12-22-2017

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

Adam B. Rosen
University of Nebraska at Omaha, arosen@unomaha.edu

Alan R. Needle

Jupil Ko
Northern Arizona University, jupilko@gmail.com

The ability of functional performance tests to identify individuals with chronic ankle instability: A systematic review with meta-analysis.

Adam B. Rosen PhD, ATC
The University of Nebraska at Omaha
arosen@unomaha.edu

Alan R. Needle, PhD, ATC
Appalachian State University
needlear@appstate.edu

Jupil Ko, PhD, ATC
Northern Arizona University,
jupil.ko@nau.edu

Conflicts of Interest and Source of Funding: The authors received no research funding and have no financial affiliation or involvement with any commercial organization that has a financial interest in this manuscript.

Corresponding Author
Adam B. Rosen,
6001 Dodge Street, HPER 207Y,
Omaha, NE, USA, 68132
arosen@unomaha.edu,
(o) 402-554-2057
(f) 402-554-3693

Word count of the abstract: 250
Word count of body of the manuscript: 4220

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 CAI and healthy controls. **Data Sources:** The National Library of Medicine Catalog (PubMed), the Cumulative Index for Nursing and Allied Health Literature (CINAHL), and 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 to 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. 29 studies met 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 (SEBT). 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<.001, n=3) and foot-lift tests (g=-0.761, p=0.020, n=3) demonstrated the best utility with large mean effect sizes, while 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 appear 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 to instrumented measures.

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] CAI has been associated with several detrimental consequences that include decreased physical activity,[9] and the early onset of post-traumatic ankle osteoarthritis.[10,11] Furthermore, the combination of recurrent injury and degenerative changes to the joint associated with chronic ankle instability represent a significant financial burden on the healthcare system, estimated to cost 6.2 billion USD per year.[5,12]

Current standards of clinical practice rely on self-reported questionnaires in order for clinicians and researchers to determine if 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 sport or activities of daily living.[14-17] While these tools have proven useful, they suffer from limitations related to their subjectivity and patient interpretation of questions (e.g. 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 in order 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 that 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] balance,[22] and functional kinematics[23] between patients with CAI and healthy participants, as well as those that have successfully "coped" following injury.[24] However, the vast majority of these tests require the use of advanced equipment including isokinetic dynamometers, force plates, and motion capture systems in order to differentiate these individuals. Clinical practitioners would benefit from non-instrumented clinical tests, such as functional performance tests (FPTs), in order 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, non-instrumented 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 test that require large degrees of lateral movement, as well as non-instrumented 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 towards the implementation of these potentially useful tests in clinical practice.[25] A comprehensive summary of the findings in this area will allow healthcare providers to make evidence-based informed decisions related to functional performance testing in order 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 (Supplemental document 1).[26]

Data Acquisition

An electronic database search was initially conducted by two of the coauthors (JK & AN) on National Library of Medicine Catalog (Medline/PubMed), the Cumulative Index for Nursing and Allied Health Literature (CINAHL), and SPORTDiscus, from inception to June, 2017. The initial key-term 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 prior to 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 utilize a functional performance test that involves hopping, landing, agility and/or non-instrumented balance assessment; and (4) studies must include a group comparison between patients with CAI and healthy controls. While studies would preferably adhere to identifying CAI individuals in accordance with standards put forward by the International Ankle Consortium[13] many articles were published prior to this criteria. Therefore, participants in the experimental group must have enrolled those with a history of at least one 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 chronic ankle instability.[27] Research studies were excluded if they utilized 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 utilizing 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. Consensus among all the authors were then sought for the final inclusion of manuscripts.

Manuscripts were then evaluated separately by two authors (AR & AN) 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 consensus between the two authors, if a situation arose where consensus was not able to be achieved, the third author was consulted.

