1 **A joint kinetic analysis of rugby place kicking technique to understand why**

2 **kickers achieve different performance outcomes**

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5

7   **Abstract**

8   We aimed to identify differences in kicking leg and torso mechanics between groups

9   of rugby place kickers who achieve different performance outcomes, and to

10   understand why these features are associated with varying levels of success. Thirty-

11   three experienced place kickers performed maximum effort place kicks, whilst three-

12   dimensional kinematic (240 Hz) and ground reaction force (960 Hz) data were

13   recorded. Kicking leg and torso mechanics were compared between the more

14   successful ('long') kickers and two sub groups of less successful kickers ('short' and

15   'wide-left') using magnitude-based inferences and statistical parametric mapping.

16   Short kickers achieved substantially slower ball velocities compared with the long

17   kickers (20.8 ± 2.2 m/s vs. 27.6 ± 1.7 m/s, respectively) due to performing substantially

18   less positive hip flexor (normalised mean values = 0.071 vs. 0.092) and knee extensor

19   (0.004 vs. 0.009) joint work throughout the downswing, which may be associated with

20   their more front-on body orientation, and potentially a lack of strength or intent. Wide-

21   left kickers achieved comparable ball velocities (26.9 ± 1.6 m/s) to the long kickers,

22   but they were less accurate due to substantially more longitudinal ball spin and a

23   misdirected linear ball velocity. Wide-left kickers created a tension arc across the torso

24   and therefore greater positive hip flexor joint work (normalised mean = 0.112)

25   throughout the downswing than the long kickers. Whilst this may have assisted kicking

26   foot velocity, it also induced greater longitudinal torso rotation during the downswing,

27   and may have affected the ability of the hip to control the direction of the foot trajectory.

28

29   **Keywords** (up to 5): football, inverse dynamics, kick, mechanics, three-dimensional

1. Introduction

Forty-five percent of the total points scored in 582 international rugby union matches (2002-2011) came from place kicks (Quarrie and Hopkins, 2015). If the success percentages of the two competing teams had been reversed, the results would have switched in 14% of these matches (Quarrie and Hopkins, 2015). Although other factors affect the outcome of a match, place kick performance is clearly important. Understanding place kicking technique is therefore crucial for improving kickers' performance levels and, ultimately, team success.

Despite the value of successful place kicking in rugby, there are relatively few in-depth investigations of place kicking technique. Previous research has typically examined how technique influences ball velocity, focussing on describing the motion of the kicking leg (Aitchison and Lees, 1983; Sinclair et al., 2014; Zhang et al., 2012), with peak knee extension velocity identified as the sole significant predictor ($R^2 = 0.48$; Sinclair et al., 2014). The support foot position has also been investigated and found to be highly consistent for individuals within a group of professional place kickers (0.03 ± 0.07 m behind and 0.33 ± 0.03 m lateral to the tee; Cockroft and van den Heever, 2016), although extreme acute alterations to this position have no effect on ball velocity (Baktash et al., 2009). Also of interest has been the applicability of common coaching cues, with evidence supporting the suggestion that players 'kick through the ball' but not the existence of a 'front-on' body position at ball contact (Ball et al., 2013).

Whilst insufficient ball velocity may lead to a place kick being unsuccessful by dropping short of the crossbar, a misdirected ball velocity vector also affects kick success by causing the ball to pass outside of the goalposts. To-date, only three studies have directly considered accuracy during rugby place kicking. Greater angular momentum

54   of the non-kicking-side arm was identified as a feature of accurate kicking because it

55   opposed the angular momentum of the kicking leg, and potentially minimised trunk

56   rotation and over-rotation of the whole-body (Bezodis et al., 2007). Sinclair et al.

57   (2017) found that, when prioritising accuracy, kickers demonstrated reduced kicking

58   hip and knee extension velocities and subsequently a reduced linear velocity of the

59   kicking foot in addition to greater ankle dorsiflexion and external rotation of the kicking

60   foot. This kicking foot orientation reflected a more side-foot technique, with ball contact

61   likely occurring closer to the metatarsals than the ankle joint. A side-foot technique

62   has previously been reported in soccer instep kicking as a mechanism to improve

63   kicking accuracy (Levanon and Dapena, 1998), and a more distal contact location is

64   associated with reduced ball velocity (Peacock and Ball, 2018). Lastly, Bezodis et al.

