Correlation of ankle dorsiflexion range of motion with lower-limb kinetic chain function and hop test performance in healthy male recreational athletes.

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Background: The study aims to identify the correlation of ankle dorsiflexion range-of-motion (ADROM) (with its related gastrocnemius and soleus extensibility) with lower-limb kinetic chain function and hop test performance in young healthy recreational athletes. **Methods:** Twenty-one young male healthy recreational athletes were tested for ADROM, gastrocnemius and soleus extensibility, lower-limb kinetic chain function with the closed kinetic chain lower extremity stability test (CKCLEST) and hop test performance with the single-leg hop for distance test (SHDT) and side hop test (SHT). **Results:** There was a positive significant (rho = 0.514, 95% CI 0.092 to 0.779, *P*<0.01) correlation between the dominant lower-limb weight-bearing/closed-chain ADROM (that represented the soleus extensibility) and the CKCLEST. There were no significant correlations between the study performance-based tests and open-chain ADROM (*P*>0.05). **Conclusion:** The CKCLEST is positively and significantly correlated with SHT and weight-bearing ADROM with knee flexion (and its related soleus extensibility) which suggests comparability among them. Open-chain ADROM has a negligible and non-significant correlation with the readings of this study performance-based tests suggesting that it is probably not an essential construct of their execution. To the best of our knowledge, this study is the first to investigate these correlations.

1 **Correlation of ankle dorsiflexion range of motion with lower-limb**

2 **kinetic chain function and hop test performance in healthy male**

3 **recreational athletes.**

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21   **ABSTRACT:**

22   **Background:** The study aims to identify the correlation of ankle dorsiflexion range-of-motion

23   (ADROM) (with its related gastrocnemius and soleus extensibility) with lower-limb kinetic

24   chain function and hop test performance in young healthy recreational athletes.

25   **Methods:** Twenty-one young male healthy recreational athletes were tested for ADROM,

26   gastrocnemius and soleus extensibility, lower-limb kinetic chain function with the closed kinetic

27   chain lower extremity stability test (CKCLEST) and hop test performance with the single-leg

28   hop for distance test (SHDT) and side hop test (SHT).

29   **Results:** There was a positive significant (rho = 0.514, 95% CI 0.092 to 0.779, *P*<0.01)

30   correlation between the dominant lower-limb weight-bearing/closed-chain ADROM (that

31   represented the soleus extensibility) and the CKCLEST. There were no significant correlations

32   between the study performance-based tests and open-chain ADROM (*P*>0.05).

33   **Conclusion:** The CKCLEST is positively and significantly correlated with SHT and weight-

34   bearing ADROM with knee flexion (and its related soleus extensibility) which suggests

35   comparability among them. Open-chain ADROM has a negligible and non-significant

36   correlation with the readings of this study performance-based tests suggesting that it is probably

37   not an essential construct of their execution. To the best of our knowledge, this study is the first

38   to investigate these correlations.

40   **Keywords:**, performance based tests, Triceps surae extensibility, Hop test, Kinetic chain

41   function, Athlete.

INTRODUCTION:

44   The kinetic chain is the limb muscle coordinated sequential activations to execute the
45   activity, which demands optimal flexibility, strength, proprioception, and endurance of the body
46   parts (Sciascia & Cromwell, 2012). Closed kinetic chain (CKC) activity, where the limb
47   terminal part meets a considerable resistance and is not free to move, generates forces that
48   decrease joint shear, boosts agonist-antagonist muscle coactivation (Lutz et al., 1993), and
49   simulates weight-bearing activities such as jumping and running (Kibler, 2000). In sports, the
50   kinetic chain means the biomechanical system used by the athlete to perform the sport-specific
51   tasks (Kibler, 2014). Alteration or breakage in the kinetic chain can be due to many factors,
52   including decreased muscle extensibility and joint range-of-motion (ROM) (Kibler, 2014). It has
53   been theorized that a joint motion deficit can cause abnormal movement series and alteration
54   (compensation) in muscle activity in the adjacent segments while performing a CKC (Alizadeh,
55   Alizadeh & Rajabi, 2017). As a result, new motor programs/patterns can develop, which may
56   cause overuse/overload injuries (Alizadeh, Alizadeh & Rajabi, 2017). Proper kinetic chain
57   function can lessen the risk of injury, as proven in a study done on university-aged recreational
58   female athletes (Cannon, Cambridge & McGill, 2019). Those with less dynamic valgus during
59   drop-jumping activity had a greater lumbar spine and gluteal elastic resistance to rotational joint
60   motion (Cannon, Cambridge & McGill, 2019). Consequently, they had less risk of sustaining
61   anterior cruciate ligament injury (ACLI) (Cannon, Cambridge & McGill, 2019). The CKC
62   function can be tested quantitatively using the CKC lower extremity stability test (CKCLEST), a
63   valid and reliable non-plyometric performance test (Arikan et al., 2021). In short, the kinetic
64   chain concept implies that the impairment of a joint can precipitate injuries to other joints (Pattyn
65   et al., 2011). Moreover, efficient energy transfers along the kinetic chain were linked to a lower
66   risk of injury and higher performance (Augustus et al., 2021).

67

68   The hop test is a performance-based test that echoes the combined influence of
69   neuromuscular control, capacity to generate power, speed, acceleration, deceleration, rebound,
70   direction changeability, and trust in the limb joints throughout its propulsive and landing phases
71   (Kotsifaki et al., 2021; Manske & Reiman, 2013; Petschnig, Baron & Albrecht, 1998). The
72   single-leg hop for distance test (SHDT) is valid and reliable in evaluating muscle strength/power

73   deficits (Reid et al., 2007). The SHDT can detect the risk of time-loss risk lower-limb and low-

74   back injuries in collegiate athletes throughout the preseason (Brumitt et al., 2013). Furthermore,

75   it can distinguish between normal and unstable ankles to a moderate extent (Vogler et al., 2017).

76   The side hop test (SHT) is a valid and reliable test for evaluating strength under the state of

77   fatigue via controlled, fast, and repetitive lateral hops (Kockum & Heijne, 2015). The SHT

78   represents the overall ankle readiness to practice sports activities (Greisberg et al., 2019).

79

80   Ankle dorsiflexion ROM (ADROM) assessment in the clinical setting is crucial as it may

81   be linked to lower-limbs harmful movement patterns (Lima et al., 2018). Moreover, ADROM

82   asymmetry was among the highly sensitive and specific risk factors of time-loss injury in

83   military service members (Teyhen et al., 2020). Decreased ADROM has been linked to ankle,

84   ACL, tendon (Achilles/patellar), and hamstring injuries (Moreno-Pérez et al., 2020).

85   Furthermore, decreased ADROM is a significant shoulder/elbow injury risk factor (Shitara et al.,

86   2021). Increased ADROM may maintain or improve dynamic postural control and prevent injury

87   occurrence (Burns et al., 2017; Nakagawa & Petersen, 2018). An increase in ADROM by 1° can

88   reduce the ACLI probability by 37.7 percentage in male athletes (Amraee et al., 2017). A study

89   on young baseball players found that if ADROM increases by 3.6°, the upper-limb injury risk

90   reduces by 19%, which is a considerable effect (Shitara et al., 2021).

