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Balsalobre-Fernández, Carlos ORCID: <https://orcid.org/0000-0002-8329-1581>, Bishop, Chris ORCID: <https://orcid.org/0000-0002-1505-1287>, Beltrán-Garrido, José Vicente ORCID: <https://orcid.org/0000-0001-9286-8453>, Cecilia-Gallego, Pau, Cuenca-Amigó, Aleix, Romero-Rodríguez, Daniel and Madruga-Parera, Marc (2019) The validity and reliability of a novel app for the measurement of change of direction performance. *Journal of Sports Sciences* . ISSN 0264-0414 (Published online first) (doi:10.1080/02640414.2019.1640029)

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1 **THE VALIDITY AND RELIABILITY OF A NOVEL APP FOR THE**
2 **MEASUREMENT OF CHANGE OF DIRECTION PERFORMANCE**

3

4 Carlos Balsalobre-Fernández¹, Chris Bishop², José Vicente Beltrán-Garrido³, Pau
5 Cecilia-Gallego³, Aleix Cuenca-Amigó³, Daniel Romero-Rodríguez⁴, Marc
6 Madruga-Parera^{3,4}

7

8 ¹Department of Physical Education, Sport and Human Movement, Autonomous
9 University of Madrid, Spain

10 ²Faculty of Science and Technology, London Sport Institute, Middlesex University,
11 London, UK

12 ³University School of Health and Sport (EUSES), University of Rovira Virgili,
13 Amposta, Spain

14 ⁴University School of Health and Sport (EUSES), University of Girona, Girona, Spain