65   (2018) demonstrated that accurate kickers exhibited different kicking foot swing planes

66   to inaccurate kickers but did not determine how the motion of the individual kicking leg

67   joints influenced these swing planes. Both upper body and kicking leg mechanisms

68   therefore require consideration when kicking for accuracy is investigated.

69   As a successful kick from distance requires both a fast and appropriately directed ball

70   velocity (i.e. distance and accuracy), a performance outcome combining these two

71   factors is necessary to truly understand the movement (Atack et al., 2018).

72   Investigating specific technique differences between kickers who achieve different kick

73   outcomes (i.e. long and straight versus long but wide or straight but short) would

74   therefore enable the understanding of technique factors that are important for ensuring

75   distance and accuracy, and provide information to enable coaches to manipulate these

76   in kickers who are less successful for different reasons. The aim of this study was

77   therefore to identify differences in key kinematic and kinetic features of technique

78 between groups of place kickers who achieve different performance outcomes, and to

79 understand why these features are associated with varying levels of success.

80 **2. Methods**

81 *Participants*

82 Thirty-three male place kickers (mean ± SD: age = 22 ± 4 years, mass = 86.2 ± 8.8

83 kg, height = 1.82 ± 0.06 m) ranging from amateur to senior international playing level

84 provided written informed consent to participate in this study, which was approved by

85 the lead researchers' university ethics committee prior to testing.

86 *Procedures*

87 After a self-directed warm-up and familiarisation, each participant performed a

88 minimum of five place kicks, as if from their maximum range. These were performed

89 indoors wearing moulded boots on a rubber floor, and from each participant's preferred

90 kicking tee towards a vertical target (representative of the centre of the goal posts)

91 suspended in a net. The global coordinate system was aligned such that the positive

92 Y-axis represented the horizontal direction towards the centre of the target, the Z-axis

93 was vertical, and the X-axis was the cross-product of the two. Eighty markers were

94 used to define a 14-segment human-body model (Supplement 1) during a static trial,

95 and 54 of these markers (including rigidly-mounted clusters on the limb segments)

96 remained on the participant during the kicks to track their motion (240 Hz) using a

97 Vicon[©] MX3 system (measurement accuracy of 0.0009 m). Ground reaction force

98 (GRF) underneath the support foot was synchronously recorded (960 Hz) using a

99 Kistler 9287BA force platform. Six circular markers were attached to the ball (Gilbert

100 Virtuo, size 5) to track its three-dimensional translation and rotation.

101 Marker trajectories were labelled using Vicon© Nexus and the raw .c3d files were

102 exported for analysis in Visual 3D (v. 5.0, C-Motion©, USA). Ball contact was identified

103 when the kicking toe marker reached peak anterior velocity, and the start of ball flight

104 when the anterior velocity of the ball centre first decreased after ball contact (Shinkai

105 et al., 2009). Linear ball velocity was calculated from polynomial functions fitted to the

106 first four frames of ball displacement during flight (first order for both horizontal

107 directions, second order for vertical), and ball angular velocities were calculated as the

108 first derivative of the respective ball orientations between the first and fourth frames.

109 These data were input into a model of rugby ball flight to calculate the maximum

110 distance that each kick could be successful from before dropping below crossbar

111 height or passing outside one of the upright posts (Atack et al., 2018). Each kicker's

112 attempt with the greatest maximum distance was used for subsequent analysis.

113 All trials were cropped at the frame prior to ball contact. Marker data were low-pass

114 filtered at 18 Hz (determined through residual analyses; Winter, 2009) using a fourth-

115 order Butterworth filter with endpoints padded (20 point reflection). The padded

116 endpoints were subsequently removed, and segmental kinematics were reconstructed

117 using an Inverse Kinematics approach (Lu and O'Connor, 1999) with three rotational

118 degrees of freedom at all joints. Joint angular displacements were calculated using an

119 XYZ Cardan rotation sequence (corresponding to the flexion-extension, abduction-

120 adduction, internal-external rotation axes) (Lees et al., 2010) and joint angular

121 velocities were calculated with the proximal segment as both the reference segment

122 and resolution coordinate system. The GRF data were also filtered at 18 Hz (Bezodis

123 et al., 2013) and combined with the kinematic and segmental inertia data (de Leva,

124 1996) in an inverse dynamics analysis to determine the kicking hip and knee joint

