each of these tests are similar to the timed-hop tests, as they each require the participants to perform a task or course as fast as they can on a single limb. The greatest differences exist regarding the amount of vertical, lateral, or forward movement across tasks. However, the relative effectiveness of these tasks, although less studied than the single-limb side-hop or figure-of-8, suggests that tests that require components of speed, power, and agility in a combination of planes will serve to differentiate patients with CAI. These findings are consistent with several theories behind CAI that suggests a multifaceted problem affecting multiple functional abilities.[61,62] Thus, including a timed-hop test such as the side-hop or figure-of-8 test during evaluation of individuals with CAI is valid and appropriate.

Interestingly, based on the results of the meta-analysis, the single-hop jump for distance does not differentiate those with CAI from healthy controls. The single-hop jump is much different than the timed-hop and side-hop jump testing because of the fact that it assesses and requires greater muscular strength and power rather than speed and agility. Although interesting, this negative result is rather unsurprising because of the evidence that the role of ankle strength in CAI is widely disputed and equivocal.[63–68] Furthermore, this test stresses the joint primarily in the sagittal plane, rather than the frontal and transverse planes that would be more difficult for patients with CAI. Similarly, another primarily uniplanar test that was studied by only 1 group, the triple-crossover hop test demonstrated a small effect size. The triple-crossover hop test such as the single-limb hop for distance requires participants to jump as far as possible, but in this test it is the maximum distance after 3 jumps across a 15-cm line. Although the incorporation of a crossover adds a lateral component, the test outcome is primarily the distance advanced in the forward direction. Therefore, using FPTs in those with CAI that require muscular power within the sagittal plane seems to be ineffective compared with agility-based hopping tests.

A third class of hopping tests observed in this review were those requiring individuals to hop across a pattern, scoring individuals on "errors" rather than a measure of time or distance. The multiple-hop test across 3 studies demonstrated a large pooled effect with the rest demonstrating conflicting results according to effect size calculations. Although similarly requiring the functional ability of muscle strength, power, and agility to perform hops, an additional component of postural stability is added by scoring individuals on their ability to "stick" a landing. Although intriguing, this does require a degree of subjectivity for the assessor that may serve to bias results. Similar measures exist throughout the CAI literature using instrumented measures derived from force plates. Moderate evidence exists establishing diminished postural control during hopping as

