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**Classification of Lower Extremity Movement Patterns Based on Visual
Assessment: Reliability and Correlation to Two Dimensional Video Analysis.**

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1 **Abstract**

2 **Context:** Abnormal movement patterns have been implicated in lower extremity injury.
3 Reliable, valid, and easily implemented assessment methods are needed for the
4 examination of existing musculoskeletal disorders and the investigation of predictive
5 factors of lower extremity injury.

6 **Objectives:** To determine the reliability of experienced and novice testers in making
7 visual assessments of lower extremity movement patterns and to determine construct
8 validity of the visual assessments.

9 **Design:** Methodological study

10 **Setting:** University athletic department and research laboratory

11 **Participants:** Convenience sample of 30 undergraduate and graduate students who
12 regularly participate in athletics (19.3±4.5 years). Testers: Two experienced physical
13 therapists and one novice, post-doctoral fellow (non-clinician).

14 **Main Outcomes:** Videos of 30 athletes performing single leg squat (SLSquat) were
15 used. Three testers observed the videos on two separate occasions and classified the
16 lower extremity movement as Dynamic Valgus, No Change or Dynamic Varus.
17 Classifications were based on the estimated change in frontal plane projection angle
18 (FPPA) of the knee from single leg stance to maximum single leg squat depth. The
19 actual FPPA change was measured quantitatively. Percentage agreement and weighted
20 kappa were used to examine tester reliability and to determine construct validity of the
21 visual assessment.

22 **Results:** Kappa values for intra- and intertester reliability ranged from 0.75-0.90,
23 indicating substantial to excellent reliability. Percent agreement between the visual
24 assessment and the quantitative FPPA change category was 90% with a kappa value of
25 0.85.

26 **Conclusion:** Visual assessments can be made reliably by experienced and novice
27 testers. Additionally, movement pattern categories based on visual assessments were
28 in excellent agreement with objective methods to measure FPPA change. Visual
29 assessments may be used in the clinic to assess movement patterns associated with
30 musculoskeletal disorders and in large epidemiologic studies to assess the association
31 between lower extremity movement patterns and musculoskeletal injury.

32 **Key Words:** movement analysis, lower extremity, screening, knee valgus

33

34 INTRODUCTION

35 Abnormal movement patterns of the lower extremity have been implicated in noncontact
36 anterior cruciate ligament (ACL) injuries¹ and other musculoskeletal pain problems such
37 as patellofemoral pain²⁻⁴ and acetabular labral tears.⁵ In addition, correction of these
38 abnormal movement patterns has been shown to prevent ACL injury⁶ and is proposed
39 to reduce symptoms in people with pre-existing pain conditions.^{5, 7, 8} Thus, assessment
40 of lower extremity movement patterns may provide an approach to guide treatment of
41 existing musculoskeletal pain problems and to identify people at risk for future injury or
42 musculoskeletal pain. To facilitate the examination of existing musculoskeletal disorders
43 and the investigation of predictive factors of lower extremity injury, reliable, valid and
44 feasible methods to assess lower extremity movement patterns are needed.

45 One method to assess lower extremity movement patterns is the Landing Error Scoring
46 System (LESS).⁹⁻¹¹ The LESS uses a standard technique to make visual assessments
47 of movement patterns during a drop vertical jump. The LESS has been shown to be
48 reliable and valid,⁹⁻¹¹ however the drop vertical jump is a relatively high level activity that
49 may not be the best approach to assess movement patterns in patients with existing
50 injury or in athletes who participate in sports that do not involve landing from a jump. In
51 addition, the drop vertical jump is a bilateral activity that may allow the participant to use
52 one limb to compensate for the other. Visual assessment of the single leg squat, a
53 unilateral limb task, may provide an alternative to the LESS.

54 We have developed standardized methods using a visual assessment of the frontal
55 plane projection angle (FPPA) to classify the lower extremity movement pattern during a

56 single leg squat (SLSquat). The FPPA is a 2 dimensional (2D) representation of the
57 lower extremity position¹² that has been used to identify differences between women
58 with patellofemoral pain and controls,^{4, 13} between men and women¹² and for detecting
59 change in movement patterns after specific training.¹⁴ We established specific criteria to
60 define the categories of lower extremity movement pattern based on the change in
61 FPPA (FPPA change) during motion. The tester observes the angle formed between a
62 line that bisects the thigh and a line that bisects the lower leg. During movement tests,
63 the tester compares the FPPA at the start position and to the FPPA at the end position.
64 For example, to assess a single leg squat, the examiner compares the FPPA during the
65 start position of single leg stance to the end position of maximum squat depth. The
66 difference observed in FPPA from the start to the end position can then be classified
67 into one of three categories, No Change, Dynamic Valgus defined as change in the
68 valgus direction or Dynamic Varus defined as change in the varus direction. We have
69 used this assessment extensively in the clinical setting, however we have not assessed
70 the rater reliability or the construct validity of our visual assessments.

