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1   **Differences in the kinetics and kinematics of supported and un-supported landings of**

2   **the rugby union line out.**

3   *Sinclair J[1], Smith A[1], Taylor PJ[2], & Hobbs SJ[1]*

4   1. *Centre for Applied Sport and Exercise Sciences, School of Sport & Wellbeing,*

5   *College of Health & Wellbeing, University of Central Lancashire, UK.*

6   2. *School of Psychology, College of Science & Technology, University of Central*

7   *Lancashire, UK.*

8   **Corresponding author contact details:**

9   Jonathan Sinclair

10   Centre for Applied Sport and Exercise Sciences

11   School of Sport & Wellbeing

12   College of Health & Wellbeing

13   University of Central Lancashire

14   Preston

15   Lancashire

16   PR1 2HE

17   E-mail: jksinclair@uclan.ac.uk

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20

21   **Abstract**

22   The aim of the current investigation was to comparatively examine the kinetics and

23   kinematics of supported and un-supported landings during the rugby union line out. Eleven

24   male line-out jumpers were tested under two conditions, 'supported' in which the lifters

25   maintained supportive contact with the jumper until the jumpers' feet touched the floor and

26   'un-supported' in which the lifters released the jumper once they had caught the ball.

27   Kinematics were examined using an eight camera motion capture system and kinetics using a

28   force platform. Differences between conditions were examined using paired t-tests. The

29   findings showed the instantaneous loading rate (supported = 212.9 ± 102.5 BW/s & un-

30   supported = 449.0 ± 142.4 BW/s) and vertical velocity (supported = 2.7 ± 0.4 m/s & un-

31   supported = 4.0 ± 0.4 m/s) at foot contact were significantly larger in the un-supported

32   condition. The findings from the current investigation indicate that if the line-out jumper is

33   un-supported by the lifters in returning to the ground then their risk from injury is likely to be

34   greater. Therefore, given the number of line-outs that are conducted per game it is

35   recommended that this law be clarified to also specify supported lowering of the jumper at all

36   levels of play.

37

38   **Introduction**

39   In rugby union the lineout is a fundamental mechanism for restarting the game when the ball

40   has left the field (Trewartha et al., 2008). The lineout is accomplished when the thrower

41   throws the ball infield towards the two opposing units of jumpers and lifters whose aim it is

42   to retain/ regain possession of the ball (Sayers, 2011). The lineout is a key attacking platform

43   in rugby union that provides a mechanism for scoring opportunities (Trewartha et al., 2008).

44   In professional rugby match play, the team who is in possession (i.e. the team that initiate the

45   infield throw) will subsequently acquire possession of the ball in around 80 % instances and

46   26 % of all tries are attained after securing possession of the ball directly from a lineout

47   (Trewartha et al., 2008).

48

49 In professional level rugby union matches there are approximately 34 lineouts in each game,

50 (IRB, 2007). The ball must be thrown directly down the middle of the two opposing teams

51 (separated by a gap of 1 m), thus teams must utilize a range of mechanisms in an attempt to

52 secure possession. The principal manner by which this is achieved is by having the lifters

53 hoist the jumper as high as possible allowing them to catch the ball prior to the opposition

54 (Croft et al., 2011). Due to this the majority of lineout throws are now caught at a height of

55 around 3.5 m (Sayers, 2011). The mass of the jumper is distributed equally between lifters at

56 the start of the motion; however this is then transferred towards the rear lifter towards the end

57 of the lineout (Sayers, 2011).

58

59 Once the ball has been caught and the lifters from both teams release the jumper resulting in a

60 landing for the jumper. As such whilst each of the distinct positions in the lineout places

61 different stresses on the body, given the height at which they are landing from it is likely that

62 the jumpers are at greatest risk from musculoskeletal injury during the lineout. This notion is

63 supported by the observations of Bathgate et al., (2002) who demonstrated that second row

64 forwards are at the highest risk from injury in relation to all other players. Similarly, Brooks

65 & Kemp, (2011) showed that firstly that second row forwards were at greater risk from injury

66 at the Achilles tendon, ankle collateral ligament and knee anterior/ medial collateral

67 ligaments in relation to other forwards and secondly that a higher proportion of these injuries

68 were sustained as a function of the lineout in relation to other forwards.

