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4 **Authors:** James J. WILD^{1, 3}, Ian N. BEZODIS², Jamie S. NORTH³, & Neil E.
5 BEZODIS⁴

6 **Affiliations:** ¹School of Biosciences and Medicine, University of Surrey, Guildford,
7 Surrey, United Kingdom, GU2 7XH; ²Cardiff School of Sport and Health Sciences,
8 Cardiff Metropolitan University, Cyncoed Road, Cardiff, United Kingdom, CF23 6XD;
9 ³Expert Performance and Skill Acquisition Research Group, School of Sport, Health,
10 and Applied Science, St Mary's University, Twickenham, United Kingdom, TW1 4SX;
11 ⁴Applied Sports, Technology, Exercise and Medicine Research Centre, Swansea
12 University, Bay Campus, Crymlyn Burrows, Swansea, United Kingdom, SA1 8EN

13
14 **Correspondence:** J. J. Wild, School of Biosciences and Medicine, University of
15 Surrey, Guildford, Surrey, United Kingdom, GU2 7XH; tel +44 (0) 1483 300800;
16 email: j.wild@surrey.ac.uk; ORCHID ID: orcid.org/0000-0001-7762-4768

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22 **Co-author details:** I.N. Bezodis, Cardiff School of Sport and Health Sciences, Cardiff
23 Metropolitan University, Cyncoed Road, Cardiff, United Kingdom, CF23 6XD; tel: +44
24 (0) 2920 41 7245; email: ibezodis@cardiffmet.ac.uk; ORCID ID: [orcid.org/0000-0002-](https://orcid.org/0000-0002-0250-032X)
25 0250-032X

26

27 J.S. North, Expert Performance and Skill Acquisition Research Group, School of Sport,
28 Health, and Applied Science, St Mary's University, Twickenham, United Kingdom, TW1
29 4SX; email: jamie.north@stmarys.ac.uk; tel: +44 2083404182; ORCID ID:
30 orcid.org/0000-0003-2429-4552

31

32 N.E. Bezodis, Applied Sports, Technology, Exercise and Medicine Research Centre,
33 Swansea University, Bay Campus, Crymlyn Burrows, Swansea, United Kingdom, SA1
34 8EN; email: n.e.bezodis@swansea.ac.uk; tel: +44 1792 295801; ORCID ID:
35 orcid.org/0000-0003-2229-3310

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46 **Differences in step characteristics and linear kinematics between**
47 **rugby players and sprinters during initial sprint acceleration**

48 The initial steps of a sprint are important in team sports, such as rugby, where
49 there is an inherent requirement to maximally accelerate over short distances.
50 Current understanding of sprint acceleration technique is primarily based on data
51 from track and field sprinters, although whether this information is transferable to
52 athletes such as rugby players is unclear, due to differing ecological constraints.
53 Sagittal plane video data were collected (240 Hz) and manually digitised to
54 calculate the kinematics of professional rugby forwards (n = 15) and backs (n =
55 15), and sprinters (n = 18; 100m PB range = 9.96 s to 11.33 s) during the first
56 three steps of three maximal sprint accelerations. Using a between-group research
57 design, differences between groups were determined using magnitude based
58 inferences, and within-group relationships between technique variables and initial
59 sprint acceleration performance were established using correlation. Substantial
60 between-group differences were observed in multiple variables. Only one
61 variable, toe-off distance, differed between groups ($d = -0.42$ to -2.62) and also
62 demonstrated meaningful relationships with sprint performance within all three
63 groups ($r = -0.44$ to -0.58), whereby a stance foot position more posterior relative
64 to the centre of mass at toe-off was associated with better sprint performance.
65 Whilst toe-off distance appears to be an important technical feature for sprint
66 acceleration performance in both sprinters and rugby players, caution should be
67 applied to the direct transfer of other kinematic information from sprinters to
68 inform the technical development of acceleration in team sports athletes.