125 kinetics prior to ball contact. The joint kinetics were normalised for comparison

126   between participants (Hof, 1996), with height substituted for leg length. Pelvis and

127   thorax orientations about the global z-axis were also calculated, and the rotation of the

128   thorax relative to the pelvis was determined using an XYZ Cardan rotation sequence

129   (Brown et al., 2013). All variables measured in the medio-lateral direction and about

130   the longitudinal axis were inverted for left-footed kickers. As there were no differences

131   in the downswing durations of the kickers (Table 1), all time-histories were normalised

132   to 101 samples using an interpolating cubic spline from the top of the backswing (the

133   highest vertical position of the kicking foot centre of mass) to ball contact.

134   *Data Analysis*

135   The kickers were grouped based on performance outcome. Initially, kickers who

136   achieved a maximum distance greater than 32 m (the average place kick distance in

137   international matches[1]) were identified and termed 'long' kickers (n = 18). Those

138   kickers who achieved a maximum distance less than 32 m were sub-divided into short

139   (n = 4), wide-left (n = 8) or wide-right (n = 1) groups based on their reason for failure.

140   Two kickers were excluded as they were within 4.0% (the accuracy of the ball flight

141   model; Atack et al., 2018) of the 32 m threshold. The wide-right group was removed

142   as only a single kicker was classified in this category. For each group, mean ± standard

143   deviations were calculated for all variables.

144   Technique variables of the long kickers were compared to those of the two less

145   successful groups. To compare discrete variables, effect sizes (Cohen, 1988) were

146   calculated with 90% confidence intervals, and magnitude-based inferences were

147   derived using a smallest important effect size of 0.2 (Batterham and Hopkins, 2006).

148   If the confidence intervals did not cross both -0.2 and 0.2, the effect was considered

149   substantial. Time-histories were compared using 1D statistical parametric mapping

150   with an α-level of 5% (Pataky, 2012). All group differences discussed subsequently

151   were found to be either substantial or significant.

152   **3. Results**

153   The short and wide-left kickers achieved comparable maximum distances, both

154   shorter than the long kickers (Table 1). The short kickers exhibited lower resultant ball

155   and kicking foot velocities compared with the long kickers but there was no difference

156   in the resultant ball velocities achieved by the long and wide-left kickers (Table 1).

157

158   *** Table 1 near here ***

159

160   For all kickers, a knee extensor moment was dominant for the majority of the

161   downswing before becoming flexor dominant during approximately the final 20%

162   (Figure 1b). This extensor moment was initially associated with knee flexion and thus

163   negative extensor power (K1, Figure 1c). During phase K1, the long kickers did more

164   negative knee extensor work than the short kickers, but there was no clear difference

165   between the long and wide-left kickers (Table 1). A positive extensor power phase

166   then occurred from approximately -60% as the knee extended (K2, Figure 1c), before

167   a negative flexor power phase initiated just prior to ball contact when the knee moment

168   became flexor dominant (K3, Figure 1c). The long kickers did more positive knee

169   extensor work (K2) and negative knee flexor work (K3) than both the wide-left and

170   short kickers (Table 1).

171

172   *** Figure 1 near here ***

173

174   For all kickers, the hip flexed throughout the downswing (Figure 1d). This was

175   accompanied by a resultant flexor moment for the majority of the downswing and thus

176   positive hip flexor power (Figure 1e,f). The flexor moment was greatest at the top of

177   the backswing before reducing until late in the downswing where a small increase in

178   the flexor moment was observed in all groups at around -20% of the phase (Figure

179   1e), before a rapid reduction prior to ball contact (Figure 1e). The long kickers did less

180   positive hip flexor work than the wide-left kickers, but more than the short kickers

181   (Table 1).

182   All the kickers orientated their pelvis and thorax segments towards the kicking leg side

183   (when viewed from above) throughout the downswing (Figure 2a,b). There was no

184   difference in pelvis orientation between the long and wide-left kickers but the long

185   kickers demonstrated greater pelvis retraction than the short kickers at the top of the

186   backswing (Figure 2a). The long kickers' thorax was orientated further towards the

187   kicking leg side (i.e. more 'retracted') for the first 70% of the downswing compared

188   with the wide-left kickers' and for the complete downswing compared with the short

189   kickers' (Figure 2b). The comparable pelvis orientations and different thorax

190   orientations between the long and wide-left kickers meant that the wide-left kickers

191   had a larger pelvis-thorax separation angle than the long kickers throughout 80% of

192   the downswing (Figure 2c).