91

92   ADROM is an indicator and clinical measure of landing quality and safety (Malloy et al.,

93   2015). Decreased ADROM is a predictor of poor landing kinematics and kinetics throughout the

94   drop-jump activity in female athletes (Malloy et al., 2015). Decreased ADROM was linked with

95   a significant reduction in sagittal plane joint displacement in the lower-limb joints in landing

96   performance (Howe et al., 2019), which can raise the risk of knee injury (Malloy et al., 2015).

97   While walking, decreased ADROM causes the pressures of body-weight-bearing to be shifted to

98   the forefoot, leading to numerous lower-limb pathologies (Abdulmassih et al., 2013).

99   Furthermore, decreased weight-bearing ADROM correlates significantly with the dynamic

100   postural control tested by the Lower Quarter Y-Balance Test (YBT-LQ) (Kang et al., 2015) and

101   Star Excursion Balance Test (SEBT) (Burns et al., 2017). ADROM under non-weight-bearing

102   conditions was significantly correlated with balance as measured with the Neurocom Smart

103 Balance Master's limits-of-stability test on spatiotemporal gait parameters using the GAITRite

104 electronic walkway in young and healthy participants (Norris et al., 2016). ADROM was

105 positively and significantly correlated with jumping performance in the Counter Movement

106 Jump test in young, healthy soccer athletes (Godinho et al., 2020). Passive ADROM was

107 significantly correlated with the quality of movement assessed with the lateral step-down test in

108 physically active individuals (Rabin et al., 2014) and those with chronic ankle instability

109 (Grindstaff, Dolan & Morton, 2017).

110

111   Injuries in sports practice are repeatedly linked with improper joint alignment and

112 movement patterns (Bates et al., 2015). Acute injuries in sports mainly affect athletes during

113 performing power events like sprinting, sharp direction changes, jumping, and landing (Bates et

114 al., 2015). Knowing risk factors is important but being conscious of how they are interlinked and

115 interacting is crucial for effective injury rehabilitation and prevention (Bittencourt et al., 2016).

116 To the best of our knowledge, no previous research has studied the correlation of the ADROM

117 with lower-limb kinetic chain function and hop test performance in young, healthy athletes. The

118 study aims to identify the correlation of ADROM (with its related gastrocnemius and soleus

119 extensibility) with lower-limb kinetic chain function (using the CKCLEST) and hop test

120 performance (using the SHDT and SHT) in young, healthy, and recreational athletes. Such

121 investigation could add to the body of knowledge of sports performance, screening, injury

122 incidence/recurrence prevention, and rehabilitation in young, healthy athletes. Consequently, this

123 can help decrease the medical cost and time lost from sports participation/competition.

124

125 **METHODS:**

126 **Participants**

127   The current study is a cross-sectional study conducted at the Physio-Trio physical therapy

128 clinic in Riyadh city in Saudi Arabia. A power analysis was used (https://www.ai-

129 therapy.com/psychology-statistics/sample-size-calculator) to calculate the sample size. The

130 calculations used data from a previous study (Swearingen et al., 2011) that investigated the

131 correlation between the hop tests and the single-leg vertical jumping in healthy males and

132 females between 18 and 30 years old. The following values were utilized to calculate the sample

133 size in this study: correlation coefficient of 0.7, significance level alpha value of 0.05, and

134 statistical power of 0.8. The calculation gave a sample size of 21 participants.

135

136   Twenty-one young (18-35 years old) male recreational athletes (who regularly practice

137 one to three times per week in sports events (Chappell et al., 2002)) with a mean age of 21.52 $\pm$

138 3.03 years, a height of 173.29 $\pm$ 6.57 cm, weight of 64.40 $\pm$ 7.17 kg, body mass index (BMI) of

139 21.51 $\pm$ 1.95 kg/m^2, participated in the study. The demographic characteristics of the participants

140 are available in Table 1. Athletes with a history of back/lower-limb injury that required medical

141 attention in the past six months, trunk/lower-limb surgery, medical condition (chronic or

142 systemic), deep venous thrombosis in the lower limbs, concussion, smoking, or red flags (i.e.,

143 night sweats, and unexplained weight loss) and athletes who took medications (which may affect

144 the execution of the tests) or had any biomechanical abnormalities, deformity, neurological

145 symptoms which may affect the testing, physical pain, ankle instability, and hamstring tightness

146 were excluded from the study. Athletes with BMI above or below normal (normal BMI is $\geq$18.5

147 to $\leq$24.9 kg/m^2) were excluded. Additionally, athletes who reported having mental health

148 conditions, were on psychiatric medication, or disturbed sleeping were also excluded from the

149 study. The participants signed the written informed consent statement form prior to participation

150 in the study. Ten participants practiced more than one type of sport. The included participants'

151 main sports that were practiced regularly were soccer (11 participants), karate (four participants),

152 basketball (two participants), running (one participant), paddle tennis (one participant), archery

153 and running (one participant), and archery and calisthenics (one participant).

154

155   Data collection was started from December 2021 to February 2022 (inclusive) and took

156 several forms. An invitation through advertisement using social media. Sports coaches in fitness

157 centers were given the advertisement to spread among their customers. There were 66

158 respondents, 21 were included, and 45 were excluded. The excluded respondents were 45 (34

159 males and 11 females). Those excluded were due to being below the required age (four athletes),

160 above the required age (four athletes), with high BMI (five athletes), smokers (three athletes),

161 injured (13 athletes), have physical pain (three athletes), have surgical history, history of head

162 injury (one athlete), suffer chronic medical conditions (three athletes) and one respondent who

163 was not an athlete. The institutional review board (IRB) ethical approval (IRB – PGS – 2021 –

164 03 – 475) was earned from Imam Abdulrahman Bin Faisal University on the 19th of December

165 2021.