Numerical data extracted included the sample sizes and outcome measures for each functional performance test by group. A single investigator (AR) conducted all effect size calculations through Comprehensive Meta-Analysis (V3.3.070, Biostat, Inc., Englewood, NJ). Effect sizes were calculated using the standardized mean difference for each of the outcome measures adjusting for small sample bias (Hedges G).[29] Due to the uncertainty of evaluating a homogenous population a mean effect size (Δ) was determined using a random effects model, if three or more studies evaluated a similar FPT.[30] Further tests were calculated to determine if 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 which 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. 996 manuscripts were identified by the initial search terms across the databases and after duplicate removal 479 remained. Following title and abstract screening 433 articles were excluded while 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, seven were cross-sectional studies, 21 were case-control and one was a randomized-control trial (Table 1). Correspondingly, the studies were deemed levels 2, 3 and 4 evidence, respectively. Only four disagreements in STROBE scoring were needed to be resolved via 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 out of a possible 22 (Supplementary document 2). 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 suffering from CAI and 637 control participants.

Pooled effect sizes were calculated for the most common FPTs which 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] While some studies reported several different timed hop tests, a single timed hop test was chosen from each available study based on 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 while 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 seen in Figures 2, 3, 4 and supplementary document 3. Mean effect and their 95% confidence intervals, tests for homogeneity and fail safe N calculations are located 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. While, 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) was 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 and SEBT are located in

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] six-meter 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 functional performance tests are located 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 three directions of the SEBT, respectively. The single-hop test for distance appears to be an ineffective FPT in CAI populations, while 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. In comparison the timed-hop tests are typically through a course such as the figure 8 which 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 to 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 appear to be effective at discriminating those with CAI.[60,61]

However, of some concern pertaining to the side-hop and timed hop tests is the funnel plots (Figures 5 and 6, supplemental documents 4, 5 and 6) 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 significant influence on the mean effect size. Although this study substantially influenced the effect sizes, when removing this particular outlier, the mean effect size for both tests remain moderate-large and significant (side-hop: $g = -1.444$, $p=.022$; timed-hop: $g = -0.446$, $p=.027$). It's 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, utilizing 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 to 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 one or two studies. The single-limb hurdle test, six-meter 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, suggest 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 suggest 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 due to the fact it assesses and requires greater muscular strength and power rather than speed and agility. While interesting, this negative result is rather unsurprising due to the evidence regarding the role of ankle strength in CAI is widely disputed and equivocal.[64-68] 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 which was studied by only one group, the triple-crossover hop test demonstrated a small effect size. The triple-crossover hop test like the single-limb hop for distance requires participants to jump as far as possible, but in this test it is the maximum distance after three jumps across a 15cm line. Although the incorporation of a crossover adds a lateral component, the test outcome is primarily the distance advanced in the forward direction. Therefore, utilizing FPT's in those with CAI which require muscular power within the sagittal plane seems to be ineffective compared to 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 three 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. While 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 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 non-instrumented 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 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. Additionally, studies were included that assessed the injured compared to uninjured limbs as well as CAI compared to controls. While the authors similarly concluded the SEBT was an effective FPT in those with CAI, their study did not re-synthesize 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. While 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 appears 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] While 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) appears to be an adequate discriminating test, while 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 two 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 is 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. While these would combine yield very high effect sizes and a strong ability to predict functional instability in these patients, there are additional components 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 two 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 relating 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. Due to these differences in reporting only pooled effect sizes were able to be calculated as opposed to cut-off scores for individual tests. Future studies, may want to better identify and address systematic ways to improve the quality of manuscripts in order to elevate the literature.

Across the studies there were also inconsistent reporting of inclusion and exclusion criteria making comparisons difficult. In 2013, recommendations put forth by International Ankle Consortium established guidelines for reporting populations of individuals with CAI; however, many of these studies pre-dated 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 non-physically 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 one or two limiting the ability to perform a meta-analysis on those individual tests. Additionally, pertaining to the SEBT anteromedial and posteromedial directions the estimates for the fail-safe N calculations indicate publication bias may be present with four 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 more studies with larger samples need to be conducted in order to properly evaluate the alterations in muscle activation strategies during jump landing activities in those with CAI.

