University of Bath

Alternative formats
If you require this document in an alternative format, please contact:
openaccess@bath.ac.uk

1 **The peak duration-specific locomotor demands and concurrent collision**

2 **frequencies of European Super League rugby.**

3 **Running Title**: Peak locomotor and collision demands of the European Super League

4 **Word Count:** 4330

5 Dan Weaving[1,2], Thomas Sawczuk[1,3], Sean Williams[4], Tannath Scott[5,6], Kevin

6 Till[1,2,7], Clive Beggs[1], Rich D Johnston[8], Ben Jones[1,2,7,9]

7 [1]Institute for Sport, Physical Activity and Leisure, Leeds Beckett University,

8 Leeds, West Yorkshire, United Kingdom.

9 [2]Leeds Rhinos Rugby League Club, Leeds, West Yorkshire, United Kingdom

10 [3]Queen Ethelburgas Collegiate, York, United Kingdom

11 [4]University of Bath, Bath, United Kingdom

12 [5]Brisbane Broncos Rugby League club, Brisbane, Australia

13 [6]School of Human Movement and Nutrition Sciences, University of

14 Queensland, Brisbane, Australia

15 [7]Yorkshire Carnegie Rugby Union club, Leeds, United Kingdom

16 [8]School of Exercise Science, Australian Catholic University, Brisbane,

17 Australia

18 [9]The Rugby Football League, Leeds, United Kingdom

19

20 **Abstract**

21 Understanding the most demanding passages of European Super League

22 competition can optimise training prescription. We established positional and match

23 half differences in peak relative distances (m·min^{-1}) across durations, and the number

24 of collisions, high-speed- and very-high-speed-distance completed in the peak 10 min

25 period. Moving-averages (10 s, 30 s, 1 min, 5 min, 10 min) of instantaneous speed

26 (m·s^{-1}) were calculated from 25 professional rugby league players during 25 matches

27 via microtechnology. Maximal m·min^{-1} was taken for each duration for each half.

28 Concurrently, collisions (n), high-speed- (5 to 7 m·s^{-1}; m) and very-high-speed-

29 distance (> 7 m·s^{-1}; m) were coded during each peak 10 min. Mixed-effects models

30 determined differences between positions and halves. Aside from peak 10 s, *trivial*

31 differences were observed in peak m·min^{-1} between positions or halves across

32 durations. During peak 10 min periods, adjustables, full- and outside-backs ran more

33 at high-speed and very-high-speed whilst middle- and edge-forwards completed more

34 collisions. Peak m·min^{-1} is similar between positional groups across a range of

35 durations and are maintained between halves of the match. Practitioners should

36 consider that whilst the overall peak locomotor 'intensity' is similar, how they achieve

37 this differs between positions with forwards also exposed to additional collision bouts.

38

Introduction

Rugby league is played professionally in the European Super League (ESL) and in Australasia within the National Rugby League (NRL). It is a team-sport characterised by prolonged intermittent bouts of locomotor and collision activity (Waldron, Twist, Highton, Worsfold & Daniels, 2011; Gabbett, Jenkins & Abernethy, 2012; Johnston, Gabbett & Jenkins, 2014; Twist et al., 2014). Practitioners prescribe numerous training modes to develop the wide range of physical qualities (e.g. muscular strength, speed) that are needed to succeed in competition (Gabbett et al., 2012; Till, Scantlebury & Jones, 2017; Weaving et al., 2017). However, in order to improve the likelihood of positive outcomes it is important to manage the accumulation and distribution of the external and internal loads prescribed to players (Impellizzeri, Rampinini & Marcora, 2005; Soligard et al., 2016; Vanrenterghem, Nedergaard, Robinson & Drust, 2017). By understanding the most intense periods of competition, practitioners can improve their prescription of the external load (i.e. running, accelerating, collisions) across training modes and ensure players are appropriately exposed to these demands in training (Impellizzeri et al., 2005; Weaving et al., 2017).

Microtechnology units incorporating global positioning systems (GPS) chips and other inertial measurement devices are now widely used to quantify both the locomotor (Johnston et al., 2014) and collision demands (Gabbett et al., 2012; Hulin, Gabbett, Johnston & Jenkins, 2017) of professional rugby league competition. Across a whole match, players typically cover between 5000 and 8000m (Waldron et al., 2011; Twist et al., 2014; Johnston et al., 2014) and are subjected to 30-65 collision events (Hulin et al., 2017) dependent on position (Gabbett et al., 2012). Whilst whole-game data are useful to understand the accumulation of load and how it varies by position, quantifying the rate in which this activity accumulates (i.e. 'intensity') is important for understanding the specificity of training.

65 Relative distance (m·min^{-1}) is a frequently reported measure used to quantify the

66 overall rate of locomotor activity during competition (Waldron et al., 2011; Twist et al.,

67 2014; Johnston et al., 2014). In a systematic review, Johnston et al. (2014) reported

68 23 positional relative distances from 9 manuscripts across the NRL (n = 7) and ESL

69 (n = 2) competitions. The mean data across these studies suggests the whole-game

70 relative distance to be ~94.7 ± 6.1 m·min^{-1}. However, the utility of this information as

71 a basis to prepare players is questionable because it under-represents periods in the

72 game where players complete greater relative distances for prolonged periods of time

73 (i.e. > 5 min) (Delaney et al., 2015). Technical-tactical training is a commonly

74 prescribed modality in professional rugby league training programmes (Gabbett et al.,

75 2011; Lovell et al., 2013; Weaving et al., 2017). Therefore, identifying the maximal

76 relative distances across a range of time periods should provide useful information

77 for technical-tactical coaches to evaluate their training prescription (Robertson &

78 Joyce, 2015).

79 Delaney et al. (2015) used a moving-average of the instantaneous sampled speed

80 (5Hz m·s^{-1}) during NRL competition. Using this approach, the authors were able to

81 determine the between-position differences in peak relative distances completed

82 across 1 to 10 min moving average periods. Logically, as the duration of activity

83 decreased, the peak relative distance for a given duration increased (Delaney et al.

84 2015). Interestingly, however, substantial differences in total distance between player

85 positions have been observed using whole-game data (Waldron et al., 2011; Twist et

86 al., 2014; Johnston et al., 2014). Delaney et al. (2015) reported that full-backs

87 completed substantially greater peak relative distances across the range of durations

88 compared with players in other positions (i.e. halves, outside backs, edge-forwards

89 and hit-up-forwards), who covered similar peak relative distances. For example, the

90 mean maximal 10 min relative distance reported across a NRL season for full-backs

91 was 105 ± 10 m·min^{-1}, with halves (93 ± 10 m·min^{-1}), middle forwards (90 ± 10 m·min^{-}

92 [1]), edge forwards (95 ± 7 m·min⁻¹) and outside backs (97 ± 14 m·min⁻¹) covering

93 substantially reduced relative distances. Due to the previously reported differences in

94 whole-game relative distances (including high-speed) between the two competitions

95 (Twist et al., 2014), this would seem important to establish in the ESL.