71 The purpose of this study was to assess the intratester and intertester reliability of three
72 testers, two experienced and one novice, categorizing the lower extremity movement
73 pattern demonstrated during a SLSquat. A standardized protocol was used to assess
74 videos of healthy participants performing the SLSquat movement. We hypothesized the
75 testers, both experienced and novice, would demonstrate good to excellent reliability
76 using the standardized methods. In addition, we used the objective measure of
77 quantifying FPPA as described by Willson¹² to determine the construct validity of our

78 visual assessments. We hypothesized that we would demonstrate good to excellent
79 agreement between our visual assessments and the quantitative FPPA change.

80 **METHODS**

81 **Participants**

82 This study was approved by the Human Research Protection Office of *Blinded*.

83 Participants in this study were a subset from a prospective cohort study developed to
84 assess risk factors for athletic injury. The cohort was a convenience sample including
85 both undergraduate and graduate students who regularly participated in athletics. All
86 participants were 18 years of age or older and were recruited to participate in the
87 longitudinal study that included a focused examination of hip range of motion, hip
88 muscle strength, provocative tests to assess for hip joint pathology and movement
89 pattern assessment. As part of the study, participants were videotaped performing a
90 SLSquat. Data collection occurred over a period of two years. Participants with an
91 existing injury that limited their ability to perform the examination items were excluded.
92 All participants read and signed an informed consent statement approved by Human
93 Research Protection Office of *Blinded* before participating in the study.

94 **Movement Task Description and Video Taping Procedures**

95 A standardized method was used to collect videos of the SLSquat. A digital camera
96 (Sony Cyber-shot DSC-w100; Sony, Tokyo, Japan) was placed on a tripod at the level
97 of the participant's knee and approximately two meters anterior to the participant.¹² The
98 image taken included the participant's feet to the mid-thoracic region throughout the

99 entire movement. To eliminate the effect of shoe wear on limb movement, the
100 participant removed their shoes prior to testing.
101
102 A research assistant instructed the participant in the movement and performed the
103 video capture. The research assistant described and demonstrated the SLSquat to the
104 participant. The research assistant stood next to rather than in front of the participant
105 while demonstrating the movement so the participant could observe the appropriate
106 depth of the squat, however could not observe the pattern of lower extremity motion in
107 the frontal plane. The participant was instructed to start with their arms across their
108 chest and their weight distributed evenly on both feet. When cued to move, the
109 participant raised their untested limb by flexing the knee while maintaining the hip in 0°
110 of extension. The participant then performed the SLSquat and returned to the standing
111 positioning with weight distributed evenly on both feet. The participant was encouraged
112 to squat as far as they could comfortably. If the participant did not reach a minimum of
113 60° of knee flexion, as judged visually by the research assistant, they were instructed to
114 increase the depth of the squat.
115 After instruction, the participant was allowed to practice the movement until they felt
116 comfortable with their performance. If the participant required more than three
117 repetitions for practice, they were allowed 2-3 minutes to rest prior to video capture.
118 Once the participant was comfortable with the movement, one movement was recorded.
119 The video was collected from standing with both feet on the ground, through the
120 SLSquat movement and back to initial standing position. The recording was repeated if
121 the participant lost their balance during the movement or if the research assistant

122 determined that the squat was not of sufficient depth. Loss of balance was defined as
123 the participant 1) placed their untested limb on the ground before completion of the
124 movement, 2) demonstrated extraneous movement of the upper extremities, 3) trunk
125 lean that resulted in excessive motion of the untested limb 4) moved the stance limb by
126 either sliding, hopping or twisting the stance foot. The participant then repeated the
127 process on the opposite limb, yielding one recording of one trial for each limb for each
128 subject.

129 **Video Selection for Reliability**

130 Over six testing sessions, 140 movements (70 participants) were collected for the
131 ongoing longitudinal study. From the 140 videos, a second research assistant (XX) not
132 involved in the original video recordings or the visual assessment selected the videos to
133 be used for reliability testing. The research assistant, who had minimal knowledge of the
134 movement patterns of interest, was instructed to select videos that included variable
135 movements. The research assistant was also instructed to exclude videos based on the
136 following criterion: the squat did not appear to achieve knee flexion of 60° or the
137 participant lost his/her balance during the testing. A total of 30 videos of 30 participants
138 one limb only, were selected for reliability testing. Of the 30 subjects, 18 were male and
139 12 were female with average age of 19.3 ± 4.5 and BMI of 23.8 ± 3.6 . To reduce the
140 likelihood of tester recall, the research assistant assigned a dummy code to each video
141 and randomly ordered the videos for each testing session. Compact discs were
142 developed and distributed to each tester along with written instructions for performance
143 of the visual assessment and a data collection sheet for each testing session.