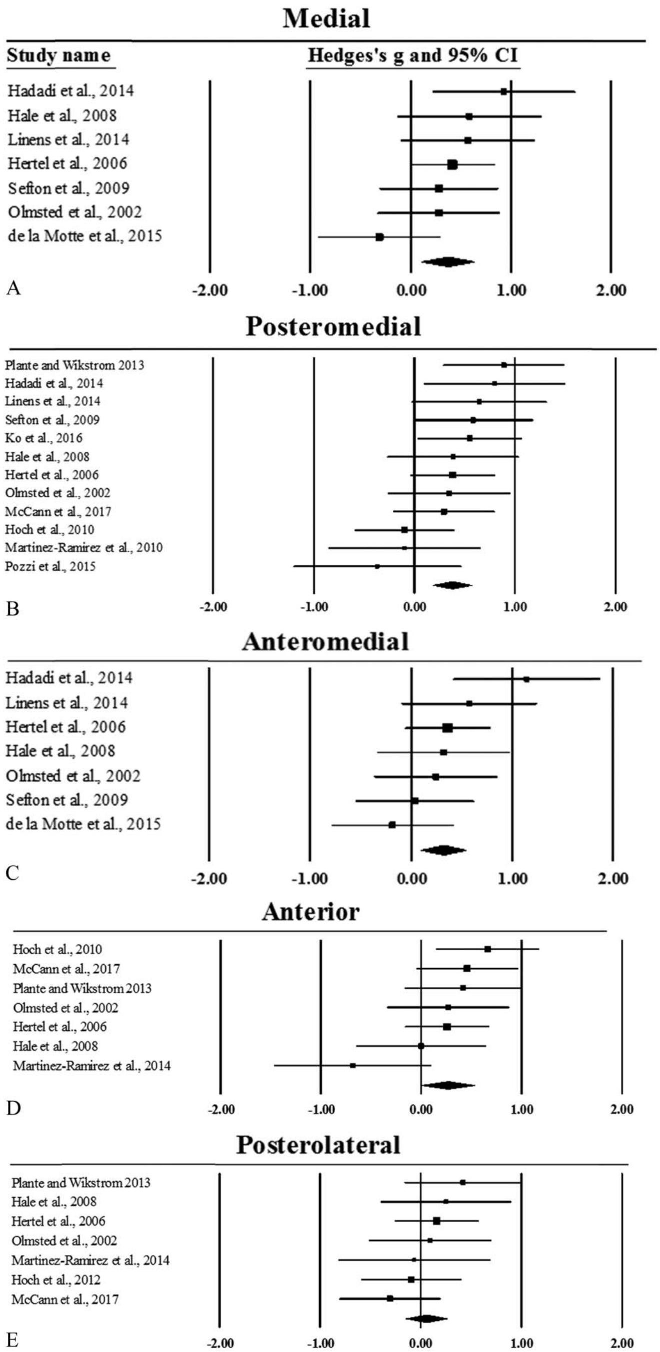

Figure 3. Forest plots of individual study effect sizes (Hedges *g*) and their 95% confidence intervals plotted in order of magnitude for the Star Excursion Balance Test (A) Medial, (B) Posteromedial, (C) Anteromedial, (D) anterior, and (E) Posterolateral directions. Effect sizes to the right of zero indicate worse dynamic postural control in the CAI group. (■ = individual study; ♦ = mean overall effect).

quantified through the dynamic Postural Stability Index.[69–72] However, this measure relies on precise force calculations with differences between uninjured and injured individuals often not grossly visual to an assessor. As conflicting results exist using noninstrumented measures, additional studies are necessary to determine the ability of FPTs using error systems during hop landing to discriminate between healthy and CAI individuals.

Balance Tests

The SEBT, depending on the direction, also provides adequate discriminative ability between those with without CAI. The anteromedial, medial, and posteromedial directions each demonstrated moderate mean-effect sizes; however, the anterior and posterolateral directions were small and considered unimportant. Based on these results, those with shorter anteromedial, medial, and posteromedial reach distances are more likely to have CAI. This could potentially be explained by considering the shifts in the center of gravity occurring through reaches in medial direction, causing tensile forces to be applied on the lateral ankle. A previous systematic review has also been completed on the SEBT[73]; however, the authors chose not only CAI, but other pathologies such as ACL injuries. In addition, studies were included that assessed the injured compared with uninjured limbs as well as CAI compared with controls. Although the authors similarly concluded that the SEBT was an effective FPT in those with CAI, their study did not resynthesize data to determine mean effects, nor was their main purpose to identify the differences in the SEBT across CAI populations. Based on the current results, not all directions of the SEBT have similar prognostic ability as the anteromedial, medial, and posteromedial directions provided the best clinical utility. Although this is not a particularly new finding, some previous studies have attempted to address this by simplifying the SEBT to the Y Balance Test, which includes only the anterior, posteromedial, and posterolateral directions.[74,75] However, it seems that the anterior direction may not be as sensitive enough to differentiate between controls, and CAI and clinicians should consider the anteromedial, medial, and posteromedial directions specifically for individuals with CAI.

Balance and postural control deficits are often described in those with CAI, which could potentially contribute to functional performance deficits observed during the SEBT.[50,70,72,76,77] Although the SEBT is considered a dynamic postural control task, requiring movement of the body over a stationary base of support, additional clinical tests are used to assess static postural control. The foot-lift test (counting the number of times a part of the foot lifts off the ground) seems to be an adequate discriminating test, whereas the time-in balance[36] also demonstrated large effects in a single study. The BESS—an error system identifying gross instability during 3 to 6 stance conditions—was reported in 2 studies[36,59] and demonstrated a moderate-large effect size between CAI and control participants. These findings suggest that FPTs requiring an individual to maintain static postural control are able to yield similar results as seen in studies using advanced equipment such as force plates.

No studies provided a direct comparison between abilities of hopping tests and balancing tests in discriminating CAI. As previously stated, these assess different components of ankle function with the former addressing muscular strength, power, and agility and the latter assessing proprioception and neuromuscular control. Given these different components, it may be recommended that both hopping- and balance-based measures be included in the assessment of patients with CAI. Although these would combine yield very high effect sizes and a strong ability to predict functional instability in these patients, there are additional components

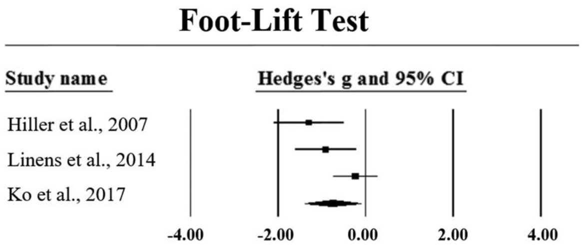

Figure 4. Forest plots of individual study effect sizes (Hedges *g*) and their 95% confidence intervals plotted in order of magnitude for the foot-lift test. Effect sizes to the left of zero indicate greater amount of foot-lifts in the CAI group. (■ = individual study; ♦ = mean overall effect).