193

194   *** Figure 2 near here ***

195

4. Discussion

197 We quantified kicking leg and torso mechanics during rugby place kicking and

198 understood the techniques adopted by groups of kickers who achieve three distinctly

199 different performance outcomes. When compared with the long kickers, the short

200 kickers demonstrated a more front-on thorax and pelvis orientation and performed less

201 positive work at the hip and knee joints during the downswing, resulting in reduced

202 foot and ball velocities, and consequently a shorter maximum distance. The wide-left

203 kickers achieved comparable foot and ball velocities to the long kickers but adopted a

204 more front-on thorax orientation and a hip-dominant technique in which they performed

205 greater positive work at the hip and less at the knee, leading to an inappropriately

206 directed ball velocity vector, greater longitudinal ball spin and subsequently an

207 inaccurate kick.

208 The general hip and knee joint kinematic patterns were consistent across all groups

209 and similar to those reported for amateur kickers (Zhang et al., 2012). This is the first

210 study to determine joint kinetics during rugby place kicking; the reductions in the hip

211 flexor moment during the downswing are consistent with studies of soccer instep

212 kicking (Lees et al., 2009; Nunome et al., 2002), but the second smaller peak just prior

213 to ball contact appears unique to rugby place kicking. Previous research has identified

214 inappropriate filtering methods through impacts as a potential source of error in data

215 close to the impact (Nunome et al., 2006); however, as data during ball contact were

216 not included in the current processing, this was unlikely to be an influencing factor.

217 One possible explanation for this second peak is the additional requirement of a high

218 ball launch angle which is typically not required in soccer instep kicking (approximately

219 30 ± 4° compared with 14.1 ± 0.5°; Holmes et al., 2006 and Alcock et al., 2012a,

220 respectively). The joint kinetics used to achieve kicks with different launch angles have

221 not been directly investigated in any football codes, but future experimental studies

222 could investigate the role of the hip joint in achieving these launch angles.

223 The faster kicking foot velocity of the long kickers compared with the short kickers

224 likely explains the faster ball velocity based on the established relationship between

225 these in other football codes (Ball, 2008; De Witt and Hinrichs, 2012; Nunome et al.,

226 2006). Given the proximal-to-distal transfer of energy down the kicking leg (Putnam,

227 1991) and the strong positive relationship between knee extension and foot velocity

228 (Sinclair et al., 2014), the slower foot velocity of the short kickers is likely due to the

229 reduced positive hip flexor and knee extensor joint work performed throughout the

230 downswing. Whilst this may be due to reduced strength capabilities, these short

231 kickers may also lack maximal intent and choose not to perform as much lower body

232 work as they could in order to maintain a straight ball flight - this mechanism has been

233 previously shown to be adopted within place kickers when prioritising accuracy, as

234 evidenced through reduced kicking leg joint angular velocities (Sinclair et al., 2017).

235 Furthermore, the more front-on pelvis of the short kickers throughout the downswing

236 may be a further mechanism which inhibited their performance as pelvic protraction is

237 a known feature of high velocity kicking (Lees et al., 2009). Coaches who work with

238 kickers who lack distance could consider technical interventions to alter approach

239 angle and therefore pelvis orientation, or technical or conditioning programmes to

240 increase hip flexor and knee extensor work.

241 As there was no difference in ball velocity magnitude between the long and wide-left

242 kickers, the wide-left kickers' poorer performance was due to the misdirected initial

243 ball flight and greater longitudinal ball spin. Over the entire downswing, the wide-left

244 kickers performed more positive hip flexor work and less positive knee extensor work

245 than the long kickers. Whilst this is the first study to quantify the work done by the

246 kicking leg joints of accurate and inaccurate kickers in any football code, two different

247 techniques based on kicking leg kinematics have been identified in Australian Rules

248 football punt kicking (Ball, 2008) which are supported, and partly explained, by the

249 current kinetic results. Ball (2008) observed a negative relationship (r = -0.90) between

250 knee angular velocity and thigh angular velocity at ball contact across a cohort of 28

251 professional players and separated the kickers into two groups ('thigh' and 'knee')

252 based on their individual ratio of knee angular velocity to thigh angular velocity. These

253 groups achieved comparable kicking foot velocities but relied on different techniques

254 to do so (Ball, 2008). The joint work data reported in the current study provide a kinetic

255 mechanism which supports and explains the existence of different kicking strategies

256 and extends this theory by associating a knee-dominant technique with more accurate

257 kicking. Greater knee dominance could also be beneficial for enabling the multi-

258 articular hip joint to be more involved in the control of the direction of the kicking foot

259 as suggested in a study of soccer instep versus curve kicking (Alcock et al., 2012b),

260 but further research is warranted to directly explore this potential mechanism.

