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1 **Three-dimensional kinematic differences between accurate and high**
2 **velocity kicks in rugby union place kicking.**

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16 **Keywords:** rugby, kicking, kinematics, ball velocity.

17
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19
20 **Abstract**

21 Place kicking occurs many times during a rugby union game with more than half of all points
22 scored coming from place kicking. Ball velocity is an important biomechanical indicator of
23 kicking success but it also evident that the ball must be kicked accurately to pass between the
24 posts. This study aimed to identify biomechanical differences in rugby place kicking
25 kinematics when kicking towards a specific target and for maximum velocity. Ten male

26 rugby union kickers performed place kicks in two conditions 1. for maximum velocity and 2.
27 towards a pre-defined target. Lower extremity kinematics were obtained using an
28 optoelectric motion capture system operating at 500 Hz. Differences in lower extremity
29 kinematics between the two kicking conditions were examined using paired t-tests. Higher
30 ball velocities were obtained when kicking for maximum velocity. Foot linear velocity, knee
31 extension velocity and hip extension velocity were also found to be greater when kicking for
32 maximum velocity. Ankle dorsiflexion and peak external rotation were found to be greater in
33 the accuracy condition. The findings suggest that rugby kickers may have selected distinct
34 kicking mechanics characterised by reduced joint angular velocities and a more externally
35 rotated foot position in a deliberate attempt to improve precision, sacrificing ball velocity and
36 thus the distance that the ball can be kicked. The specific findings from the current work have
37 implications for coaches and applied practitioners which may facilitate improvements in
38 kicking performance.

39

40 **Introduction**

41 Place kicking is used frequently during rugby union games (Baktash et al., 2009), and is now
42 a key determinant of success in the modern game. Of the total points scored in 2012 by the
43 highest seeded international sides, more than half of all points scored come from place
44 kicking either in the form of a conversion or a penalty (Sinclair et al., 2014).

45

46 Like soccer instep kicks, place kicks involve a series of motions that include an initial address
47 to the ball, planting of the support leg beside the ball, and striking of the ball with the instep
48 of the kicking foot (Barfield 1995; Lees & Nolan 1998). Whilst the basic mechanical actions
49 of the place kick are similar to the instep kick in soccer players, differences in ball shape, tee
50 support, and release angles make the place kicking technique unique (Baktash et al., 2009;
51 Bezodis et al., 2009; Zhang et al., 2011).

52

53 The release velocity of the ball is considered the main biomechanical indicator of kicking
54 success in most sports that involve stationary kicking and it is the result of various factors,
55 including technique (Lees & Nolan, 1998). As such place kicking for maximal resultant ball

56 velocity is desirable, particularly in modern rugby union where kicks in excess of 50 m are
57 not uncommon (Zhang et al., 2011). Nonetheless, whilst it is clear that the ball must be struck
58 with sufficient velocity to reach the posts it is also evident that the ball must be kicked
59 accurately in order for it to pass between the posts to allow the points to register. The analysis
60 of accurate kicks has however received little attention compared with maximal velocity kick
61 biomechanics in rugby place kicking analyses.

62

63 Place kicking analyses in soccer have shown differences when kicking accurately and for
64 maximum ball velocity. Godik et al. (1993) found that higher ball velocities were associated
65 with the greatest level of accuracy in players who executed instep kicks at their own approach
66 speed. Conversely, when soccer players were instructed to kick the ball with the highest
67 possible velocity, higher approach velocities were linked to less accurate kicking mechanics.
68 Lees and Nolan (1998) showed that when a player is instructed to perform a kick accurately
69 there is a reduction in ball velocity and also in angular velocities of the lower extremity
70 joints. Teixeira et al. (1999) found that soccer kicks aimed towards a defined target were
71 associated with longer duration and smaller ankle displacement and velocity compared with
72 kicks performed towards an undefined target. The research cited above suggests that the
73 target determines the actual constraints on accuracy; its manipulation leads to a trade-off
74 between speed and accuracy of the kick. In other words, when the player is required to
75 perform an accurate kick, then the approach as well as the joint rotations and velocities are
76 also lower compared with those recorded during a powerful kick.

77

78 Despite the depth of research in soccer-specific analyses, knowledge regarding rugby union
79 place-kicking remains largely unexplored in biomechanics literature. Specifically, there does
80 not appear to be any published information regarding the potential trade-off between accurate
81 kicking and the generation of ball velocity. Therefore, this study aimed to identify
82 biomechanical differences in rugby place kicking kinematics when kicking towards a specific
83 target and for maximum velocity. A study of this nature may be of practical significance to
84 place kickers and coaches, who wish to better understand the differences in mechanics under
85 different constraints pertinent to successful kicking execution,

86

87 **Methods**

88 *Participants*

89 Ten male participants volunteered to take part in this investigation (age 22.4 ± 1.2 years;
90 height 1.81 ± 0.07 m; body mass 86.1 ± 4.2 kg). All participants were regular place kickers at
91 University first team level. All were free from musculoskeletal injury and provided written
92 informed consent in accordance with the declaration of Helsinki. Ethical approval for this
93 project was obtained from the School of Sport Tourism and Outdoors ethical committee at the
94 University of Central Lancashire.