166

167 **Procedure:**

168   Before testing the study variables, the principal investigator described the testing

169 procedure to the study participants. The data collection process was done by getting the

170 demographical data, screening for eligibility, getting the signed informed consent form from the

171 participant, conducting the ADROM measurement, and performance-based tests. The data

172 collection sheet was designed to document the data collected from the testing procedure. The

173 variables were ADROM, gastrocnemius-soleus extensibility (represented by the weight-bearing

174 ADROM), lower-limb kinetic chain function, and single-leg hop performance. The study

175 variables were tested with outcome measures described in Table 2 with the testing process

176 timeline. The principal investigator conducted all the testing to reduce the measurement

177 variability (Encarnación-Martínez et al., 2020). The dominant lower-limb dominancy was

178 recognized by asking the athlete to execute three tests that the athlete must instinctively (without

179 being aware of the purpose) choose one lower limb to do at least two ball kicking, fake fire

180 extinguishing, and drawing figures on the ground tasks. The chosen lower limb for the minimum

181 of two of the above-mentioned tasks was considered the dominant lower limb (Schneiders et al.,

182 2010; Vaisman et al., 2017). The evening time was the period of the day that the tests were

183 performed for all the study participants. The testing of the lower-limb kinetic chain function, and

184 single-leg hop performance was started with warming up session with five minutes lower-limbs

185 cycling with stationary bike at a self-selected and self-perceived moderate level of intensity

186 (Negrete et al., 2021) to increase muscle temperature (Bishop, 2003). The order of the tests was

187 random among the study participants to help in avoiding the possibility of that one test might

188 affect the performance of the other. In the hop tests, a coin-flip governs which lower limb will be

189 examined first (Brumitt et al., 2013) and both lower limbs were tested alternatively.

190

191 ***Open-chain ADROM:***

192   The Modified Root protocol was used to evaluate the passive ADROM for both lower

193 limbs (Rowlett et al., 2019). A universal goniometer (Elite Medical Instruments, USA) was the

194 tool to evaluate open-chain/non-weight-bearing ADROM in knee-angle-based positions: with the

195 knee in 0-degree extension (position 1) and with the knee in 90 degrees flexion (position 2)

196 (Rowlett et al., 2019) as illustrated in Figure 1. The goniometer axis was put on the lateral

197 malleolus. One goniometer arm was aligned with the fibula, indicating toward the fibular head.

198 The other arm was put parallel to the fifth metatarsal longitudinal axis. The body landmarks were

199 marked to have an accurate measurement (Weaver, 2001; Fong et al., 2011; Krause et al., 2011;

200 Rowlett et al., 2019). One tester (the principal investigator) completed the joint ROM

201 measurement because the assessment of the joint ROM with a universal goniometer has been

202 shown to have greater intra-tester than inter-tester reliability (Boone et al., 1978).

203

204 ***Gastrocnemius and soleus extensibility (weight-bearing ADROM with knee***

205 ***flexion/extension):***

206   Muscle extensibility was measured by the universal goniometer (illustrated in Figure 2)

207 using the weight-bearing/closed-chain ADROM. The soleus extensibility was measured using

208 the weight-bearing ADROM with knee flexion. The gastrocnemius extensibility was measured

209 using the weight-bearing ADROM with knee extension (Encarnación-Martínez et al., 2020).

210

211   Similar anatomical landmarks and universal goniometer arms placement were used for

212 open-chain ADROM and extensibility (for gastrocnemius and soleus) testing. The universal

213 goniometer stationary arm was placed on a marked fibular distal long axis (a line linking the

214 center of the lateral malleolus with the center of the fibula head) (Worrell, McCullough &

215 Pfeiffer, 1994). While the moveable arm of the universal goniometer was placed parallel to the

216 fifth metatarsal for the open-chain measurements, it was placed parallel to the floor for the

217 weight-bearing measurements (Worrell, McCullough & Pfeiffer, 1994). The ADROM was

218 recorded from each participant using the methods mentioned above during three trials, and the

219 average ROM reading was calculated (Rowlett et al., 2019).

220

221 ***Lower-limb performance tests:***

222 ***CKC lower-extremity stability test (CKCLEST):***

223   A stable base floor, mat, and stopwatch were the tools used to perform CKCLEST. The

224 starting position of the CKCLEST was the plank position using the support of the forearms with

225 the feet shoulder-width apart, the toes were in contact with the ground, and the body was in a

226 straight line. While maintaining this initial body position, the athlete was asked to cross the outer

227 side of the other foot with one foot and return. Then, the athlete made the same cross-and-return

228 movement using the other foot. The athlete did this movement with both feet alternatively as fast

229 as possible, as illustrated in figure 3. The number of repetitions in 15 seconds was recorded by

230 counting the number of times the foot touched the other foot's lateral side and the floor. Three

231 repetitions of the 15-second CKCLEST were performed with an interval of one minute between

232 each test. Each athlete was allowed to perform the test once as a trial to be familiar before the

233 actual test. Three trials were done, and the best trial score was used in the data analyses (Arikan

234 et al., 2021).

235

236 ***Single leg hop for distance test (SHDT):***

237   The athlete stood on the test lower limb and then hopped as far as he could and landed on

238 the same lower limb with no extra hops until two-to-three seconds, as illustrated in Figure 4.

239 Then the investigator measured the distance (in centimeters using a tape measure) from the big

240 toe at the push-off to the heel at the landing (Gustavsson et al., 2006). Single leg hop for distance

241 test was accomplished with arms behind the back because it is the most sensitive procedure to

242 identify poor functional performance (Ageberg & Cronström, 2018). A coin-flip governed which

243 lower limb the athlete hopped with first (Brumitt et al., 2013). The single-legged hop test was

244 executed barefoot (Harrison et al., 2017). The test was performed three times alternatively

245 between the right and left lower limb (Ageberg & Cronström, 2018). The best distance achieved

246 was the score needed for data analysis.

247

248 ***Side hop test (SHT):***

249   The athlete stood on the tested leg, with hands behind the athlete's back, and jumped from

250 side to side between two parallel tape strips (with a 40-centimetre distance between them), as

251 illustrated in figure 5. The athlete was directed to jump as many times as he could throughout 30

252 seconds. The successful jumps repetition (without touching the tape) was documented

253 (Gustavsson et al., 2006). The test was performed for three trials alternating the trials between

254 lower limbs. The test was executed barefoot (Harrison et al., 2017). The best score (the one with

255 the highest repetition) was the score needed for data analysis.

256

257 **Statistical analysis:**

258   The analysis was performed using the IBM SPSS version 27. Shapiro-Wilk test was used

259 to check normal distribution (P>0.05 was considered normal). The outcome data were presented

260 as mean and standard deviation for the parametric data with a normal distribution. The outcome

261 data were presented as median (25-75 percentile) for the variables that were not normally

262 distributed and those that were nonparametric. Demographical analysis was used to summarize

263 the athletes' age (in years), participation in sport (in minutes per day, days per week and years),

264 athlete mass (in kilograms), height (in centimeters), and calf muscle girth/maximal

265 circumference (in centimeters).