69 *Keywords: biomechanics; constraints; rugby union; sprinting; technique*

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74 **Introduction**

75 Sprint acceleration is an important performance feature in team sports such as rugby,
76 where the typical sprint time is between one and three seconds (Deutsch, Kearney, &
77 Rehrer, 2007; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). However, the
78 majority of the current understanding of acceleration technique is from studies of track
79 and field sprinters (e.g. Bezodis, Salo, & Trewartha, 2014; Bezodis, Salo, & Trewartha,
80 2015; Debaere, Delecluse, Aerenhouts, Hagman, & Jonkers, 2013; Ettema, McGhie,
81 Danielsen, Sandbakk, & Haugen, 2016; Jacobs & van Ingen Schenau, 1992; Mero,
82 Luhtanen, & Komi, 1983; Morin et al., 2015; Nagahara, Matsubayashi, Matsuo, &
83 Zushi, 2014; Rabita et al., 2015), and the techniques adopted by high performing
84 sprinters have been used for the development of general technical models during the
85 initial steps of a sprint (Mann & Murphy, 2015). This information is potentially
86 attractive to coaches of athletes in team sports since it is based on the fastest of all
87 athletes and may be used to help inform their players' sprint training practices.
88 However, this approach implies that an ideal movement template exists for all athletes
89 and does not take into account the differing movement strategies which may emerge
90 from the interaction of divergent constraints imposed (Newell, 1986; Saltzman & Kelso,
91 1987).

92 The constraints thought to influence movement have been separated, by Newell
93 (1986), into three distinct categories – task, environment and organismic (hereafter
94 referred to as ‘performer’). Variations in technique and movement patterns can
95 therefore emerge between team sport athletes (such as rugby players) and sprinters as a
96 function of differing interacting constraints (Davids, Button, & Bennett, 2008; Newell,
97 1986). Although the broad goal of maximal linear sprinting for sprinters and rugby
98 players during the initial steps is the same (i.e. to cover as much distance in as short a

99 time as possible), different task constraints exist due to sprint start conditions. The block
100 exit (sprinters) and standing (rugby players) start conditions, for instance, require
101 different body segment orientations which may influence techniques adopted in the
102 subsequent steps. The environment in which each group performs also differs. For
103 example, rugby is typically played on a grass surface, whereas sprinters compete on a
104 running track. Rugby players are also required to sprint as one of many match demands
105 in their training and competition environments. Differences in such demands are also
106 further evident across playing position in rugby (i.e. forwards versus backs; Quarrie,
107 Hopkins, Anthony, & Gill, 2013). Regarding performer constraints, movement
108 strategies adopted between athlete groups are also likely to be affected by physical and
109 anatomical constraints (Holt, 1998). Different performer constraints between sprinters
110 and rugby players, such as physical stature and body mass, musculoskeletal structure
111 (Lee & Piazza, 2009), and strength qualities may therefore result in different patterns of
112 movement. It is therefore important to understand which, if any, of the technical
113 features identified as important for sprint acceleration performance in a sprint-trained
114 population may be useful to inform the practices of coaches in attempts to enhance the
115 acceleration abilities of rugby players, given the differing constraints imposed.

116 There are likely many technical factors which influence initial sprint
117 acceleration performance. In fact, spatiotemporal variables, including step length and
118 step rate (the product of which determines step velocity) have received substantial
119 attention in the literature (e.g. Debaere, Jonkers, & Delecluse, 2013; Lockie, Murphy,
120 Schultz, Jeffriess, & Callaghan, 2013; Mackala, Fostiak, & Kowalski, 2015; Mann &
121 Murphy, 2015; Mero, Luhtanen, & Komi, 1983; Murphy, Lockie, & Coutts, 2003;
122 Nagahara, Naito, Morin, & Zushi, 2014; Rabita et al., 2015). Despite this coverage,
123 there remain conflicting perspectives on the importance of step length and step rate

