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

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

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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.

54 **Introduction**

55   Lateral ankle sprains are consistently among the most common injuries observed in

56 physically active populations, including high school and collegiate athletes, and the military.[1-4]

57 Although once considered a benign injury causing only a small loss of time from activity, the past

58 several decades have established this injury as the first in a cascade that has the potential to

59 contribute to decreased health-related quality of life.[5,6] Most commonly described following ankle

60 injury is the development of chronic ankle instability (CAI) – repeated sensations of "giving way"

61 or "rolling" of the ankle, often associated with recurrent injury.[7,8] CAI has been associated with

62 several detrimental consequences that include decreased physical activity,[9] and the early onset of

63 post-traumatic ankle osteoarthritis.[10,11] Furthermore, the combination of recurrent injury and

64 degenerative changes to the joint associated with chronic ankle instability represent a significant

65 financial burden on the healthcare system, estimated to cost 6.2 billion USD per year.[5,12]

66   Current standards of clinical practice rely on self-reported questionnaires in order for

67 clinicians and researchers to determine if patients or participants meet the criteria of having CAI.[13]

68 A wide variety of questionnaires are implemented, with questions ranging from asking individuals

69 to estimate the number of giving-way episodes they experience, to rating any pain or difficulty in

70 performing varying functional task related to sport or activities of daily living.[14-17] While these

71 tools have proven useful, they suffer from limitations related to their subjectivity and patient

72 interpretation of questions (e.g. individual understandings of "giving way").[16] The reliance on

73 solely subjective measures of ankle function to diagnose individuals as having CAI is in stark

74 contrast to similar models of knee instability that rely not only on subjective questionnaires, but

75 also on a combination of special and functional tests in order to characterize sensations of giving

76 way.[18] For instance, various hop tests, including a triple-hop for distance, have been used to

77   discriminate functional status for patients that have experienced a rupture of the knee's anterior

78   cruciate ligament.[19] However, a similar set of standardized tests have not been documented with

79   regard to their efficacy in discriminating individuals with CAI.

80   An abundance of research has been conducted to determine functional deficits such as

81   strength,[20] proprioception,[21] balance,[22] and functional kinematics[23] between patients with CAI and

82   healthy participants, as well as those that have successfully "coped" following injury.[24] However,

83   the vast majority of these tests require the use of advanced equipment including isokinetic

84   dynamometers, force plates, and motion capture systems in order to differentiate these individuals.

85   Clinical practitioners would benefit from non-instrumented clinical tests, such as functional

86   performance tests (FPTs), in order to determine the functional ability of patients with suspected

87   CAI. These FPTs have the advantage of being inexpensive, quick to administer, and accessible in

88   clinical and field settings, with examples including single-leg heel and toe raises, non-instrumented

89   balance tests, and hopping tasks. A simple outcome measurement that could include time in

90   position or to completion of a task, distance moved, or number of repetitions in a given time allow

91   for standardized measures that can be compared across patients and at numerous time points

92   throughout a patient's rehabilitation.

93   To date, investigations into FPTs in chronically unstable ankles have largely consisted of

94   hopping test that require large degrees of lateral movement, as well as non-instrumented tests of

95   balance such as the Star Excursion Balance Test (SEBT). However, a large degree of differences

96   in methodology, outcome measures, and results have served as a clear barrier towards the

97   implementation of these potentially useful tests in clinical practice.[25] A comprehensive summary

98   of the findings in this area will allow healthcare providers to make evidence-based informed

99   decisions related to functional performance testing in order to aid the diagnosis of – and track the

100   rehabilitation for – patients with CAI. Therefore, the purpose of this systematic review with meta-

101   analysis was to search the available literature to identify studies that implemented FPTs to

102   differentiate patients with CAI from healthy controls, and to perform a quantitative and qualitative

103   appraisal of the methodology and findings reported throughout these investigations. These findings

104   may, therefore, provide estimates regarding the effect sizes for varying FPTs for discriminating

105   CAI, providing guidance to clinicians regarding which tests may best be implemented in practice.

106   **Methods**

107   This systematic review and meta-analysis was completed in a manner in accordance with

108   recommendations made in the preferred reporting items for systematic reviews and meta-analyses

109   (PRISMA) statement (Supplemental document 1).[26]

