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Title: Within-session reliability for inter-limb asymmetries in ankle dorsiflexion range of motion during the weight-bearing lunge test

21 **ABSTRACT**

22 *Background:* The identification of asymmetrical inter-limb ankle dorsiflexion range of
23 motion (DF ROM) has the potential to influence the course of treatment during the
24 rehabilitation process, with limitations in ankle DF ROM potentially increasing injury risk.
25 However, reliability for identifying ankle DF ROM asymmetries has not yet been established.

26 *Hypothesis/Purpose:* i) To establish values of ankle DF ROM asymmetry; ii) to identify the
27 influence of leg dominance on inter-limb asymmetries for ankle DF ROM; iii) to determine
28 the reliability of the trigonometric measurement method during the weight-bearing lunge test
29 (WBLT) for both a single limb and the asymmetry values.

30 *Study Design:* Cross-sectional study.

31 *Methods:* Ankle DF ROM was measured bilaterally in 50 healthy and recreationally active
32 participants (28 men, 22 women, age = 22 ± 4 years, height = 172.8 ± 10.8 cm, body mass
33 71.5 ± 15.1 kg), using the trigonometric measurement method during the WBLT. Each ankle
34 was measured twice in a single testing session to establish within-session reliability.

35 *Results:* Values are presented for asymmetries in DF ROM. No differences were identified
36 between the dominant and non-dominant limb ($P = 0.862$). Within-session reliability for
37 measuring a single limb was classified as 'good' (ICC = 0.98) with a minimal detectable
38 change value of 1.7° . For measuring ankle DF ROM asymmetry, reliability was established
39 as 'good' (ICC = 0.85) and a minimal detectable change value of 2.1° .

40 *Conclusions:* Although symmetry in ankle DF ROM may not be assumed, the magnitude of
41 asymmetry may be less than previously reported in a population of recreationally active
42 individuals. Discrepancies between previous research and the findings of the present study
43 may have been caused by differences in measurement methods. Furthermore, clinicians

44 should be aware that the error associated with measures of asymmetry for ankle DF ROM
45 during the WBLT is greater than that of a single limb.

46 *Level of Evidence: 2b*

47 *Key words: ankle dorsiflexion, inter-limb asymmetry, reliability.*

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64 INTRODUCTION

65 During many athletic activities, ankle dorsiflexion range of motion (DF ROM) is required for
66 the efficient dissipation of ground reaction forces.^{1,2} Limited ankle DF ROM has been
67 reported to affect lower-limb force profiles within athletic activities, as ankle DF ROM
68 restriction has been shown to correlate with greater peak vertical ground reaction forces
69 during landings.² As a result, athletes with limited ankle DF ROM may exhibit movement
70 strategies with gross technical errors during bilateral²⁻⁴ and unilateral^{3,5} squatting and landing
71 tasks, as well as during gait.⁶ Reduced **weight-bearing** ankle DF ROM has been identified as
72 being a modifiable risk factor for many lower limb injuries, with **weight-bearing** ankle DF
73 ROM of 34° being associated with 2.5 times greater injury risk in military recruits.⁷
74 Proximally, a limitation in **weight-bearing** ankle DF ROM has been shown to present as a risk
75 factor for hamstring strains in Australian football athletes (relative risk = 2.32).⁸ Furthermore,
76 elite junior basketball players with **weight-bearing** ankle DF ROM values <36.5° possess a
77 18.5% to 29.4% risk of developing patella tendinopathy within a year.⁹ This risk is
78 significantly greater than the 1.8% to 2.1% for players with >36.5° ankle DF ROM.⁹
79 Therefore, restrictions in **weight-bearing** ankle DF ROM may increase injury risk through the
80 development of mechanical compensations during athletic activities.