124 during the initial steps of a sprint. For instance, in field sport athletes, higher step rates
125 were reported during the first three steps for a faster group (time to 15 m) compared
126 with a slower group (Murphy, Lockie, & Coutts, 2003), yet in 39 soccer players,
127 running speeds over the first four steps of a sprint were positively correlated with
128 average step length ($r = 0.60$; $p < 0.001$), but not average step rate (Nagahara, Takai,
129 Kanehisa, & Fukunaga, 2018). Moreover, neither step length or step rate of sprinters
130 were significantly correlated with 10 m sprint performance from a block start (Debaere,
131 Jonkers, & Delecluse, 2013). In addition to these mixed findings, information on the
132 determining factors of step length and step rate (Hay, 1994; Hunter, Marshall, &
133 McNair, 2004) is also sparse.

134 Due to the limited information available during the initial steps and conflicting
135 findings on the relative importance of step length and step rate to sprint performance,
136 establishing the importance of specific technical features for sprint acceleration is
137 currently challenging for a coach. This is further compounded by different measures
138 used (e.g. absolute or relative), study designs adopted (e.g. correlations or group
139 comparisons) and disparities between how acceleration performance is quantified,
140 which may explain some of the contradictions (Bezodis, Salo, & Trewartha, 2010).
141 Furthermore, due to the aforementioned inherent differences in the tasks, environments,
142 and performer constraints of rugby players' sprint acceleration compared with that of
143 sprinters, the relevance of the available information on the technical features deemed
144 important for performance in sprint-trained populations for enhancing the acceleration
145 abilities of performers in team sports (e.g. rugby) is unknown. Therefore, a direct
146 comparison between groups, with start conditions representative of their respective
147 environments and standardised measures of the technical features of interest and sprint
148 performance in the initial steps, is warranted. The purpose of this study was to

149 investigate differences in step characteristics and linear kinematics between professional
150 rugby players and sprinters during the initial steps of acceleration, and determine how
151 each variable of interest relates to initial sprint performance within each group. We
152 hypothesised that: 1) substantial differences in technique would be evident between
153 sprinters and rugby players; 2) relationships between specific technique variables and
154 initial sprint acceleration performance would be consistent across each group.

155

156 **Methods**

157 *Participants*

158 Eighteen male sprinters (mean \pm *SD*: age 21 ± 4 years; stature 1.80 ± 0.10 m; body mass
159 75.7 ± 5.2 kg; 100 m personal best (PB) 10.60 ± 0.40 s, range 9.96 - 11.33 s) and 30
160 male professional rugby union players competing in the English Premiership, separated
161 into forwards ($n = 15$; mean \pm *SD*: age 25 ± 4 years; stature 1.88 ± 0.06 m; body mass
162 111.6 ± 8.9 kg) and backs ($n = 15$; mean \pm *SD*: age 26 ± 4 years; stature 1.81 ± 0.06 m;
163 body mass 88.6 ± 7.1 kg) volunteered to participate. All participants provided written
164 informed consent and the study protocols were submitted to, and approved by, the Local
165 Research Ethics Committee. At the time of testing, participants were injury free and
166 completed maximal effort sprint accelerations on a weekly basis as part of their routine
167 training. For the rugby players, data were collected during pre-season following 48
168 hours of abstinence from running, sprinting, and lower body strength training. For the
169 sprinters, data were collected during track training sessions just prior to the competition
170 phase of the outdoor season on days where the emphasis of training was to sprint
171 maximally.

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173

174 *Procedures*

175 The rugby players completed a 20 minute standardised warm-up, and then performed
176 three maximal effort 10 m sprints from a standing start (preferred foot forward), on an
177 outdoor acrylic surface, wearing a t-shirt, shorts and trainers, which was common
178 during speed and acceleration training at the stage of pre-season when data was
179 collected. Rest periods between each sprint were approximately 3-4 minutes. The
180 sprinters completed their regular warm-up routine overseen by their technical coach,
181 and then completed three maximal effort sprints over distances between 30 and 60 m
182 from blocks, on an outdoor running track, wearing spikes, shorts and either a vest or no
183 top. Rest periods between each sprint were between 7-12 minutes. Differences in the
184 sprint performance measure between the first and third sprint trials within each group
185 were less than the smallest worthwhile difference ($d = < 0.20$; Hopkins, 2002; Winter,
186 Abt, & Nevill, 2014), thus the different rest period durations used by rugby players and
187 sprinters did not bias any outcomes. For all sprints, video images (448×336 pixels)
188 were obtained at 240 Hz (Sanyo Xacti VPC-HD2000). The camera was positioned 20 m
189 from, and perpendicular to, the running lane to capture sagittal plane images from
190 touchdown and toe-off across the first three steps for each athlete within an
191 approximately 6 m wide field of view. A 5.00 m horizontal video calibration was
192 recorded at each data collection session.