15

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26

27 **Carlos Balsalobre-Fernández**

28 Department of Physical Education, Sport and Human Movement, Universidad

29 Autónoma de Madrid, Spain

30 Address: C/ Fco Tomas y Valiente 3, 28049, Cantoblanco, Madrid, Spain

31

E-mail: carlos.balsalobre@icloud.com

32

33

Chris Bishop

34 Faculty of Science and Technology, London Sport Institute, Middlesex University,

35 London, UK

36 Address: The Burroughs, Hendon, NW4 4BT London, United Kingdom

37

E-mail: C.Bishop@mdx.ac.uk

38

39 **José Vicente Beltrán-Garrido**

40 University School of Health and Sport (EUSES), University of Rovira Virgili,

41 Amposta, Spain

42 Address: C/ Sebastià Joan Arbó, 2 43870 Amposta-Tarragona, Spain

43

E-mail: jose.vicente@euseste.es

44

45 **Pau Cecilia-Gallego**

46 University School of Health and Sport (EUSES), University of Rovira Virgili,

47 Amposta, Spain

48 Address: C/ Sebastià Joan Arbó, 2 43870 Amposta-Tarragona, Spain

49

E-mail: pau.cecilia@euseste.es

50

51

52 **Aleix Cuenca-Amigó**

53 University School of Health and Sport (EUSES), University of Rovira Virgili,

54 Amposta, Spain

55 Address: C/ Sebastià Joan Arbó, 2 43870 Amposta-Tarragona, Spain

56

E-mail: aleixcuenca@yahoo.es

57

58

Daniel Romero-Rodriguez

59 University School of Health and Sport (EUSES), University of Girona, Girona, Spain

60 Address: C/ President Francesc Macià, 65, 17190 Salt-Girona, Spain

61

E-mail: danirrphysco@gmail.com

62

63

Marc Madruga-Parera

64 University School of Health and Sport (EUSES), University of Girona, Girona, Spain

65 Address: C/ President Francesc Macià, 65, 17190 Salt-Girona, Spain

66

E-mail: marcmparera@gmail.com

67

68 **Corresponding author: Carlos Balsalobre-Fernández**

69 Department of Physical Education, Sport and Human Movement, Universidad

70 Autónoma de Madrid, Spain

71 Address: C/ Fco Tomas y Valiente 3, 28049, Cantoblanco, Madrid, Spain

72

E-mail: carlos.balsalobre@icloud.com

73

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75

76 **Abstract**

77 The aim of the present investigation was to analyze the validity and reliability of a
78 novel iPhone app (CODTimer) for the measurement of total time and interlimb
79 asymmetry in the 5+5 change of direction test (COD). To do so, twenty physically
80 active adolescent athletes (age=13.85±1.34 years) performed six repetitions in the
81 COD test while being measured with a pair of timing gates and CODTimer. A total
82 of 120 COD times measured both with the timing gates and the app were then
83 compared for validity and reliability purposes. There was an almost perfect
84 correlation between the timing gates and the CODTimer app for the measurement of
85 total time (r=0.964; 95% Confidence interval (CI)=0.95-1.00; Standard error of the
86 estimate=0.03s.; p<0.001). Moreover, non-significant, trivial differences were
87 observed between devices for the measurement of total time and interlimb
88 asymmetry (Effect size<0.2, p>0.05). Similar levels of reliability were observed
89 between the timing gates and the app for the measurement of the 6 different trials of
90 each participant (Timing gates: Intraclass correlation coefficient (ICC)=0.651-0.747,
91 Coefficient of variation (CV)=2.6-3.5%; CODTimer: ICC=0.671-0.840, CV=2.2-
92 3.2%). The results of the present study show that change of direction performance
93 can be measured in a valid, reliable way using a novel iPhone app.

94 **Keywords:** sprinting; agility; biomechanics; technology; smartphone

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101 **Introduction**

102 Change of direction speed (CODS) is a critical component of athletic performance and
103 its importance has been well documented in many sports. For example, it has been
104 suggested that soccer players can perform 1200-1400 changes of direction in a game
105 (Bangsbo, 1992), that CODS is a crucial for both rugby league and union athletes of
106 all standards (Baker & Newton, 2008; Delaney et al., 2015; Gabbett, Kelly, &
107 Sheppard, 2008), and even fencers can cover as much as 1000 m with up to 200
108 changes of direction during elimination bouts (Turner et al., 2016). Thus, with CODS
109 being such a prominent physical quality during competition, it is no surprise that it is
110 often included in fitness testing batteries for the assessment of athletic performance
111 (Baker & Newton, 2008; Chaouachi et al., 2012; Cooke, Quinn, & Sibte, 2011;
112 Nimphius, Callaghan, Bezodis, & Lockie, 2018).

113 When measuring CODS, several timing-based technologies have been used in the
114 literature such as electronic timing gates, infrared photo-beam cells, radar guns and
115 stop watches (Haugen & Buchheit, 2016; Morin, 2013; Samozino et al., 2015), with
116 electronic timing gates often considered as the gold standard instrument to measure
117 time events (Sheppard & Young, 2006). However, one key drawback of this
118 technology is its high cost. This prevents its use to coaches and institutions where
119 budgets are limited. Solving these limitations, smartphone applications (apps) have
120 been proved to be a valid, reliable and accurate alternative to traditional laboratory
121 equipment for the measurement of several physical capabilities like vertical jumping
122 (Balsalobre-Fernández, Glaister, & Lockett, 2015; Haynes, Bishop, Antrobus, &
123 Brazier, 2018), barbell velocity (Balsalobre-Fernández, Marchante, Muñoz-López, &
124 Jiménez, 2018; Pérez-Castilla, Piepoli, Delgado-García, Garrido-Blanca, & García-
125 Ramos, 2019) or linear running and sprinting (Balsalobre-Fernández, Agopyan, &

126 Morin, 2017; Romero-Franco et al., 2017) thanks to the built-in slow-motion cameras
127 present in current devices that can record at 240 frames per second. Moreover, the
128 validity of some slow-motion apps has been confirmed in different populations like
129 adolescent athletes (Rogers et al., 2019), old adults (Cruvinel-Cabral et al., 2018) or
130 even professional Cerebral palsy players (Coswig et al., 2019). However, to date no
131 app has been developed to specifically measure CODS performance.