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. While a multitude of additional tests exist presenting a wide range of effect sizes, it appears that those tests that include timed measures of lateral hopping, and those quantifying balance may have clinical utility. Recent evidence suggests 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 FPT's 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 to 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 upon evaluation methods and decrease publication bias in order to more appropriately determine clinical measures to assess those with CAI. Furthermore, consistency in test implementation must be encouraged in order to calculate precise protocols and cut-off scores that may improve clinical utility. Lastly, it remains largely unknown in which ways current treatment methods may serve to modify these values, affecting the implementation of these measures through patient rehabilitation.

References

1. Waterman BR, Belmont PJ, Jr., Cameron KL, Deberardino TM, Owens BD. Epidemiology of Ankle Sprain at the United States Military Academy. Am J Sports Med. 2010;38(4):797-803.

2. Waterman BR, Owens BD, Davey S, Zacchilli MA, Belmont PJ, Jr. The epidemiology of ankle sprains in the United States. J Bone Joint Surg Am. 2010;92(13):2279-84.

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(2):311-9.

4. Yeung MS, Chan KM, So CH, Yuan WY. An epidemiological survey on ankle sprain. Br J Sports Med. 1994;28(2):112-6.

5. Gribble PA, Bleakley CM, Caulfield BM, Docherty CL, Fourchet F, Fong DT, 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 [Epub ahead of print].

6. Houston MN, Van Lunen BL, Hoch MC. Health-related quality of life in individuals with chronic ankle instability. J Athl Train. 2014 Nov-Dec;49(6):758-63.

7. Freeman MA, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. J Bone Joint Surg Br. 1965;47(4):678-85.

8. Hertel J. Functional Anatomy, Pathomechanics, and Pathophysiology of Lateral Ankle Instability. J Athl Train. 2002;37(4):364-75.

9. Hubbard-Turner T, Turner MJ. Physical Activity Levels in College Students With Chronic Ankle Instability. J Athl Train. 2015;50(7):742–747.

10. Golditz T, Steib S, Pfeifer K, Uder M, Gelse K, Janka R, 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. Osteoarthr Cartil. 2014;22(10):1377-85.

11. Valderrabano V, Hintermann B, Horisberger M, Fung TS. Ligamentous posttraumatic ankle osteoarthritis. Am J Sports Med. 2006;34(4):612-20.

12. Shah S, Thomas AC, Noone JM, Blanchette CM, Wikstrom EA. Incidence and Cost of Ankle Sprains in United States Emergency Departments. Sports health. 2016 [Epub ahead of print].

13. Gribble PA, Delahunt E, Bleakley CM, Caulfield B, Docherty CL, Fong DT, 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(1):121-7.

14. Hiller CE, Refshauge KM, Bundy AC, Herbert RD, Kilbreath SL. The Cumberland ankle instability tool: a report of validity and reliability testing. Arch Phys Med Rehabil. 2006;87(9):1235-41.

15. Docherty CL, Gansneder BM, Arnold BL, Hurwitz SR. Development and reliability of the ankle instability instrument. J Athl Train. 2006;41(2):154-8.

16. Simon J, Donahue M, Docherty C. Development of the Identification of Functional Ankle Instability (IdFAI). Foot Ankle Int. 2012;33(9):755-63.

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(2):179-83.

18. Hegedus EJ, McDonough S, Bleakley C, Cook CE, Baxter GD. 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(10):642-8.

19. Zwolski C, Schmitt LC, Thomas S, Hewett TE, Paterno MV. 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(8):2030-8.

20. Witchalls J, Blanch P, Waddington G, Adams R. Intrinsic functional deficits associated with increased risk of ankle injuries: a systematic review with meta-analysis. Br J Sports Med. 2012;46(7):515-23.

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(1):2-12.

22. Arnold BL, De la Motte S, Linens S, Ross SE. Ankle Instability Is Associated with Balance Impairments: A Meta-Analysis. Med Sci Sport Exer. 2009;41(5):1048-62.

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(4):232-9.

24. Wikstrom EA, Brown CN. Minimum reporting standards for copers in chronic ankle instability research. Sports Med. 2014;44(2):251-68.

25. Kaminski TW, Hertel J, Amendola N, Docherty CL, Dolan MG, Hopkins JT, et al. National Athletic Trainers' Association position statement: conservative management and prevention of ankle sprains in athletes. J Athl Train. 2013;48(4):528-45.