193 The kinematic variables of interest were determined from the video frames
194 identified as the instants of touchdown (first frame the foot was visibly in contact with
195 the ground) and toe-off (first frame the foot had visibly left the ground) across the first
196 three steps of each sprint using 6 \times zoom in Kinovea (v.0.8.15). The human body was
197 modelled as 14 rigid segments: feet, shanks, thighs, hands, lower arms, upper arms,
198 trunk, and head. This required manual digitisation of the following: vertex of the head,

199 halfway between the supra-sternal notch and the 7th cervical vertebra, shoulder, elbow
200 and wrist joint centres, head of third metacarpal, hip, knee and ankle joint centres, the
201 most posterior part of the heel, and the tip of the toe.

202 The scaled digitised coordinates were exported to Excel (Microsoft Office
203 2013), where the following spatiotemporal step characteristics were determined: contact
204 time (s), flight time (s), step length (m; horizontal displacement between the toe tips at
205 adjacent touchdowns), step rate (Hz; the reciprocal of step duration, which was
206 determined as the sum of contact time and the subsequent flight time), and step velocity
207 (m/s; the product of step length and step rate). Whole body centre of mass (CM)
208 location was calculated using de Leva's (1996) segmental inertia data. This enabled the
209 calculation of touchdown and toe-off distances (m; horizontal distance between the toe
210 and whole body CM, with positive values representing the toe ahead of the CM),
211 contact length (m; horizontal distance the CM travelled during stance) and flight length
212 (m; horizontal distance the CM travelled during flight). All lengths and distances were
213 normalised to stature. Finally, average horizontal external power was calculated, based
214 on the change in kinetic energy as outlined by Bezodis et al. (2010), from the instant of
215 the first touchdown until the end of the third contact phase, and used as an objective
216 measure of sprint acceleration performance. In order to facilitate between-group
217 comparisons, average horizontal external power was normalised according to a
218 modification of the equation presented by Hof (1996) as used by Bezodis et al. (2010).

219

220 *Statistical analyses*

221 Test-retest intra-rater reliability of manual digitisation was determined using an
222 intraclass correlation coefficient (ICC 3,1) with 90% confidence intervals. The segment

223 endpoints at the instant of touchdown and toe-off, for ten participants selected at
224 random, were digitised on two separate occasions, one week apart.

225 The data obtained for each kinematic variable were averaged across the three
226 sprint trials of each participant. Differences between group means (sprinters, backs, and
227 forwards) for all step characteristics and kinematic variables were analysed using a
228 magnitude-based inference approach (Hopkins, Marshall, Batterham, & Hanin, 2009).
229 Cohen's *d* (Cohen, 2013) was calculated between groups, with an effect size of 0.20
230 used to define the smallest worthwhile difference (Hopkins, 2002; Winter, Abt, &
231 Nevill, 2014). The magnitudes of these standardised differences were expressed relative
232 to the smallest worthwhile difference as follows: <0.2, trivial; 0.2, small; 0.6, moderate;
233 1.2, large; 2.0, very large and 4.0, extremely large (Hopkins et al., 2009). Confidence
234 intervals (90%) were calculated to measure the uncertainty of the effect sizes, and the
235 quantitative chances of finding between group differences in the variables tested greater
236 than the smallest worthwhile difference were assessed as follows: 25 - < 75%, possibly;
237 75 - < 95% likely; 95 - < 99.5%, very likely; > 99.5%, most likely (Hopkins et al.,
238 2009). If 90% confidence intervals included positive and negative values greater than
239 the smallest meaningful difference (where the chances of positive and negative value
240 differences are both >5%), the true difference was deemed unclear.