266

267   The Pearson product-moment test was used to test the correlations between ADROM

268 readings (in degrees) and single-leg hop distances (in centimeters) when the normal distribution

269 was confirmed. Because the normal distribution was not confirmed, Spearman's rank test was

270 used for correlating the dominant lower-limb open-chain ADROM (in degrees) with knee

271 extension with other variables. Spearman's rank test was used to test the correlation between the

272 ADROM (in degrees) and the SHT number of successful side-hops (in 30 seconds). Spearman's

273 rank test was used to test the correlation between the ADROM (in degrees) and the CKCLEST

274 number of cross-and-return movements (in 15 seconds). The Spearman's and Pearson's

275 correlation coefficients interpretations to determine the strength of the correlations are negligible,

276 weak, moderate, strong, and very strong for +/- (0.00 – 0.10), (0.10 – 0.39), (0.40 – 0.69), (0.70

277 – 0.89), and (0.90 – 1.00), respectively (Schober, Boer & Schwarte, 2018). The correlation

278 testing was of two-tailed directionality (Cho & Abe, 2013). For all correlations, the 95%

279 confidence intervals (CI) were calculated. An alpha level ($P < 0.05$) was used for statistical

280 significance (Andrade, 2019).

281

RESULTS:

There was no significant difference between the current study participants in height, weight, BMI, maximal calf circumference, main sport practice years, or minutes of practicing the main sport per day. Nevertheless, there was a significant difference in age and the number of days of practicing the main sport per week. The normality test (Shapiro – Wilk test) for the study variables displayed that all the study variables were normally distributed except the dominant lower-limb open-chain ADROM with knee extension and CKCLEST (repetition/15 seconds) data. Table 3 displays the mean +/- standard deviation for each normally distributed study variable. Table 4 displays the median (25-75 percentile) for the dominant lower-limb ADROM with knee extension (since they were not normally distributed), CKCLEST, SHT (repetition/30 seconds) for the dominant lower-limb, and SHT (repetition/30 seconds) for the non-dominant lower-limb data.

Table 5 shows the 24 correlations tested among the study variables using Spearman for the non-parametric analysis and Pearson correlation tests for the parametric analysis. There was a positive, moderate (Spearman's correlation coefficient rho = 0.514, 95% CI 0.092 to 0.779), and significant ($P<0.01$) correlation between the dominant lower-limb weight-bearing/closed chain ADROM that represented the soleus muscle extensibility and the CKCLEST. This correlation was visually illustrated by the scatter plot in figure 6. Other correlations were non-significant and ranged between weak and negligible correlations, as displayed numerically in table 5. In addition, a significant positive correlation between the CKCLEST and SHT was found in both dominant and non-dominant lower limbs (rho = 0.495, 95% CI 0.067 to 0.769, $P = 0.022$, and rho = 0.528, 95% 0.112 to 0.787, $P = 0.014$, respectively).

DISCUSSION:

The current study is the first (to the best of our knowledge) to investigate the correlation of the ADROM and its related gastrocnemius-soleus muscle extensibility with the hop test performance and the CKC function of the lower limbs. In young and healthy male recreational athletes, the current study found that the dominant lower-limb weight-bearing ADROM with knee flexion and its related soleus muscle extensibility was positively and significantly correlated with CKCLEST. Other correlations lack strength and significance.

313

314   Performing the CKCLEST requires repetitive mid-line crossing alternative reciprocal

315 movements between lower limbs while maintaining the planking with both ankles in dorsiflexion

316 for 15 seconds (Arikan et al., 2021). It could be that such a demanding and integrated task

317 requires neurocognitive function (an integrated task that requires visual focus, self-monitoring,

318 agility, dual tasking, accurate motor performance, reaction time, and speed (Herman et al.,

319 2015)). The neurocognitive function may be associated with brain areas found in a previous

320 study (Francis et al., 2009) to be activated with sustained ankle dorsiflexion. Furthermore, the

321 ankle dorsiflexion could enhance the abdominal isometric action related deep musculofascial

322 corset effect on the lumbopelvic region and its associated improved lumbar spinal stability

323 (Chon, Chang & You, 2010) required to perform the CKCLEST test.

324

325   Moreover, the soleus muscle extensibility could acquire the link with the CKC function

326 through being a part of the superficial back line (one of the myofascial chains) (Myers, 2012).

327 The superficial back line can facilitate effective force transmission between the core and limbs

328 by integrating the tension across it (Krause et al., 2016). Therefore, the higher soleus

329 extensibility may help integrate the tension along the superficial back line to facilitate force

330 transmission to execute the CKCLEST efficiently. A previous study (Outram, Wilson &

331 Wesselingh, 2020) found strong, positive, and significant associations between the weight-

332 bearing ADROM with knee flexion and backswing-related shoulder rotations, downswing-

333 related pelvis and shoulder rotations, and pelvis, shoulder, and upper arm segments' velocities in

334 male young healthy golfers. The CKCLEST requires pelvis rotations with speed to accomplish

335 the lower-limbs' alternative mid-line crossing movements. Therefore, it can be derived that

336 weight-bearing flexed-knee ADROM is linked to the diagonal/crosswise whole-body

337 contribution in the CKCLEST performance.

338

339   There was a negligible and non-significant correlation between the non-weight-bearing

340 open-chain ADROM and the CKCLEST. The closed-chain position augments the proprioceptive

341 stimuli (Kibler & Livingston, 2001). These augmented proprioceptive stimuli could result in

342 improved lower-limb activity coordination (Tuthill & Azim, 2018) needed in the CKCLEST

343 execution. Therefore, it could be that the open-chain position lacked the action-specific

344   alignment and its neuromuscular implications (augmented proprioceptive stimuli) where the

345   ankle ROM could be relevant to the CKCLEST execution. The probable interpretation of the

346   non-significant correlation between the single leg hop tests and the ADROM and its related

347   soleus-gastrocnemius extensibility is likely to be joint-contribution related. The single-leg hop

348   performance was correlated with hip function and the lower-limb proximal joints and muscles

349   involvement than the ankle joint and muscles (Kotsifaki et al., 2021; Ono et al., 2021).

350

351   **Additional findings:**

352   ***The CKCLEST and SHT correlation:***

353   The correlation between the CKCLEST and SHT was positive and significant for the

354   dominant and non-dominant lower limbs. To the best of our knowledge, this is the first study to

355   find this correlation. The quick side hop performance was found to reflect hip function in terms

356   of hip flexion, extension, and abduction torque in competitive sports performers (Ono et al.,

357   2021). Moreover, hip abduction torque was a core stability booster while executing the single-leg

358   side-stepping (Inaba et al., 2013). Therefore, there is a possibility that the SHT-related lower-

359   limb biomechanical constructs mimic those of the CKCLEST.