81 Restrictions in ankle DF ROM may result from injury to the rearfoot complex and have been
82 identified.¹⁰ Furthermore, changes in ankle DF ROM have been suggested to occur in
83 response to the functional demands placed on the ankle complex.¹¹ As such, athletes with a
84 history of lower-leg injury or those exposed to asymmetrical loading might have an inter-
85 limb asymmetry in ankle DF ROM. Although current literature does not provide a clear
86 understanding of the influence inter-limb asymmetries may have on an athlete's
87 performance,¹² asymmetries in ankle DF ROM have been positively correlated with
88 performance deficits during change of direction tests.¹³

89 However, research investigating normative values for **weight-bearing** ankle DF ROM has
90 provided conflicting evidence regarding the extent of asymmetries.^{11, 13-16} Cosby and Hertel¹⁴
91 showed only a 0.8° difference in **weight-bearing** ankle DF ROM using a lunge test with a
92 bent knee. Similarly, Konor et al¹⁶ found no difference between left and right sides during the
93 weight-bearing lunge test (WBLT) in healthy adults. However, normative data from Hoch
94 and McKeon¹⁵ demonstrated inter-limb asymmetries for ankle DF ROM in healthy
95 participants frequently reached 1.5 cm when measuring toe-wall distance. Furthermore,
96 Rabin et al¹¹ identified greater ankle DF ROM for the non-dominant leg exceeding 10° in
97 23% of male military recruits.

98 Better delineation of relative ankle DF ROM symmetry as measured in a weight-bearing
99 position has several potential clinical and research purposes. Clinically, this information
100 could be used to inform the course of treatment during the rehabilitation process or while
101 prescribing interventions to increase ankle DF ROM. Furthermore, it is common practice to
102 perform bilateral comparisons when assessing deficits in DF ROM, which might lead to
103 diagnostic errors if symmetry is assumed. Without prior assessment and knowledge of
104 normative DF ROM asymmetries, the rehabilitation program for an athlete with a similar
105 asymmetry could be misjudged through a lack of consideration for the functional demands
106 placed on the ankle joint.

107 In order to identify asymmetries in ankle DF ROM that are relevant to functional activities, it
108 has been suggested that using an active weight-bearing assessment provides the most valid
109 representation of ankle DF capacity during dynamic tasks such as squatting and landing.^{3,17}
110 As such, the WBLT has been the subject of many recent investigations.^{16,18,19} However, a
111 number of different measurement methods can be used to quantify ankle DF ROM during the
112 WBLT, including measuring tibia angle with either a standard goniometer or
113 inclinometer,^{16,18} Achilles tendon angle with an inclinometer,¹⁸ or the distance of the greater

114 toe from the wall using a tape measure.^{18,20} In an attempt to establish the most reliable
115 method to measure ankle DF ROM during the WBLT, Langarika-Rocafort et al¹⁸ compared
116 five commonly used techniques; heel-wall distance, toe-wall distance, tibia angle, Achilles
117 tendon angle and a trigonometric angle derived from heel-wall distance and ground-knee
118 distance. The trigonometric measurement method was found to have the highest between-
119 session intra-rater reliability (ICC = 0.95, SEM = 1.18°) compared to measurements of tibia
120 angle (ICC = 0.87, SEM = 2.17°) and Achilles angle (ICC = 0.87, SEM = 2.28°).¹⁸ As a
121 result, the trigonometric measurement method may present as a more reliable tool for the
122 clinician to establish ankle DF ROM during the WBLT.

123 While the between-session intra-rater reliability of the trigonometric method has been
124 established, the within-session intra-rater reliability has yet to be determined. Furthermore,
125 the extent of inter-limb asymmetries in a young, healthy, and active cohort has yet to be
126 established. The aims of this study, therefore, were: i) to establish values of ankle DF ROM
127 asymmetry, ii) identify the influence of leg dominance on ankle DF ROM and iii) to
128 determine the within-session, intra-rater reliability of the trigonometric measurement method
129 during the WBLT in healthy and recreationally active participants for both a single limb and
130 the symmetry values measured.

131

132 **METHODS**

133 **Study design**

134 Participants reported to the laboratory for a single testing session. Testing was conducted by
135 the lead investigator who had 10 years' experience measuring ankle DF ROM during the
136 WBLT and an accredited member of the British Association of Sport Rehabilitators and
137 Trainers. Prior to data collection, all participants completed a pre-exercise questionnaire and

138 provided written informed consent. Following the recording of height and body mass,
139 participants reported their dominant leg, defined as their preferred leg for kicking a ball.
140 Ankle DF ROM for both legs was then measured using the WBLT with no prior warm-up
141 using a randomized counterbalanced design. Following a 10-minute rest, participants were re-
142 tested in order to determine within-session reliability of the WBLT using the trigonometric
143 measurement method.