144 **Testers**

145 Three testers participated in the study. The first tester (experienced) (XXX) is a board-
146 certified clinical specialist in orthopaedic physical therapy and has 13 years of clinical
147 and research experience. The second tester (experienced) (XXX) is a physical therapist
148 with 24 years of clinical and research experience specific to the lower extremity. The
149 third tester (novice) (XXX) is a post-doctoral fellow who has four years of research
150 experience, only one of these years specific to musculoskeletal assessment and no
151 clinical background. The first and second testers were involved in method development
152 and standardization of the movement assessment. The third tester was trained by the
153 second tester. Training included review of a written manual describing the criteria for
154 group classification, followed by observing and discussing 8-10 practice videos
155 together.

156 **Visual Assessment Procedures**

157 On two separate occasions, each tester viewed the selected videos and classified the
158 movement pattern demonstrated by each participant. To reduce the likelihood of tester
159 recall, a minimum of one week occurred between the two testing sessions. No
160 discussion of the testing procedures or the classification criteria occurred during the
161 testing.

162 Each tester classified the movement pattern using methods developed. For each video,
163 they compared the FPPA in single leg stance (start position) to the FPPA at the
164 maximum depth of the squat movement (end position). Based on her visual appraisal,
165 the tester determined if the FPPA changed more than 10° from the start position to the
166 end position. We used the 10° criteria, because during the development of our methods,

167 we found a 10° change to be easily detectable by visual appraisal. If the angle did not
168 change more than 10°, the movement was classified as “No Change”. If the angle
169 changed more than 10°, the tester also determined if the knee moved toward or away
170 from the midline of the body. Movement toward the midline was classified as “Dynamic
171 Valgus” and movement away from the midline was classified as “Dynamic Varus”
172 (Figure 1).

173 Each tester was allowed to view each video as often as she needed, however was not
174 allowed to stop or slow down the rate of the video. In addition, she was not allowed to
175 measure the angle using imaging software or goniometric devices.

176 **Objective Measurement Procedures**

177 The videos were also used to obtain objective 2D measures of the FPPA change. The
178 research assistant who selected the videos performed all measurement methods. Using
179 a free and open source program, VLC media player (VideoLAN non-profit organization,
180 Paris, France) snapshots were obtained by capturing still frames of the video at the start
181 position and end position. The start position was defined as the frame when the
182 participant had placed all of their body weight on the tested limb and just before the
183 tested knee started to flex. The end position was defined as the frame when knee had
184 flexed maximally and just before the tested knee started to extend.

185 Google SketchUp version 7.1 (Google Inc, Mountain View, CA) was used to perform the
186 angle measurements on the captured snapshots. For each start and end position, two
187 lines were drawn to represent the FPPA, one that bisected the thigh and one that
188 bisected the lower leg (Figure 1). The 360° protractor function in Google SketchUp was

189 used to measure the angle formed by the two lines. Precision was set to 1/10 degree.
190 The FPPA change was determined by subtracting the start FPPA from the end FPPA.
191 Positive values represented movement of the knee toward the midline and negative
192 values represented movement of the knee away from the midline. To assess the
193 intratester reliability of the FPPA change, fifteen videos were measured a second time,
194 two weeks following the first measurement session. The measurement reliability was
195 high, ICC_{2,1} was .98 (95% CI: .95-.99) with standard error of measurement (SEM) (95%)
196 of 1.79° (95% CI: 3.58°).

197 Quantitative FPPA change based on the objective measures were categorized as
198 follows: values less than or equal to 10° in the either negative or positive direction were
199 categorized as No Change; > 10° in the positive direction were categorized as Dynamic
200 Valgus; > 10° in the negative direction were categorized as Dynamic Varus.

201 The group classification from the first session of the two experienced testers was used
202 to compare the quantitative FPPA change. In cases where the two testers agreed, the
203 agreed upon classification was used. In the two cases where the testers disagreed, a
204 third expert was consulted to determine the final classification. This consensus rating is
205 considered our best estimate of the “true” condition.

206 **Statistical Analysis**

207 Statistical analysis was completed using SAS version 9.1 of the SAS System for Linux
208 (SAS Institute Inc. Cary, NC). Descriptive statistics were calculated for demographics.
209 Percentage of observations yielding perfect agreement (i.e., percent agreement) and
210 weighted kappa coefficients¹⁵ with 95% confidence intervals (CIs) were used to examine

211 the intratester and intertester reliability of the visual assessment classification and to
212 compare the visual assessment category to the quantitative FPPA change category
213 based on the objective measures. We used weighted kappa coefficients to represent
214 the fraction of agreement beyond that expected by chance, and account for the
215 magnitude of the disagreement between readings. Intratester agreement statistics were
216 reported comparing session one and session two readings of each tester. Intertester
217 agreement statistics were reported comparing session one classifications across
218 testers. P value < .05 was considered significant.

219

220 **RESULTS**

221 The percentage agreement and tester reliability of the visual assessment classification
222 are provided in Table 1. Weighted kappa values ranged from 0.80-0.90 for intratester
223 reliability and from 0.75-0.90 for intertester reliability, indicating substantial to excellent
224 reliability.¹⁶ Table 2 represents the number of participants classified as Dynamic Valgus,
225 No Change, and Dynamic Varus for each tester's session one and session two
226 readings. Table 3 represents the number of participants classified by each pair of
227 testers.