69

70 The World-Rugby Law 19.10 (g) indicates that ''players who support a jumping team-mate

71 must lower that player to the ground as soon as the ball has been won by a player of either

72 team'' (IRB, 2005). This rule is somewhat ambiguous in that it does not stipulate that

73   supported lowering of the jumper by the lifters is a specific requirement. Rather it mandates

74   that the lifters must not continue to support the jumper in the air once the ball is secured by

75   either the attacking or defensive side. Therefore, in their haste to make it quickly to the next

76   play, the jumper rotating 90˚ in order to set-up a driving maul from an attacking lineout,

77   interference from the opposing jumpers challenging for the ball or competition from opposing

78   forwards necessitating the rapid establishment of an attacking/ defensive maul; lifters may

79   neglect or are unable to support the jumper appropriately in returning to the ground (Patton et

80   al., 2006).

81

82   Despite the importance of the line-out to success in modern rugby union there is currently a

83   paucity of published biomechanical information regarding the line-out and the majority has

84   concerned the mechanics of the thrower (Sayers, (2005; Trewartha et al., 2008). However,

85   whilst there is some information in scientific literature concerning the biomechanics of the

86   thrower and the accuracy of the throw, there is currently no information regarding the

87   mechanics of the jumper. Therefore, the aim of the current investigation was to examine the

88   kinetics and kinematics of supported and un-supported landings during the rugby union line

89   out. The current investigation may give important information to officials regarding the

90   interpretation and clarity of law World-Rugby Law 19.10 (g).

91

92   **Methods**

93   *Participants*

94   Eleven male rugby union players volunteered to take part in this investigation. Each player

95   had a minimum of 2 years of lineout jumping experience and played competitive rugby union

96 at university first team level. All participants were free from musculoskeletal pathology at the

97 time of data collection and provided written informed consent in accordance with the

98 principles outlined in the Declaration of Helsinki. The mean characteristics of the participants

99 were: age 22 ± 4 years, height 1.9 ± 0.1 m and body mass 93 ± 6 kg. The procedure utilized

100 for this investigation was approved by the University of Central Lancashire, Science,

101 Technology, Engineering and Mathematics, ethical committee.

102

103 *Procedure*

104 The test protocol required jumpers to catch 10 throws (5 supported and 5 un-supported) from

105 a single thrower with 5 years of lineout throwing experience who competed at university first

106 team level. World-Rugby Law mandates that front of the lineout must be at least 5 m infield,

107 therefore in order to simulate a throw to a jumper at the front of the lineout, a linear distance

108 of 6 m was chosen. The jumpers all wore taped jumping supports on their thighs and were

109 supported by the same two lifters throughout, who had a minimum of 5 years of lineout

110 lifting experience and who also were competitive at university first team level. In the

111 supported condition the lifters were instructed to maintain supportive contact with the jumper

112 until the point at which the jumpers' feet touched the floor, whereas in the un-supported

113 condition the lifters were required to release the jumper once they had caught the ball. The

114 lifters and jumpers were positioned so that the jumpers dominant foot landed on an embedded

115 piezoelectric force platform (Kistler, Kistler Instruments Ltd., Alton, Hampshire). To prevent

116 any order effects, the supported and un-supported conditions were presented in a

117 counterbalanced manner whereby five participants performed their supported trials first

118 followed by the un-supported trials and vice versa. Participants (lifters and jumpers) were

119 required to undergo a traditional warm-up procedure and several minutes of practice lineout

120 drills prior to the commencement of data collection. The landing movement was defined as

121 the duration from foot contact (defined as > 20 N of vertical force applied to the force

122 platform) to maximum knee flexion.