261 One aspect which appears to play an important role in the different techniques adopted

262 by the long and wide-left kickers is the torso motion in the transverse plane. Both

263 groups exhibited a comparable pelvis orientation throughout the downswing, but the

264 wide-left kickers' thorax was more front-on for the first 70%. This larger relative pelvis-

265 thorax angle at the top of the backswing corresponds to a 'tension arc' mechanism

266 which has previously been discussed in soccer instep kicking (Shan and Westerhoff,

267 2005). This mechanism corresponds to a large pelvis-thorax angle at the top of the

268 backswing which is thought to create a greater muscular stretch across the torso.

269 When released during the downswing, this enables kickers to achieve faster kicking

270 foot velocities (Shan and Westerhoff, 2005). The 'tension arc' mechanism could

271 therefore explain the wide-left kickers' greater positive hip flexor work compared with

272 the long kickers, with a greater initial stretch of the hip flexors leading to enhanced

273 force production during the subsequent contraction. However, although a 'tension arc'

274 may be beneficial for increasing foot velocity (Shan and Westerhoff, 2005), our results

275 suggest that this may not be a beneficial mechanism for kick accuracy. The release of

276 the torso stretch in the current study appeared to cause the thorax of the wide-left

277 kickers to longitudinally rotate towards the kicking leg during the downswing (through

278 approximately 20°), whereas the long kickers' displayed less rotation (<10°). As a

279 minimal amount of thorax angular momentum about the longitudinal axis at ball contact

280 is associated with more accurate rugby place kicking (Bezodis et al., 2007), use of the

281 'tension arc' may have negatively affected the wide-left kickers' accuracy through both

282 the aforementioned reliance on hip flexor work and also thorax rotation affecting the

283 control of their whole-body angular momentum. If the 'tension arc' release does affect

284 foot velocity (Shan and Westerhoff, 2005) then it could also affect the direction of this

285 vector in addition to its magnitude. Analysis of the kicking foot vector at ball contact

286 indicated that the long kickers' vector was directed further towards the right-hand-side

287 of the target (26° from the centre compared with 24° for the wide-left kickers). These

288 foot velocity vectors become progressively straighter (towards the target) during the

289 ball contact phase, and are slightly to the left of the target by the end of ball contact

290 (Bezodis et al., 2018). The long kickers' more laterally oriented foot velocity at initial

291 ball contact may be required because of the shallower inclination of their kicking foot

292 swing planes (Bezodis et al., 2018), and therefore helps to facilitate their ball launch

293   directions being slightly to the right of the target (Table 1), although higher-speed

294   analysis of the foot-ball impact is required to confirm this. Adjustments to the

295   orientation of the wide-left kickers' thorax at the top of the backswing, to be less front-

296   on, may help to encourage a change in the joint work strategies as there will be less

297   stretch across the torso and therefore less contribution from the stretch-shortening

298   cycle to the positive work done by the hip flexors. A torso orientation more closely

299   aligned to pelvis orientation has been associated with greater accuracy in elite

300   National Rugby league kickers (Ball et al., 2013), providing further support for this

301   suggestion; however, the efficacy of such an intervention requires investigation and

302   the effect on ball velocity magnitude also requires consideration.

303   The participants in this study were all regular place kickers at playing levels ranging

304   from University to full senior international and were therefore considered to be

305   proficient kickers. All data collection was undertaken in a laboratory to reduce the

306   sources of error in our joint kinetic calculations, which therefore reduced the ecological

307   validity of the study. However, the performance outcomes achieved by the kickers in

308   our study were comparable to those recorded in outdoor studies (Holmes et al., 2006)

309   and in international matches (Quarrie and Hopkins, 2015). Additional factors such as

310   location of the kick on the pitch or match-related pressures which can influence kick

311   success (Pocock et al., 2018) were controlled for in the current study and could be

312   considerations for future research.