144

145 **Participants**

146 Using the findings of Rabin et al¹¹ for inter-limb asymmetries for ankle DF ROM between
147 the dominant and non-dominant limb (effect size = 0.83), we performed a representative
148 analysis to determine the appropriate sample size based on. Calculations indicated that to
149 achieve 80% statistical power, a minimum of 39 participants were required to detect inter-
150 limb asymmetries. A total of 50 participants volunteered for the study (28 men, 22 women,
151 age = 22 ± 4 years, height = 172.8 ± 10.8 cm, body mass 71.5 ± 15.1 kg). All participants
152 self-reported to be physically active, defined as regularly performing at least 30 min of
153 moderate intensity physical activity 3 times per week for at least 6 months prior to testing.⁵
154 Participants were excluded if they had a history of a lower-extremity surgical procedure or
155 injury to the lower-extremity in the six-months prior to testing. Ethical approval was provided
156 by the lead authors institution's Research Ethics Panel.

157

158 **Procedures**

159 In order to measure the heel-wall distance, a 70 cm tape measure was fixed to the floor,
160 perpendicular to the wall used for testing. Measurements of ground-knee distance were
161 obtained with a 70 cm tape measure fixed vertically to the wall and perpendicular to the tape

162 measure on the ground. A longitudinal line was marked down on each of the scales for testing
163 purposes. Prior to performing the test, participants were provided with a demonstration and
164 standardized instructions. Participants then completed three familiarization trials for each leg
165 before performing three trials on each limb, with the mean value from the three attempts from
166 each foot being used for data analysis.

167 To ensure neither the participant nor investigator could target a specific outcome on
168 subsequent attempts, no markings were made on the tape measure that would indicate the
169 previous attempt. Following a 10-minute break participants were retested using the same
170 procedures on both legs in order to establish within-session reliability. The results were
171 recorded on a separate sheet in order to blind the investigator from previous distances and
172 participants were not informed of their previous scores. For all participants, leg order was
173 randomized for both trial 1 and 2. Ankle DF symmetry was calculated in degrees as the
174 absolute difference between the means of the right and left legs. See figure 1 for an
175 illustration of testing procedures and measurements used for the trigonometric calculation.

176

177 ***INSERT FIGURE 1 HERE***

178

179 Participants began the test by facing a bare wall, with the greater toe of the test leg positioned
180 against the wall. The greater toe and the center of the heel were aligned using the marked line
181 on the ground. Participants were instructed to place the non-test foot behind them, with the
182 heel raised and at a distance that they felt helped maximize their performance on the test.
183 This position was established during familiarization. In order to maintain balance,
184 participants were asked to keep both hands firmly against the wall throughout. The
185 participants were then instructed to slowly lunge forward by simultaneously flexing at the

186 ankle, knee and hip on the test leg in an attempt to make contact between the centre of the
187 patella and the vertical marked line on the wall. No attempt was made to control trunk
188 alignment. Subtalar joint position was controlled by keeping the test foot in the standardized
189 position and ensuring the patella contact with the vertical line was accurate.¹⁶

190 The aim of the test was for the participant to get their heel as far away as possible from the
191 wall, while making contact between the patella and the wall and maintaining firm pressure
192 between the heel and the ground. Throughout the test, the investigator was positioned behind
193 the participant in a low crouched position in order to visually monitor heel-lift. Heel lift was
194 defined as the visual lifting of the calcaneus, resulting in a greater ground surface area
195 observed under the rearfoot. Any elevation of the heel during the test was regarded as a failed
196 attempt and feedback was provided to the participants regarding their inability to prevent the
197 heel from rising.

198 Upon successful completion of an attempt, where contact between the patella and the wall
199 was made with no change in heel position relative to the ground, participants were instructed
200 to move the test foot further away from the wall by approximately 0.5 cm. No restrictions
201 were placed on the number of attempts made by a participant. At the last successful attempt,
202 the distances between the heel and the wall, and the distance between the anterosuperior edge
203 of the patella and the ground were recorded to the nearest 0.1 cm. Ankle DF angle for each
204 attempt was calculated with the heel-wall and ground-knee distances, using the trigonometric
205 function outlined by Langarika-Rocafort et al¹⁸ ($DF\ ROM = 90 - \arctan[\text{ground-knee}/\text{heel-}$
206 $\text{wall}]$).