that should be considered. Dorsiflexion deficits are consistently observed in those with CAI.[78–80] To some extent, this may be assessed through the anterior reach of the SEBT, as a recent study found that dorsiflexion range of motion, eversion strength, and time-to-boundary contributed most to SEBT reach distances.[77] However, further studies assessing dorsiflexion range-of-motion through simple tests such as the weight-bearing lunge should be considered.[79]

Limitations

The included studies in the systematic review were case–control and cross-sectional studies, described as level IV and III evidence, respectively, indicating limited methodological quality. In addition, the average STROBE score indicates relative consistency in the methodological quality of the evidence. With a maximum of 22, the average score as a percentage was 78.6% ± 7.3%. The 2 most common faults were no indication of addressing sources of bias, including blinding procedures as well as providing a sample size justification. Other notable sources of demerits included providing information related to distributive statistics, funding sources, and indications of study design early in the manuscript. Improving methodological quality and study design stands to greatly improve FPT evidence. Because of these differences in reporting only pooled effect sizes were able to be calculated as opposed to cutoff scores for individual tests. Future studies may want to better identify and address systematic ways to improve the quality of manuscripts to elevate the literature.

Across the studies, there was also inconsistent reporting of inclusion and exclusion criteria making comparisons difficult. In 2013, recommendations put forth by the International Ankle Consortium established guidelines for reporting populations of individuals with CAI; however, many of these studies predated these recommendations and therefore did not provide information necessary to understand these populations. One notable point of caution that should be added is that most of the studies included in the analysis were conducted on relatively physically active individuals. This is because most of the research on CAI is conducted by sports medicine specialists. Whether these results apply to more sedentary populations is unknown. Thus, additional CAI research may want to focus on nonphysically active populations. It remains possible that different measures may better apply to different populations.

Other limitations include the sample size of both the included studies and the total number of studies included in this meta-analysis. The sample sizes of the studies themselves limit their statistical power and generalizability of the effects found. Larger samples would provide superior evidence for the use of FPTs in those with CAI. The total number of studies also limits the effects of this meta-analysis. As reported, many of the FPTs have only been assessed in 1 or 2 limiting the ability to perform a meta-analysis on those individual tests. In addition, pertaining to the SEBT anteromedial and posteromedial directions, the estimates for the fail-safe *N* calculations indicate that publication bias may be present with 4 additional publications necessary to negate the present results.[81] Although this is concerning for the SEBT, the fail-safe *N* calculations for the timed-hop and side-hop calculations are very high, indicating strong, stable effect sizes. This provides evidence that more studies with larger samples need to be conducted to properly evaluate the alterations in muscle activation strategies during jump landing activities in those with CAI.

TABLE 2. Summary Statistics for FPTs of Which Mean Effect Sizes Were Calculated Between Control and CAI Participants Across All Included Studies

FPT	n	Mean Δ (95% Confidence Interval)	*P*	*Q*	I^2	Fail-Safe n
Timed hop tests*	9	−1.056 (−1.844, −0.267)	0.009	25.31	68.39	103
Side-hop*	7	−2.314 (−3.650, −0.979)	0.001	19.16	68.69	235
Single-hop	3	0.033 (−0.0330, 0.396)	0.859	0.06	0.00	0
Multiple hop test*	3	1.399 (1.044, 1.755)	<0.001	1.37	0.00	45
Foot-lift test*	3	−0.761 (−1.400, −0.121)	0.020	1.871	0.00	9
SEBT—posteromedial*	13	0.374 (0.183, 0.566)	<0.001	11.28	2.44	44
SEBT—medial*	7	0.369 (0.105, 0.632)	0.006	6.20	3.21	13
SEBT—anteromedial*	7	0.326 (0.048, 0.604)	0.022	6.46	7.6	9
SEBT—anterior	7	0.264 (−0.002, 0.529)	0.051	6.72	10.7	3
SEBT—posterolateral	7	0.056 (−0.152, 0.263)	0.599	4.47	0.00	0
SEBT—anterolateral	3	0.246 (−0.060, 0.551)	0.116	0.19	0.00	0
SEBT—posterior	3	0.232 (−0.074, 0.538)	0.137	0.22	0.00	0
SEBT—lateral	3	0.253 (−0.053, 0.559)	0.105	0.29	0.00	0

*Significant mean effect size ($P < 0.05$).