96 Given the interplay that occurs between locomotor and collision activity in rugby

97 league, one limitation of the above study (Delaney et al., 2015) is that the collision

98 activities completed by players during periods of peak locomotor intensity were not

99 reported. Hit-up-forwards have less playing time (Johnston et al., 2014), despite

100 Delaney et al. (2015) demonstrating little practical difference in the peak running

101 demands for this position compared to positions which complete the full match.

102 Increased collision activity (Gabbett et al., 2012) and body mass (Darrall-Jones et al.,

103 2015; Jones et al., 2015) compared to other positions are possible mechanisms for

104 this reduced involvement. However, whilst the frequency of collision activity of whole-

105 match NRL competition has previously been detailed (Gabbett, Jenkins & Abernethy,

106 2011; Gabbett et al., 2012; Cummins & Orr, 2015), concurrent data relating to collision

107 activity embedded within the peak locomotor (i.e. relative distances) distances

108 covered during ESL competition is currently unavailable. However, provision of such

109 data would provide practitioners with extremely useful information with which to

110 generate a holistic understanding of the most demanding passages of play for the

111 positional groups. These data could then be used as collective markers of "intensity"

112 to assist practitioners to plan the incremental progression of both collision and

113 locomotor activity during physical preparation (i.e. pre-season) and return-to-play

114 protocols.

115 Based on the information above, we designed the current study with the specific aim

116 of: 1) establishing the positional differences in duration-specific peak relative

117 distances covered during ESL competition; 2) establishing the positional differences

118 in high-speed-distance (5 to 7 m·s⁻¹), very-high-speed-distances (> 7 m·s⁻¹) and the

119 number of concurrent collisions within the peak 10 min relative distances of ESL

120 rugby; and 3) establishing the within-position differences in these demands between

121 halves of the match.

122 **Method**

123 **Participants**

124 Data were collected from 25 male professional rugby league players (age = 27.3 ±

125 4.8 yrs, body mass = 96.0 ± 12.6 kg and height = 184.5 ± 6.8 cm) from the same ESL

126 club during 25 matches during the 2017 ESL regular season (18 wins, 7 losses; mean

127 ± SD score margin: 4 ± 21 points). Players were coded for position at the start of each

128 match, with the number of match observations and individual player appearances for

129 each position including: fullbacks (5 players; n = 25), outside backs (centres and

130 wings; 9 players; n = 96), adjustables (half-back, five-eighth; hooker; 6 players; n =

131 72), middle-forwards (middle- and loose-forward; 10 players; n = 92) and edge-

132 forward (6 players; n = 48). The mean ± SD number of matches per player was 16 ±

133 6. When a player changed position within a half their data was omitted from the

134 dataset (n = 7). Players provided informed consent and ethics approval was gained

135 from the institutions review board.

136 Microtechnology (Optimeye S5, Catapult Innovations, Melbourne, Victoria) was

137 positioned in a customised padded pouch sewn into the players shirt which was

138 positioned in the centre of the upper back. To reduce the influence of inter-unit error,

139 each player was provided with the same device for the period of data collection. The

140 test-retest reliability of Catapult 10Hz devices to measure instantaneous speed

141 across a range of starting velocities has been reported to be acceptable (coefficient

142 of variation: 2.0 to 5.3%) (Varley et al., 2012). The number of satellites and horizontal

143 dilution of precision (HDOP) during data collection were (mean ± SD) 15 ± 2 and 0.8

144 ± 0.6, respectively. Greater than 6 connected satellites and HDOP values less than 1

145 are considered ideal for GPS data collection (Malone, Lovell, Varley & Coutts, 2016).

146 *Duration-specific peak relative distance (m·min⁻¹)*

147 During matches, each players period of involvement in the game was coded in real-

148 time using proprietary software (Catapult Openfield v1.14; firmware: 7.27) (Weaving,

149 Whitehead, Till & Jones, 2017; Barrett, 2017). A Greenwich mean time (GMT) 'time-

150 stamp' was created to determine the 'start' and 'end' time of each players involvement

151 in each half. This was also completed for interchange players to ensure that only

152 match time were included in the analysis and to ensure appropriate coding of their

153 involvement. For inclusion in any match half, a players involvement had to be greater

154 than 20 min. This criteria was applied so that even if a player had two involvements

155 in a single half, only one data entry per half per player could be included in the final

156 analysis (Delaney et al., 2015). All natural match breaks (e.g. injury, try

157 scored/conceded) were included in the analysis.

158 To establish the duration-specific running intensities (m·min⁻¹), a players

159 instantaneous speed (m·s⁻¹), derived from the Doppler Shift method, was recorded

160 every 0.1s (i.e. 10Hz). A time-series file, detailing a record of instantaneous speed

161 every 0.1s was then exported from the proprietary software (Catapult Openfield

162 v1.14). Therefore, the first speed sample represents the 'start' of their match

163 involvement (i.e., half or interchange period), whilst the final speed sample represents

164 the 'end' of their involvement.

165 A custom-built algorithm using the *zoo* package (Zeileis & Grothendieck, 2005) in R

166 (v R-3.1.3, R Foundation for Statistical Computing, Vienna, Austria) was developed

167 to compute a moving-average of each player's instantaneous speed across different

168 durations. Moving-averages were calculated across five different durations (10 s, 30

169 s, 1 min, 5 min, 10 min) for each half. Like previous studies (Delaney et al., 2015),

170   these durations were arbitrarily chosen to represent shorter and prolonged durations

171   of activity due to their use in training prescription. For example, for a 10 min moving-

172   average, the algorithm computed a moving-average for every 6000 instantaneous

173   speed samples (i.e. 10 samples per second for 600 seconds [10 min]). This process

174   was repeated for each of the respective 'durations' in the study. For each player and

175   half, the respective computed moving-average values for each duration were then

176   concatenated into a data frame (with the columns representing the different moving

177   average durations [i.e. 10 s to 10 min] and the rows representing the moving average

178   instantaneous speed value). This was then exported to Microsoft Excel to determine

179   the maximum moving-average for each duration. This was multiplied by the moving-

180   average duration to determine a players maximal moving-average of relative distance

181   ($m·min^{-1}$).

182   *Concurrent collision-, high-speed- and very-high-speed-distance within peak 10 min*

183   *relative distances*

184   The number of collisions, high-speed-distance (5 to 7 $m·s^{-1}$) and very-high-speed-

185   distance (>7 $m·s^{-1}$) were selected to provide additional information of the concurrent

186   locomotor and collisions with the peak 10 min relative distances ($m·min^{-1}$) identified

187   during ESL competition (Twist et al., 2014; McLellan, Lovell & Gass, 2011). The

188   minimum effort duration for high-speed and very-high-speed distance was set at 1

189   second (Varley, Jaspers, Helsen & Malone, 2017; Malone et al., 2017).