207

208 **Statistical Analysis**

209 The assumption of normality for data sets was checked using the Shapiro-Wilk test, with
210 normative data for the inter-limb mean difference for ankle DF ROM graphically presented
211 using a frequency-distribution histogram. An independent *t*-test were performed to establish
212 the difference between the dominant and non-dominant for ankle DF ROM during the
213 WBLT. Effect sizes were calculated for each comparison, with 0.2 being considered *small*,
214 0.5 *moderate* and 0.8 or greater *large*.²¹

215 The within-session intra-rater reliability for single limb measurements of ankle DF ROM and
216 ankle DF symmetry was initially assessed using a paired samples *t*-test to calculate
217 systematic bias between trial 1 and 2.²² Relative reliability was determined using intra-class
218 correlation coefficient (ICC) calculated as suggested by Hopkins²³ and reported with 95%
219 confidence intervals, with ICCs interpreted as follows: 0.00-0.25 *poor*, 0.26-0.50 *fair*, 0.51-
220 0.75 *moderate*, and 0.76-1.00 *good* reliability.²⁴ Absolute reliability was calculated using the
221 coefficient of variation (CV; $SD / \text{mean} * 100$), the 95% limits of agreement, standard error of
222 measurement (SEM; $SD\sqrt{1-ICC}$)²² and minimal detectable change (MDC; $SEM*1.96*\sqrt{2}$).²⁵
223 All statistical tests were performed using SPSS[®] statistical software package (v.24; SPSS
224 Inc., Chicago, IL, USA), with the *a-priori* level of significance set at $P < 0.05$. ICC and CV%
225 were calculated using a customized spreadsheet.²⁶

226

227 **RESULTS**

228 The mean difference for ankle DF ROM was $2.3^\circ \pm 2.0^\circ$. Forty-one participants (82%)
229 reported their dominant leg to be their right, with the remaining nine participants (18%)
230 reporting their left leg as dominant. WBLT values are summarized in Table 1. Mean WBLT
231 values for the dominant and non-dominant limb were $36.5 \pm 4.5^\circ$ and $36.5 \pm 4.3^\circ$,

232 respectively. No statistical difference was identified between the dominant and non-dominant
233 limb.

234

235 ***INSERT FIGURE 2 AND TABLE 1 HERE***

236

237 The within-session reliability of the WBLT is summarized in Table 2. There were no
238 systematic biases for the WBLT using the trigonometric measurement method between trials
239 for either ankle DF ROM or ankle DF symmetry ($P > 0.05$). The relative reliability was
240 established as 'good' for within-session reliability for a single measure ($ICC = 0.98$) and
241 inter-limb asymmetries in ankle DF ROM ($ICC = 0.85$). All values representing relative and
242 absolute reliability are reported in Table 2.

243

244

245 ***INSERT TABLE 2***

246

247 **DISCUSSION**

248 The primary aim of this study was to establish values for the inter-limb asymmetries of ankle
249 DF ROM during the WBLT among healthy recreationally active individuals. Of all
250 participants, 44% presented asymmetries in ankle DF ROM exceeding the MDC of 2.1°
251 found in this investigation (Table 2), with 8% of participants demonstrating an inter-limb
252 asymmetry greater than 5° , with the largest asymmetry being 8.8° . Therefore, with 44% of

253 our sample having asymmetry values greater than the MDC, our findings suggest that the
254 clinician should not assume symmetry without conducting thorough *a-priori* assessments.

255 Our data support the findings of Hoch and McKeon¹⁵ and Rabin et al¹¹, by identifying the
256 existence of inter-limb asymmetries in ankle DF ROM during the WBLT in healthy
257 populations. Using the toe-wall distance during the WBLT, Hoch and McKeon et al¹⁵
258 reported that 68% of participants exhibited an asymmetry of 1.5 cm or less, with some
259 participants approaching asymmetries of approximately 3 cm. Using the conversion
260 calculation suggested by Konor et al¹⁶ where 1 cm in toe-wall distance corresponds with
261 approximately 3.6° of ankle DF ROM, 32% of the sample in Hoch and McKeon¹⁵
262 demonstrated ankle DF ROM asymmetries of > 5.4°, with some participants approaching
263 asymmetries of 10.8°. This is similar to that of Rabin et al¹¹, where 64 healthy male military
264 recruits possessed a bilateral mean difference of 5.8° in favour of the non-dominant leg
265 during the WBLT. Equally, 23% of participants had asymmetries >10°. ¹¹