26. Moher D, Liberati A, Tetzlaff J, Altman DG. Reprint -- Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. The PRISMA Group. Preferred

reporting items for systematic reviews and meta-analyses: the PRISMA statement. Phys Ther. 2009;89(9):873-80.

27. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Epidemiology. 2007;18(6):800-4.

28. Jeremy Howick ICJLL, Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti,, Bob Phillips HT, Olive Goddard and Mary Hodgkinson. The Oxford 2011 Levels of Evidence. Oxford Centre for Evidence-Based Medicine 2011.

29. Hedges LV, Olkin I. Statistical methods for meta-analysis. Ingram Olkin: Orlando : Academic Press; 1985.

30. Lipsey MW, Wilson DB. Practical meta-analysis. Thousand Oaks, CA US: 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(4):342-6.

32. Caffrey E, Docherty CL, Schrader J, Klossner J. 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(11):799-806.

33. de Noronha M, Refshauge KM, Kilbreath SL, Crosbie J. Loss of proprioception or motor control is not related to functional ankle instability: an observational study. Aust J Physiother. 2007;53(3):193-8.

34. Docherty CL, Arnold BL, Gansneder BM, Hurwitz S, Gieck J. Functional-Performance Deficits in Volunteers With Functional Ankle Instability. J Athl Train. 2005;40(1):30-4.

35. Jerosch J, Thorwesten L, Frebel T, Linnenbecker S. Influence of external stabilizing devices of the ankle on sport-specific capabilities. Knee Surg Sport Tr A. 1997;5(1):50-7.

36. Linens SW, Ross SE, Arnold BL, Gayle R, Pidcoe P. Postural-stability tests that identify individuals with chronic ankle instability. J Athl Train. 2014;49(1):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(4):249-58.

38. Someeh M, Norasteh AA, Daneshmandi H, Asadi A. 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(1).

39. Wikstrom EA, Tillman MD, Chmielewski TL, Cauraugh JH, Naugle KE, Borsa PA. Self-assessed disability and functional performance in individuals with and without ankle instability: a case control study. J Orthop Sports Phys Ther. 2009;39(6):458-67.

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(4):394-9.

41. Hertel J, Braham RA, Hale SA, Olmsted-Kramer LC. Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability J Orthop Sport Phys Ther. 2006;36(3):131-7.

42. Gribble PA, Hertel J, Denegar CR, Buckley WE. The Effects of Fatigue and Chronic Ankle Instability on Dynamic Postural Control. J Athl Train. 2004;39(4):321-9.

43. Martinez-Ramirez A, Lecumberri P, Gomez M, Izquierdo M. Wavelet analysis based on time-frequency information discriminate chronic ankle instability. Clin Biomech. 2010;25(3):256-64.

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(3):255-68.

45. Sefton JM, Hicks-Little CA, Hubbard TJ, Clemens MG, Yengo CM, Koceja DM, et al. Sensorimotor function as a predictor of chronic ankle instability. Clin Biomech. 2009;24(5):451-8.

46. Hadadi M, Mousavi ME, Fardipour S, Vameghi R, Mazaheri M. 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(4):430-3.

47. Olmsted LC, Carcia CR, Hertel J, Shultz SJ. Efficacy of the Star Excursion Balance Tests in Detecting Reach Deficits in Subjects With Chronic Ankle Instability. J Athl Train. 2002;37(4):501-6.

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(4):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(6):303-311.

50. Hoch MC, Staton GS, Medina McKeon JM, Mattacola CG, McKeon PO. Dorsiflexion and dynamic postural control deficits are present in those with chronic ankle instability. J Sci Med Sport. 2012;15(6):574-579.

51. McCann RS, Crossett ID, Terada M, Kosik KB, Bolding BA, Gribble PA. Hip strength and star excursion balance test deficits of patients with chronic ankle instability. J Sci Med Sport. 2017.

52. Plante JE, Wikstrom EA. Differences in clinician-oriented outcomes among controls, copers, and chronic ankle instability groups. Phys Ther Sport. 2013;14(4):221-226.

53. Pozzi F, Moffat M, Gutierrez G. Neuromuscular control during performance of a dyanmic balance task in subjects with and without ankle instability. Int J Sport Phys Ther. 2015;10(4):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(2):124-9.