190   PlayerLoad™ was quantified as per previous methods which has demonstrated

191   acceptable reliability (Boyd, Ball & Aughey, 2011). The number of collisions were

192   quantified using the 'tackle' algorithm provided by the manufacturer which is derived

193   from the 100Hz tri-axial accelerometer and gyroscope also housed within the

194   microtechnology device as per previous methods. This has been reported to possess

195   acceptable validity to detect collision events, with specificity and sensitivity of 91.7 ±

196   2.5% and 93.9 ± 2.4%   respectively, when short duration (< 1 second) and low-

197   intensity (i.e. < 1 AU of PlayerLoad™) events were excluded (Hulin et al. 2017).

198   To export the number of collisions, high-speed- and very-high-speed-distance

199   completed by each player, the GMT associated with the identified peak 10 m·min^{-1}

200   moving-average for each half match file were coded within the proprietary software

201   (Openfield v1.14, Catapult Innovations, Scoresby, Victoria, Australia) and exported

202   into a customised spreadsheet.

203   **Statistical Analysis**

204   Linear mixed-effects models were used to estimate the differences between the

205   positional groups and match half. For the continuous variables of 10 s, 30 s, 1-min, 5

206   min and 10 min peak m·min^{-1}, 10 min high-speed-distance and very-high-speed-

207   distance, estimations were made via PROC MIXED in SAS University Edition (SAS

208   Institute, Cary, NC). For collision data, a generalised linear mixed-effects model was

209   used, assuming a negative binomial distribution, via the *lme4* package (Bates,

210   Maechler, Bolker & Walker 2015) in R (version 3.3.1). In both models the (fixed)

211   effects of playing position and match-half were estimated. The interaction between

212   these fixed effects was also explored, by including a multiplicative term in the models.

213   The random effects in both models were match identity (differences between average

214   match demands not accounted for by the fixed effects), athlete identity (differences

215   between athletes' mean match demands) and the residual (within-athlete match-to-

216   match variability). Magnitude-based inferences were used to provide an interpretation

217   of the real-world relevance of the outcomes. For all peak relative distance durations,

218   a difference of 10 m·min^{-1} was set as the smallest worthwhile effect threshold. This

219   was chosen based on previous research (Delaney et al., 2015) as practitioners are

220   unlikely to utilise between-position training prescription that is more specific than a 10

221   metre   difference.   For   collisions,   high-speed-   and   very-high-speed-distance

222   comparisons, a value equivalent to a difference in means of 0.20 was set as the

9

223   smallest worthwhile effect threshold. For all comparisons, effects were classified as

224   *unclear* if the percentage likelihood that the true effect crossed both positive and

225   negative smallest worthwhile effect thresholds were both greater than 5%. Otherwise,

226   the effect was deemed clear, and was qualified with a probabilistic term using the

227   following scale: <0.5%, *most unlikely*; 0.5-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%,

228   *possible*; 75-95%, *likely*; 95-99.5%, *very likely*; >99.5%, *almost certainly* (Hopkins,

229   2009).

230   **Results**

231   *Duration-specific peak relative distance (m·min^{-1})*

232   Table 1 details the mean ± SD for peak relative distances from 10 s to 10 min by 1st

233   and 2nd half. Between halves of the match (1st *vs* 2nd) there were *likely* to *most likely*

234   trivial differences in these variables for all within-position comparisons.

235   Table 2 details the raw least square means positional differences and magnitude

236   based inferences for these variables. Although, full backs, outside backs and

237   adjustables covered substantially greater relative distances across 10 s periods, there

238   were *possibly* to *almost certainly* trivial differences between all positional groups in

239   peak 1, 5 and 10 min relative distances.

240   *Concurrent collisions, high-speed- and very-high-speed-distances within peak 10 min*

241   *relative distances (m·min^{-1})*

242   Table 1 displays the mean ± SD for peak 10 min relative distance and concurrent

243   number of collisions, high-speed- and very-high-speed-distance for each positional

244   group.

245   Figure 1, 2 and 3 displays the standardised mean difference plus 90% confidence

246   intervals for positional differences in the concurrent number of collisions, high-speed-

247   and very-high-speed-distance completed during the peak 10 min relative distances.

248   Whilst there were *unclear* differences in the number of collisions between full backs,

249   adjustables and outside backs, edge and middle forwards completed a substantially

250   greater number of collisions compared to these three positional groups.

251   Between 1st and 2nd halves there were *possibly* reductions in high-speed distance for

252   full-backs (ES: 0.25 [-0.20 to 0.69]), *very likely* reductions for outside backs (ES: 0.54

253   [0.32 to 0.76]), *possibly* trivial reductions for adjustables (ES: 0.13 [-0.12 to 0.38]),

254   *possibly* reductions for middle forwards (ES: 0.29 [0.06 to 0.51]) and *likely* reductions

255   for edge forwards (ES: 0.40 [0.09 to 0.71]). For very-high-speed-distance, there were

256   *likely* reductions between 1st and 2nd halves for full backs (ES: 0.44 [-0.03 to 0.92])

257   and outside backs (ES: 0.40 [0.16 to 0.64]) and *possibly* trivial differences for

258   adjustables (ES: -0.10 [-0.36 to 0.17]) and middle forwards (ES: 0.12 [-0.13 to 0.36]).

259   *Unclear* differences were observed for wide-forwards (ES: -0.04 [-0.37 to 0.29]). For

260   collisions, there were *likely* trivial differences between 1st and 2nd halves for all

261   positional groups.

262   **Discussion**

263   The primary aim of the study was to establish the positional differences in peak

264   duration-specific relative distances and the number of collisions, high-speed-, and

265   very-high-speed-distances completed within the peak 10 min locomotor period of ESL

266   competition. A secondary aim was to determine whether these peak demands differed

267   between the 1st half and 2nd half of competition within positional groups.

268   The main findings were that whilst adjustables, outside- and full-backs completed

269   greater peak running 'intensities' during 10 s locomotor bouts, *likely* to *almost certainly*

270   trivial differences were observed between all the positional groups as the duration

271   increased (30 s to 10 min). Although, during the peak 10 min locomotor period,

272   adjustables outside- and full-backs covered greater high-speed and very-high-speed-

273   distances than middle- and edge-forwards, the latter positional groups completing a

274   substantially greater number of collisions. The difference in demands between 1st and

275   2nd halves were *likely* to *almost certainly* trivial across the majority of variables,

276   although there were small decreases in high-speed- and very-high-speed-distance

277   across all positional groups during the peak 10 min locomotor period of the 2nd half.

278   Collectively this suggests for prolonged periods of an ESL match (i.e. 2 x 10 min

279   periods), the positions demonstrate limited practical differences in overall relative

280   distance, although middle- and edge-forwards complete a greater number of

281   collisions, whereas fullbacks, outside backs and adjustables complete greater

282   distances at high-speed during this time. This study is the first to provide data of the

283   peak locomotor and concurrent collision activity of ESL rugby by halves of the match.