110   *Data Acquisition*

111   An electronic database search was initially conducted by two of the coauthors (JK & AN)

112   on National Library of Medicine Catalog (Medline/PubMed), the Cumulative Index for Nursing

113   and Allied Health Literature (CINAHL), and SPORTDiscus, from inception to June, 2017. The

114   initial key-term search consisted of exactly: *"Functional Performance Test*"* **OR** *"Dynamic Balance*

115   *Test*"* **OR** *"Postural Stability Test*"* OR *"Star Excursion Balance Test*"* **OR** *"Hop Test*"* **AND** *"Ankle*

116   *Instability"* **OR** *"Ankle Sprain"*. Key terms searched were determined from our purpose and

117   research question, and confirmed by all investigators prior to conducting the search.

118   *Inclusion and Exclusion Criteria*

119   All articles included in the systematic review and meta-analysis met the following

120   inclusion criteria: (1) written in the English language; (2) research conducted on human

121   participants; (3) studies must utilize a functional performance test that involves hopping, landing,

122   agility and/or non-instrumented balance assessment; and (4) studies must include a group

123   comparison between patients with CAI and healthy controls. While studies would preferably

124   adhere to identifying CAI individuals in accordance with standards put forward by the

125   International Ankle Consortium[13] many articles were published prior to this criteria. Therefore,

126   participants in the experimental group must have enrolled those with a history of at least one ankle

127   sprain with subsequent complaints of "rolling" or "giving-way" identified through self-reporting

128   or use of a patient-reported outcomes, consistent with criteria related to functional or chronic ankle

129   instability.[27] Research studies were excluded if they utilized the uninjured limb as a comparison,

130   or if functional testing required instrumentation such as force platforms, electromyography and

131   other biomechanical data as primary outcome measures.

132   *Data extraction and analysis*

133   After the initial search was conducted utilizing the aforementioned key terms, duplicates

134   from across the databases were removed. The titles and abstracts were then inspected for relevance

135   to the inclusion and exclusion criteria, followed by obtaining full-text manuscripts for those

136   identified. Post-full text retrieval, manuscripts were further scrutinized for inclusion and exclusion

137   criteria and the reference lists of each were cross-checked for additional manuscripts. Consensus

138   among all the authors were then sought for the final inclusion of manuscripts.

139   Manuscripts were then evaluated separately by two authors (AR & AN) for their

140   methodological quality via the 22-item checklist for observational studies put forth by the

141   Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[27]

142   STROBE scores were averaged across all studies and assessed as a percentage. Studies were also

143   assessed for their level of evidence based on the Oxford Centre for Evidence-Based Medicine's

144   2011 guidelines.[28] Disagreements in scoring were resolved with consensus between the two

145   authors, if a situation arose where consensus was not able to be achieved, the third author was

146   consulted.

147   Numerical data extracted included the sample sizes and outcome measures for each

148   functional performance test by group. A single investigator (AR) conducted all effect size

149   calculations through Comprehensive Meta-Analysis (V3.3.070, Biostat, Inc., Englewood, NJ).

150   Effect sizes were calculated using the standardized mean difference for each of the outcome

151   measures adjusting for small sample bias (Hedges G).[29] Due to the uncertainty of evaluating a

152   homogenous population a mean effect size (Δ) was determined using a random effects model, if

153   three or more studies evaluated a similar FPT.[30] Further tests were calculated to determine if

154   heterogeneity existed by assessing the I^2 and the Q-statistics. Finally, fail safe N was determined

155   to evaluate the potential number of unpublished studies which would bring the value to a level of

156   insignificance for each of the mean effect sizes.[30]

157

158   **Results**

159   Figure 1 provides a flow chart of the article retrieval. 996 manuscripts were identified by

160   the initial search terms across the databases and after duplicate removal 479 remained. Following

161   title and abstract screening 433 articles were excluded while 46 remained and their full-texts were

162   retrieved. Seven additional manuscripts were then identified by cross-checking the reference lists

163   of the full-text manuscripts. Twenty-four of these articles were then excluded: 14 for assessing

164   only instrumented or biomechanical data, 6 not comparing against a control group, 3 not having

165   an experimental CAI group and 1 being repetitive data from a previous study. Ultimately, 29

166   manuscripts were assessed, seven were cross-sectional studies, 21 were case-control and one was

167   a randomized-control trial (Table 1). Correspondingly, the studies were deemed levels 2, 3 and 4

168   evidence, respectively. Only four disagreements in STROBE scoring were needed to be resolved

169   via consensus and most often, disagreements occurred regarding whether the experimental design,

170   participant demographics or results were stated with enough detail. The average STROBE score

171   across the evaluated studies was 17.3±1.6 out of a possible 22 (Supplementary document 2). In

172   total, 97 individual effect sizes for FPTs' were calculated, as well as 11 overall mean effect sizes.