123

124 Kinematics and ground reaction forces data were synchronously collected via an analogue

125 board. Kinematic data was captured at 250 Hz via an eight camera motion analysis system

126 (Qualisys Medical AB, Goteburg, Sweden). Dynamic calibration of the motion capture

127 system was performed before each data collection session. Lower extremity segments were

128 modelled in 6 degrees of freedom using the calibrated anatomical systems technique

129 (Cappozzo et al., 1995). To define the segment co-ordinate axes of the foot, shank and thigh,

130 retroreflective markers were placed bilaterally onto 1st metatarsal, 5th metatarsal, calcaneus,

131 medial and lateral malleoli, medial and lateral epicondyles of the femur. To define the pelvis

132 segment further markers were posited onto the anterior (ASIS) and posterior (PSIS) superior

133 iliac spines. Carbon fiber tracking clusters were positioned onto the shank and thigh

134 segments. The foot was tracked using the 1st metatarsal, 5th metatarsal and calcaneus

135 markers and the pelvis using the ASIS and PSIS markers. The centres of the ankle and knee

136 joints were delineated as the mid-point between the malleoli and femoral epicondyle markers

137 (Sinclair et al., 2015; Graydon et al., 2015), whereas the hip joint centre was obtained using

138 the positions of the ASIS markers (Sinclair et al., 2014). Static calibration trials were

139 obtained allowing for the anatomical markers to be referenced in relation to the tracking

140 markers/ clusters. The Z (transverse) axis was oriented vertically from the distal segment end

141 to the proximal segment end. The Y (coronal) axis was oriented in the segment from posterior

142 to anterior. Finally, the X (sagittal) axis orientation was determined using the right hand rule

143 and was oriented from medial to lateral.

144

145 *Data processing*

146 Lineout trials from both supported and un-supported conditions were processed in Qualisys

147 Track Manager and then exported as C3D files. Kinematic parameters were quantified using

148 Visual 3-D (C-Motion Inc, Gaithersburg, USA) after marker data was smoothed using a low-

149 pass Butterworth 4th order zero-lag filter at a cut off frequency of 15 Hz. Kinematics of the

150 hip, knee and ankle were quantified using an XYZ cardan sequence of rotations (where X is

151 flexion-extension; Y is ab-adduction and is Z is internal-external rotation). All data were

152 normalized to 100 % of the landing phase then processed trials were averaged. Sagittal plane

153 kinematic measures from the hip, knee and ankle which were extracted for statistical analysis

154 were 1) angle at foot contact 2) angle at landing termination, 3) peak angle during landing, 4)

155 angular range of motion (ROM) from footstrike to landing termination, and 5) relative ROM

156 from foot contact to peak angle.

157

158 From the force platform instantaneous loading rate was calculated as the maximum increase

159 in vertical force between adjacent data points (Sinclair et al., 2013). The instantaneous

160 loading rate was normalized by dividing the values by each participant's body weight

161 (BW/s). In addition limb stiffness was quantified using a mathematical spring-mass model

162 Blickman, (1989). Limb stiffness was calculated by dividing the peak vertical GRF by the

163 amount of limb compression (Farley & Morgenroth, 1999). Limb stiffness was normalized to

164 by dividing by participant's bodyweight (BW/m).

165

166 *Statistical analyses*

167 Descriptive statistics (means and standard deviations) were obtained for each line-out

168 condition. Shapiro-Wilk tests were used to screen the data for normality. Differences in

169 kinetic and kinematic parameters were examined using paired t-tests. Statistical significance

170 was accepted at the P≤0.05 level. All statistical actions were conducted using SPSS v22.0

171 (SPSS Inc, Chicago, USA).

172

173 **Results**

174 *Kinetics*

175 The kinetic analysis showed that instantaneous loading rate was significantly (t=5.54,

176 P<0.05) larger in the un-supported (449.0 ± 142.4 BW/s) condition in relation to supported

177 (212.9 ± 102.5 BW/s). In addition it was revealed that limb stiffness was significantly

178 (t=5.03, P<0.05) greater in the supported (8.5 ± 2.6 BW/m) condition compared to un-

179 supported (5.5 ± 2.0 BW/m).

180

181 *Kinematics*

182 The kinematic analysis showed that vertical velocity at foot contact was significantly

183 (t=10.02, P<0.05) greater in the un-supported (4.0 ± 0.3 m/s) condition compared to

184 supported (2.7 ± 0.4 m/s).