132 Therefore, the aim of the present investigation was to test the concurrent validity and
133 reliability of a novel iOS app (named: *CODTimer*) that was specifically designed to
134 measure the total time and interlimb asymmetry in the 5+5 change of direction test
135 (i.e., a 180° COD task) (Nimphius et al., 2018) in adolescent athletes. Based on
136 previous literature that analyzed the validity of slow-motion apps to measure linear
137 running and sprinting (Balsalobre-Fernández et al., 2017; Romero-Franco et al., 2017),
138 we hypothesize that *CODTimer* would be a valid, reliable and accurate alternative for
139 the measurement of total time in the 5+5 test when compared with a set of electronic
140 timing gates.

141

142 **Methods**

143 *Participants*

144 Twenty voluntary adolescent soccer players were recruited (mean (SD): age = 13.85
145 \pm 1.34 years; height = 1.67 \pm 0.45 m; body weight = 47.98 \pm 7.48 kg). The study
146 protocol complied with the Declaration of Helsinki for Human Experimentation and
147 was approved by the ethics committee at the institutional review board. Written
148 informed consent was obtained from each participant and their parents/legal tutors in
149 advance.

150

151 *Study design*

152 In order to analyze the validity and reliability of the *CODTimer* mobile application,
153 the participants performed a 5+5 180° COD test (Castillo-Rodríguez, Fernández-
154 García, Chinchilla-Minguet, & Carnero, 2012) on an artificial outdoor grass surface.
155 Every participant performed a total of 6 trials (3 trials with COD executed with the
156 right lower limb and 3 trials with COD executed with the left lower limb). Time of
157 each trial was measured by both the photocells (Witty gate) and the COD timer
158 application simultaneously. The 120 times registered of both instruments were
159 compared in order to perform validity and reliability analysis with statistical
160 procedures. All tests were performed during the afternoon (6pm to 8pm) in similar
161 temperature (23°C) and humidity (60%) conditions.

162

163 *Instruments*

164 A single beam photocell (Witty gate, Microgate, Bolzano, Italy,
165 <http://www.microgate.it>) were used as criterion variable to measure the execution time
166 of the trials. One photocell was allocated at the start/finish gate of the test in order to
167 quantify the time employed by the participant to perform each trial. The photocell
168 possesses an integrated transmission system with a 150 m range and a precision of ±
169 0.4 ms. The radiofrequency signal was collected by the central unit via remote that
170 interprets the start and end times of each trial. The photocell height was individually
171 adjusted to match each athlete's ground-to-hip height.

172 The *CODTimer* app was specifically developed for this study using Xcode 10.2.1 for
173 macOS High Sierra 10.14.4 and the Swift 5 programming language with iOS 12 SDK
174 (Apple Inc., USA). The AVFoundation and AVKit frameworks (Apple Inc., USA)
175 were used for capturing, importing and manipulating high-speed videos. Then, the app

176 (version 1.0) was installed on an iPhone X running iOS 12.2 (Apple Inc., USA) which
177 has a recording frequency of 240 frames per second (fps) at a quality of FullHD
178 (1920x1080 pixels). The app's user interface was designed to record and high-speed
179 videos and to allow a frame-by-frame inspection of them. Then, the app calculates the
180 total time in the 5+5 change of direction test (5+5) as the difference between two time
181 events which were manually selected by an independent user as follows: the beginning
182 of the 5+5 was considered as the first frame in which the participant crossed the timing
183 gate in the starting/end line of the test, and the end was considered as the first frame
184 in which the participant crossed that gate again. A video-tutorial showing the complete
185 procedure can be found in the following URL: [https://youtu.be/ Y2xZjMA7fc](https://youtu.be/Y2xZjMA7fc).

186

187 *5+5 COD test measurement*

188 In order to record the videos, the mobile phone was attached in a tripod in vertical
189 position. The trials were recorded from a perpendicular plane to the starting/finishing
190 gate of the test. The mobile was placed 2 m away from the photocell position to record
191 the instant in which any part of the participant's body crossed the starting/finishing
192 gate of the test, interrupting the beam of the light of the photocell. See Figure 1 for
193 more details.