241 Each step characteristic and kinematic variable was then averaged over the first
242 three steps for each participant. These values were used to determine the relationships
243 of each technique variable with normalised average horizontal external power (NAHEP)
244 within each group using Pearson's product moment correlation coefficient (*r*).
245 Confidence intervals (90%) for the observed relationships were calculated to detect the
246 smallest clinically important correlation coefficient. The magnitude of relationships
247 were deemed unclear when confidence limits overlapped substantial positive and

248 negative values ($r = \pm 0.1$) (Hopkins, 2002). The strength of relationships were defined
249 as (\pm): 0.35 (forwards and backs) and 0.31 (sprinters), unclear; 0.36 (forwards and
250 backs) and 0.32 (sprinters) to 0.50 moderate; 0.50 to 0.70, high; 0.70 to 0.90, very high;
251 0.90 to 1.00, practically perfect (Hopkins, 2002).

252

253 **Results**

254 Intraclass correlation coefficients between the first and second digitising occasions
255 indicated excellent (Portney & Watkins, 2000) intra-rater reliability for all step
256 characteristics and kinematic variables (ICC >0.90; CL 0.85-0.99).

257 Regarding acceleration performance over the first three steps, backs most likely
258 produced greater NAHEP than forwards, and the NAHEP of sprinters was most likely
259 greater than the forwards and backs, the magnitude of these differences were extremely
260 large and large, respectively (Figure 1). Of the spatiotemporal step characteristics, backs
261 very likely achieved greater step velocities (Figure 2a) compared with forwards, the
262 difference being moderate ($d = 0.76$ to 1.08 ; Table I). Sprinters very likely produced
263 step velocities higher than forwards of moderate magnitudes ($d = 0.95$ to 1.18 ; Table I),
264 although when compared with backs, the difference (in the same direction) was only
265 possibly evident and small at the third step ($d = 0.06$ to 0.49 ; Table I).

266

267 ****Figure 1 near here****

268 ****Table I near here****

269

270 The step rates (Figure 2c) of backs were likely (step one) and very likely (steps
271 two and three) greater than the forwards and of moderate magnitudes ($d = 0.64$ to 1.16 ;
272 Table I). Sprinters possibly (step one) and likely (steps two and three) achieved greater

273 step rates than the forwards. The magnitude of the differences were small and moderate,
274 respectively ($d = 0.28$ to 0.77 ; Table I). However, the sprinters' step rates were possibly
275 lower than those of the backs, with a small difference evident across all three steps ($d =$
276 -0.46 to -0.32 ; Table I).

277

278 ****Figure 2 near here****

279

280 The contact times (Figure 2d) of backs were likely shorter compared with
281 forwards in step one (moderately) and very likely shorter in steps two and three, where
282 the magnitudes of these differences were large and very large, respectively ($d = -2.67$ to
283 -1.00 ; Table I). Sprinters' contact times were consistently shorter than forwards and
284 longer than backs. Sprinters' contact times in the first step were possibly shorter (small
285 magnitude), and by the second and third steps very likely and most likely shorter
286 (moderate magnitudes), than those achieved by forwards ($d = -1.89$ to -0.47 ; Table I).
287 Likely differences between sprinters' and backs' contact times were evident in step one
288 (moderate magnitude) and possibly in steps two and three, of small magnitudes ($d =$
289 0.50 to 0.63 ; Table I).

290 The flight times (Figure 2e) of backs were possibly greater (moderate
291 magnitude) during the first and second steps compared with forwards and likely greater
292 (moderate magnitude) during the third step ($d = 0.37$ to 0.81 ; Table I). Differences in
293 flight times between sprinters and forwards were likely (sprinters producing moderately
294 greater flight times) for steps two and three ($d = 0.13$ to 0.76 ; Table I).