284   The findings suggest that it is important for coaches to prescribe periods of training

285   that provide positional groups with similar exposures to relative distance, while still

286   ensuring that the respective positions achieve this in a different manner (i.e. backs

287   more high-speed running) and that they are concurrently exposed to varying collision

288   activity (i.e. forwards more collisions).

289   Compared to previous literature (Delaney et al., 2015), the peak duration-specific

290   relative distances of ESL competition appear comparable to those reported within the

291   NRL. This suggests that the peak locomotor demands of the two competitions are

292   consistent. Consequently, there appears to be a growing body of evidence to suggest

293   that the peak duration-specific relative distances of professional rugby league

294   competition are consistent across teams and competitions and therefore, when

295   controlling for contextual influences, there appears to be a 'ceiling' requirement of

296   relative distance that professional rugby league players are required to complete.

297   Importantly, it must be considered that the data in the current study represents the

298   average of the maximal relative distances covered by players per half, per game.

299   Therefore, detailing the range of peak demands experienced by players, including the

300   maximal recorded exposure during competition can also provide useful information of

301 the highest recorded demands (Table 1). For example, whilst whole-game relative

302 distances are ~94.7 m·min^{-1} (Johnston et al., 2014), at least 10% of the match (i.e. 2

303 x 5 min) is spent covering relative distances between 107 and 116 m·min^{-1}. Depending

304 on position, this rose to between 134 to 165 m·min^{-1} during some matches (Table 1).

305 Practitioners should therefore aim to ensure players receive an appropriate exposure

306 to technical-tactical activities at these maximal competition 'intensities'.

307 Due to the importance of 'winning' the collision contest and its interplay with locomotor

308 activity, a novel aspect of the current investigation was the detail and positional

309 comparison of the frequency of collision bouts during the peak 10 min locomotor

310 periods of ESL competition. These appear similar to the whole-game collision

311 frequencies (number·min^{-1}) reported in the NRL (Gabbett et al., 2012) which revealed

312 middle-forwards (mean [range]: 1.09 [0.96 to 1.22]) to exhibit the greatest frequency

313 of collisions, with differences also observed between wide-running-forwards (0.76

314 [0.69 to 0.84]), adjustables (0.58 [0.45 to 0.71]) and outside backs (0.38 [0.32 to

315 0.43]). This suggests that during the peak locomotor passages of ESL competition,

316 the frequency of collision activity is maintained at whole-game 'intensities'. Therefore,

317 practitioners should consider the amalgamation of collision activity whilst aiming to

318 replicate the 'peak' relative distances reported in the current study. However, it is

319 important to note that the current study quantified the collisions embedded within the

320 peak locomotor demands and it is plausible that the peak frequency of collisions for

321 a given duration could be substantially greater than those reported. Future research

322 should therefore seek to establish the peak collision frequencies experienced by the

323 positional groups for a range of durations to further strengthen the understanding

324 between locomotor and collision activity during professional rugby league

325 competition.

326 In professional rugby league it is commonplace for forwards (particularly middle-

327 forwards) to complete reduced time on the pitch during matches (Waldron et al., 2011;

13

328   Twist et al., 2014; Johnston et al., 2014). This has previously been attributed to

329   forwards possessing reduced prolonged intermittent running capacity (Scott et al.,

330   2017), greater body mass (Jones et al., 2015; Darrall-Jones et al., 2016) and greater

331   collision activity compared to backs (Gabbett et al., 2012). Our study suggests that

332   this is likely because middle-forwards complete similar peak locomotor intensities to

333   backs whilst concurrently completing substantially more collisions for prolonged

334   periods of the match (i.e. 2 x 10 min). When locomotor bouts are controlled, the

335   addition of collisions have been reported to increase a players rating of perceived

336   exertion, blood lactate concentration and heart rate (Johnston & Gabbett, 2011;

337   Mullen, Highton & Twist, 2015; Norris, Highton, Hughes & Twist, 2016), suggesting

338   that the internal physiological cost of competition would be greater in the forwards

339   position. In addition, the total number of contacts in the forwards position has

340   previously been reported to relate to decrements in perceptual muscle soreness ($r =$

341   0.62), perceptual fatigue ($r = 0.69$) and countermovement jump flight time ($r = -0.55$)

342   24 hours post ESL competition (Twist, Waldron, Highton, Burt & Daniels, 2012).

343   Despite this, such substantial relationships appear to be absent in the backs

344   (soreness: $r = 0.20$; fatigue: $r = 0.11$; jump flight time: $r = -0.25$) (Twist et al., 2012).

345   Collectively, this suggests that rugby league forwards are subjected to greater

346   psycho-physiological and biomechanical loads (Soligard et al., 2016; Vanrenterghem

347   et al., 2017) per min of competition than backs, leading to similar amounts of "fatigue"

348   in the days following competition, despite forwards competing for a reduced amount

349   of time (Twist et al., 2012; Johnston et al., 2014). Therefore, practitioners should

350   ensure that training prescription and recovery periodisation reflect this, particularly

351   when forwards complete substantially greater playing times than typically

352   accustomed to.

353   Whilst this study is the first to detail the interplay between locomotor and collision

354   activity during the peak passages of competition and how they differ between position

355   and halves of the match, the study is not without limitations. Firstly, the data were

356   collected from a single ESL club, which may not be representative of the differences

357   observed with other teams in the competition. Secondly, the collision, high-speed-

358   and very-high-speed-distance demands embedded within the peak 10 min duration

359   were extracted on the assumption that the measurement of instantaneous speed

360   ($m·s^{-1}$) provides a valid representation of the peak locomotor demands of professional

361   rugby league competition (Delaney et al., 2015). Acceleration and deceleration events

362   are prevalent in professional rugby league, due to the spatial constraints imposed by

363   the 10-metre rule separating the opposing structures of the attacking and defending

364   teams. Therefore, determining the collisions, high-speed- and very-high-speed

365   distances completed within the peak acceleration demands could arguably provide a

366   more valid representation of the peak locomotor demands of competition.

367   Despite this, for the practitioner wishing to optimise training prescription, it is important

368   to find the balance between the validity of the measurement and practical/actionable

369   data. In particular, during the planning and prescription of training a fundamental

370   strategy adopted by practitioners is to control and manipulate the overall distance

371   covered per unit of time (i.e. relative distance). This warrants consideration, as

372   technical-tactical training is the most frequently prescribed modality in professional

373   rugby league, particularly during the in-season period which lasts the majority of the

374   calendar year (Gabbett et al., 2012; Lovell et al., 2013; Weaving et al., 2017).