194

195 ** FIGURE 1 ABOUT HERE **

196

197 The start and finish of every trial was considered as the first frame in which the
198 participant crossed the timing gate with any part of his body (specifically, when the
199 participant crossed the imaginary line linking sender and receiver of the photocell, i.e.,
200 the infrared line that activates the timing). Once the frames were selected, the

201 application exported the data to a spreadsheet for posterior analysis. Trained sports
202 scientists with at least one year of experience in slow motion apps analyzed all of the
203 videos. Previous investigations showed a very high intra-rater reliability of trained
204 observers when analyzing slow motion (Stanton, Wintour, & Kean, 2016).

205 After a 10-15 min standard warm-up consisted of jogging, dynamic stretching and
206 activation exercises of increasing intensity, the participants performed the 5+5 180°
207 COD test (Castillo-Rodríguez et al., 2012). Starting position was standardized to all
208 participants. The participant was in the middle of a 1.5 m lane, with a two-point
209 staggered stance. The most advanced foot was placed 30 cm from the starting line and
210 the other one in line with the heel of the forward foot. Each participant was instructed
211 to perform a 10-m sprint with a 180° COD at 5 m before return to the starting point
212 (Figure 1). All participants wore soccer boots, and they were familiar with the 5+5
213 COD test from their regular soccer practice.

214

215 *Statistical analyses*

216 The app's concurrent validity was tested by means of a linear regression, Pearson's r
217 correlation matrix with 95% confidence intervals (CI), the standard error of the
218 estimate (SEE), and the slope of the regression line were analyzed. To test collinearity,
219 the Durbin-Watson test was also computed. Second, to analyze the level of agreement
220 (reliability) between the app and the timing gates for the measurement of total time in
221 the change of direction test, the intraclass correlation coefficient with 95% CI (ICC,
222 two-way random, absolute agreement). ICC was interpreted as follow: $ICC > 0.9 =$
223 excellent, $0.75-0.9 =$ good, $0.5-0.74 =$ moderate, $< 0.50 =$ poor (Koo & Li, 2016). Also,
224 paired samples t -test and Bland-Altman plots were used to identify potential
225 systematic bias, reported via mean bias, standard deviations and the analysis of the

226 regression line on the Bland–Altman plots. If some variables failed to comply with the
227 normality and homogeneity assumptions (which were computed using Shapiro-Wilk
228 and Levene’s tests), Mann-Whitney U-test was used to test the difference between
229 variables. The standardized mean difference (SMD) between the measures obtained
230 with each instrument was calculated using Cohen’s *d* effect size and reported as trivial
231 (0-0.2), small (0.2-0.6), moderate (0.6-1.2) or large (>1.2) (Rhea, 2004). When
232 analyzing the reproducibility of the *CODTimer* app for the measurement of the 3
233 different trials conducted with each leg, the coefficient of variation (CV) was used.
234 The level of significance was set at 0.05. Inter-limb asymmetries were calculated using
235 the following equation:

236

237 $100 - (100 / \text{maximum value}) * \text{minimum value}.$

238

239 All calculations were performed using JASP 0.9.2 for Mac (University of Amsterdam,
240 Netherlands).

241

242 **Results**

243 *Concurrent validity*

244 The analysis of the whole dataset (i.e., 120 individual points) showed a very high
245 correlation between the *CODTimer* app and the timing gates (TG) for the measurement
246 of the total time in the change of direction test ($r = 0.964$; 95% CI = 0.95-1.00; SEE =
247 0.03 s.; Slope of the regression line = 0.998; $p < 0.001$). No collinearity was observed
248 as revealed by the Durbin-Watson test ($d = 2.10$) (Figure 2).

249

250

** FIGURE 2 ABOUT HERE **

251

252 Non-significant, trivial differences were observed in the total time of the change of
253 direction test between the *CODTimer* app and the TG (Mean difference = -0.02 ± 0.03
254 s.; ES = -0.19; 95% CI = -0.46 to 0.06; $p = 0.14$). The analysis of the Bland-Altman
255 plot showed a systematic bias between the *CODTimer* app and the TG for the total
256 time (Bias = 0.02 s.; 95% CI = 0.01 to 0.03 s.; Lower limit of agreement = -0.04 s.;
257 Upper limit of agreement = 0.09 s.). Finally, the regression line in the Bland-Altman
258 plot showed no heteroscedasticity in the distribution of the difference between devices
259 as revealed by its regression line ($r^2 = 0.014$). See Figure 3.