360

361   The study presented preliminary data about the prevalence of decreased ADROM.

362   Regarding the open-chain ADROM with knee extension, the study found that 17 out of the 21

363   participants (81%) have less than normal in dominant and non-dominant lower limbs (the normal

364   ADROM with knee extension is 20 degrees (Coetzee & Castro, 2004)). As for compatibility with

365   this findings, it was found (in a previous study) that young male soccer players may manifest a

366   marked and early decrease in open-chain ADROM with knee extension from the first few years

367   of practicing sports activities (Francia et al., 2021). For the open-chain ADROM with knee

368   flexion, 15 out of 21 participant (71%) have decreased range in the dominant lower limb (the

369   normal ADROM with knee extension is 35 degrees (Baumbach et al., 2016)). In the non-

370   dominant lower limb, 17 out of the 21 participants (81%) were with decreased range.

371

372   In the study sample, the weight-bearing closed-chain ADROM with knee flexion

373   (representing the soleus extensibility) was decreased in 16 out of 21 participants (76%) in the

374   dominant lower limb and in 16 out of 21 participants (76%) had decreased range in the non-

375   dominant lower limb. The normal weight-bearing closed-chain ADROM with knee flexion is 43

376   degrees (Baumbach et al., 2016). For the weight-bearing closed-chain ADROM with knee

377   extension (representing the gastrocnemius extensibility), there were 20 out of 21 participants

378   (95%) with a decreased range in the dominant lower limb. Likewise, 20 out of 21 participants

379   had decreased range in the non-dominant lower limb. The normal weight-bearing closed-chain

380   ADROM with knee extension is 34 degrees (Baumbach et al., 2016). Therefore, the study

381   participants had a high prevalence of triceps surae decreased extensibility (in gastrocnemius

382   more than soleus).

383

384   The possible explanation of the decreased ADROM to less than normal in the study

385   participants can be made clear with the following correlations. In the study participants, a

386   positive and significant (rho = 0.504, 95% CI 0.079 to 0.774, $P = 0.02$) correlation was found

387   between the soleus extensibility and open-chain ADROM with knee extension of the dominant

388   lower limb. Similarly, in the non-dominant lower limb, the correlation was positive and highly

389   significant with soleus ($r = 0.705$, 95% CI 0.393 to 0.871, $P<0.001$) and gastrocnemius

390   extensibility ($r = 0.609$, 95% CI 0.240 to 0.824, $P = 0.003$). Likewise, in the dominant and non-

391   dominant lower limbs, the correlation between the soleus extensibility and open-chain ADROM

392   with knee flexion was positive ($r = 0.702$, 95% CI 0.387 to 0.870, and 0.812, 95% CI 0.525 to

393   0.906, respectively) and highly significant ($P<0.001$). In the dominant and non-dominant lower

394   limbs, the correlation between gastrocnemius extensibility and open-chain ADROM with knee

395   flexion was positive ($r = 0.567$, 95% CI 0.179 to 0.802, and 0.805, 95% CI 0.572 to 0.918,

396   respectively) and highly significant ($P = 0.007$ and $P <0.001$, respectively). Moreover, it was

397   found in a previous study (Guillén-Rogel, San Emeterio & Marín, 2017) that there was a

398   significant positive link between the ADROM and ankle dorsiflexors strength in young and

399   healthy male students. So, it can be derived that decreased ADROM is possibly linked to

400   decreased plantar flexors' (soleus and gastrocnemius) extensibility and dorsiflexors' strength.

401

402   Knowing that the sports-related repetitive movements can shorten and thicken the fascia

403   around the overused muscles (de Witt & Venter, 2009), affecting their extensibility. Therefore,

404   the decreased soleus and gastrocnemius extensibility in the study sample can be referred to their

405   extensive use in sports as confirmed in the following lines. In the running, just before the toe-off

406   phase, the soleus and gastrocnemius absorb the peak mechanical power (Sasaki & Neptune,

407   2006). This peak power absorption increases when the ankle dorsiflexion is decreased (Pope,

408   Herbert & Kirwan, 1998; Kaufman et al., 1999). Furthermore, in fast arm movements, the

409   muscle activation sequence starts in the contralateral gastrocnemius/ (Zattara & Bouisset, 1988)

410   and then through the core and thoracolumbar fascia reaches up to the arm (Cordo & Nashner,

411   1982; Hirashima et al., 2002). The ankle is a key joint to perform optimal vertical jumping (Kilic

412   et al., 2017). In the jumping take-off phase, the mechanical energy flows through the ankle joint

413   that is adapting its plantarflexion motion making 23% of the velocity (Hubley & Wells, 1983),

414   which is dependent on the force amount generated by the gastrocnemius muscle (Bobbert & van

415   Zandwijk, 1999). In landing from a jump, the gastrocnemius-soleus complex provides 44% of

416   the energy absorption total muscle work (Devita & Skelly, 1992) and slows the ground reaction

417   forces propagation speed to the knee (Boden et al., 2010).

418

419   On the other hand, in the study sample, it was found that 19 out of 21 participants (90%)

420   had passive ankle plantarflexion ROM that is above the normal range in the dominant lower limb

421   with mean of 66.3 degrees. Moreover, we found that all participants have beyond normal ankle

422   plantarflexion ROM in their non-dominant lower limb, with a mean of 68.3 degrees. The normal

423   plantarflexion passive ROM is 50.0 degrees (Alazzawi et al., 2017).

424

425   For the dominant lower limb, this finding can be justified when the study found a positive

426   and highly significant correlation between the time spent practicing the main sport per day and

427   passive ankle plantarflexion ROM in the dominant lower limb ($r = 0.677$, 95% CI 0.346 to

428   0.858, P <0.001). This correlation was weak and non-significant ($r = 0.280$, 95% CI -0.172 to

429   0.635, $P = 0.218$) in the non-dominant lower limb. The study participants' main sports involve

430   many stretch-shortening activities (e.g., running, sprinting, side hopping, and vertical jumping).

431   Previous studies (İNal, Erbuğ & Kotzamanidis, 2012; Sugiyama et al., 2014) confirmed the

432   relationship between the dominant lower limb higher ankle plantarflexion ROM and the stretch-

433   shortening activities' performance in young and healthy male athletes. A previous study (İNal,

434   Erbuğ & Kotzamanidis, 2012) found that the 100-meter sprint running time was positively and

435   significantly correlated with the ankle plantarflexion ROM in the dominant lower limb in young,

436   healthy male sprinters. Likewise, it was found in collegiate young, healthy male basketball

437   players during the running-single-leg-jumps that the ankle plantarflexion joint angles were

438   significantly higher in the dominant than the non-dominant lower limb during the take-off phase

439   (Sugiyama et al., 2014). It was found that the take-off phase higher ankle plantarflexion angles

440   were linked with the effective ability to transfer the velocity of the run-up phase to higher jump

441   height (Sugiyama et al., 2014). In side-hopping, at the end of the contact phase and preparation

442   of the flight phase, the gastrocnemius-soleus muscle complex contract strongly to lift the body

443   weight upwards (Yoshida, Taniguchi & Katayose, 2011). This strong contraction produces a fast

444   ankle plantarflexion that has to be controlled by the tibialis anterior to properly adjust the ankle

445   position (Yoshida, Taniguchi & Katayose, 2011).