266 Although our findings support the notion that bilateral differences are present in healthy
267 populations, our data indicate that the magnitude of inter-limb asymmetry for ankle DF ROM
268 is likely less than previously reported. Our findings identify a much smaller mean asymmetry
269 in comparison to previous investigations,^{11,15} with 56% of our population possessing inter-
270 limb asymmetries on the WBLT of less than the MDC of 2.1°. This resulted in rightward
271 skew of our data (Figure 2), indicating that a large portion of our sample presented with a
272 negligible asymmetry in ankle DF ROM, relative to the MDC. Furthermore, none of the
273 participants who volunteered for our study exceeded an asymmetry of 10°, with the greatest
274 asymmetry recorded being 8.8° between limbs.

275 One possible reason for not observing a similar magnitude in asymmetry may be the
276 measurement method of ankle DF angle. Both measurement methods adopted by Hoch and

277 McKeon¹⁵ and Rabin et al¹¹ used to record ankle DF ROM during the WBLT have been
278 identified to possess a greater MDC for a single limb than the 1.7° found in our investigation
279 (Table 2).¹⁸ As the MDC represents the boundaries of measurement error,²⁵ it is possible that
280 the testing procedures used by both investigations may have contributed to the level of inter-
281 limb asymmetry observed. For example, the MDC for the measurement method used by
282 Rabin et al¹¹ has been reported to be 6.0° for testing a single limb.¹⁸ Although it is unclear
283 why the trigonometric measurement method provides greater reliability than other
284 measurements of ankle DF ROM during the WBLT,¹⁸ it may be that measuring distances
285 produces superior repeatability than measurements of angles. This suggestion is supported by
286 Langarika-Rocafort et al,¹⁸ where ICC values for all distances associated with the
287 trigonometric method were much higher (ranging 0.95 – 0.96) than measuring tibia (0.87)
288 and Achilles angle (0.87) during the WBLT.

289 To our knowledge, no previous investigation has established the within-session intra-rater
290 reliability for measuring asymmetries in ankle DF ROM during the WBLT. Our findings
291 indicate that the error in measurement for inter-limb differences in ankle DF ROM (MDC =
292 2.1°) is greater than the error associated with testing a single limb (MDC = 1.7°).

293 Measurements of tibia angle for single limb ankle DF ROM during the WBLT have
294 previously been shown to possess MDC values >6.0°.¹⁸ As our investigation showed greater
295 error associated with measures of inter-limb asymmetries in ankle DF ROM, the mean inter-
296 limb difference of 5.8° in ankle DF ROM (measured as tibia angle) reported by Rabin et al¹¹
297 may represent error in the measurement technique that is compounded by testing both limbs.
298 Although other investigations have reported intra-rater MDC values as low as 3.2° when
299 measuring tibia angle for a single limb,¹⁹ none have established the reliability for measuring
300 asymmetry. Therefore, it remains possible that the difference between the findings of Rabin

301 et al¹¹ and that of our study is due to measurement error associated with the techniques
302 employed to establish inter-limb differences in ankle DF ROM.

303 No systematic bias was found in our data between trials using the within-session design. This
304 demonstrates that the procedures were well-controlled during testing. As a result, learning
305 effects, acute changes caused by the previous trials (e.g. fatigue or warming up of relevant
306 tissues) and participant bias were not confounding factors during testing.²⁵ This is an
307 important consideration for clinicians when administering the WBLT in practice in order to
308 establish real measurements in ankle DF ROM, with poor control of conditions negatively
309 impacting the clinician's ability to interpret data.

310 Within the present study, the MDC for a single limb measurement for ankle DF ROM during
311 the WBLT was identified as 1.7°, with a SEM of 0.6° (Table 2). These values for reliability
312 are lower than reported for alternative measurement methods of ankle DF ROM during the
313 WBLT, with MDC and SEM values ranging between 3.1° to 6.4° and 1° to 2.4°,
314 respectively.¹⁹ Although all reported methods for measuring ankle DF ROM during the
315 WBLT have been identified as 'good' (ICC >0.7),¹⁹ Langarika-Rocafort et al¹⁸ demonstrated
316 that the trigonometric measurement method used in our study possessed the highest intra-
317 rater reliability and smaller MDC value in comparison to four other measurement methods.
318 Based on our results and those reported by Langarika-Rocafort et al¹⁸, we posit that the
319 trigonometric method should be used when measuring ankle DF ROM asymmetries, as it
320 appears to be a more sensitive measure. Practically, the trigonometric method does not
321 require specialised equipment, is time efficient and presents as a simple method for
322 calculating ankle DF ROM.¹⁸ Regardless, clinicians and practitioners should be aware of the
323 different results based on the method used, so as to avoid erroneous conclusions when
324 comparing their patients' or clients' results to the literature.