173   Altogether, across the 29 studies 1317 participants were surveyed, with 680 participants suffering

174   from CAI and 637 control participants.

175   Pooled effect sizes were calculated for the most common FPTs which included the single-

176   limb timed hopping tests ($n=9$),[31-39] the single-limb side-hop test ($n=7$),[32,34,36-40] all directions of

177   the star-excursion balance test ($n=15$),[36, 40-53] the single-limb hop test for distance ($n=3$),[34,37,39] the

178   multiple-hop test ($n=3$),[54-56] and the foot-lift test ($n=3$).[36,40, 57] While some studies reported several

179   different timed hop tests, a single timed hop test was chosen from each available study based on

180   similarity to limit the influence of individual studies on the mean effect. The figure-of-8 hopping

181   test was the most common test ($n=6$)[32,34,36-39] included in the single-timed hopping tests mean

182   effect while the other 3 studies reported FPTs described as the single-limb hopping test,[31] hopping

183   test,[33] and single-leg jump landing test,[35] respectively.

184   The distribution for all unweighted effects calculated are seen in Figures 2, 3, 4 and

185   supplementary document 3. Mean effect and their 95% confidence intervals, tests for homogeneity

186   and fail safe N calculations are located in table 2. The single-limb side-hop ($g= -2.314$, $p=0.001$),

187   timed single limb hop tests ($g= -1.056$, $p=0.009$), multiple-hop test ($g= 1.399$, $p=0.001$) and foot-

188   lift test ($g= -0.761$, $p=0.020$) had large, significant mean effects across the included studies. While,

189   the SEBT-AM ($g= 0.326$, $p=0.022$), SEBT-M ($g=0.369$, $p<0.006$), and SEBT-PM ($g=0.406$,

190   $p<0.001$) directions demonstrated small to moderate, significant main effects. The single-hop ($g=$

191   0.033, *p*=0.859), SEBT-A (*g*= 0.264, *p*=0.051), SEBT-PL (*g*= 0.056, *p*=0.599), SEBT-AL (*g*=

192   0.246, *p*=0.116), SEBT-P (*g*= 0.232, *p*=0.137) and SEBT-L (*g*= 0.253, *p*=0.105) was not

193   significant between groups. The timed hop and side-hop tests had relatively high *Q, I²* and fail-

194   safe *N* values. Funnel plots for the single-limb hop and SEBT are located in

195   Other FPTs reported in the literature included; the agility hop test (*g*= -0.039),[58] balance

196   error scoring system (BESS) (*g*= -1.026; -0.696),[36,59] co-contraction test (*g*= -0.235), japan test

197   (*g*= 0.670),[35] shuttle run test (*g*= -0.114),[58] single-limb hurdle test (*g*= -3.748; -0.168),[31,37] six-

198   meter crossover hop test (*g*= -3.484),[32] square hop test (*g*= -13.256; -3.416),[32,37] time-in-balance

199   test (*g*= 0.898; -0.362),[36, 40] triple-crossover hop (*g*= -0.256)[39] and the up-down hop test (*g*= -

200   0.609).[34] Descriptions of individual functional performance tests are located in Table 3.

201

202   **Discussion**

203   The purpose of this systematic review with meta-analysis was to synthesize the literature

204   to determine the relative effectiveness of various FPTs in differentiating between those with CAI

205   and healthy individuals. The most effective FPTs to discriminate those with CAI, in descending

206   order based on the magnitude of the pooled effect size, are the side-hop test, the multiple-hop test,

207   timed-hop tests, foot-lift test and the three directions of the SEBT, respectively. The single-hop

208   test for distance appears to be an ineffective FPT in CAI populations, while a multitude of other

209   FPTs lacked sufficient evidence to determine effectiveness although presented promising initial

210   findings.