95

96 *Procedure*

97 Kinematic information was obtained using an optoelectric motion capture system with 8
98 cameras (Qualisys Medical AB, Gothenburg, Sweden) using a capture frequency of 500 Hz.
99 Each participant performed place kicks of a standard rugby ball (Gilbert Virtuo, size 5) into a
100 net positioned 8 m away in two conditions. In the maximum velocity kicking condition
101 participants were instructed simply to kick the ball as hard as they could into the net. In the
102 accuracy constrained condition participants were instructed to kick the ball towards a 0.5 x
103 0.5 m square positioned 5 m behind the net onto the wall of the biomechanics laboratory.
104 The rugby ball was placed on a kicking tee positioned such that participants were able to
105 adopt their preferred approach towards the ball. An additional four retroreflective markers
106 were positioned onto the surface of the rugby ball, at one end of its longitudinal axis. Foot-
107 ball contact was delineated using the initial displacement of these markers. Ten trials were
108 obtained for each participant in each of the two conditions. The order in which participants
109 performed in each of the conditions was counterbalanced.

110

111 The current investigation used the calibrated anatomical systems technique (CAST) to
112 quantify angular kinematics (Cappozzo et al., 1995). To define the anatomical axes of the
113 right and left feet, shanks and thigh segments, retroreflective markers were positioned
114 bilaterally onto the calcaneus, 1st and 5th metatarsal heads, medial and lateral malleoli,
115 medial and lateral epicondyle of the femur and greater trochanter. To delineate the pelvic
116 segment co-ordinate axes, additional markers were positioned onto the anterior (ASIS) and
117 posterior (PSIS) superior iliac spines. The hip joint centre was estimated using a regression
118 technique based on the ASIS marker separation (Sinclair et al., 2013). Rigid carbon fiber

119 tracking clusters with four non-linear retroreflective markers were positioned onto the pelvis,
120 shank and thigh segments. Static calibration trials (not normalised to standing posture) were
121 obtained for each participant to allow the anatomical positions of the retroreflective markers
122 to be referenced in relation to the tracking clusters. Following the acquisition of the
123 calibration trial markers not used for tracking were removed.

124

125 *Data-processing*

126 Discrete 3-D kinematic parameters were quantified using Visual 3-D (C-Motion Inc,
127 Germantown MD, USA) and filtered at 15 Hz using a zero-lag low pass Butterworth 4th
128 order filter. Joint rotations were created using an XYZ sequence of rotations referenced to co-
129 ordinate axes created about the proximal end of the segment. 3-D kinematic measures from
130 the hip, knee and ankle from the stance and kicking limbs which were extracted for statistical
131 analysis were 1) angle at ball impact, 2) peak angle, 3) range of motion from stance limb
132 contact to ball impact, 4) peak range of motion from foot contact to peak angle, 5) angular
133 velocity at ball impact and 6) peak angular velocity. In addition to this linear ball velocity
134 was also obtained. Finally, the duration of the kick phase from stance limb foot contact to ball
135 impact and the medial-lateral distance from the kicking foot to the ball were extracted.

136

137 *Statistical analyses*

138 Means and standard deviations of 3-D kinematic parameters were calculated for each kicking
139 condition. Differences in these parameters were examined using paired samples t-tests. The
140 alpha criterion was adjusted using a Bonferroni adjusted alpha criterion ($p \leq 0.0005$) to control
141 type I error. Effect sizes for all significant tests were quantified using partial eta squared (η^2).
142 Effect sizes were characterized in accordance with Cohen (1988), small = 0.2, medium = 0.5,
143 and large = 0.8. In accordance, with the Winter et al., (2014) an effect size of >0.2 was
144 considered to be practically important. The data were also **screened** for normality using a
145 Shapiro-Wilk which conformed that the normality assumption was met. Statistical analyses
146 were conducted using SPSS 21.0 (SPSS Inc, Chicago, USA).

147

148 **Results**

149 Figures 1-4 present the mean 3-D angular kinematics of the hip, knee and ankle joints for the
150 stance and kicking limbs. Tables 1–4 present the 3-D kinematic parameters from the hip,
151 knee and ankle observed as a function of kicking condition.