228 The percentage agreement between the visual assessment category and the
229 quantitative FPPA change category was 90% (95% CI: 78-100%) with a weighted kappa
230 of 0.85 (95% CI: 0.69-1.0) (Table 4).

231 **DISCUSSION**

232 The goal of this study was to assess the reliability of experienced and novice testers in
233 making visual assessments of lower extremity movement patterns during a SLSquat
234 and to determine the construct validity of our visual assessments compared to a
235 quantitative measure of FPPA change. We hypothesized that the testers, both
236 experienced and novice, would demonstrate good to excellent reliability using the
237 standardized methods and that movement pattern categories based on visual
238 assessments would be in good to excellent agreement with categories based on the
239 quantitative FPPA change. Both hypotheses were supported.

240 We have demonstrated that visual assessments can be made reliably by testers of
241 variable experience levels when standardized methods are used. In addition, there was
242 substantial agreement between the visual assessment and the quantitative FPPA
243 change category. The standardized criteria used during the visual assessments to
244 determine classifications of lower extremity movement patterns requires minimal
245 training. Thus, it would be feasible to use visual assessment in the clinic to identify and
246 treat movement-related musculoskeletal disorders and in large research studies to
247 assess the association between lower extremity movement patterns and
248 musculoskeletal injury.

249 Our study builds upon previous studies that report tester reliability of movement
250 assessment specific to the lower extremity.¹⁷⁻²⁰ One of the earliest studies to assess
251 SLSquat was performed by Chmielewski et al.¹⁸ The authors reported low reliability
252 (weighted kappa: 0-0.55) among three experienced testers when assessing SLSquat.
253 From their experience, they hypothesized that reliability would likely improve with
254 standardized methods that provided specific criteria to assist with decision making. We

255 believe the standardization and inclusion of strict criteria to define each classification
256 has resulted in our high levels of agreement. The testers in our study were provided
257 standard instruction to determine FPPA (bisection of thigh and lower leg), specific timing
258 of FPPA visualization (single leg stance and maximum depth of squat) and quantitative
259 value of FPPA change (10°) to make their visual assessment.

260

261 Ekegren et al²¹ reported substantial reliability among experienced testers assessing a
262 different task, the drop vertical jump. They also used different criteria to classify lower
263 extremity movement pattern. While our decisions focused on the motion of the thigh
264 relative to the lower leg, Ekegren et al²¹ used the relationship of the patella to the big
265 toe. They classified the lower extremity movement pattern as follows: “if the patella
266 moves inward and ends up medial to the first toe, rate the individual as high risk [for
267 ACL injury] or if the patella lands in line with the first toe, rate the individual as low risk
268 [for ACL injury]”. Similar to our study, they reported high reliability (kappa coefficients
269 0.75-0.85), however we believe our methods more directly represent the relationship of
270 the lower leg to the thigh during the SLSquat. During initial method development, we
271 attempted to use the criteria reported by Ekegren et al.²¹ We found, during performance
272 of SLSquat, the patella would often end in line with the first toe, however the end
273 position of the knee appeared to be in dynamic valgus position. This may suggest that
274 use of the patella is appropriate for the drop vertical jump test, however our methods
275 may be more suited for visual assessment of the SLSquat.

276

277 Other studies have reported on the tester reliability of a score representing the
278 movement pattern of the trunk, pelvis and lower extremity combined.^{9, 11, 20} In each of
279 these studies, explicit criteria were provided to assess the combined movement.
280 Crossley et al²⁰ reported substantial to excellent reliability (kappa: 0.60-0.80) among
281 experienced testers assessing a SLSquat. Padua et al⁹ used the LESS to assess the
282 drop vertical jump and reported the intertester reliability to be good (ICC_{2,k}: 0.84).
283 Although movements of the lower extremity were observed for the combined score, the
284 authors of these studies did not assess the reliability of testers specifically judging the
285 movement pattern of the lower extremity. Assessing the combined movement quality
286 may be useful, however the assessment of the lower extremity may provide more
287 specific information for lower extremity disorders.

288 We have demonstrated that a tester with minimal experience assessing lower extremity
289 movement patterns may classify movements reliably if provided with training and
290 specific criteria to determine the classifications. To our knowledge, this is the first study
291 to report the reliability of a novice tester categorizing lower extremity movement patterns
292 during a single leg squat. Onate et al¹¹ reported excellent expert versus novice
293 intertester reliability using the LESS to assess a drop vertical jump, thus supporting our
294 findings that a novice tester may reliably assess lower extremity movement patterns.
295 Our methods may be used by coaches during preseason screening to assess
296 movement patterns of athletes or by healthcare providers to identify those who may
297 benefit from specific treatment to address impaired movement patterns. In addition, use
298 of our methods may improve our ability to prospectively assess the relationship between

299 movement patterns and musculoskeletal injury by increasing the number of testers that
300 may be used during screening studies.