375   Therefore, it would be preferable to appropriately expose players to these peak

376   demands (e.g. 10 min continuous bouts) within this mode of training to concurrently

377   satisfy both the physical and technical-tactical requirements of training. Achieving this

378   would allow practitioners to prescribe an appropriate range of training stimuli whilst

379   also ensuring players are contained within an appropriate overall accumulation of

380   training load (Gabbett, 2016). Furthermore, instantaneous speed can also be

381   monitored in real-time (Barrett et al., 2017; Weaving et al., 2017). This is unlike

382 acceleration data, which can only be monitored post-session. Consequently,

383 acceleration variables can be difficult for the practitioner to translate into the

384 actionable manipulation of training content. Regardless, previous work has reported

385 the peak duration-specific acceleration and relative distance demands to occur at

386 different periods within a match (Delaney et al., 2016). This highlights that the

387 retrospective analysis of acceleration demands during specific training drills is

388 warranted. In particular, within a specific duration of rugby league activity, it is likely

389 that the interplay between the magnitude of instantaneous speed and acceleration

390 plus collision activity would provide the best representation of the 'most demanding'

391 durations of professional rugby league competition.

392 It is therefore recommended that further research be undertaken in order to better

393 understand the interaction between these three components coupled with their own

394 individual peak demands (which may occur at different times to each other) during

395 the peak passages of competition. Ideally, future research should look to the link the

396 peak interactions between these three modes of activity and the associated technical-

397 tactical/skill activities that are completed within such periods.

Conclusions

399 Aside from very-short-duration bouts (i.e. 10 s), there are trivial differences in the peak

400 relative distances covered between positions during ESL competition. However,

401 adjustables, outside- and full-backs cover substantially greater high-speed- and very-

402 high-speed-distances during the peak 10 min relative distance period than middle-

403 and edge-forwards whilst the forwards positional groups complete a greater number

404 of collisions. There are likely trivial differences between these demands between

405 halves of competition, suggesting that players are likely to be exposed to similar peak

406 intensities for each given period in both halves of the match.

Practical Applications

408   •   To simulate the peak running intensities of ESL competition, practitioners

409   should expose positional groups to similar peak relative distances and

410   durations during training.

411   •   Given the similarities between match halves across durations, programming

412   multiple peak bouts within a training session could help to prepare players for

413   competition.

414   •   How positions achieve this overall relative distance should differ, with

415   adjustables, outside- and full-backs completing greater high-speed- and very-

416   high-speed-distances.

417   •   During the peak 10 min running 'intensity' of ESL, forwards complete a greater

418   frequency of collisions and should be exposed to these demands whilst

419   completing similar relative distances.

420 **References**

421 Barrett, S. (2017). Monitoring elite soccer players external loads using real-time data.

422 *International Journal of Sports Physiology and Performance*, *2*, 1-9.

423 Bates, D., Sarkar, D., Bates, M. D., & Matrix, L. (2007). The lme4 package. *R package*

424 *version*, *2*(1), 74.

425 Boyd, L.J., Ball, K. & Aughey, R.J. (2011). The reliability of MinimaxX accelerometers

426 for measuring physical activity in Australian football. *International Journal of Sports*

427 *Physiology and Performance*, *6*, 311-321.

428 Cummins, C., & Orr, R. (2015). Analysis of physical collisions in elite National Rugby

429 League match play. *International Journal of Sports Physiology and Performance*, *10*

430 (6), 732-739.

431 Darrall-Jones J., Roe G., Carney S., Clayton R., Phibbs P., Read D., Weakley J., Till

432 K., & Jones B. (2016). The effect of body mass on the 30-15 intermittent fitness test

433 in rugby union players. *International Journal of Sports Physiology and Performance*,

434 *11*(3), 400-403.

435 Delaney, J.A., Duthie, G.M., Thornton, H.R., Scott, T.J., Gay, D., Dascombe, B.J.

436 (2016). Acceleration-based running intensities of professional rugby league match

437 play. *International Journal of Sports Physiology and Performance*, *11*(6), 802-809.

438 Delaney J.A., Scott T.J., Thornton H.R., Bennett K.J., Gay, D., Duthie, G.M., &

439 Dascombe, B.J. (2015). Establishing duration-specific running intensities from match-

440 play analysis in rugby league. *International Journal of Sports Physiology and*

441 *Performance*, *10*(6), 725-731.

442 Gabbett T.J., Jenkins D.G., & Abernethy, B. (2011). Physical collisions and injury in

443 professional rugby league match-play. *Journal of Science and Medicine in Sport*, *14*,

444 210–215.

445 Gabbett T.J., Jenkins D.G., & Abernethy, B. (2012). Physical demands of professional

446 rugby league training and competition using microtechnology. *Journal of Science and*

447 *Medicine in Sport*, *15*, 80–86.

448 Gabbett, T.J. (2016). The training-injury prevention paradox: should athletes be

449 training smarter and harder? *British Journal of Sports Medicine*, *50*(5), 273-280.

450 Hopkins, W.G., Marshall, S.W., Batterham, A.M., Hanin, J. (2009). Progressive

451 statistics for studies in sports medicine and exercise science. *Medicine and Science*

452 *in Sports and Exercise*, *41*, 3-13.

453 Hulin B.T., Gabbett T.J., Johnston R.D., Jenkins D.G. (2017). Wearable

454 microtechnology can accurately identify collision events during professional rugby

455 league match-play. *Journal of Science and Medicine in Sport*, *20*(7), 638-642.

456 Impellizzeri, F.M., Rampinini, E., & Marcora, S.M. (2005). Physiological assessment

457 of aerobic training in soccer. *Journal of Sports Sciences*, *23*, 583-592.

458 Johnston, R.D., Gabbett, T.J., & Jenkins, D.G. (2014). Applied sport science of rugby

459 league. *Sports Medicine*, *44*(8), 1087-1100.

460 Johnston, R.D., Gabbett, T.J., Jenkins, D.G., Hulin, B.T. (2015). Influence of physical

461 qualities on post-match fatigue in rugby league players. *Journal of Science and*

462 *Medicine in Sport*, *18*(2), 209-213.

463 Jones B., Till, K., Barlow, M., Lees, M., O'Hara, JP., & Hind, K. (2015). Anthropometric

464 and three-compartment body composition differences between Super League and

465 Championship Rugby League Players: Considerations for the 2015 season and

466 beyond. *PLoS One*, *10*(7), e0133188.

467 Lovell, T.W.J., Sirotic, A.C., Impellizzeri, F.M., & Coutts, A.J. (2013). Factors affecting

468 perception of effort (session rating of perceived exertion) during Rugby League

469 training. *International Journal of Sports Physiology and Performance*, *8*, 62-69.

470 Malone, J.J., Lovell, R., Varley, M.C., Coutts, A.J. Unpacking the black box:

471 applications and considerations for using GPS devices in sport. (2017). *International*

472 *Journal of Sports Physiology and Performance*, *12* (Suppl 2), S218-S226.

473 McLellan C.P., Lovell D.I., & Gass G.C. (2011). Performance analysis of elite rugby

474 league match play using global positioning systems. *Journal of Strength and*

475 *Conditioning Research*, *25*(6), 1703-1710.