446

447   Additionally, activities like kicking the ball that is repetitively practiced in football code

448   sports demand more plantarflexion ROM and no dorsiflexion (Líška et al., 2021). Furthermore, it

449   was found that young, healthy recreational athletes with decreased weight-bearing ankle

450   dorsiflexion ROM with knee flexion (the mean was 36.3 degrees) tended to acquire greater ankle

451   plantar flexion and knee extension at initial landing contact in young, healthy recreational

452   athletes (Howe et al., 2019). Therefore, it can be derived that the increased ankle plantarflexion

453   ROM in the study participants was possibly related to the time spent per day practicing stretch-

454   shortening activities and decreased plantar flexors' (gastrocnemius and soleus) extensibility.

455

456   From the above mentioned discussed information about ADROM and ankle

457   plantarflexion findings in the study sample, it can be derived that the possible explanation of the

458   participants' increased range of ankle plantarflexion and decreased ADROM is linked to the

459   sports-practice imposed musculoskeletal maladaptation and insufficient recovery after the

460   training. The study is the first to have preliminary information about the prevalence of increased

461   ankle plantarflexion ROM, decreased ankle dorsiflexion ROM, and decreased soleus and

462   gastrocnemius muscle extensibility among healthy young recreational male athletes in Saudi

463   Arabia. No such previous study was done in Saudi Arabia.

464

465   ***The ankle ROM correlation between dominant and non-dominant lower limbs:***

466   In terms of ankle plantar flexion ROM, the study found that the dominant and non-

467   dominant lower limbs are weakly and non-significantly correlated ($r = 0.398$, 95% CI -0.041 to

468 0.708, *P* = 0.074). However, the ADROM was positively, strongly, and significantly correlated
469 between the dominant and non-dominant lower limbs. In details, for open-chain ADROM with
470 knee flexion (*r* = 0.703, 95% CI 0.389 to 0.870, P<0.001) and with knee extension (rho = 0.606,
471 95% CI 0.223 to 0.827, *P* = 0.004). For weight-bearing closed-chain ADROM with knee flexion
472 (*r* = 0.782, 95% CI 0.529 to 0.908, P<0.001) and knee extension (*r* = 0.852, 95% CI 0.664 to
473 0.938, P<0.001). As for compatibility with such findings of the current study, a previous study
474 found a positive and significant correlation between non-weight-bearing and weight-bearing
475 ADROM with knee flexion on the dominant and non-dominant lower limbs (Rabin et al., 2014).
476
477 From a joint motion perspective, the ankle dorsiflexors and plantar flexors are crucial
478 (Lauber, Gollhofer & Taube, 2018). However, during functional activities, the soleus (plantar
479 flexor) is a high-force producer, while the tibialis anterior (dorsiflexor) generates lower forces
480 (Lieber & Fridén, 2000). The training-related brain cortical adaptation is more optimal for the
481 most proficient/dominant limb (Farthing, 2009). Moreover, previous studies' findings (İNal,
482 Erbuğ & Kotzamanidis, 2012; Sugiyama et al., 2014) proved the relationship between the
483 dominant lower-limb higher ankle plantarflexion ROM and stretch-shortening activities'
484 performance in young, healthy male athletes. So, since the dominant lower-limb plantar flexors
485 are more proficient in producing force to help execute the activity, the ankle plantarflexion ROM
486 may become uncorrelated between the dominant and the non-dominant lower limb.
487
488 **Study limitations:**

489 There are some limitations in the study. The study is a cross-sectional study. Therefore,
490 no causal inferences can be concluded (Rohrer, 2018). There was a lack of sufficient control over
491 the psychological condition and motivation to perform the tests. The psychological aspect that
492 could affect the execution of the performance tests was not addressed in this study. Although, it
493 is known that the athlete's motivation to practice sports increases when they perceive high self-
494 confidence, self-perception, and self-trust in their abilities (Sari et al., 2015). However, in the
495 study eligibility screening of the athletes, they were asked whether they had mental conditions
496 (e.g., depression, anxiety, sleeping disorders, or panic attacks). Though, those conditions were
497 not ruled out by a specialized health care provider. The study participants were normal, young
498 (18 to 27 years old), and recreational level male athletes. Therefore, there is a generalizability

499 concern when using the current study's findings on non-athletes, females, inured athletes, or

500 athletes with different health statuses, age groups, and practice levels. However, having no

501 females in the current study included participants increased the sample homogeneity and,

502 consequently, the study's internal validity (Halperin, Pyne & Martin, 2015). Furthermore, the

503 study involved athletes from different sports, and many practiced more than one type of sports.

504 This diversity in the sports practice could influence the current study's internal validity

505 (Halperin, Pyne & Martin, 2015). However, such variety helped increase the external validity

506 (Ferguson, 2004). Moreover, there was a lack of control over the nutritional status of the

507 participants. However, the current study involved anthropometric data (the BMI and the calf

508 maximal circumference) that were normally distributed and reflect elements of the nutritional

509 status (Bailey & Ferro-Luzzi, 1995; Bahat, 2021).

510

511 **Recommendation for future studies:**

512 A deeper understanding of the link between ADROM and sports performance is

513 important and can help refine the knowledge and efforts to provide better care to the athlete. So,

514 it is recommended that future research addresses the current study research questions on another

515 gender (i.e., females), age groups, sports practice level (i.e., elite), and health status (those with a

516 health condition or injuries). Moreover, it is recommended to conduct the current research

517 question on athletes who practice one type of sport to explore the differences among the sports.

518 Furthermore, since no causality inferences can be derived from correlational study results,

519 conducting experimental studies is valuable to determine the cause-and-effect relationship. The

520 study provided preliminary data concerning the deceased ADROM and increased plantarflexion

521 ROM prevalence among healthy recreational male athletes in Saudi Arabia. The percentage in

522 the study sample was high. Though, a prevalence study must be conducted to have a

523 representative precise conclusion.

524

525 **Clinical implications:**

526 The current study findings suggested that, in young, healthy, and recreational male

527 athletes, giving more attention to the dominant lower-limb weight-bearing ADROM with knee

528   flexion and its related soleus extensibility in clinical examination and preseason screening could

529   help add to the efforts of refining sports performance and minimizing the risk of injury. The

530   CKCLEST and SHT scores are comparable. However, the CKCLEST puts compressive forces

531   on the upper limbs, while the SHT puts compressive forces on the lower limbs. Therefore, the

532   coach or health care provider can switch between CKCLEST and SHT to examine equivalent

533   performance constructs based on the required or avoided compressive forces' effect on limbs.