TABLE 3. Descriptions of FPTs and Their Outcome Measures Described in the Literature Used to Assess Individuals With CAI

FPT	Description	Outcome Measure
Hopping tests		
Agility hop test	Participant performs single-leg hops across 6 spots, changing directions. Participant is instructed to "stick" each landing and hold the position for 5 s.	Error scoring
Figure-of-8 hop*	Two cones are placed 5 m apart. Participant is instructed to hop as quickly as possible in the figure-of-8 pattern around cones, twice through.	Time to completion (s)
Hopping test*	Participant hops through a course of 8 squares, 4 leveled and 4 with 15 degrees in various directions. Participants are instructed to hop as quickly as possible through the course while on a single limb.	Time to completion (s)
Multiple-hop test	Participant hops across a pattern of 11 numbered 2 × 2 cm floor markers. Participant is instructed to maintain their balance throughout and avoid balance errors	Error scoring
Side-hop test†	Participant hops on a single limb medially and laterally over a 3-cm distance. Ten repetitions are performed as quickly as possible.	Time to completion (s)
Single-leg jump landing test*	Participant jumps to randomly lit rectangles on coordination, measuring, and training system. Participant completes 12 single-leg jumps as quickly as possible.	Time to completion (s)
Single-limb hopping test*	Completed over 2 rows of 4, 33 × 33 cm squares. The middle squares have a 15-degree lateral, with the outside ones having a 15-degree incline and decline. Participants are instructed to hop as quickly as possible through the course while on a single limb.	Time to completion (s)
Single-limb hop test for distance†	Participants stand on a single limb and are asked to hop as far forward as possible.	Distance (cm)
Single-limb hurdle test	Participant hops as fast as they can across 10 squares with three 15-cm high hurdles along course.	Time to completion (s)
Six-meter crossover hop test	Participant hops as fast as possible across a 15-cm wide, 6-m long line as fast as possible, while alternating sides.	Time to completion (s)
Square hop test	Participant hops 5 times as fast as possible in and out of a 40 × 40 cm square on the ground.	Time to completion (s)
Triple-crossover hop test	Participants stand on a single-limb and hop 3 times for distance over a zigzag pattern across a 15-cm line.	Distance completed (m)
Up-down hop test	Participants hop up and down on a 20-cm step, 10 times as fast as possible	Time to completion (s)
Balance tests		
Balance Error Scoring System (BESS)	Participants hold a double-limb, single-limb, and tandem stance on firm and soft surfaces for 20 s each. Clinicians tally list of errors within each stance condition.	Error scoring
Foot-lift test	Participants stand on a single limb on a firm surface. Clinician counts number of times participants lifts any portion of stance foot off ground over a 30 s period.	Number of foot lifts
Star Excursion Balance Test (SEBT)†	Participants stand on single limb and maintain balance while reaching with the opposite limb into 1 of 8 directions and returning upright.	Distance reached (% leg length)
Time-in-balance test	Participants stand on a single leg on a firm surface as long as possible.	Time in balance (s)
Other FPTs		
Co-contraction test	Participants shuffle-steps backward and forward 5 times across a semicircle with a radius of 2.44 m.	Time to completion (s)
Japan test	Participants sidestep as fast as possible across 4 mo course as fast as possible.	Time to completion (s)
Shuttle run test	Participants run across a 6.1-m distance, touch ground, and run back twice as fast as possible.	Time to completion (s)

** The FPT is included in the mean effect size for timed-hopping tests.*
† A mean effect size was calculated for this FPT.