325 Despite our study using the same measurement technique as Langarika-Rocafort et al¹⁸, we
326 report an improved reliability. We speculate that one potential reason may be due to the
327 administration of the WBLT. In order to identify peak ankle DF angle during the WBLT,
328 Langarika-Rocafort et al¹⁸ relied upon participants informing the investigator of when they
329 had reached maximum distance from the wall prior to measurement. In contrast, our
330 measurement was taken at the last successful attempt, which was defined as the furthest
331 distance away from the wall where they could make contact between the patella and the wall
332 and prior to the point of heel lift. These two approaches are markedly different and are likely
333 to produce different results. Heel lift was carefully monitored by the investigator and defined
334 as the visual lifting of the heel, where a greater surface area of the ground could be seen
335 under the rearfoot. We believe that this is an important distinction, as it is questionable that
336 participants can identify at what point ankle DF ROM has terminated and compensatory
337 strategies will be adopted, thus influencing the outcome measurement through a lack of
338 standardization. This is especially problematic during the WBLT, as participants are unable
339 to observe ankle motion on the test leg and the accuracy of identifying movement strategy,
340 primarily through the sensorimotor system varies by task.²⁷

341 Leg dominance has previously been shown to possess a relationship with inter-limb
342 asymmetry in ankle DF ROM, with greater ankle DF ROM observed in the non-dominant
343 limb.¹¹ However, our results did not identify a difference in ankle DF ROM during the
344 WBLT between the dominant and non-dominant leg. Although it remains unclear why we did
345 not see a similar finding within our investigation, a few possibilities exist. Firstly, Rabin et
346 al¹¹ proposed that asymmetries in ankle DF ROM between the dominant and non-dominant
347 leg may exist due to the mechanical loading placed on the ankle complex during habitual
348 activities. This is based on a rationale that the ankle joint complex adapts to the demands
349 imposed upon it, with the non-dominant leg being subjected to larger requirements for

350 balance and stability, resulting in greater joint ROM.¹¹ As all participants in Rabin et al¹¹
351 were military recruits, it may be that specific physical activities undertaken by the
352 participants in preparation for basic military training resulted in the ankle DF ROM
353 asymmetries identified between the dominant and non-dominant leg, as opposed to our
354 sample who were physically active but not military trained.

355 Another possible explanation for the lack of agreement may be due to difference in
356 procedures when conducting the WBLT. Unlike our study that used the trigonometric
357 measuring method for recording ankle dorsiflexion ROM, Rabin et al¹¹ used an inclinometer
358 placed on the tibia, 15 cm below the tibial tuberosity. As previously discussed, intra-rater
359 reliability for this method has been reported to be inferior to the trigonometric method.¹⁸ As
360 an analysis of intra-rater reliability was not conducted as part of Rabin et al¹¹ design, it is
361 possible that the procedures used may have contributed to the contrast in findings.

362 Whether the asymmetry in ankle DF ROM observed in this investigation is clinically
363 meaningful is at present unknown. Limitations in ankle DF ROM have been linked to greater
364 peak forces² and increased knee abduction moments²⁸ during landing activities and these
365 suboptimal movement strategies are associated with ACL injuries.²⁹ Large asymmetries in
366 ankle DF ROM may, therefore, present as a modifiable variable for reducing risk factors
367 associated with lower extremity injury during dynamic activities.

368 Asymmetry in ankle DF ROM has been shown to impact change of direction performance.
369 Gonzalo-Skok et al¹³ found a negative relationship between ankle DF ROM asymmetry
370 during the WBLT and 180° change of direction test in elite youth male basketball players. As
371 **weight-bearing** peak DF angle can approach approximately 50° during change of direction
372 tasks,³⁰ it is likely that limitations in ankle DF ROM have the potential to alter movement
373 patterns during such athletic activities. This may result in asymmetries in ankle DF ROM

374 contributing to suboptimal movement strategies to be utilized on the limited side, leading to
375 reduced performance in athletic tasks. Unfortunately, Gonzalo-Skok et al¹³ did not report
376 values for inter-limb asymmetries and, therefore, it is unclear if the asymmetries found in our
377 study have the potential to negatively impact performance. More research is required to
378 establish a threshold for when an asymmetry may present as a risk factor for the development
379 of injury or a cause towards suboptimal performance.