313   This study identified important differences in kicking leg and torso mechanics between

314   successful (long) kickers and less successful (either wide-left or short) kickers

315   throughout the downswing of a rugby place kick. The short kickers did less positive

316   joint work than the long kickers and subsequently achieved slower kicking foot and

317 ball velocities. This may have been due to their more front-on orientation or a lack of

318 strength or maximal intent. The wide-left kickers were able to achieve comparable ball

319 velocities to the long kickers but were not able to appropriately control the direction

320 and spin of the initial ball flight. This may have been because the wide-left kickers

321 used a more hip-dominant technique through the creation of a 'tension arc' across the

322 torso, whereas the long kickers adopted a knee-dominant technique. The knee-

323 dominant technique may have enabled the long kickers to better control the kicking

324 foot path through adjustments at the hip joint, whilst the greater longitudinal rotations

325 of the wide-left kickers' thorax also further negatively affected their accuracy.

326 **5. Conflict of interest**

327 There are no conflicts of interest to declare.

328 **Acknowledgements**

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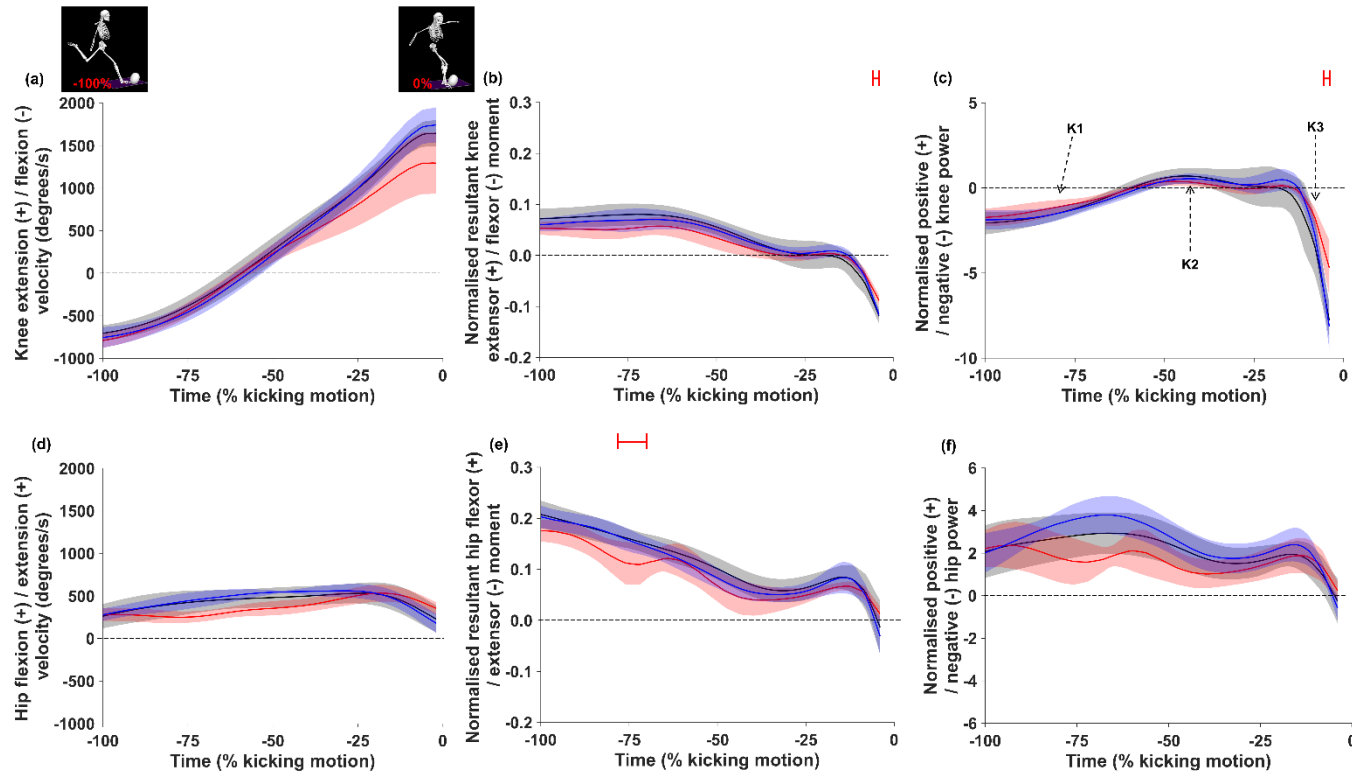373   *Journal of Sports Sciences*, 34(4), 321-329.