476 McNamara D.J., Gabbett, T.J., Chapman, P., Naughton, G., Farhart, P. (2015).

477 Variability of PlayerLoad, bowling velocity, and performance execution in fast bowlers

478 across repeated bowling spells. *International Journal of Sports Physiology and*

479 *Performance*, *10*, 1009-1014.

480 Mullen, T., Highton, J., Twist, C. (2015). The internal and external responses to a

481 forward-specific rugby league simulation protocol performed with and without physical

482 contact. *International Journal of Sports Physiology and Performance*, *10*(6), 746-753.

483 Norris, J.P., Highton, J., Hughes, S.F., Twist, C. (2016). The effects of physical contact

484 type on the internal and external demands during a rugby league match simulation

485 protocol. *Journal of Sports Sciences*, *34*(19), 1859-66.

486 Robertson, S.J. & Joyce, D.G. (2015). Informing in-season tactical periodisation in

487 team sport: development of a match difficulty index for Super Rugby. *Journal of Sports*

488 *Sciences*, *33*(1), 99-107.

489 Scott, M.T., Scott, T.J., Kelly, VG. (2016). The validity and reliability of global

490 positioning systems in team sport: a brief review. *Journal of Strength and Conditioning*

491 *Research*, *30*(5), 1470-1490.

492 Scott, T.J., Thornton, H.R., Scott, M.T.U., Dascombe, B.J., & Duthie, G.M. (2017).

493 Differences between relative and absolute speed and metabolic thresholds in rugby

494 league. *International Journal of Sports Physiology and Performance*, *28*, 1-21.

495 Soligard, T., Schwellnus, M., Alonso, J.M., Bahr, R., Clarsen, B., Dijkstra, H.P.,

496 Gabbett, T., … Engebretsen, L. (2016). How much is too much? (Part 1) International

497 Olympic Committee concensus statement on load in sport and risk of injury. *British*

498 *Journal of Sports Medicine*, *50*(17), 1030-1041.

499 Twist, C., Highton, J., Waldron, M., Edwards, E., Austin, D., & Gabbett, T.J. (2014).

500 Movement demands of elite rugby league players during Australian National Rugby

501 League and European Super League matches. *International Journal of Sports*

502 *Physiology and Performance*, *9*(6), 925-930.

503 Twist, C., Waldron, M., Highton, J., Burt, D., & Daniels, M. (2012). Neuromuscular,

504 biochemical and perceptual post-match fatigue in professional rugby league forwards

505 and backs. *Journal of Sports Sciences*, *30*, 359-367.

506 Speranza, M.J., Gabbett, T.J., Johnston, R.D., Sheppard, J.M. (2016). Effect of

507 strength and power training on tackling ability in semi-professional rugby league

508 players. *Journal of Strength and Conditioning Research*, *30*(2), 336-343.

509 Scott T.J., Thornton, H.R., Scott, M.T.U., Dascombe, B.J., & Duthie, G.M. (2017).

510 Differences between relative and absolute speed and metabolic thresholds in rugby

511 league. *International Journal of Sports Physiology and Performance*, *28*, 1-21.

512 Vanrenterghem J., Nedergaard N.J., Robinson M.A., & Drust, B. (2017). Training load

513 monitoring in team sports: a novel framework seperating physiological and

514 biomechanical load-adaptation pathways. *Sports Medicine*, *47*(11), 2135-2142.

515 Varley M.C., Jaspers, A., Helsen, W.F., & Malone, J.J. Methodological considerations

516 when quantifying high-intensity efforts in team sport using global positioning system

517 technology. (2017). *International Journal of Sports Physiology and Performance*,

518 *12*(8), 1059-1068.

519 Waldron, M., Twist, C., Highton, J., Worsfold, P., & Daniels, M. (2011). Movement and

520 physiological match demands of elite rugby league using portable global positioning

521 systems. *Journal of Sports Sciences*, *29*(11), 1223-1230.

522 Waldron, M., Worsfold, P.R., Twist, C., & Lamb, K. (2014). The relationship between

523 physical abilities, ball-carrying and tackling among elite youth rugby league players.

524 *Journal of Sports Sciences*, *32*(6), 542-49.

525 Weaving, D., Jones, B., Till, K., Marshall, P., Earle, K., Abt, G. (2017). Quantifying

526 the external and internal loads of professional rugby league training modes:

527 consideration for concurrent field-based training prescription. *Journal of Strength*

528 *and Conditioning Research*. doi: 10.1519/JSC.0000000000002242.

529   Weaving, D., Jones, B., Marshall, P., Till, K., & Abt, G. (2017). Multiple measures are

530   needed to quantify training loads in professional rugby league. *International Journal*

531   *of Sports Medicine*, *38*(10), 735-740.

532   Weaving D., Whitehead S., Till K., & Jones, B. (2017). Validity of real-time data

533   generated by a wearable microtechnology device. *Journal of Strength and*

534   *Conditioning Research*, *31*(10), 2876-2879.

535   Zeileis, A., & Grothendieck, G. (2005). zoo: S3 Infrastructure for Regular and Irregular

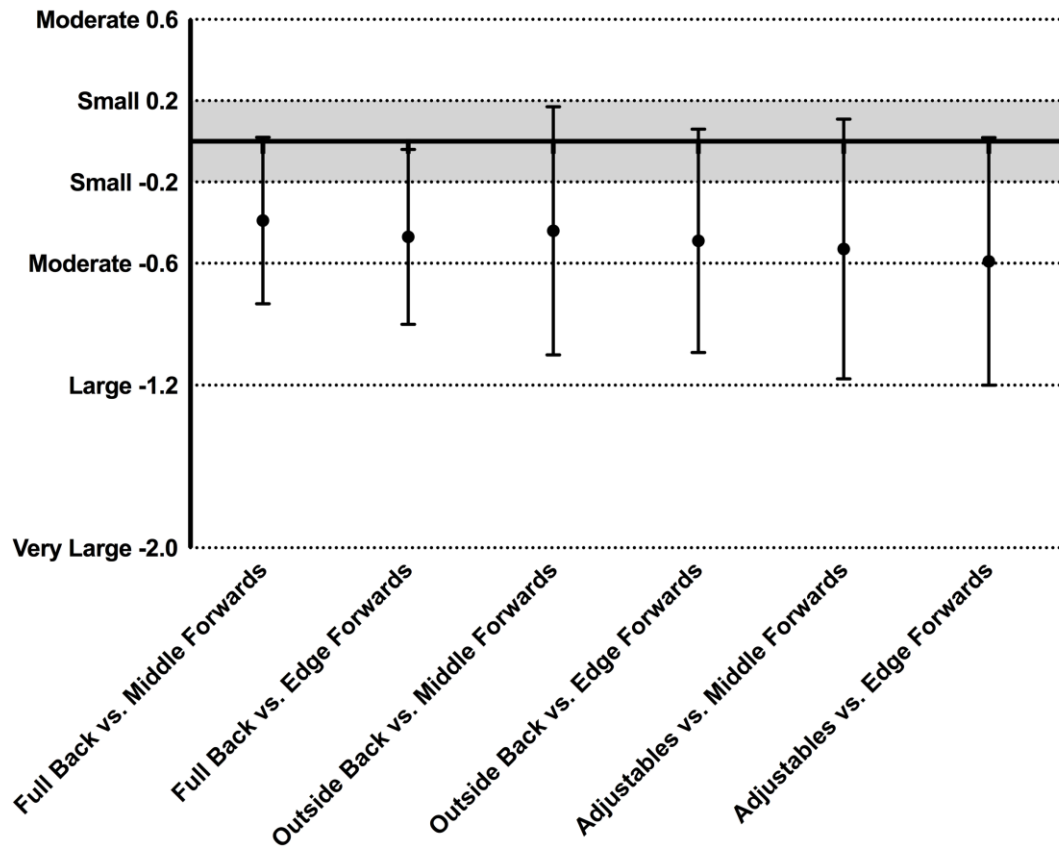536   Time Series. *Journal of Statistical Software*, *14*(6), 1–27.