295 Backs likely produced greater step lengths (Figure 2b), which were moderately
296 different compared with forwards during the first two steps and possibly longer step
297 lengths of a small magnitude during step three ($d = 0.51$ to 0.75 ; Table I). Sprinters

298 most likely produced longer step lengths compared with forwards and backs across each
299 step. The magnitude of the differences were large ($d = 1.36$ to 1.46 ; Table I) relative to
300 forwards, yet small and only possible in step one and moderate with likely differences
301 in steps two and three in relation to backs ($d = 0.52$ to 0.92 ; Table I).

302 Backs' contact lengths (Figure 2f) were possibly smaller during steps one and
303 three compared with forwards' ($d = -0.25$ and -0.33 ; Table I). Sprinters achieved contact
304 lengths which were possibly shorter compared with forwards in step one and longer
305 compared with backs in step three ($d = -0.40$ and 0.59 ; Table I). Backs likely achieved a
306 greater flight length (moderate magnitude) compared with forwards during the first step
307 and very likely greater flight lengths of moderate (step two) and large (step three)
308 magnitudes ($d = 0.87$ to 1.63 ; Table I). The flight lengths of sprinters were most likely
309 greater compared with forwards across all steps ($d = 1.41$ to 2.45 ; Table I). Sprinters'
310 flight distance was also greater compared with backs where possibly and likely
311 differences of small magnitudes were evident ($d = 0.38$ to 0.48 ; Table I).

312 Backs touched down with their toe more posterior to their CM than forwards
313 across each step (Figure 2h). During step one they were possibly different (moderate
314 magnitude), whereas the difference was likely and most likely during steps two and
315 three (large magnitude), respectively ($d = -1.19$ to -0.57 ; Table I). Sprinters' touchdown
316 distances (Figure 2h) were consistently more posterior across all steps relative to
317 forwards and backs. The difference was most likely large (step one) and very large
318 (steps two and three) compared with forwards ($d = -2.64$ to -1.92 ; Table I). Compared
319 with backs, the differences were most likely and large in magnitude (step one), very
320 likely and moderate in magnitude (step two), and likely and moderate in magnitude
321 (step three; $d = -0.89$ to -1.69 ; Table I).

322 At toe-off backs possibly (steps one and three) and most likely (step two)
323 positioned their toe more posterior relative to their CM position (Figure 2i) compared
324 with forwards ($d = -1.22$ to -0.42). The magnitude of this difference was small in steps
325 one and three and moderate in the second step. Sprinters most likely positioned their toe
326 more posterior relative to their CM at toe-off compared with forwards and backs, where
327 the difference was very large in each step ($d = -2.62$ to -2.05).

328 Regarding correlation coefficients, only toe-off distance consistently
329 demonstrated a meaningful relationship with NAHEP in each group (Figure 3h), the
330 magnitude of which was moderate for backs and large for forwards and sprinters ($r = -$
331 0.58 to -0.44). Moderate relationships were also observed between step length and
332 NAHEP (Figure 3a) in both forwards and sprinters ($r = 0.39$ and 0.45 , respectively). In
333 the same two groups negative relationships between contact time and NAHEP (Figure
334 3c) were observed ($r = -0.39$ and $r = -0.35$, respectively). The step rate of sprinters was
335 moderately positively correlated to horizontal NAHEP ($r = 0.44$; Figure 3b), as was the
336 contact length ($r = 0.46$; Figure 3e) of forwards.