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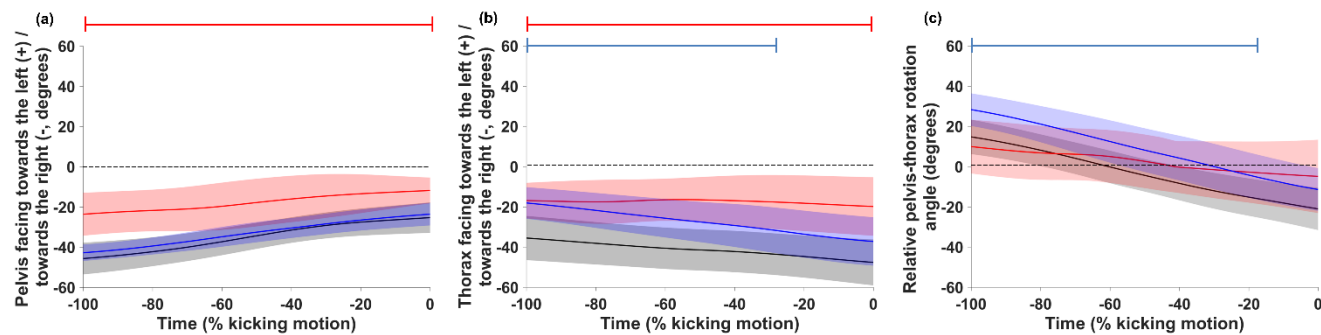
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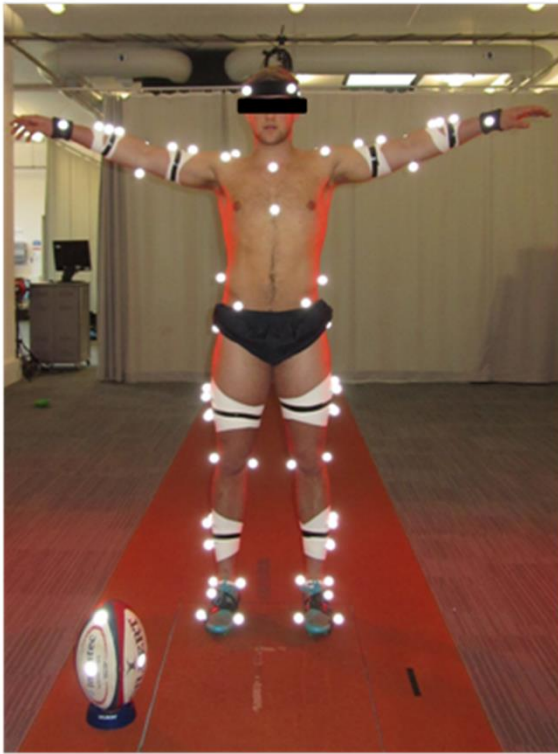
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Figure 1. Mean ± SD knee and hip flexion-extension angular velocities (a,d), resultant joint moments (b,e), and joint powers (c,f) from the top of the backswing (-100%) to ball contact (0%) for the long (black), wide-left (blue) and short (red) kickers. Red bars above the figures indicate regions where the short kickers were significantly different from the long kickers (p<0.05).
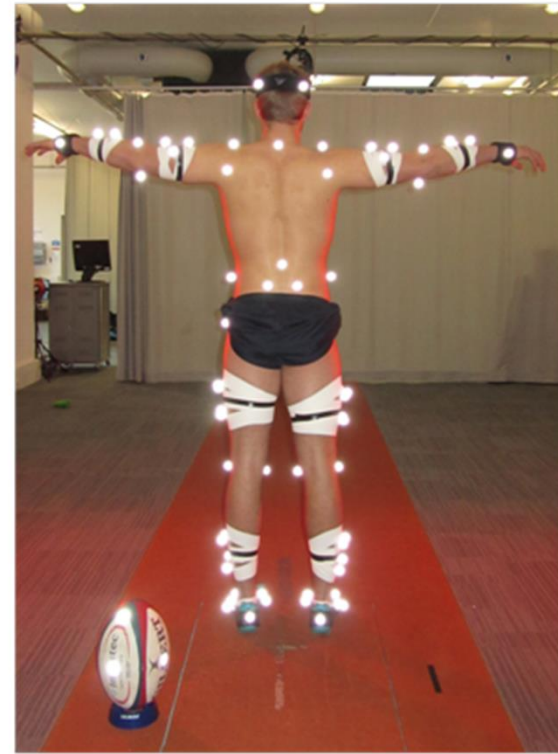
Figure 2. The pelvis (a), thorax (b), and relative pelvis-thorax (c) orientations about the longitudinal axis (mean ± SD cloud) from the top of the backswing (-100%) to ball contact (0%) for the long (black), wide-left (blue) and short (red) kickers. Bars above the figures indicate regions where the wide-left (blue) and short (red) kickers were significantly different from the long kickers ($p<0.05$)