211   *Single-Limb Hop tests*

212   The single-limb side-hop and timed hop tests provided the best clinical utility to identify

213   those with CAI demonstrating large effect sizes. Although both tests are timed, the side-hop

214   demonstrated greater utility than other single-limb timed-hopping tests such as the figure-of-8. It

215   may be hypothesized that hopping tests that challenge an individual directly in the frontal plane

216   would provide an additional challenge for patients with CAI, than challenging individuals directly

217   in the sagittal plane The side-hop test is performed by completing 10 medial-lateral single-limb

218   hops for a total of 20 jumps as quickly as possible, a movement occurring directly in the frontal

219   plane. In comparison the timed-hop tests are typically through a course such as the figure 8 which

220   incorporates both sagittal and frontal plane aspects. Perhaps, the medial-lateral stress placed on the

221   joint is more effective to disrupt those with CAI compared to frontal plane tasks. Although no

222   studies have quantified the direct stress on the lateral ligament complex during these tasks, it has

223   been revealed that the side hop requires a significant amount of peroneus longus activation, of

224   which patients with CAI may be deficient. Nonetheless both appear to be effective at

225   discriminating those with CAI.[60,61]

226   However, of some concern pertaining to the side-hop and timed hop tests is the funnel plots

227   (Figures 5 and 6, supplemental documents 4, 5 and 6) and the heterogeneity statistics analyses

228   indicate there may be some variations among the included studies. Driving these values was a

229   study by Sharma et al.,[37] which had significant influence on the mean effect size. Although this

230   study substantially influenced the effect sizes, when removing this particular outlier, the mean

231   effect size for both tests remain moderate-large and significant (side-hop: $g=$ -1.444, $p=.022$;

232   timed-hop: $g=$ -0.446, $p=.027$). It's difficult to ascertain why this study in particular had such a

233   massive individual effect size; however, one possible explanation is that the authors dichotomized

234   their instability group by those with CAI who reported giving way during the test, and those who

235   did not.[37] The group reporting giving way was used for the meta-analysis and perhaps this drove

236   the large effect sizes. Thus, utilizing FPTs in those with CAI with those who report feeling unstable

237   during their performance may be much more likely to identify those with CAI compared to their

238   healthy counterparts or those who self-report CAI yet fail to report instability during the FPT.

239   Several other hopping tests may also provide adequate discriminative ability yet have only

240   been reported by one or two studies. The single-limb hurdle test, six-meter crossover hop test,

241   square hop test and up-down hop test also demonstrated moderate-large individual effect sizes.

242   Each of these tests are similar to the timed-hop tests, as they each require the participants to

243   perform a task or course as fast as they can on a single-limb. The greatest differences exist

244   regarding the amount of vertical, lateral, or forward movement across tasks. However, the relative

245   effectiveness of these tasks, although less studied than the single-limb side-hop or figure-of-8,

246   suggest that tests that require components of speed, power, and agility in a combination of planes

247   will serve to differentiate patients with CAI. These findings are consistent with several theories

248   behind CAI that suggest a multifaceted problem affecting multiple functional abilities [61,62]. Thus,

249   including a timed-hop test such as the side-hop or figure-of-8 test during evaluation of individuals

250   with CAI is valid and appropriate.

251   Interestingly based on the results of the meta-analysis the single-hop jump for distance

252   does not differentiate those with CAI from healthy controls. The single-hop jump is much different

253   than the timed-hop and side-hop jump testing due to the fact it assesses and requires greater

254   muscular strength and power rather than speed and agility. While interesting, this negative result

255   is rather unsurprising due to the evidence regarding the role of ankle strength in CAI is widely

256   disputed and equivocal.[64-68] Furthermore, this test stresses the joint primarily in the sagittal plane,

257   rather than the frontal and transverse planes that would be more difficult for patients with CAI.

258   Similarly, another primarily uniplanar test which was studied by only one group, the triple-

259   crossover hop test demonstrated a small effect size. The triple-crossover hop test like the single-

260   limb hop for distance requires participants to jump as far as possible, but in this test it is the

261   maximum distance after three jumps across a 15cm line. Although the incorporation of a crossover

262   adds a lateral component, the test outcome is primarily the distance advanced in the forward

263   direction. Therefore, utilizing FPT's in those with CAI which require muscular power within the

264   sagittal plane seems to be ineffective compared to agility-based hopping tests.