185

186 *Hip*

187 @@@ *Table 1 near here* @@@

188

189 For the angle at landing termination the hip was shown to be flexed to a significantly (t=6.15,

190 P<0.05) greater extent in the un-supported condition. In addition, peak hip flexion was found

191 to the significantly (t=6.02, P<0.05) greater in the un-supported condition. Finally, both ROM

192 (t=10.04, P<0.05) and relative ROM (t=9.59, P<0.05) were shown to be significantly larger

193 in the un-supported condition.

194

195 *Knee*

196 *@@@ Table 2 near here @@@*

197 For the angle at landing termination landing termination the knee was shown to be flexed to a

198 significantly (t=6.89, P<0.05) greater extent in the un-supported condition. In addition, peak

199 knee flexion was found to the significantly (t=6.75, P<0.05) greater in the un-supported

200 condition. Finally, both ROM (t=5.74, P<0.05) and relative ROM (t=5.67, P<0.05) were

201 shown to be significantly larger in the un-supported condition.

202

203 *Ankle*

204 *@@@ Table 3 near here @@@*

205 In addition, peak dorsiflexion was found to the significantly (t=3.17, P<0.05) greater in the

206 un-supported condition.

207

208 **Discussion**

209   The aim of the current investigation was to examine the kinetics and kinematics of supported

210   and un-supported landings of the rugby union line out. To the authors knowledge this

211   research represents the first to examine the biomechanics of lineout jumpers during different

212   conditions. The current investigation may give important information to coaches, clinicians

213   and officials regarding the appropriate implementation of the lineout.

214

215   The first key observation from the current investigation is that instantaneous load rate was

216   significantly larger in the un-supported condition in relation to the supported jumps. This

217   observation may have important implications as there is believed to be a strong association

218   between the magnitude of repeated impact loading and the aetiology of chronic lower limb

219   injuries (Whittle, 1999). Therefore, this investigation suggests that in un-supported conditions

220   jumpers are at increased risk from injury in relation to being supported until they reach the

221   ground.

222

223   The current investigation importantly showed that the vertical velocity of the jumpers at foot

224   contact was significantly larger in the un-supported condition. It is proposed that this change

225   vertical velocity relates to the vertical (upwards) forces applied to the jumper by the lifters in

226   the supported line-out condition. This provided resistance to the constant acceleration caused

227   by gravity and thus reduced the velocity of the jumper at the instance of foot contact. It is

228   likely that the increased vertical velocity at the point of foot contact is the mechanism

229   responsible for the larger instantaneous rate of loading that was observed during the un-

230   supported lineouts. The rate of loading is proportional to the change in momentum of the

231   body during landing (Whittle, 1999), therefore an increased vertical velocity of the body at

232   the instance of foot contact will mediate a proportional change in the vertical loading rate

233   experienced by the body (Whittle, 1999).

234

235   In addition, the findings from the current investigation confirmed that significant changes in

236   sagittal plane kinematics at all of the lower extremity joints were evident between lifting

237   conditions. Specifically it was shown that peak angles at the hip, knee and ankle and ranges

238   of motion at the hip and knee joints were significantly larger in the un-supported condition. It

239   is proposed that jumpers utilized these mechanical alterations to promote deceleration as a

240   result of the increased vertical velocity observed in the un-supported condition (Derrick,

241   2004). These alterations in lower extremity biomechanics serve to reduce the bodies'

242   effective mass, and are utilized extensively in sports movements in response to a perceived

243   high impact situation in order to decrease the proportion of total body mass that is decelerated

244   during the impact phase (Derrick, 2004).

245

246   Of further importance to the current investigation is that limb stiffness was shown to be

247   significantly larger in the supported in relation to the un-supported condition. This was to be

248   expected given the kinematic observations as limb stiffness is expressed as a function of limb

249   deformation under a given load (Farley & Morgenroth, 1999). It is proposed that this

250   alteration in limb stiffness is a result of the changes in sagittal plane kinematics that were

251   observed between the line-out conditions, which served to mediate increases in limb

252   deformation. It is alleged that limb stiffness during the absorption phase preconditions the

253   muscle-tendon units to store elastic energy, which may improve power production during

254   explosive movements (Kyrolainen et al., 2001). It is currently unknown what implications

255   this may have for performance at the line-out; but it is nonetheless an avenue that future

256   investigations may wish to explore.