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Supplement 1. The marker setup viewed from (a) the front, (b) the rear.

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450 **Table 1.** Selected discrete variables, including performance outcome and initial ball flight characteristics, kicking foot kinematics and

451 kicking leg joint work, for each of the three groups (mean ± SD) and the magnitude-based inferences for the group comparisons.

	Long	Wide-left	Short	Long vs. wide-left kickers Effect size ± 90% CI	Long vs. short kickers Effect size ± 90% CI
Ball Flight					
Maximum distance (m)	39.3 ± 4.9$^\Delta$	25.9 ± 3.2$^{\dagger\Delta}$	27.3 ± 3.8$^{\dagger\Delta}$	1.63 ± 0.37	1.61 ± 0.49
Resultant velocity (m/s)	27.6 ± 1.7$^\Delta$	26.9 ± 1.6$^{\Delta\Delta}$	20.8 ± 2.2$^{\dagger\Delta}$	0.42 ± 0.78	1.95 ± 0.45
Lateral direction (°)*	1 ± 3	-1 ± 2$^{\dagger\Delta}$	2 ± 3†	0.49 ± 0.61	-0.70 ± 0.90
Longitudinal spin (°/s)	288 ± 206	746 ± 466†	473 ± 394$^\Delta$	-1.13 ± 0.79	-0.68 ± 1.12
Kicking Foot					
Resultant velocity (m/s)	20.3 ± 1.0†	19.7 ± 0.9†††	17.0 ± 1.5†††	0.61 ± 0.77	3.01 ± 0.83
Medio-lateral velocity (m/s)	8.8 ± 1.5	7.8 ± 1.6†	5.4 ± 2.5†	0.63 ± 0.78	2.00 ± 0.90
Forward velocity (m/s)	18.1 ± 1.1†	17.8 ± 0.8††	15.8 ± 0.9††	0.30 ± 0.72	2.07 ± 0.86
Vertical velocity (m/s)**	-2.5 ± 1.1	-3.0 ± 1.2†	-2.1 ± 0.6†	0.48 ± 0.69	-0.31 ± 0.98
Normalised Joint Work					
Total negative knee extensor (K1)	-0.026 ± 0.005	-0.026 ± 0.006	-0.020 ± 0.008†	0.05 ± 0.77	-0.97 ± 0.93
Total positive knee extensor (K2)	0.009 ± 0.008	0.004 ± 0.004†	0.004 ± 0.002†	0.74 ± 0.69	0.74 ± 0.97
Total negative knee flexor (K3)	-0.016 ± 0.008	-0.009 ± 0.010†	-0.008 ± 0.004†	-0.73 ± 0.69	-0.99 ± 1.00
Total positive hip flexor	0.092 ± 0.018	0.112 ± 0.020†	0.071 ± 0.032†	-1.05 ± 0.79	1.01 ± 0.93
Event Duration					
Downswing (s)	0.107 ± 0.014	0.109 ± 0.012	0.102 ± 0.008	-0.18 ± 0.70	0.36 ± 0.92

† Denotes a substantial effect compared with the long kickers.

* A negative lateral direction indicates that the ball was initially travelling towards the left-hand-side of the goalposts, with a positive value directed towards the right-hand-side.

** A negative vertical velocity indicates that the foot was travelling down towards the ground.

K1, K2, K3 denote phases of negative and positive knee joint work, depicted in Figure 1.

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