152

153 *Velocity, distance and temporal measures*

154 The results showed that ball velocity was greater ($t(9) = 5.61, p < 0.0005, \eta^2 = 0.78$) when
155 kicking for maximum velocity ($28.6 \pm 2.3 \text{ m.s}^{-1}$) in comparison to accuracy ($25.0 \pm 2.6 \text{ m.s}^{-1}$).
156 Release angle was not different ($t(9) = 1.25, p > 0.0005, \eta^2 = 0.15$) between maximum
157 velocity ($27 \pm 7^\circ$) and accurate ($29 \pm 4^\circ$) kicks. Foot linear velocity was greater ($t(9) = 4.76,$
158 $p < 0.0005, \eta^2 = 0.78$) when kicking for maximum velocity ($22.4 \pm 2.5 \text{ m.s}^{-1}$) in comparison to
159 accuracy ($19.2 \pm 3.0 \text{ m.s}^{-1}$). In addition, no ($t(9) = 3.91, p > 0.0005, \eta^2 = 0.63$) differences
160 were observed between maximum velocity ($0.38 \pm 0.04 \text{ m}$) and accurate ($0.34 \pm 0.07 \text{ m}$) for
161 the horizontal distance from the plant foot to the ball. Finally, it was observed that there was
162 no difference ($t(9) = 3.30, p > 0.0005, \eta^2 = 0.55$) in the duration of the kick phase between
163 maximum velocity ($0.13 \pm 0.02 \text{ s}$) and accurate kicking ($0.11 \pm 0.02 \text{ s}$).

164

165 *Kicking limb*

166 @@@ *Figure 1 near here* @@@

167 @@@ *Figure 2 near here* @@@

168 @@@ *Table 1 near here* @@@

169 @@@ *Table 2 near here* @@@

170

171 The results show in the sagittal plane that peak hip flexion angular velocity was greater ($t(9)$
172 $= 5.11, p < 0.0005, \eta^2 = 0.74$) when kicking for maximal velocity when compared to accurate
173 kicking. Furthermore, knee extension angular velocity at ball contact was also shown to be
174 greater ($t(9) = 6.21, p < 0.0005, \eta^2 = 0.81$) in the maximum velocity condition in comparison
175 to the accuracy condition. Finally, it was revealed that that ankle was ($t(9) = 5.78, p < 0.0005,$
176 $\eta^2 = 0.79$) more plantar-flexed in the maximum velocity condition compared to when kicking
177 for accuracy. In the transverse plane the results indicate that in the accuracy condition that the

178 ankle was ($t(9) = 5.09, p < 0.0005, \eta^2 = 0.74$) more externally rotated at ball contact in
179 comparison to kicking for maximum velocity. Finally, it was also shown that the ankle
180 transverse plane rotation angular velocity was different ($t(9) = 6.13, p < 0.0005, \eta^2 = 0.81$)
181 **between** the two conditions at ball contact, with the accuracy condition showing the ankle to
182 be externally rotating and the maximum velocity showing the ankle to be internally rotating.

183

184

185 *Stance limb*

186 @@@ *Figure 3 near here* @@@

187 @@@ *Figure 4 near here* @@@

188

189 @@@ *Table 3 near here* @@@

190 @@@ *Table 4 near here* @@@

191

192 The results show in the transverse plane that peak hip internal rotation was ($t(9) = 5.61,$
193 $p < 0.0005, \eta^2 = 0.78$) greater when kicking for maximal velocity when compared to accurate
194 kicking. Finally, it was also shown that peak ankle internal rotation was greater ($t(9) = 5.29,$
195 $p < 0.0005, \eta^2 = 0.76$) when kicking for maximal velocity when compared to accurate kicking.

196

197 **Discussion**

198 The aim of the current investigation was to determine the 3-D kinematic differences in rugby
199 place kicking kinematics when kicking towards a specific target and for maximum velocity.
200 This represents the first investigation to compare the biomechanics of rugby place kicking
201 when kicking for maximum velocity and when kicking for accuracy.

202

203 With regards to ball velocity, the results of the current investigation are to be expected and
204 show that kicking for maximum velocity is associated with greater ball velocity than when
205 kicking for accuracy. This is supported by the increases in knee extension angular velocity
206 and foot linear velocity at impact when kicking for maximum velocity. This observation
207 supports the findings of Sinclair et al. (2014) who showed that knee extension velocity was
208 correlated with ball velocity during rugby place kicking. The findings from the current
209 investigation appear to support those from soccer in-step kicking analyses regarding the
210 existence of a speed/accuracy trade-off (Plamondon & Alimi, 1997; Teixeira et al., 1999) in
211 that the alterations in kicking mechanics necessary to promote accuracy were used at the
212 expense of maximising ball velocity.