301 The testers did not demonstrate perfect agreement in the lower extremity movement
302 pattern classifications. In review of the data, the novice tester was more likely to classify
303 a movement pattern as Dynamic Valgus, than the experienced testers. This may have
304 important implications. If the test is used as a screening assessment to identify those
305 athletes at risk for injury, the assessments made by the novice tester would result in a
306 greater number of athletes identified as “at risk”. This would result in athletes receiving
307 additional training or treatment that may not be necessary. If the risk or cost of
308 treatment is high relative to the possible benefits, an experienced clinician may be
309 preferred. However, the novice tester’s intratester reliability was high suggesting that
310 novice testers may serve as the initial screener to identify individuals to be referred to
311 an experienced clinician for a more thorough movement pattern assessment.

312 We have also demonstrated that movement pattern categories based on visual
313 assessments are in excellent agreement with categories based on the quantitative
314 FPPA change category. This is the first study to report on three movement pattern
315 categories. Previous studies have focused primarily on the dynamic knee valgus^{4, 19-21}
316 as a potential risk factor for injury and labeled all other lower extremity movements as
317 “good” or “low risk for injury”. We have reported a third classification, a varus-like
318 movement pattern that may be described as a dynamic knee varus. There are no
319 studies to implicate a dynamic knee varus as a risk factor for injury, however varus
320 alignment of the knee has been implicated in the progression of osteoarthritis.²² The
321 association between a varus alignment and progression of osteoarthritis suggests that it

322 may be important to identify a dynamic knee varus in future studies. Dynamic knee
323 varus may be a risk factor that has yet to be identified, and therefore should be further
324 explored. In addition, excluding dynamic knee varus from the “good” or “low risk for
325 injury” categories may provide a more homogenous group of participants who are
326 classified as having no deviation.

327 Our study findings should be considered in light of several limitations. The first limitation
328 pertains to the criteria used to determine the Dynamic Valgus or Dynamic Varus
329 classification. We do not know if an FPPA change greater than 10° is associated directly
330 to injury or musculoskeletal pain. Based on our clinical experience with people reporting
331 hip or knee pain, we have found that people who demonstrate Dynamic Valgus during a
332 single leg squat often report an increase in their pain. If the Dynamic Valgus is
333 corrected, this pain often reduces or abolishes. We therefore felt it important to
334 standardize this test and assess its reliability and validity. As stated previously, during
335 the development and refinement of our methods, we found a FPPA change to be
336 representative of the lower extremity movement pattern that we were observing
337 clinically and that 10° was easily detected by our visual assessment. Future studies with
338 larger sample sizes, however are needed to assess the sensitivity, specificity and
339 predictive values associated with our methods.

340 We have not validated our visual assessments using laboratory-based three
341 dimensional (3D) motion analysis, the gold standard for movement pattern assessment.
342 We instead compared our visual assessment to 2D projection angles using video
343 recordings. Projection angles, while not a direct substitute for 3D angles,¹⁴ have been
344 shown to be correlated to 3D angles.²³ We believe our methods were a reasonable first

345 step to validation that can be easily replicated in clinical settings where 3D motion
346 analysis is not available. Comparison of our visual assessments to 3D motion is needed
347 and is the focus of our next study.

348 We did not standardize the SLSquat for depth or speed, however this is typical of
349 clinical practice. Variations in either squat depth or speed may affect the angle changes
350 measured and observed. The testers, however were able to determine the
351 classifications of the lower extremity movement patterns with substantial to excellent
352 reliability despite this variability. This limitation is being addressed in our current study
353 where the depth of the squat is standardized and the time to complete the movement is
354 being collected as a covariate.

355 To assess tester reliability, we used a video recording of one SLSquat that could be
356 viewed by each tester multiple times. Using a video recorder would not be feasible in
357 clinical practice, however our methods for visual assessment may be used by the
358 clinician to observe one or multiple movements performed by their patient. We chose to
359 use the video recordings to reduce the variability in the participant's performance. The
360 participant's performance of the SLSquat may vary across testing sessions, resulting in
361 different movement patterns being assessed during the two sessions, thus limiting our
362 ability to accurately assess tester reliability. We therefore used one video recording so
363 the participant's performance would remain stable across testing sessions.

364 We did not assess test-retest reliability by observing participants on multiple occasions.
365 Test-retest reliability would be important, particularly if lower extremity movement
366 assessment were to be implemented as an outcome measure for treatment. Stensrud et

367 al¹⁹ reported fair to moderate test-retest reliability when one tester assessed SLSquat,
368 however the criteria to classify the movement pattern was not as specific as those
369 outlined in the current study. We believe use of our standardized methods will improve
370 upon the test-retest results previously reported. Future work will include movement
371 testing performed by the participants on multiple occasions.