265   A third class of hopping tests observed in this review were those requiring individuals to

266   hop across a pattern, scoring individuals on "errors" rather than a measure of time or distance. The

267   multiple-hop test across three studies demonstrated a large pooled effect with the rest

268   demonstrating conflicting results according to effect size calculations. Although similarly

269   requiring the functional ability of muscle strength, power, and agility to perform hops, an

270   additional component of postural stability is added by scoring individuals on their ability to "stick"

271   a landing. While intriguing, this does require a degree of subjectivity for the assessor that may

272   serve to bias results. Similar measures exist throughout the CAI literature using instrumented

273   measures derived from force plates. Moderate evidence exists establishing diminished postural

274   control during hopping as quantified through the dynamic postural stability index.[69-72] However,

275   this measure relies on precise force calculations with differences between uninjured and injured

276   individuals often not grossly visual to an assessor. As conflicting results exist using non-

277   instrumented measures, additional studies are necessary to determine the ability of FPTs using

278   error systems during hop landing to discriminate between healthy and CAI individuals.

279   *Balance Tests*

280   The SEBT, depending on the direction also provides adequate discriminative ability

281   between those with without CAI. The anteromedial, medial and posteromedial directions each

282   demonstrated moderate mean-effect sizes, however the anterior and posterolateral were small and

283   considered unimportant. Based on these results, those with shorter anteromedial, medial and

284   posteromedial reach distances are more likely to have CAI. This could potentially be explained by

285   considering the shifts in the center of gravity occurring through reaches in medial direction,

286   causing tensile forces to be applied on the lateral ankle. A previous systematic review has also

287   been completed on the SEBT;[73] however, the authors chose not only CAI, but other pathologies

288   such as ACL injuries. Additionally, studies were included that assessed the injured compared to

289   uninjured limbs as well as CAI compared to controls. While the authors similarly concluded the

290   SEBT was an effective FPT in those with CAI, their study did not re-synthesize data to determine

291   mean effects, nor was their main purpose to identify the differences in the SEBT across CAI

292   populations. Based on the current results, not all directions of the SEBT have similar prognostic

293   ability as the anteromedial, medial and posteromedial directions provided the best clinical utility.

294   While this is not a particularly new finding, some previous studies have attempted to address this

295   by simplifying the SEBT to the Y balance test, which includes only the anterior, posteromedial

296   and posterolateral directions.[74,75] However, it appears that the anterior direction may not be as

297   sensitive enough to differentiate between controls and CAI and clinicians should consider the

298   anteromedial, medial and posteromedial directions specifically for individuals with CAI.

299   Balance and postural control deficits are often described in those with CAI, which could

300   potentially contribute to functional performance deficits observed during the SEBT.[50,70,72,76,77]

301   While the SEBT is considered a dynamic postural control task, requiring movement of the body

302   over a stationary base of support, additional clinical tests are used to assess static postural control.

303   The foot-lift test (counting the number of times a part of the foot lifts off the ground) appears to

304   be an adequate discriminating test, while the time-in balance[36] also demonstrated large effects in

305   a single-study. The BESS – an error system identifying gross instability during 3 to 6 stance

306 conditions – was reported in two studies[36,59] and demonstrated a moderate-large effect size

307 between CAI and control participants. These findings suggest that FPTs requiring an individual to

308 maintain static postural control is able to yield similar results as seen in studies using advanced

309 equipment such as force plates.

310   No studies provided a direct comparison between abilities of hopping tests and balancing

311 tests in discriminating CAI. As previously stated, these assess different components of ankle

312 function with the former addressing muscular strength, power, and agility and the latter assessing

313 proprioception and neuromuscular control. Given these different components, it may be

314 recommended that both hopping and balance based measures be included in the assessment of

315 patients with CAI. While these would combine yield very high effect sizes and a strong ability to

316 predict functional instability in these patients, there are additional components that should be

317 considered. Dorsiflexion deficits are consistently observed in those with CAI.[78-80] To some extent,

318 this may be assessed through the anterior reach of the SEBT, as a recent study found that