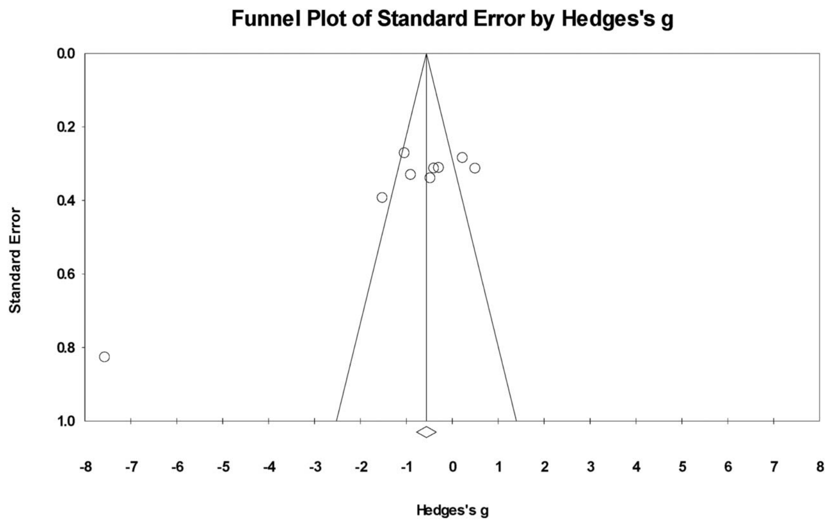

Figure 5. Funnel plot of the individual study effect sizes (Hedges *g*) plotted against the SE for timed single-limb hop tests (○ = individual study; ◊ = mean overall effect).

CONCLUSIONS

Level B evidence exists suggesting that the side-hop, timed-hopping, multiple-hop tests, and foot-lift test are able to discriminate between those with CAI and healthy individuals. Level B evidence also exists suggesting that the medial, anteromedial, and posteromedial components of the SEBT are similarly able to differentiate. Although a multitude of additional tests exist presenting a wide range of effect sizes, it seems that those tests that include timed measures of lateral hopping and those quantifying balance may have clinical utility. Recent evidence suggests that combining the results of multiple FPTs has greater clinical utility than singular tests.[40] Specifically, a combination of a version of the side-hop test and SEBT displayed the greatest clinical utility. However, limited research is available to corroborate additional tests, and a more comprehensive assessment of FPTs may be necessary to determine the best combination of FPTs to assess CAI.

These tests present an advantage to clinicians aiming to address functional deficits in patients with CAI as they are cheap, effective alternatives compared with instrumented measures. However, further research is necessary to aid in the full implementation of these tests clinically. Greater sample sizes and study volume would improve on evaluation methods and decrease publication bias to more appropriately determine clinical measures to assess those with CAI. Furthermore, consistency in test implementation must be encouraged to calculate precise protocols and cutoff scores that may improve clinical utility. Last, it remains largely unknown in which ways the current treatment methods may serve to modify these values, affecting the implementation of these measures through patient rehabilitation.

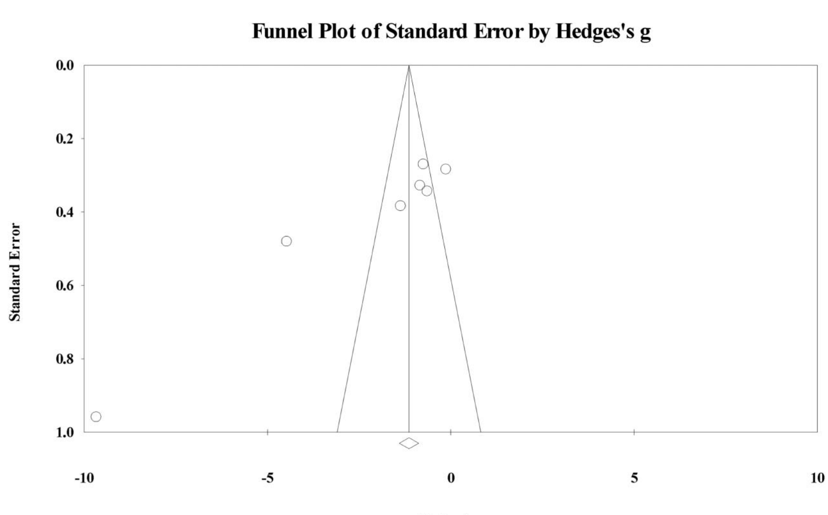

Figure 6. Funnel plot of the individual study effect sizes (Hedges *g*) plotted against the SE for single-limb side-hop test (○ = individual study; ◊ = mean overall effect).