372 **CONCLUSION**

373 With training and use of standardized techniques, testers both experienced and novice
374 can reliably classify lower extremity movement patterns based on visual assessment.
375 Although experience testers demonstrate higher intertester reliability, reliability between
376 the novice and experienced testers was substantial, indicating novice testers may be
377 used initial screening programs. Additionally, movement pattern categories based visual
378 assessments were found to be in excellent agreement with objective methods to
379 measure FPPA change. Visual assessment may be used in the clinic to categorize
380 movement patterns that may be associated with musculoskeletal disorders, and in large
381 epidemiologic studies to assess the association between lower extremity movement
382 patterns and musculoskeletal injury. Future studies are needed to determine if an
383 association exists between the identified movement patterns and musculoskeletal
384 disorders.

385

386 **KEY POINTS**

- 387 • With training and use of standardized techniques, testers both experienced and
388 novice reliably classified lower extremity movement patterns based on visual
389 assessment.

- 390
- Movement pattern categories based visual assessments were in excellent
- 391 agreement with objective methods to measure FPPA change.
- Visual assessment based on the methods described in this study may be used in
- 392 the clinical setting, as well as large epidemiologic studies and large screening
- 393 assessments for sport participation to identify distinct categories of lower
- 394 extremity movement pattern.
- 395

396

397

- 399 1. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular
400 control and valgus loading of the knee predict anterior cruciate ligament injury
401 risk in female athletes: A prospective study. *Am J Sports Med.* 2005;33(4):492-
402 501.
- 403 2. Willson JD, Binder-Macleod S and Davis IS. Lower extremity jumping mechanics
404 of female athletes with and without patellofemoral pain before and after exertion.
405 *Am J Sports Med.* 2008;36(8):1587-1596.
- 406 3. Powers CM. The influence of altered lower-extremity kinematics on
407 patellofemoral joint dysfunction: A theoretical perspective. *J Orthop Sports Phys
408 Ther.* 2003;33(11):639-646.
- 409 4. Levinger P, Gilleard W and Coleman C. Femoral medial deviation angle during a
410 one-leg squat test in individuals with patellofemoral pain syndrome. *Phys Ther
411 Sport.* 2007;8:163-168.
- 412 5. Austin AB, Souza RB, Meyer JL and Powers CM. Identification of abnormal hip
413 motion associated with acetabular labral pathology. *J Orthop Sports Phys Ther.*
414 2008;38(9):558-565.
- 415 6. Hewett TE, Lindenfeld TN, Riccobene JV and Noyes FR. The effect of
416 neuromuscular training on the incidence of knee injury in female athletes. A
417 prospective study. *Am J Sports Med.* 1999;27(6):699-706.
- 418 7. Harris-Hayes M, Sahrman SA, Norton BJ and Salsich GB. Diagnosis and
419 management of a patient with knee pain using the movement system impairment
420 classification system. *J Orthop Sports Phys Ther.* 2008;38(4):203-213.
- 421 8. Sahrman SA. Diagnosis and treatment on movement impairment syndromes.
422 *Mosby, Inc;* 2002.
- 423 9. Padua DA, Boling MC, Distefano LJ, Onate JA, Buetler AI, Marshall SW.
424 Reliability of the landing error scoring system-real time, a clinical assessment tool
425 of jump-landing biomechanics. *J Sport Rehabil.* 2011;20(2):145-156.
- 426 10. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE Jr, Beutler AI. The
427 landing error scoring system (less) is a valid and reliable clinical assessment tool
428 of jump-landing biomechanics. *Am J Sports Med.* 2009;37(10):1996-2002.
- 429 11. Onate J, Cortes N, Welch C and Van Lunen BL. Expert versus novice interrater
430 reliability and criterion validity of the landing error scoring system. *J Sport
431 Rehabil.* 2010;19(1):41-56.
- 432 12. Willson JD, Ireland ML and Davis I. Core strength and lower extremity alignment
433 during single leg squats. *Med Sci Sports Exerc.*2006; 38(5):945-52.
- 434 13. Willson JD and Davis IS. Utility of the frontal plane projection angle in females
435 with patellofemoral pain. *J OrthopSports Phys Ther.* 2008;38(10):606-615.
- 436 14. Olson TJ, Chebny C, Willson JD, Kernozek TW, Straker JS. Comparison of 2d
437 and 3d kinematic changes during a single leg step down following neuromuscular
438 training. *Phys Ther Sport.* May 2011;12(2):93-99.
- 439 15. Sim J and Wright CC. The kappa statistic in reliability studies: Use, interpretation,
440 and sample size requirements. *Phys Ther.* 2005;85(3):257-268.
- 441 16. Landis JR and Koch GG. The measurement of observer agreement for
442 categorical data. *Biometrics.* 1977;33:159-174.