319 dorsiflexion range of motion, eversion strength and time-to-boundary contributed most to SEBT

320 reach distances.[77] However, further studies assessing dorsiflexion range-of-motion through simple

321 tests such as the weight-bearing lunge should be considered.[79]

322 *Limitations*

323   The included studies in the systematic-review were case-control and cross-sectional

324 studies, described as level IV and III evidence, respectively, indicating limited methodological

325 quality. In addition, the average STROBE score indicates relative consistency in the

326 methodological quality of the evidence. With a maximum of 22, the average score as a percentage

327 was $78.6 \pm 7.3\%$. The two most common faults were no indication of addressing sources of bias,

328 including blinding procedures as well as providing a sample size justification. Other notable

329   sources of demerits included providing information relating to distributive statistics, funding

330   sources and indications of study design early in the manuscript. Improving methodological quality

331   and study design stands to greatly improve FPT evidence. Due to these differences in reporting

332   only pooled effect sizes were able to be calculated as opposed to cut-off scores for individual tests.

333   Future studies, may want to better identify and address systematic ways to improve the quality of

334   manuscripts in order to elevate the literature.

335   Across the studies there were also inconsistent reporting of inclusion and exclusion criteria

336   making comparisons difficult. In 2013, recommendations put forth by International Ankle

337   Consortium established guidelines for reporting populations of individuals with CAI; however,

338   many of these studies pre-dated these recommendations and therefore did not provide information

339   necessary to understand these populations. One notable point of caution that should be added is

340   that most of the studies included in the analysis were conducted on relatively physically active

341   individuals. This is because most of the research on CAI is conducted by sports medicine

342   specialists. Whether these results apply to more sedentary populations is unknown. Thus,

343   additional CAI research may want to focus on non-physically active populations. It remains

344   possible that different measures may better apply to different populations.

345   Other limitations include the sample size of both the included studies and the total number

346   of studies included in this meta-analysis. The sample sizes of the studies themselves limit their

347   statistical power and generalizability of the effects found. Larger samples would provide superior

348   evidence for the use of FPTs in those with CAI. The total number of studies also limits the effects

349   of this meta-analysis. As reported, many of the FPTs have only been assessed in one or two limiting

350   the ability to perform a meta-analysis on those individual tests. Additionally, pertaining to the

351   SEBT anteromedial and posteromedial directions the estimates for the fail-safe N calculations

352   indicate publication bias may be present with four additional publications necessary to negate the

353   present results.[81] Although this is concerning for the SEBT, the fail-safe N calculations for the

354   timed-hop and side-hop calculations are very high, indicating strong, stable effect sizes. This

355   provides evidence more studies with larger samples need to be conducted in order to properly

356   evaluate the alterations in muscle activation strategies during jump landing activities in those with

357   CAI.

Conclusions

359   Level B evidence exists suggesting that the side-hop, timed-hopping, multiple-hop tests

360   and foot-lift test are able to discriminate between those with CAI and healthy individuals. Level B

361   evidence also exists suggesting that the medial, anteromedial, and posteromedial components of

362   the SEBT are similarly able to differentiate. While a multitude of additional tests exist presenting

363   a wide range of effect sizes, it appears that those tests that include timed measures of lateral

364   hopping, and those quantifying balance may have clinical utility. Recent evidence suggests

365   combining the results of multiple FPTs has greater clinical utility than singular tests.[40] Specifically,

366   a combination of a version of the side-hop test and SEBT displayed the greatest clinical utility.

367   However, limited research is available to corroborate additional tests and a more comprehensive

368   assessment of FPT's may be necessary to determine the best combination of FPTs to assess CAI.

369   These tests present an advantage to clinicians aiming to address functional deficits in

370   patients with CAI as they are cheap, effective alternatives compared to instrumented measures.

371   However, further research is necessary to aid in the full implementation of these tests clinically.

372   Greater sample sizes and study volume would improve upon evaluation methods and decrease

373   publication bias in order to more appropriately determine clinical measures to assess those with

374   CAI. Furthermore, consistency in test implementation must be encouraged in order to calculate

375   precise protocols and cut-off scores that may improve clinical utility. Lastly, it remains largely

376   unknown in which ways current treatment methods may serve to modify these values, affecting

377   the implementation of these measures through patient rehabilitation.

378

379

380   References

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