References

1. Waterman BR, Belmont PJ Jr, Cameron KL, et al. Epidemiology of ankle sprain at the United States Military Academy. *Am J Sports Med*. 2010;38:797–803.
2. Waterman BR, Owens BD, Davey S, et al. The epidemiology of ankle sprains in the United States. *J Bone Joint Surg Am*. 2010;92:2279–2284.
3. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42:311–319.
4. Yeung MS, Chan KM, So CH, et al. An epidemiological survey on ankle sprain. *Br J Sports Med*. 1994;28:112–116.
5. Gribble PA, Bleakley CM, Caulfield BM, et al. Evidence review for the 2016 International Ankle Consortium consensus statement on the prevalence, impact and long-term consequences of lateral ankle sprains. *Br J Sports Med*. 2016;50:1496–1505.
6. Houston MN, Van Lunen BL, Hoch MC. Health-related quality of life in individuals with chronic ankle instability. *J Athl Train*. 2014;49:758–763.
7. Freeman MA, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br*. 1965;47:678–685.
8. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37:364–375.
9. Hubbard-Turner T, Turner MJ. Physical activity levels in college students with chronic ankle instability. *J Athl Train*. 2015;50:742–747.
10. Golditz T, Steib S, Pfeifer K, et al. Functional ankle instability as a risk factor for osteoarthritis: using T2-mapping to analyze early cartilage degeneration in the ankle joint of young athletes. *Osteoarthritis Cartilage*. 2014;22:1377–1385.
11. Valderrabano V, Hintermann B, Horisberger M, et al. Ligamentous posttraumatic ankle osteoarthritis. *Am J Sports Med*. 2006;34:612–620.
12. Shah S, Thomas AC, Noone JM, et al. Incidence and cost of ankle sprains in United States emergency departments. *Sports Health*. 2016;8:547–552.
13. Gribble PA, Delahunt E, Bleakley CM, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *J Athl Train*. 2014;49:121–127.
14. Hiller CE, Refshauge KM, Bundy AC, et al. The Cumberland ankle instability tool: a report of validity and reliability testing. *Arch Phys Med Rehabil*. 2006;87:1235–1241.
15. Docherty CL, Gansneder BM, Arnold BL, et al. Development and reliability of the ankle instability instrument. *J Athl Train*. 2006;41:154–158.
16. Simon J, Donahue M, Docherty C. Development of the identification of functional ankle instability (IdFAI). *Foot Ankle Int*. 2012;33:755–763.
17. Carcia CR, Martin RL, Drouin JM. Validity of the foot and ankle ability measure in athletes with chronic ankle instability. *J Athl Train*. 2008;43:179–183.
18. Hegedus EJ, McDonough S, Bleakley C, et al. Clinician-friendly lower extremity physical performance measures in athletes: a systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *Br J Sports Med*. 2015;49:642–648.
19. Zwolski C, Schmitt LC, Thomas S, et al. The utility of limb symmetry indices in return-to-sport assessment in patients with bilateral anterior cruciate ligament reconstruction. *Am J Sports Med*. 2016;44:2030–2038.
20. Witchalls J, Blanch P, Waddington G, et al. Intrinsic functional deficits associated with increased risk of ankle injuries: a systematic review with meta-analysis. *Br J Sports Med*. 2012;46:515–523.
21. Munn J, Sullivan SJ, Schneiders AG. Evidence of sensorimotor deficits in functional ankle instability: a systematic review with meta-analysis. *J Sci Med Sport*. 2010;13:2–12.
22. Arnold BL, De la Motte S, Linens S, et al. Ankle instability is associated with balance impairments: a meta-analysis. *Med Sci Sport Exer*. 2009;41:1048–1062.
23. Chinn L, Dicharry J, Hertel J. Ankle kinematics of individuals with chronic ankle instability while walking and jogging on a treadmill in shoes. *Phys Ther Sport*. 2013;14:232–239.
24. Wikstrom EA, Brown CN. Minimum reporting standards for copers in chronic ankle instability research. *Sports Med*. 2014;44:251–268.
25. Kaminski TW, Hertel J, Amendola N, et al. National Athletic Trainers' Association position statement: conservative management and prevention of ankle sprains in athletes. *J Athl Train*. 2013;48:528–545.
26. Moher D, Liberati A, Tetzlaff J, et al. The PRISMA Group. Reprint—preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Phys Ther*. 2009;89:873–880.
27. von Elm E, Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Epidemiology*. 2007;18:800–804.