- 443 **17.** Eastlack ME, Arvidson J, Snyder-Mackler L, Danoff JV, McGarvey CL. Interrater
444 reliability of videotaped observational gait-analysis assessments. *Phys Ther.*
445 1991;71(6):465-472.
- 446 **18.** Chmielewski TL, Hodges MJ, Horodyski M, Bishop MD, Conrad BP, Tillman SM.
447 Investigation of clinician agreement in evaluating movement quality during
448 unilateral lower extremity functional tasks: A comparison of 2 rating methods. *J*
449 *Orthop Sports Phys Ther.* 2007;37(3):122-129.
- 450 **19.** Stensrud S, Myklebust G, Kristianslund E, Bahr R, Krosshaug T. Correlation
451 between two-dimensional video analysis and subjective assessment in
452 evaluating knee control among elite female team handball players. *Br J Sports*
453 *Med.* 2010;10:1136
- 454 **20.** Crossley KM, Zhang WJ, Schache AG, Bryant A, Cowan SM. Performance on
455 the single-leg squat task indicates hip abductor muscle function. *Am J Sports*
456 *Med.* 2011;39(4):866-873.
- 457 **21.** Ekegren CL, Miller WC, Celebrini RG, Eng JJ, MacIntyre DL. Reliability and
458 validity of observational risk screening in evaluating dynamic knee valgus. *J*
459 *Orthop Sports Phys Ther.* 2009;39(9):665-674.
- 460 **22.** Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD. The role of
461 knee alignment in disease progression and functional decline in knee
462 osteoarthritis. *JAMA.* 2001;286(2):188-195.
- 463 **23.** McLean SG, Walker K, Ford KR, Myer GD, Hewett TE, van den Bogert AJ.
464 Evaluation of a two dimensional analysis method as a screening and evaluation
465 tool for anterior cruciate ligament injury. *Br J Sports Med.* 2005;39(6):355-362.

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470 **TABLE 1. Intratester and intertester reliability for visual assessment of the single leg**
 471 **squat.**

Examiners	Percent Agreement (95% CI)	Weighted Kappa (95% CI)
Intratester reliability		
1	87 (73, 100)	0.80 (0.61, 0.99)
2	93 (83, 100)	0.90 (0.77, 1.00)
3	90 (78, 100)	0.84 (0.67, 1.00)
Intertester reliability		
1 vs. 2	93 (83, 100)	0.90 (0.77, 1.00)
1 vs. 3	83 (68, 98)	0.75 (0.54, 0.96)
2 vs. 3	83 (68, 98)	0.75 (0.54, 0.96)

472 1 = experienced tester

473 2 = experienced tester

474 3 = novice tester

475

476

477 **TABLE 2.** Kappa tables for intratester ratings. **Each tester viewed the videos and classified**
 478 **the movement pattern on two separate occasions. Each box represents the**
 479 **classifications provided by one tester.**

Tester 1 Experienced tester		Session 2			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Session 1	Dynamic Valgus	13	3	0	16
	No Change	1	10	0	11
	Varus	0	0	3	3
	Total	14	13	3	30

480

Tester 2 Experienced tester		Session 2			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Session 1	Dynamic Valgus	15	1	0	16
	No Change	1	10	0	11
	Dynamic Varus	0	0	3	3
	Total	16	11	3	30

481

Tester 3 Novice tester		Session 2			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Session 1	Dynamic Valgus	18	3	0	21
	No Change	0	6	0	6
	Dynamic Varus	0	0	3	3
	Total	18	9	3	30

482 Cell values are the number of participants for each pair of classifications.

483 **TABLE 3.** Kappa tables for intratester ratings. **Classifications from the first session of each**
 484 **tester were used for intertester reliability testing.**

		Tester 2 Experienced tester			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Tester1 Experienced Tester	Dynamic Valgus	15	1	0	16
	No Change	1	10	0	11
	Dynamic Varus	0	0	3	3
	Total	16	11	3	30

485

		Tester 3 Novice tester			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Tester1 Experienced Tester	Dynamic Valgus	16	0	0	16
	No Change	5	6	0	11
	Dynamic Varus	0	0	3	3
	Total	21	6	3	30

486

		Tester 3 Novice tester			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Tester2 Experienced Tester	Dynamic Valgus	16	0	0	16
	No Change	5	6	0	11
	Dynamic Varus	0	0	3	3
	Total	21	6	3	30

487 Cell values are the number of participants for each pair of classifications.

488

489 **TABLE 4.** Kappa table for comparison of categories based on visual
490 assessment and quantitative FPPA change.