257

258   A potential limitation to the current research is the laboratory based nature of the data

259   collection protocol. Although this was necessary in order to scientifically obtain synchronous

260   kinetic and kinematic data in a controlled manner, the ecological validity of the procedure

261   from a practical context was compromised. Furthermore, in the interest of generating an

262   impartial comparison between the two line-out conditions the current investigation simulated

263   an attacking line-out, during which there was no requirement to continue play after the

264   jumper had landed. This indicates that the variants of the line-out that are dictated by the state

265   of play and the position of the set-piece on the pitch were not accounted for. Future work may

266   wish to concentrate on the different variants of the line-out in order to provide a more

267   comprehensive representation of the biomechanics of jumper during the line-out.

268

269   In conclusion, although the biomechanics of the line-out have been examined previously

270   (Sayers, 2005; Trewartha et al., 2008), there is currently no information regarding the

271   mechanics of the jumper and therefore the effect of supported and un-supported conditions on

272   injury risk has not been investigated. As such the current investigation adds to the current

273   knowledge by generating a comprehensive evaluation of both kinetic and kinematic

274   parameters measured during supported and un-supported line-outs. The results from this

275   investigation indicate that both instantaneous loading rate and vertical velocity at foot contact

276   were significantly larger in the un-supported condition, despite lower body kinematics in this

277   condition being modified in favour of deceleration. The findings from the current

278   investigation indicate that if the line-out jumper is un-supported by the lifters in returning to

279 the ground then increased exposure to the mechanisms linked to injury are likely to be
280 greater. Therefore, given the number of line-outs that are conducted per game it is
281 recommended that this law be clarified to also specify supported lowering of the jumper at all
282 levels of play.

283

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333

334 **Tables**

335 Table 1: Hip joint kinematics as a function of un-supported and supported conditions.

	Un-supported		Supported		P-value
	Mean	*SD*	*Mean*	*SD*	
Sagittal plane (+ =flexion & - = extension)					
Angle at foot contact (°)	26.8	13.7	24.4	13.8	0.41
Angle at landing termination (°)	76.7	20.8	45.8	18.6	***0.0001***
Peak flexion (°)	76.9	20.7	46.3	18.3	***0.0001***
ROM (°)	49.9	14.0	21.5	10.0	***0.000002***
Relative ROM (°)	50.1	14.0	21.9	9.9	***0.000004***

336 *Notes: Bold/ italic p-values denote statistical significance*

337 Table 2: Knee joint kinematics as a function of un-supported and supported conditions.

	Un-supported		Supported		P-value
	Mean	*SD*	*Mean*	*SD*	
Sagittal plane (+ =flexion & - = extension)					
Angle at foot contact (°)	18.7	5.1	15.0	6.6	0.36
Angle at landing termination (°)	93.1	22.6	63.2	16.2	***0.00004***
Peak flexion (°)	93.1	22.6	63.2	16.2	***0.00004***
ROM (°)	74.4	22.7	48.2	14.3	***0.0001***
Relative ROM (°)	74.4	22.7	48.2	14.3	***0.0002***

338 *Notes: Bold/ italic p-values denote statistical significance*

339

340 Table 3: Ankle joint kinematics as a function of un-supported and supported conditions.

	Un-supported		Supported		P-value
	Mean	*SD*	*Mean*	*SD*	
Sagittal plane (+ =dorsiflexion & - = plantarflexion)					

Angle at foot contact (°)	-34.4	8.3	-36.8	7.3	0.11
Angle at landing termination (°)	15.5	7.7	14.2	7.3	0.21
Peak dorsiflexion (°)	20.8	8.5	17.6	7.1	***0.01***
ROM (°)	49.9	8.2	50.9	6.3	0.48
Relative ROM (°)	55.2	6.9	54.3	5.8	0.47

341   *Notes: Bold/ italic p-values denote statistical significance*