537

538

539

540

541

542

Figure 1. The standardised mean positional differences plus 90% confidence intervals for the number of collisions completed during the peak 10 min of European Super League rugby. Only substantial differences are detailed. Outside backs vs. fullbacks (-0.07 [-0.47 to 0.34]), adjustables vs. fullbacks (-0.15 [-0.61 to 0.32]), outside backs vs. adjustables (0.09 [-14.59 to 14.76]) and middle forwards vs. edge forwards (-0.06 [-3.76 to 3.64]) were all *unclear*.
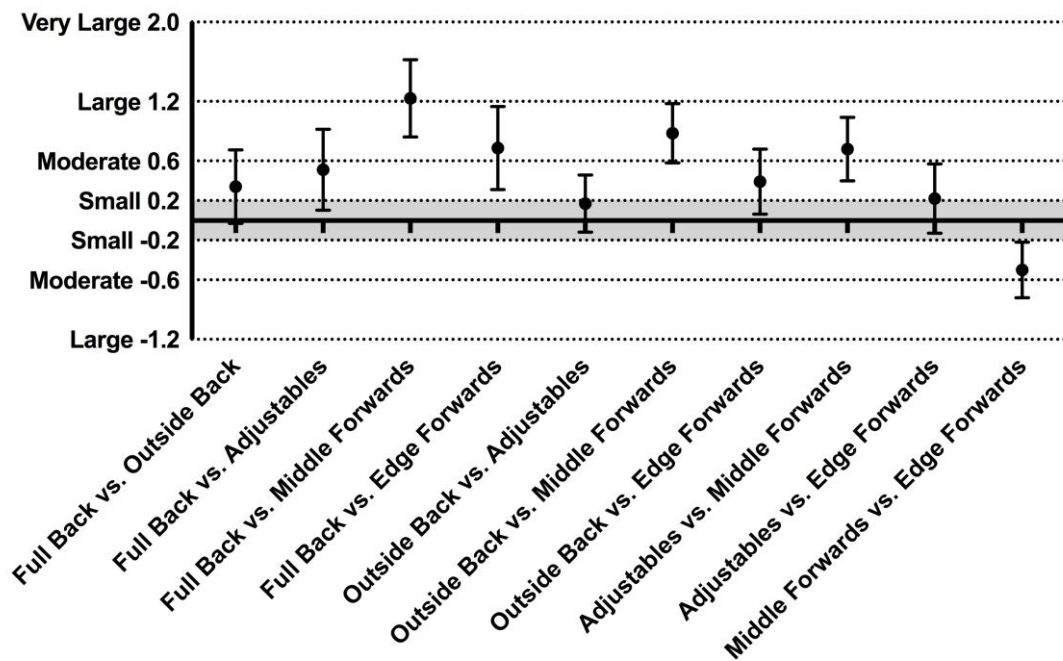
543

544

545

546

547

548

549

550

551

552

553

554

Figure 2. Standardised mean positional differences plus 90% confidence intervals in high-speed-distance (5 to 7 m·s⁻¹) completed during the peak 10 min of European Super League rugby.
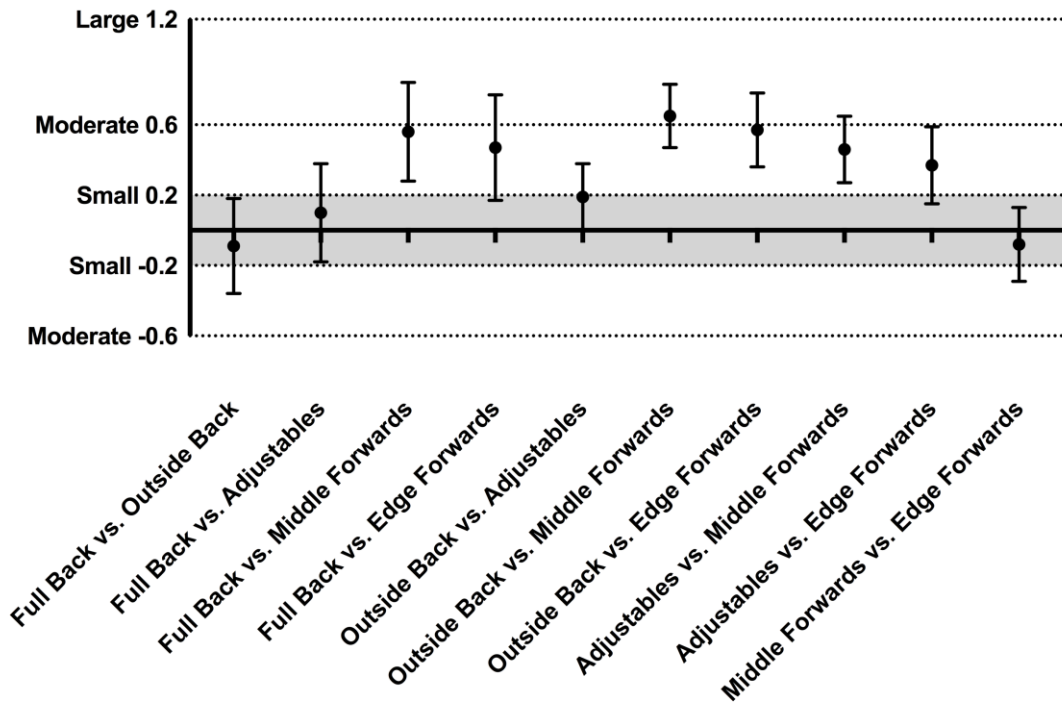
555

556

557

558
559

560

561

562

563

564

565

566

567

Figure 3. Standardised mean differences plus 90% confidence intervals for the positional differences in very-high-speed-distance (> 7 m·s^{-1}) completed during the peak 10 min of European Super League rugby.