28. Howick J, Chalmers I, Glasziou P, et al. *The Oxford 2011 Levels of Evidence*. Oxford Centre for Evidence-Based Medicine; 2011. Available at: http://www.cebm.net/index.aspx?o=5653.
29. Hedges LV, Olkin I. *Statistical Methods for Meta-Analysis*. Orlando, FL: Academic Press; 1985.
30. Lipsey MW, Wilson DB. *Practical Meta-Analysis*. Thousand Oaks, CA: Sage Publications, Inc; 2001.
31. Buchanan AS, Docherty CL, Schrader J. Functional performance testing in participants with functional ankle instability and in a healthy control group. *J Athl Train*. 2008;43:342–346.
32. Caffrey E, Docherty CL, Schrader J, et al. The ability of 4 single-limb hopping tests to detect functional performance deficits in individuals with functional ankle instability. *J Orthop Sport Phys Ther*. 2009;39:799–806.
33. de Noronha M, Refshauge KM, Kilbreath SL, et al. Loss of proprioception or motor control is not related to functional ankle instability: an observational study. *Aust J Physiother*. 2007;53:193–198.
34. Docherty CL, Arnold BL, Gansneder BM, et al. Functional-performance deficits in volunteers with functional ankle instability. *J Athl Train*. 2005;40:30–34.
35. Jerosch J, Thorwesten L, Frebel T, et al. Influence of external stabilizing devices of the ankle on sport-specific capabilities. *Knee Surg Sports Traumatol Arthrosc*. 1997;5:50–57.
36. Linens SW, Ross SE, Arnold BL, et al. Postural-stability tests that identify individuals with chronic ankle instability. *J Athl Train*. 2014;49:15–23.
37. Sharma N, Sharma A, Singh Sandhu J. Functional performance testing in athletes with functional ankle instability. *Asian J Sports Med*. 2011;2:249–258.
38. Someeh M, Norasteh AA, Daneshmandi H, et al. Influence of Mulligan ankle Taping on functional performance tests in healthy athletes and athletes with chronic ankle instability. *Int J Athl Ther Train*. 2015;20:39–45.
39. Wikstrom EA, Tillman MD, Chmielewski TL, et al. Self-assessed disability and functional performance in individuals with and without ankle instability: a case control study. *J Orthop Sports Phys Ther*. 2009;39:458–467.
40. Ko J, Rosen AB, Brown CN. Comparison between single and combined clinical postural stability tests in individuals with and without chronic ankle instability. *Clin J Sport Med*. 2017;27:394–399.
41. Hertel J, Braham RA, Hale SA, et al. Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability. *J Orthop Sport Phys Ther*. 2006;36:131–137.
42. Gribble PA, Hertel J, Denegar CR, et al. The effects of Fatigue and chronic ankle instability on dynamic postural control. *J Athl Train*. 2004;39:321–329.
43. Martinez-Ramirez A, Lecumberri P, Gomez M, et al. Wavelet analysis based on time-frequency information discriminate chronic ankle instability. *Clin Biomech*. 2010;25:256–264.
44. Nakagawa L, Hoffman M. Performance in static, dynamic, and clinical tests of postural control in individuals with recurrent ankle sprains. *J Sport Rehabil*. 2004;13:255–268.
45. Sefton JM, Hicks-Little CA, Hubbard TJ, et al. Sensorimotor function as a predictor of chronic ankle instability. *Clin Biomech*. 2009;24:451–458.
46. Hadadi M, Mousavi ME, Fardipour S, et al. Effect of soft and semirigid ankle orthoses on Star Excursion Balance Test performance in patients with functional ankle instability. *J Sci Med Sport*. 2014;17:430–433.
47. Olmsted LC, Carcia CR, Hertel J, et al. Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *J Athl Train*. 2002;37:501–506.
48. de la Motte S, Arnold BL, Ross SE. Trunk-rotation differences at maximal reach of the star excursion balance test in participants with chronic ankle instability. *J Athl Train*. 2015;50:358–365.
49. Hale SA, Hertel J, Olmsted-Kramer LC. The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *J Orthop Sport Phys Ther*. 2007;37:303–311.
50. Hoch MC, Staton GS, Medina McKeon JM, et al. Dorsiflexion and dynamic postural control deficits are present in those with chronic ankle instability. *J Sci Med Sport*. 2012;15:574–579.
51. McCann RS, Crossett ID, Terada M, et al. Hip strength and star excursion balance test deficits of patients with chronic ankle instability. *J Sci Med Sport*. 2017;20:992–996.