213

214 In addition, it was also observed that peak hip flexion angular velocity was also greater when
215 kicking for maximum velocity. This supports the notion that the velocity of the distal
216 segments is resolved via a pattern of segmental interactions termed the proximal to distal
217 sequence. Hip flexion angular velocity contributes to about 50% of the resultant angular
218 velocity of the more distal segments (Putnam, 1993). During the second half of the kick
219 movement the hip flexion velocity is reduced as the knee extension velocity increases.
220 Although the thigh angular velocity is decreased in the latter part of the kick phase it is
221 nonetheless important when ball velocity is desirable to generate greater hip flexion velocities
222 in order to angular velocity to the distal segments.

223

224 A further significant observation occurred at the ankle in both sagittal and transverse planes.
225 It was found that the ankle was more dorsiflexed and externally rotated at ball contact, when
226 kicking for accuracy. This finding concurs with those from soccer based analyses which have
227 documented similar findings in accurate kicks in comparison to when kicking for maximum
228 velocity (Lees & Nolan, 2002; Teixeira, 1999). It is hypothesized that this observation relates
229 to the kicking mechanics used by participants when kicking for accuracy. In order to
230 maximize accuracy participants may have used a more side foot technique by externally
231 rotating the ankle in order to ensure ball contact with the medial aspect of the foot. This is
232 supported by Levanon & Dapena (1998) who theorized that side foot or kicking in soccer is
233 employed when there is a requirement for precision. Increased dorsiflexion ensures that the
234 contact point is closer to the metatarsals than the ankle. Kellis and Katis, (2007) showed that

235 when the ball is kicked with the aspect of the foot near the ankle, the ball is released with a
236 much greater linear velocity.

237

238 In modern rugby union a significant number of points are now secured from place kicking,
239 making successful execution of place kicks vital to the final outcome. The current
240 investigation has importantly characterized the mechanics of both accurate and high velocity
241 rugby union place kicks. Therefore based on the findings from the current work, coaches and
242 applied practitioners should be encouraged to emphasize the importance of generating high
243 knee angular velocity in kickers who are striving to generate greater kicking distance. This
244 may involve exercises which develop explosive power in the quadriceps muscle group which
245 serve to extend the joint. Conversely in kickers who are seeking to improve the accuracy of
246 their place kicks should be encouraged to focus on drills which promote increased
247 dorsiflexion and external rotation of the foot at the instance of ball contact. This may
248 ultimately enable kickers to combine these two key aspects and increase the likelihood of
249 victory for their team.

250

251 A limitation of the current investigation is the laboratory based nature of the data collection
252 procedures. Firstly, whilst accuracy was the focus of one of the experimental conditions it
253 could not be specifically examined, rather the participants were instructed simply to aim for a
254 specific target positioned onto the laboratory wall. In addition, the confines of the laboratory
255 may also have affected the ecological validity of the ball release characteristics. Linthorne &
256 Stokes (2014) demonstrated in a field based experiment that the optimum projection angle is
257 around 30 °, with increasing projection angles leading to reductions in ball release velocity.
258 Thus it appears that the trials examined during this study may not be truly representative
259 of a kick at goal. Future field based analyses may wish to consider the effects of accurate and
260 maximum velocity kicking mechanics. A further limitation is the playing level of the
261 participants used in this experiment. A sample of skilled yet not elite rugby union place
262 kickers was tested as part of this investigation. This indicates that the observations may not
263 be generalizable to populations outside this study. Future work should seek to quantify
264 mechanical differences between accurate and maximum velocity kicks in more skilled place
265 kickers.

267 In conclusion, the current investigation has demonstrated that differences in kicking
268 mechanics exist when kicking for accuracy when compared to kicking for maximum velocity.
269 It is likely that kickers may have chosen utilize these mechanics when kicking for accuracy in
270 a deliberate attempt to improve precision, but at the expense of sacrificing ball velocity and
271 thus the distance that the ball can be kicked. Therefore, the specific findings from the current
272 work have implications for coaches and applied practitioners which may facilitate
273 improvements in kicking performance.

274

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327

328 **Figures**

329 Figure 1: Hip, knee and ankle joint kinematics from the kicking limb as a function of the
330 dominant and non-dominant limbs (black = max velocity & dash = accuracy).

331 Figure 2: Hip, knee and ankle joint angular velocities parameters from the kicking limb as a
332 function of the dominant and non-dominant limbs (black = max velocity & dash = accuracy).

333 Figure 3: Hip, knee and ankle joint kinematics from the stance limb as a function of the
334 dominant and non-dominant limbs (black = max velocity & dash = accuracy).

335 Figure 4: Hip, knee and ankle joint angular velocities parameters from the stance limb as a
336 function of the dominant and non-dominant limbs (black = max velocity & dash = accuracy).