260

261 ** FIGURE 3 ABOUT HERE **

262

263 *Reliability*

264 The ICC showed a very high agreement between the *CODTimer* app and the TG for
265 the measurement of total time in the change of direction test (ICC = 0.97; 95% CI =
266 0.90 to 0.99). When analyzing the reproducibility of the *CODTimer* app for the
267 measurement of 3 different trials with each leg, similar levels of reliability were
268 observed in comparison with those obtained with the TG (TG left leg: CV = 3.5 ± 2.2
269 %, ICC = 0.651, 95% CI = 0.266 to 0.851; TG right leg: CV = 2.6 ± 1.3 %, ICC =
270 0.747, 95% CI = 0.467 to 0.892; *CODTimer* left leg: CV = 3.2 ± 2.3 % ICC = 0.671,
271 95% CI = 0.306 to .859, *CODTimer* right leg: CV = 2.2 ± 1.0 %, ICC = 0.840, 95%
272 CI = 0.663 to 0.932). Non-significant differences were observed between the CV
273 calculated with the *CODTimer* app and the TG (ES < 0.2, $p > 0.05$). See Figure 4.

274

275 ** FIGURE 4 ABOUT HERE **

276

277

278 *Measurement of interlimb asymmetry*

279 Finally, trivial, non-significant differences were observed in the inter-limb
280 asymmetries in the change of direction tests between devices (timing gates = $1.67 \pm$
281 1.65% ; *CODTimer* = $1.70 \pm 1.16\%$; ES = 0.13; 95% CI = -0.22 to 0.45; $p = 0.50$).

282

283 **Discussion**

284 The primary aim of the present study was to test the concurrent validity and reliability
285 of a novel iOS app (named: *CODTimer*) that was specifically designed to measure the
286 total time in the 5+5 change of direction test. Results in our study showed that the
287 *CODTimer* app is highly valid and reliable for the measurement of the total time in the
288 5+5 change of direction test in adolescent soccer players. Additionally, similar
289 interlimb asymmetry scores were obtained with the app in comparison with the timing
290 gates (ES < 0.2, $p > 0.05$).

291 Specifically, the linear regression analysis showed a very high association ($r^2 = 0.93$)
292 between the app and the timing gates, with a slope coefficient very close to the identity
293 line (Slope = 0.998). Moreover, no collinearity was observed as revealed by the
294 Durbin-Watson test ($d = 2.1$). When different measures from a same participant are
295 included in a regression model, collinearity might occur, producing overestimations of
296 the fit (Naclerio & Larumbe-Zabala, 2018). Even if six trials from the same participant
297 were included, it did not affect the fit of the linear regression model. Trivial, non-
298 significant differences were observed between the total time/completion times
299 measured with the app and the timing gates (ES < 0.2; $p > 0.05$). These results are in
300 line with previous research that analyzed the ability of a slow-motion app for the

301 measurement of time events during a 30-m. sprint, were very high associations were
302 observed between the app and the timing gates ($r^2 > 0.97$), with no significant
303 differences between devices (Romero-Franco et al., 2017). Thus, when compared to
304 electronic timing gates, the *CODTimer* can be considered as a valid and cost-effective
305 alternative for practitioners who are looking to measure total time during the 5+5 test.
306 Determining the reliability of the *CODTimer* app was another aim of the present study
307 and the results show that the app is highly reliable. Relative reliability (as reported by
308 the ICC) was moderate on both limbs when calculated from the timing gates (ICC =
309 0.651-0.747), whilst the *CODTimer* reported moderate reliability on the left limb (ICC
310 = 0.671), but good reliability on the right limb (ICC = 0.840). In addition, the ICC was
311 also used to compare the agreement between the timing gates and app and showed near
312 perfect reliability (ICC = 0.97). When considering absolute reliability using the CV,
313 similar and acceptable values of reliability were observed with both devices, with CVs
314 ranging from 2.2-3.2% for the app, and 2.6-3.5% for timing gates. Previous research
315 has highlighted that CV values < 10% are considered acceptable (Cormack, Newton,
316 McGuigan, & Doyle, 2008). Thus, practitioners can have confidence that the
317 *CODTimer* is a reliable method for measuring total time during the 5+5 test.