534   The high prevalence of ankle decreased dorsiflexion ROM, soleus-gastrocnemius extensibility,

535   and increased plantar flexion among the study participants may encourage proactive efforts to

536   screen athletes for these impairments, identify the vulnerable ones, provide them with proper

537   intervention, and consequently improve sports performance and minimize injury risk. Regarding

538   the ADROM, using the non-affected or contralateral lower limb as a reference in the clinical

539   examination for young male recreational athletes is justified and reasonable. On the other hand,

540   for the ankle plantar flexion ROM, the non-affected or contralateral lower limb should not be

541   used as a clinical examination reference.

542

543   **CONCLUSION:**

544   According to the study principal findings attained in young, healthy, and recreational

545   male athletes, weight-bearing/closed-chain ADROM with knee flexion and related soleus muscle

546   extensibility in the dominant lower limb is positively and significantly correlated with CKC

547   function in the lower limbs. Therefore, including the dominant lower-limb weight-bearing

548   ADROM with knee flexion and its related soleus extensibility in the athletes' screening and

549   clinical examination could add to the efforts and body of knowledge of sports performance and

550   injury prevention. However, the non-weight-bearing/open-chain ADROM is not an essential

551   component in the study performance-based tests (CKCLEST, SHDT, and SHT). Furthermore,

552   the study's additional findings revealed a positive and significant correlation between the SHT

553   and the CKCLEST, suggesting that they can provide comparable data on male, young, and

554   healthy athletes. Thus, the SHT and the CKCLEST can be used interchangeably in clinical

555   examination and screening. Moreover, the study is the first to report preliminary information

556   about the prevalence of increased ankle plantarflexion ROM, decreased ankle dorsiflexion ROM,

557   and decreased soleus and gastrocnemius muscle extensibility among young, healthy, and

558 recreational male athletes in Saudi Arabia. This preliminary data encourages conducting a

559 prevalence study to provide representative information that can add to sports injury prevention

560 efforts.

561

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Demographic characteristics of the study participants.

1 **Table 1:** Demographic characteristics of the study participants.

Variable	Mean ± SD
Age (in years)	21.52 ± 3.03
Height (centimeters)	173.29 ± 6.57
Mass (kilograms)	64.40 ± 7.17
Body mass index (BMI) (kilograms per meter square)	21.51 ± 1.95
Dominant calf circumference (centimeters)	35.67 ± 2.04
Non dominant calf circumference (centimeters)	35.52 ± 1.97
Main sports practice (years)	8.90 ± 5.15
Main sports practice (days/week)	5.10 ± 1.58
Main sports practice (minutes/day)	137.62 ± 61.07

2 **SD**, Standard Deviation; **BMI**, Body Mass Index.

The time-line of the process of testing the study variables.

1   **Table 2:** The time-line of the process of testing the study variables.

Testing variables	Testing order
First: **Using universal goniometer for ADROM testing:** - With knee extension - With knee flexion Average score was used for data analysis.	- Explaining testing procedure using the goniometer to the participant and that he needs to be in prone position. - Then, testing both lower limbs for three trials.
Second: **Using universal goniometer for muscle extensibility testing:** - Weight-bearing ADROM with the knee extended (for the gastrocnemius extensibility). - Weight-bearing ADROM with the knee flexed (for the soleus extensibility). Average score is used for data analysis.	- Explaining testing procedure using the goniometer to the participant and that he needs to be standing with the tested lower limb flexed and then extended at the knee to the maximum before the heel got lifted from the floor. - Then, testing both lower limbs for three trials. - Next, each test of the study performance-based tests in the third step got explained with the participant demonstrated the test to proof his understanding of the test before the scoring got started.

Third:
The following performance-based tests are tested in a random order:
- **CKCLEST** (for three trials with resting for one minute between trials).
- **Hop tests:**
   - SHDT (for three trials).
   - SHT (for three trials).
The best score among the three trials is the score used for data analysis.
	Starting the third step with warming up session with five minutes lower-limbs cycling with stationary bike at a self-selected and self-perceived moderate level of intensity (Negrete et al., 2021) to increase muscle temperature (Bishop, 2003). The order of the tests in the third step was random among the study participants to help in avoiding the possibility of that one test might affect the performance of the other.
	
	In the hop tests, a coin-flip governs which lower limb will be examined first (Brumitt et al., 2013). Both lower limbs were tested alternatively.

2   **ADROM**, Ankle Dorsiflexion Range-of-Motion; **CKCLEST**, Closed Kinetic Chain Lower
3   Extremity Stability Test; **SHDT**, Single-leg Hop for Distance Test; **SHT**, Side Hop Test.

Tested variables' mean and standard deviation.

3 **Table 3:** Tested variables' mean and standard deviation.

The normally distributed and parametric tested variables	Mean $\pm$ SD
Dominant lower-limb open-chain ADROM with knee flexion (degrees)	25.62 $\pm$ 10.11
Non-dominant lower-limb open-chain ADROM with knee flexion (degrees)	25.14 $\pm$ 12.34
Non-dominant lower-limb open-chain ADROM with knee extension (degrees)	11.90 $\pm$ 7.96
Dominant leg gastrocnemius extensibility (weight-bearing ADROM with knee extension) (degrees)	29.90 $\pm$ 8.26
Non-dominant lower-limb gastrocnemius extensibility (weight-bearing ADROM with knee extension) (degrees)	29.33 $\pm$ 9.06
Dominant lower-limb soleus extensibility (weight-bearing ADROM with knee flexion) (degrees)	34.95 $\pm$ 9.05
Non-dominant lower-limb soleus extensibility (weight-bearing ADROM with knee flexion) (degrees)	34.67 $\pm$ 9.60
SHDT (centimeters) for the dominant lower limb	146.67 $\pm$ 25.10
SHDT (centimeters) for the non-dominant lower limb	147.67 $\pm$ 25.09

4 **ADROM,** Ankle Dorsiflexion Range-of-Motion; **SHDT**, Single-leg Hop for Distance Test.

Tested variables' median and 25 – 75 percentiles.

1   **Table 4:** Tested variables' median and 25 – 75 percentiles.

The non-normally distributed/non-parametric tested variables	Median (25 – 75 percentiles)
Dominant lower-limb open-chain ADROM with knee extension (degrees)	10 (6 – 13)
CKCLEST reading (repetition/15 seconds)	22 (21 – 29)
SHT reading (repetition/30 seconds) for the dominant lower limb	43 (34 – 53)
SHT reading (repetition/30 seconds) for the non-dominant lower limb	44 (34.50 – 54.50)

2   **ADROM**, Ankle Dorsiflexion Range-of-Motion; **CKCLEST**, Closed Kinetic Chain Lower
3   Extremity Stability Test; **SHT**, Side Hop Test.

The correlations between ADROM and performance-based tests.