380 Our results indicate that ankle DF symmetry should not be assumed by the clinician. The
381 assumption of symmetry in ankle DF ROM during the rehabilitation of an athlete would be
382 inappropriate for restoring function. Instead, it may be more reasonable to identify whether
383 the athlete possesses sufficient ankle DF ROM to cope with the movement demands placed
384 on them by the sport and relevant training. As athletic activities, such as squatting,³¹
385 landing,³² running³³ and change of direction tasks³⁰ may all require large quantities of ankle
386 DF, ensuring an athlete possesses sufficient ROM to cope with these demands appears to be a
387 more logical guide.

388 Our investigation was not without limitations. Firstly, we used a relatively young population
389 of recreationally trained individuals. As such, the findings presented in our study provide
390 preliminary data and are not yet representative of a wider population. Further work is
391 required to establish normative values across the wider population. The degree to which
392 asymmetry in ankle DF ROM becomes clinically relevant is currently unclear. Whether a
393 threshold exists that may increase an athlete's injury risk or result in a decline in performance
394 outputs requires further investigation in order to inform a clinician's practice.

395 During testing, as the investigator was not blinded to the measurements, it is possible that the
396 investigator had knowledge of the initial values. Although an attempt was made to control for
397 this, recollection of values may have occurred. This investigation also used only one,

398 experienced tester to establish values during the WBLT. Therefore, these results are not
399 generalizable to the novice clinician. Furthermore, the intra-rater reliability for the
400 trigonometric measurement method has not yet been established. Without data on the inter-
401 rater reliability the wide-spread adoption of this measurement technique should be used with
402 caution.

403

404 **CONCLUSIONS**

405 Recreationally active individuals may present with asymmetrical **weight-bearing** ankle DF
406 ROM during the WBLT that is normal and not necessarily associated with leg dominance.
407 Our findings suggest the extent of asymmetry found using this technique is less than what has
408 been previously reported in the literature. Furthermore, measuring **weight-bearing** ankle DF
409 ROM for a single limb using the trigonometric method presents as a simple and reliable tool;
410 however, the error associated with identifying asymmetries in **weight-bearing** ankle DF ROM
411 may exceed the absolute inter-limb difference. Therefore, asymmetries in **weight-bearing**
412 ankle DF ROM may be error associated with the testing procedures and not a true inter-limb
413 difference. Future investigations should look to identify the intra-rater reliability of the
414 trigonometric measurement method, as well as investigating the mechanical implications of
415 ankle DF ROM asymmetry during functionally relevant activities.

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Table 1. Asymmetry within the weight bearing lunge test for dominant-to-non-dominant limb comparison (n=50).

Table 2. Within-session intra-rater reliability for the weight-bearing lunge test using the trigonometric measurement method for testing ankle DF ROM for a single limb and ankle DF symmetry (n=50).

Figure 1. Participant performing the WBLT with example calculation. Abbreviations: GK, ground-knee distance; HW, heel-wall distance; TA, trigonometric angle.

Figure 2. Frequency-distribution histogram for inter-limb mean difference with the weight-bearing lunge test (n=50).