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(2):107-114.

56. Groters S, Groen BE, van Cingel R, Duysens J. Double-leg stance and dynamic balance in individuals with functional ankle instability. Gait Posture. 2013;38(4):968-973.

57. Hiller CE, Refshauge KM, Herbert RD, Kilbreath SL. Balance and Recovery From a Perturbation are Impaired in People With Functional Ankle Instability. Clin J Sport Med. 2007; 17(4): 269-75.

58. Demeritt KM, Shultz SJ, Docherty CL, Gansneder BM, Perrin DH. Chronic Ankle Instability Does Not Affect Lower Extremity Functional Performance. J Athl Train. 2002;37(4):507-11.

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(3):203-8.

60. Palmieri-Smith RM, Hopkins JT, Brown TN. Peroneal activation deficits in persons with functional ankle instability. Am J Sports Med. 2009;37(5):982-8.

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(8):2255-64.

62. Donovan L, Hertel J. A new paradigm for rehabilitation of patients with chronic ankle instability. Phys Sportsmed. 2012;40(4):41-51.

63. Hiller CE, Kilbreath SL, Refshauge KM. Chronic ankle instability: evolution of the model. J Athl Train. 2011;46(2):133-41.

64. Kaminski TW, Buckley BD, Powers ME, Hubbard TJ, Ortiz C. 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(5):410-5; discussion 5.

65. Kaminski TW, Perrin DH, Gansneder BM. Eversion strength analysis of uninjured and functionally unstable ankles. J Athl Train. 1999;34(3):239-45.

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(2):78-86.

67. Ryan L. Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. Aust J Physiothr. 1994;40(1):41-7.

68. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and Muscle Strength in Subjects With a History of Ankle Sprains and Chronic Instability. J Athl Train. 2002;37(4):487-93.

69. Liu K, Glutting J, Wikstrom E, Gustavsen G, Royer T, Kaminski TW. Examining the diagnostic accuracy of dynamic postural stability measures in differentiating among ankle instability status. Clin Biomech. 2013;28(2):211-7.

70. Brown CN, Ko J, Rosen AB, Hsieh K. Individuals with both perceived ankle instability and mechanical laxity demonstrate dynamic postural stability deficits. Clin Biomech. 2015;30(10):1170-4.

71. Wikstrom EA, Tillman MD, Chmielewski TL, Cauraugh JH, Borsa PA. Dynamic postural stability deficits in subjects with self-reported ankle instability. Med Sci Sports Exerc. 2007;39(3):397-402.

72. Wikstrom EA, Tillman MD, Chmielewski TL, Cauraugh JH, Naugle KE, Borsa PA. Dynamic postural control but not mechanical stability differs among those with and without chronic ankle instability. Scand J Med Sci Sports. 2010;20(1):e137-44.

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(3):339-57.

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(5):475-85.

75. Kang MH, Lee DK, Park KH, Oh JS. 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(1):62-7.

76. Brown CN, Bowser B, Orellana A. Dynamic postural stability in females with chronic ankle instability. Med Sci Sports Exerc. 2010;42(12):2258-63.

77. Gabriner ML, Houston MN, Kirby JL, Hoch MC. Contributing factors to star excursion balance test performance in individuals with chronic ankle instability. Gait Posture. 2015;41(4):912-6.

78. Drewes LK, McKeon PO, Kerrigan DC, Hertel J. Dorsiflexion deficit during jogging with chronic ankle instability. J Sci Med Sport. 2009;12(6):685-7.

79. Hoch MC, Farwell KE, Gaven SL, Weinhandl JT. Weight-Bearing Dorsiflexion Range of Motion and Landing Biomechanics in Individuals With Chronic Ankle Instability. J Athl Train. 2015;50(8):833–839.

80. Wright IC, Neptune RR, van den Bogert AJ, Nigg BM. The influence of foot positioning on ankle sprains. J Biomech. 2000;33(5):513-9.

81. Rosenthal R. The file drawer problem and tolerance for null results. *Psychological bulletin.* 1979;86(3):638-641.