1 **Table 5:** The correlations between ADROM and performance-based tests.

	Open-chain ADROM				Weight-bearing ADROM			
	Dominant lower limb		Non-dominant lower limb		Dominant lower limb		Non-dominant lower limb	
	With knee flexion	With knee extension	With knee flexion	With knee extension	With knee flexion (Soleus extensibility)	With knee extension (Gastrocnemius extensibility)	With knee flexion (Soleus extensibility)	With knee extension (Gastrocnemius extensibility)
CKCLEST	rho = 0.255 95% CI [-0.211, .0627] $P = 0.264$	rho = 0.149 95% CI [- 0.314, 0.555] $P = 0.518$	rho = 0.291 95% CI [-0.174, 0.650] $P = 0.200$	rho = 0.335 95% CI [- 0.127, 0.677] $P = 0.138$	rho = 0.514* 95% CI [0.092, 0.779] $P = 0.017*$	rho = 0.330 95% CI [- 0.132, 0.674] $P = 0.145$	rho = 0.343 95% CI [- 0.118, 0.682] $P = 0.128$	rho = 0.271 95% CI [- 0.195, 0.637] $P = 0.234$
SHDT for the dominant lower limb	$r = - 0.291$ 95% CI [- 0.642, 0.161] $P = 0.201$	rho = 0.060 95% CI [- 0.394, 0.489] $P = 0.798$			$r = 0.059$ 95% CI [- 0.382, 0.479] $P = 0.799$	$r = 0.50$ 95% CI [- 0.390, 0.471] $P = 0.830$		
SHDT for the non-dominant lower limb			$r = - 0.160$ 95% CI [- 0.554, 0.292] $P = 0.488$	$r = - 0.042$ 95% CI [- 0.465, 0.397] $P = 0.856$			$r = - 0.157$ 95% CI [-.0.551, 0.295] $P = 0.497$	$r = - 0.239$ 95% CI [- 0.608, 0.215] $P = 0.297$
SHT for the dominant lower limb	rho = 0.182 95% CI [- 0.283, 0.578] $P = 0.429$	rho = 0. 288 95% CI [- 0.177, 0.648] $P = 0.205$			rho = 0.198 95% CI [- 0.268, 0.589] $P = 0.389$	rho = 0.145 95% CI [- 0.318, 0.552] $P = 0.530$		
SHT for the non-dominant lower limb			rho = 0.235 95% CI [- 0.323, 0.614] $P = 0.305$	rho = 0.378 95% CI [- 0.078, 0.703] $P = 0.091$			rho = 0.252 95% CI [- 0.214, 0.625] $P = 0.270$	rho = 0.030 95% CI [- 0.418, 0.466] $P = 0.898$

1 **ADROM,** Ankle Dorsiflexion Range-of-Motion; **CKCLEST**, Closed Kinetic Chain Lower Extremity Stability Test; **SHDT**, Single-leg Hop for Distance Test; **SHT**, Side
2 Hop Test; **CI**, Confidence Interval; **rho**, Spearman's Correlation Coefficient; *r*, Pearson's Correlation coefficient; *P*, the probability value of getting the resulted data when
3 the null hypothesis is assumed to be true.*P<0.05, the significance level was set at less than 0.05 with the star sign indicating the statistically significant finding.

Figure 1

Figure 1: Modified Root position 1 (illustrated in the photo on the left) and position 2 (illustrated in the photo on the right) for open-chain ADROM testing. The fibular distal long axis was marked to guide the placement of the universal goniometer stati

Figure 2

The gastrocnemius (illustrated in the photo on the left) and soleus (illustrated in the photo on the right) extensibility testing. The universal goniometer stationary arm was placed on a marked fibular distal long axis. The moveable arm was placed paralle

Figure 3

CKCLEST test application. The photos on the top demonstrate the starting position (the plank position using the support of the forearms with the feet shoulder-width apart, the toes were in contact with the ground, and the body was in a straight line). The
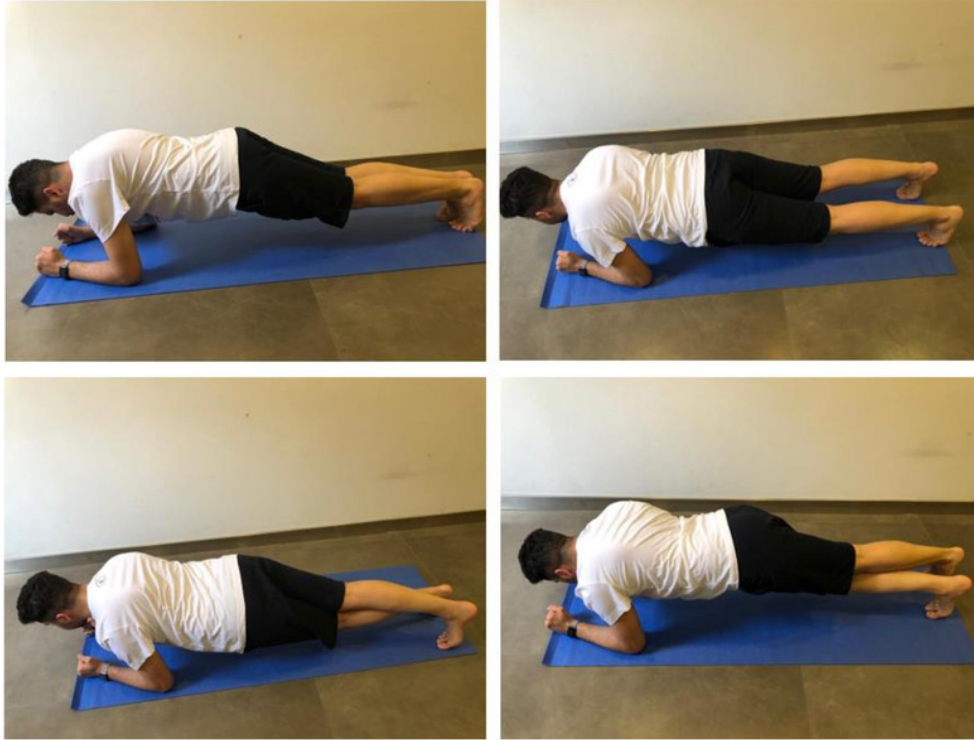
Figure 4

SHDT with bare feet and arms behind the back. The score is the distance travelled in centimeters (represented by the blue double headed arrow) from the starting line (the athlete's big toe was behind the line) to the heel after landing.

Figure 5

Illustration of the SHT. The athlete was directed to jump as many times as he could throughout 30 seconds. The successful jumps repetition (without touching the tape on the floor) was the score needed.

Figure 6

Scatter plot illustrating visually the positive and moderately strong correlation between dominant lower-limb soleus extensibility represented by the weight-bearing ADROM with knee flexion and the CKCLEST.