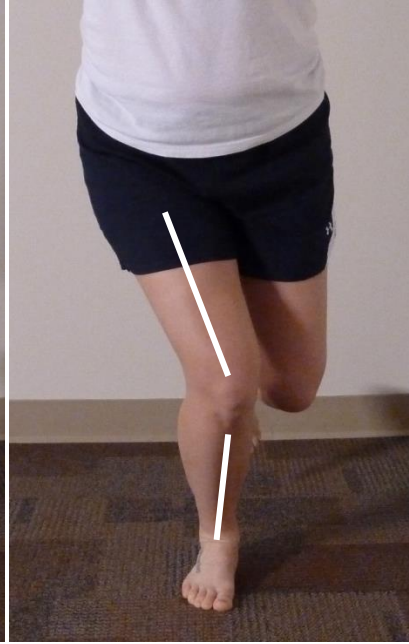
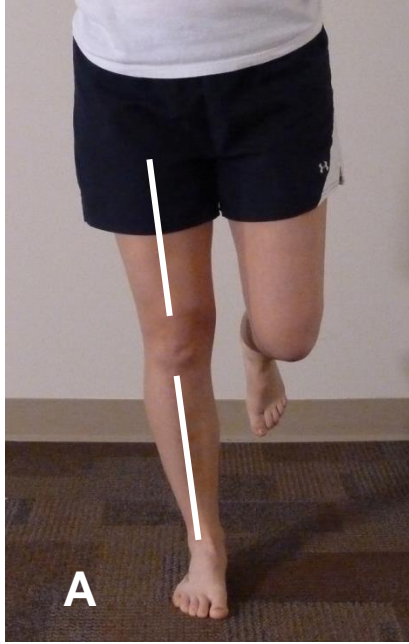
		Visual Assessment (consensus rating)			
		Dynamic Valgus	No Change	Dynamic Varus	Total
Quantitative FPPA change	Dynamic Valgus	14	1†	0	15
	No Change	2*	10	0	12
	Dynamic Varus	0	0	3	3
	Total	16	11	3	30

491 * The FPPA change values for these two discrepancies are 3.2° and 8.0°.

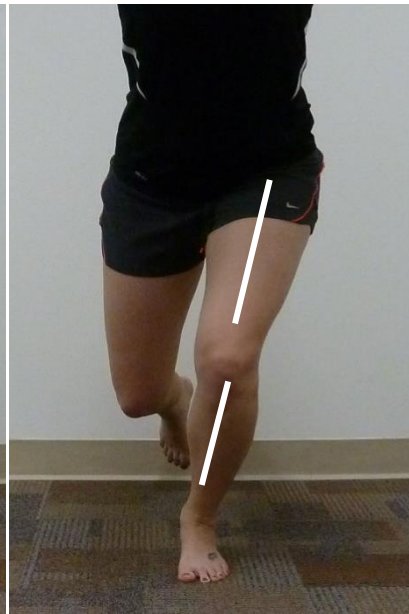
492 † The FPPA change value for this discrepancy is 13.4°

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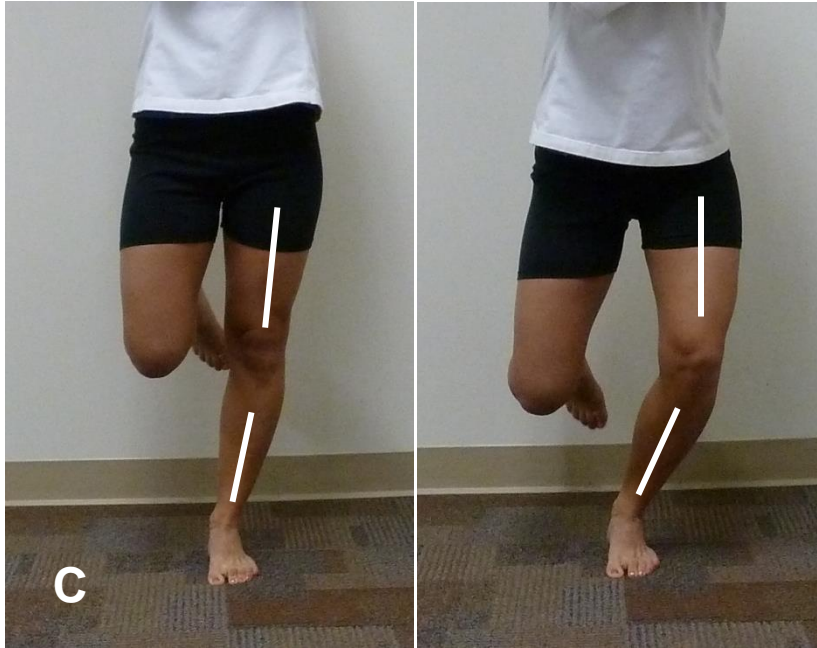
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498 **FIGURE 1.** Images to demonstrate methods for objective measurement of the frontal
499 plane projection angle (FPPA) change. Two lines are drawn to represent the FPPA, one
500 bisects the thigh segment and one bisects the lower leg. The angles were then
501 measured using a protractor function in measurement software. FPPA change was
502 calculated by subtracting the end FPPA (figures in right column) from the start FPPA
503 (figures from the left column). Representative examples of the three lower extremity
504 movement classifications are provided. A) Dynamic Valgus = angle between the femoral
505 bisection and lower leg bisection changes more that 10° and the knee moves toward the
506 midline of the body. B) No Change = angle between the femoral bisection and lower leg
507 bisection changes less than 10° during the motion. C) Dynamic Varus – angle between
508 the femoral bisection and lower leg bisection changes more than 10° and the knee
509 moves away from the midline of the body.

510