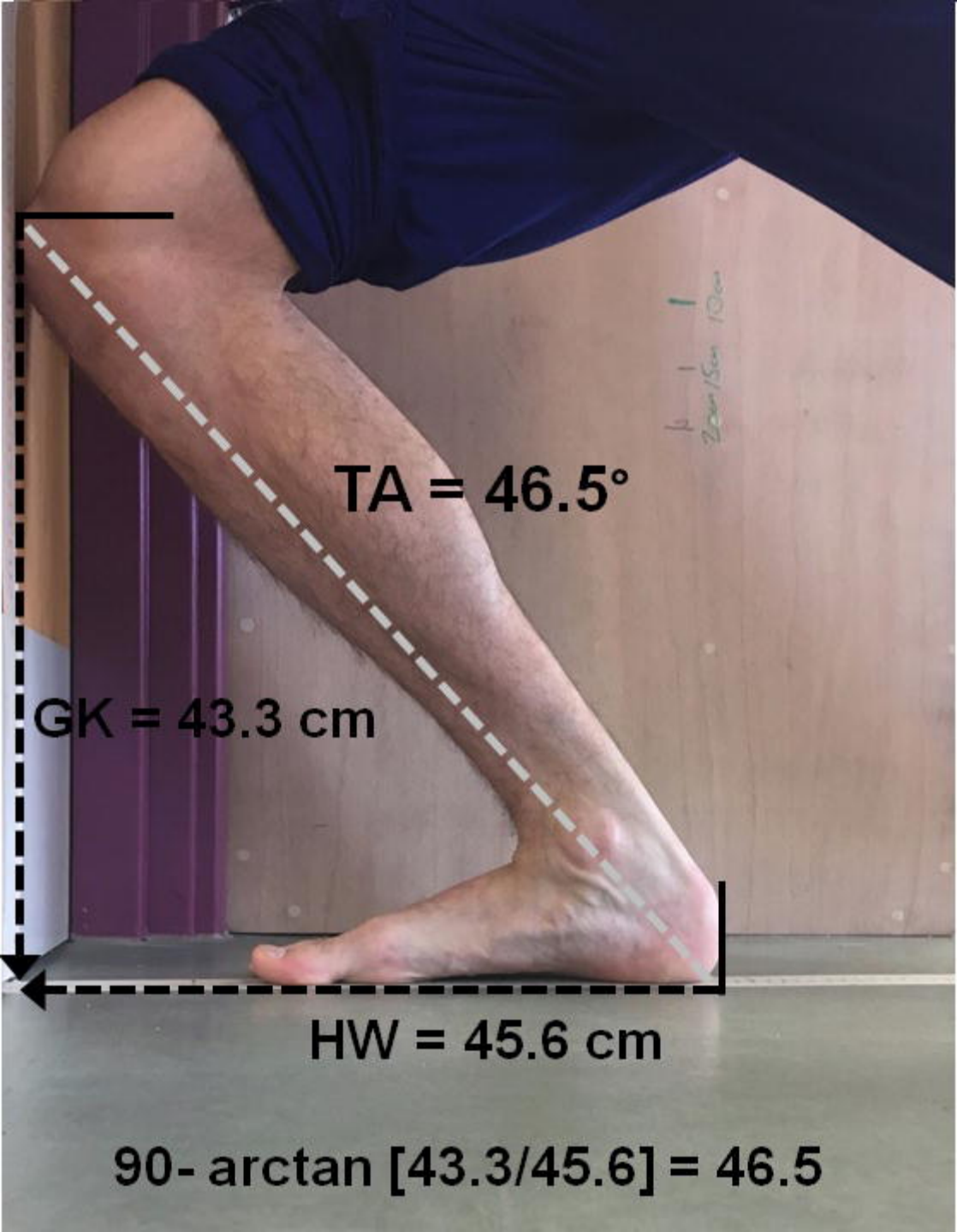
Table 1. Asymmetry within the weight bearing lunge test for dominant-to-non-dominant limb comparison (n=50).

Ankle dorsiflexion	Range of motion, ° (Mean ± SD)	Difference, ° (95% Confidence Interval)	Effect size
Dominant side	36.5 ± 4.5	-0.08 (-0.95, 0.80)	0.02
Nondominant side	36.5 ± 4.3		

^a Significant difference ($P < .05$).

Table 2. Within-session intra-rater reliability for the weight-bearing lunge test using the trigonometric measurement method for testing ankle DF ROM for a single limb and ankle DF symmetry (n=50).

Reliability measure	Change in mean, °	ICC (95% confidence interval)	95% Limits of agreement, °	CV % (95% confidence interval)	Standard error of measurement, °	Minimal detectable change, °
Ankle DF ROM	-0.10	0.98 (0.97, 0.99)	0.1 ± 1.8	1.70 (1.50, 2.00)	0.6	1.7
Ankle DF symmetry	-0.03	0.85 (0.73, 0.92)	0.1 ± 2.2	91.4 (69.4, 135.0)	0.8	2.1



TA = 46.5°

GK = 43.3 cm

HW = 45.6 cm

90- arctan [43.3/45.6] = 46.5