318 Another feature of the 5+5 test is the ability to detect inter-limb asymmetry scores,
319 regardless of whether the app or timing gates were used. Results showed comparable
320 asymmetry values between test methods (timing gates = $1.67 \pm 1.65\%$; *CODTimer* =
321 $1.70 \pm 1.16\%$), which is unsurprising given that both test methods reported very similar
322 test variability. However, it is worth noting that the mean asymmetry scores from the
323 5+5 test can be considered very small (Bishop, Turner, & Read, 2017). Previous
324 research has suggested that the use of total time as a metric to detect inter-limb
325 differences is poor (Dos'Santos, Thomas, Jones, & Comfort, 2018; Madruga-Parera et

326 al., 2019) and the asymmetry results in the present study would appear to support such
327 a suggestion. Recently, when aiming to measure asymmetry during CODS tasks, it has
328 been suggested that the change of direction deficit (CODD) could be a more useful
329 tool (Dos'Santos et al. 2018). The CODD subtracts an athlete's linear speed time (e.g.,
330 10-m) from a CODS time of equivalent distance (e.g., 5+5 test) and has been suggested
331 to better isolate the change of direction component in a CODS test (Nimphius et al.
332 2018). Dos'Santos et al. (2018) reported mean asymmetry values for total time of -
333 2.3% during the 505 test, but -11.9% for the CODD within the same test in 43 youth
334 netball players. Thus, if practitioners wish to profile an athlete's between-limb
335 differences, it is suggested that using the CODD could be a more sensitive measure of
336 detecting inter-limb asymmetries. However, it is worth noting that in order for this to
337 be achieved, a linear speed test of comparable distance would also need to be
338 measured. As with COD, linear sprint can be measured in a valid and reliable way
339 using a smartphone app (Romero-Franco et al., 2017).

340 Despite the novelty and usefulness of the present study, there is one key limitation
341 which should be acknowledged. Firstly, the results of the present study can be applied
342 only to the 5+5 test (i.e., a 180° COD task). Future research should aim to determine
343 the reliability of the *CODTimer* app across multiple CODS tests, such as the 505, pro-
344 agility or even cutting tasks like 90° COD. Practitioners may have specific
345 requirements or preferences when measuring CODS performance; thus, this would
346 increase the usability of the app in the field.

347 In conclusion, the *CODTimer* app was shown to be a highly valid and reliable tool to
348 measure total time in the 5+5 180° COD test in adolescent soccer players. Additionally,
349 it was shown that the app was able to detect interlimb asymmetries with small, non-
350 significant differences in comparison with timing gates. The present investigation adds

351 to the literature by showing that slow-motion video analysis can be a valid and reliable
352 alternative for the measurement of very short, 180° CODS tests.

353

354

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357

358 **Disclosure statement**

359 The first author of the article is the developer of the app mentioned. The data from the
360 app were obtained from an independent observer not related to the app's development.

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492

493 **FIGURE CAPTIONS**

494 **Figure 1.** Schematic representation of the 5+5 change of direction test, showing were
495 the timing gates and the smartphone were placed. A supplemental video showing how
496 to use the app to analyze the test can be found in the following URL:
497 https://youtu.be/_Y2xZjMA7fc

498

499 **Figure 2.** Linear regression between the *CODTimer* app and the timing gates for the
500 measurement of total time in the change of direction test.

501

502 **Figure 3.** Bland-Altman plot showing the bias (with 95% CI) between instruments, its
503 limits of agreement (± 1.96 standard deviations), and the regression line of the residual
504 (bold grey line). Overlapping points are represented with wider circles.

505

506 **Figure 4.** Boxplots with jitter points for the CVs of the different trials performed with
507 each leg, and each instrument.