573

574

575

Table 1. The mean ± standard deviation of duration-specific peak 1st and 2nd half relative distances of European Super League rugby and the concurrent number of collisions, and high-speed- and very-high-speed-distances covered during the peak 10-minute relative distances.

	10s (m·min⁻¹)	30s (m·min⁻¹)	1-min (m·min⁻¹)	5-min (m·min⁻¹)	10-min (m·min⁻¹)	10-min HSD (m)	10-min VHSD (m)	Collisions (n)
Fullback								
1st Half	320.8 ± 10.6	209.7 ± 5.2	169.7 ± 3.8	118.7 ± 2.8	102.9 ± 2.3	89.2 ± 8.4	9.3 ± 2.1	5.2 ± 3.0
2nd Half	331.4 ± 10.9	209.5 ± 5.3	167.7 ± 3.8	115.2 ± 2.8	101.6 ± 2.3	80.9 ± 8.6	4.8 ± 2.2	5.7 ± 3.6
Outside back								
1st Half	325.2 ± 6.3	200.5 ± 3.3	169.7 ± 3.8	110.9 ± 1.9	96.1 ± 1.8	82.6 ± 5.2	10.1 ± 1.1	5.1 ± 2.6
2nd Half	325.2 ± 6.3	203.1 ± 3.3	167.7 ± 3.8	106.4 ± 1.9	92.3 ± 1.8	64.5 ± 5.2	5.9 ± 1.1	4.9 ± 2.5
Adjustable								
1st Half	313.0 ± 7.1	200.3 ± 3.7	160.7 ± 2.4	113.8 ± 2.1	99.9 ± 2.0	70.1 ± 5.9	5.5 ± 1.3	5.5 ± 3.3
2nd Half	322.5 ± 6.9	205.8 ± 3.6	159.5 ± 2.4	111.6 ± 2.1	96.9 ± 1.9	65.7 ± 5.8	6.5 ± 1.2	5.2 ± 3.2
Middle forward								
1st Half	291.5 ± 6.2	195.5 ± 3.2	163.1 ± 2.4	111.1 ± 1.9	99.0 ± 1.8	48.7 ± 5.1	1.9 ± 1.1	9.7 ± 2.6
2nd Half	281.7 ± 6.3	195.8 ± 3.2	160.8 ± 2.4	106.0 ± 1.9	94.2 ± 1.8	39.2 ± 5.1	0.7 ± 1.2	9.1 ± 2.8
Edge forward								
1st Half	296.2 ± 7.9	191.8 ± 3.9	159.9 ± 2.9	110.0 ± 2.2	99.3 ± 2.0	60.6 ± 5.4	2.0 ± 1.5	8.9 ± 2.7
2nd Half	298.3 ± 7.7	197.8 ± 3.8	160.4 ± 2.8	105.9 ± 2.1	95.1 ± 1.9	53.9 ± 6.1	2.4 ± 1.5	8.2 ± 2.7

HSD = high-speed-distance (5-7 m·s⁻¹); VHSD = very-high-speed-distance (>7 m·s⁻¹)

Table 2. Raw mean positional differences [90% confidence limits] and likelihoods in peak relative distances across durations

	10s (m·min^{-1})	30s (m·min^{-1})	1 min (m·min^{-1})	5 min (m·min^{-1})	10 min (m·min^{-1})
FB vs. OB	0.96 [-14.2 to 16.1] *Unclear*	7.8 [0.4 to 15.2] *Possibly trivial*	8.6 [3.2 to 14.1] *Possibly trivial*	8.3 [4.4 to 12.1] *Likely trivial*	8.0 [5.2 to 10.9] *Likely trivial*
FB vs. ADJ	8.38 [-7.7 to 24.4] *Unclear*	6.5 [-1.5 to 14.6] *Likely trivial*	5.3 [-0.7 to 11.3] *Likely trivial*	4.2 [-0.1 to 8.5] *Very likely trivial*	3.8 [0.5 to 7.1] *Almost certainly trivial*
FB vs. MF	39.6 [24.2 to 55.0] *Almost Certainly ↑*	14.0 [6.3 to 21.7] *Likely ↑*	6.7 [1.0 to 12.5] *Likely trivial*	8.4 [4.3 to 12.6] *Possibly trivial*	5.7 [2.3 to 9.1] *Very likely trivial*
FB vs. EF	28.9 [12.3 to 45.4] *Very likely ↑*	14.8 [6.6 to 23.0] *Likely ↑*	8.5 [2.4 to 14.7] *Possibly* trivial	9.0 [4.6 to 13.4] *Possibly trivial*	5.0 [1.4 to 8.6] *Very likely trivial*
OB vs. ADJ	7.4 [-3.8 to 18.6] *Possibly Trivial*	-1.3 [-7.0 to 4.4] *Very likely trivial*	-3.3 [-7.6 to 1.0] *Almost certainly trivial*	-4.0 [-7.1 to -1.0] *Almost certainly trivial*	-4.2 [-6.6 to 1.8] *Almost certainly trivial*
OB vs. MF	38.6 [27.8 to 49.4] *Almost Certainly ↑*	6.2 [0.5 to 11.8] *Likely trivial*	-1.9 [-6.2 to 2.5] *Almost certainly trivial*	0.1 [-3.1 to 3.4] *Almost certainly trivial*	-2.4 [-5.3 to 0.6] *Almost certainly trivial*
OB vs. EF	27.9 [15.6 to 40.2] *Very likely ↑*	7.0 [0.7 to 13.3] *Likely trivial*	-0.1 [-4.9 to 4.7] *Almost certainly trivial*	0.7 [-2.8 to 4.2] *Almost certainly trivial*	-3.0 [-6.1 to 0.1] *Almost certainly trivial*
ADJ vs. MF	31.2 [19.6 to 42.8] *Almost certainly ↑*	7.4 [1.4 to 13.5] *Likely trivial*	1.4 [-3.2 to 6.1] *Almost certainly trivial*	4.2 [0.71 to 7.6] *Almost certainly trivial*	1.83 [-1.3 to 5.0] *Almost certainly trivial*
ADJ vs. EF	20.5 [7.5 to 33.5] *Likely ↑*	8.3 [1.6 to 15.0] *Possibly trivial*	3.2 [-1.9 to 8.3] *Very likely trivial*	4.7 [1.0 to 8.5] *Very likely trivial*	1.17 [-2.2 to 4.5] *Almost certainly trivial*

MF vs. EF	-10.7 [-22.0 to 0.7]	0.9 [-4.7 to 6.4]	1.8 [-2.3 to 5.9]	0.6 [-2.3 to 3.5]	-0.7 [-2.8 to 1.47]
	Possibly ↓	*Almost certainly trivial*	*Almost certainly trivial*	*Almost certainly trivial*	*Almost certainly trivial*

FB = fullback; OB = outside back; ADJ = adjustables; MF = middle forward; EF = edge forward. The direction of difference is in relation to the first named positional group.