52. Plante JE, Wikstrom EA. Differences in clinician-oriented outcomes among controls, copers, and chronic ankle instability groups. *Phys Ther Sport*. 2013;14:221–226.
53. Pozzi F, Moffat M, Gutierrez G. Neuromuscular control during performance of a dharmic dyadic dynamic pyaemic adamic agamic anaemic anemic anomic balance task in subjects with and without ankle instability. *Int J Sport Phys Ther*. 2015;10:520–529.
54. Eechaute C, Vaes P, Duquet W. Functional performance deficits in patients with CAI: validity of the multiple hop test. *Clin J Sport Med*. 2008;18:124–129.
55. Eechaute C, Vaes P, Duquet W. The dynamic postural control is impaired in patients with chronic ankle instability: reliability and validity of the multiple hop test. *Clin J Sport Med*. 2009;19:107–114.
56. Groters S, Groen BE, van Cingel R, et al. Double-leg stance and dynamic balance in individuals with functional ankle instability. *Gait Posture*. 2013;38:968–973.
57. Hiller CE, Refshauge KM, Herbert RD, et al. Balance and recovery from a perturbation are impaired in people with functional ankle instability. *Clin J Sport Med*. 2007;17:269–275.
58. Demeritt KM, Shultz SJ, Docherty CL, et al. Chronic ankle instability does not affect lower extremity functional performance. *J Athl Train*. 2002;37:507–511.
59. Docherty CL, Valovich McLeod TC, Shultz SJ. Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. *Clin J Sport Med*. 2006;16:203–208.
60. Palmieri-Smith RM, Hopkins JT, Brown TN. Peroneal activation deficits in persons with functional ankle instability. *Am J Sports Med*. 2009;37:982–988.
61. Yoshida M, Taniguchi K, Katayose M. Analysis of muscle activity and ankle joint movement during the side-hop test. *J Strength Cond Res*. 2011;25:2255–2264.
62. Donovan L, Hertel J. A new paradigm for rehabilitation of patients with chronic ankle instability. *Phys Sportsmed*. 2012;40:41–51.
63. Hiller CE, Kilbreath SL, Refshauge KM. Chronic ankle instability: evolution of the model. *J Athl Train*. 2011;46:133–141.
64. Kaminski TW, Buckley BD, Powers ME, et al. Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability. *Br J Sports Med*. 2003;37:410–415; discussion 415.
65. Kaminski TW, Perrin DH, Gansneder BM. Eversion strength analysis of uninjured and functionally unstable ankles. *J Athl Train*. 1999;34:239–245.
66. Wilkerson GB, Pinerola JJ, Caturano RW. Invertor vs. evertor peak torque and power deficiencies associated with lateral ankle ligament injury. *J Orthop Sport Phys Ther*. 1997;26:78–86.
67. Ryan L. Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. *Aust J Physiothr*. 1994;40:41–47.
68. Willems T, Witvrouw E, Verstuyft J, et al. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *J Athl Train*. 2002;37:487–493.
69. Liu K, Glutting J, Wikstrom E, et al. Examining the diagnostic accuracy of dynamic postural stability measures in differentiating among ankle instability status. *Clin Biomech*. 2013;28:211–217.
70. Brown CN, Ko J, Rosen AB, et al. Individuals with both perceived ankle instability and mechanical laxity demonstrate dynamic postural stability deficits. *Clin Biomech*. 2015;30:1170–1174.
71. Wikstrom EA, Tillman MD, Chmielewski TL, et al. Dynamic postural stability deficits in subjects with self-reported ankle instability. *Med Sci Sports Exerc*. 2007;39:397–402.
72. Wikstrom EA, Tillman MD, Chmielewski TL, et al. Dynamic postural control but not mechanical stability differs among those with and without chronic ankle instability. *Scand J Med Sci Sports*. 2010;20:e137–e144.
73. Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;47:339–357.
74. Chimera NJ, Smith CA, Warren M. Injury history, sex, and performance on the functional movement screen and Y balance test. *J Athl Train*. 2015;50:475–485.
75. Kang MH, Lee DK, Park KH, et al. Association of ankle kinematics and performance on the y-balance test with inclinometer measurements on the weight-bearing-lunge test. *J Sport Rehabil*. 2015;24:62–67.
76. Brown CN, Bowser B, Orellana A. Dynamic postural stability in females with chronic ankle instability. *Med Sci Sports Exerc*. 2010;42:2258–2263.
77. Gabriner ML, Houston MN, Kirby JL, et al. Contributing factors to star excursion balance test performance in individuals with chronic ankle instability. *Gait Posture*. 2015;41:912–916.
78. Drewes LK, McKeon PO, Kerrigan DC, et al. Dorsiflexion deficit during jogging with chronic ankle instability. *J Sci Med Sport*. 2009;12:685–687.
79. Hoch MC, Farwell KE, Gaven SL, et al. Weight-bearing dorsiflexion range of motion and landing biomechanics in individuals with chronic ankle instability. *J Athl Train*. 2015;50:833–839.
80. Wright IC, Neptune RR, van den Bogert AJ, et al. The influence of foot positioning on ankle sprains. *J Biomech*. 2000;33:513–519.
81. Rosenthal R. The file drawer problem and tolerance for null results. *Psychol Bull*. 1979;86:638–641.