337

338 ****Figure 3 near here****

339

340 **Discussion**

341 The purpose of this study was to investigate the differences in step characteristics and
342 linear kinematics between professional rugby players and sprinters during the initial
343 steps of acceleration, and how each of these variables relates to initial sprint
344 performance. This provides information to enhance the understanding of how
345 knowledge of sprinters' acceleration techniques may be transferred to inform training
346 practices aimed at enhancing the acceleration abilities of rugby players. The main

347 finding of this study was that there were multiple differences in the magnitudes of
348 various touchdown and toe-off kinematics between sprinters and rugby groups,
349 confirming our first hypothesis. However, only one technical feature (toe-off distance)
350 was consistently related to sprinting performance in all groups, and thus our second
351 hypothesis was largely rejected. There may therefore be limitations in how the available
352 information concerning the touchdown and toe-off kinematics and step characteristics
353 of sprinters can be used by coaches tasked with enhancing the acceleration abilities of
354 rugby players, possibly due to the different constraints imposed (Newell, 1986).

355 Sprinters achieved substantially greater levels of performance (NAHEP)
356 compared with forwards and backs, by 40% and 19%, respectively. This is explained by
357 their greater change in velocity from the beginning of the first contact phase to the end
358 of the third (sprinters = 3.26 ± 0.28 m/s; backs = 2.60 ± 0.26 m/s; forwards = 2.48 ± 0.28
359 m/s), since less than 0.03 s separated the groups with respect to the time taken to
360 achieve this change. However, no substantial differences in absolute step velocity were
361 found between sprinters and backs until step three, where sprinters possibly reached a
362 higher step velocity ($d = 0.49$), because the backs entered the first step with a higher
363 velocity than the sprinters (3.61 ± 0.16 vs. 3.36 ± 0.31 m/s; forwards = 3.38 ± 0.26 m/s).
364 This is likely reflective of the differences in start conditions, where a longer distance
365 between the feet in the standing start may lead to a longer push-off phase (Salo &
366 Bezodis, 2004), thus affording the opportunity to produce higher impulse where the
367 rapid initiation of a sprint in response to an external stimulus (e.g. starter's gun) is not
368 required.

369 Sprinters consistently produced longer step lengths than backs, who also
370 achieved longer step lengths than forwards (Figure 2b), whilst backs achieved the
371 highest step rates in each step, followed by sprinters and then forwards (Figure 2c). The

372 inconsistent findings of previous research as to the relative contribution of step length
373 and step rate to initial sprint acceleration performance (Debaere et al., 2013; Mackala,
374 Fostiak, & Kowalski, 2015; Murphy et al., 2003) is further compounded by the results
375 of the current study where positive moderate relationships of step length and step rate
376 with NAHEP in sprinters were found ($r = 0.45$ and 0.44), whereas only step length was
377 correlated to the NAHEP of forwards ($r = 0.39$) and no meaningful relationships of step
378 length or step rate with the NAHEP of backs were found (Figures 3a; 3b).

379 The differences in step length between groups were achieved primarily through
380 different flight lengths, but not contact lengths (Figure 2; Table I). However, the
381 location of the foot relative to the CM position was more posterior at both touchdown
382 and toe-off for sprinters compared with both rugby groups, and for backs compared
383 with forwards (Figures 2h; 2i). Smaller touchdown distances have been shown to be
384 related to a more forward-orientated ground reaction force (GRF) vector (Bezodis,
385 Trewartha, & Salo, 2015; Kugler & Janshen, 2010), which has been identified as a key
386 determinant of acceleration performance (Kawamori, Nosaka, & Newton, 2013; Kugler
387 & Janshen, 2010; Morin, Edouard, & Samozino, 2011; Morin et al., 2012). However, no
388 meaningful relationships between touchdown distance and NAHEP were evident in any
389 group in the current study, which may be explained by a number of factors. For
390 example, Bezodis et al. (2015) demonstrated the existence of a within-individual
391 curvilinear relationship between touchdown distance and NAHEP in the first stance
392 phase for an international-level sprinter, whilst vertical impulse production was found
393 to increase linearly as the foot was placed further forward relative to the CM. Limiting
394 how far posteriorly the foot makes contact relative to the CM may therefore be
395 important in producing sufficient vertical GRF to support bodyweight. Consequently, an
396 optimal touchdown distance is likely to exist for each individual influenced by varying

397 constraints. For instance, greater vertical GRF will need to be produced with increased
398 body mass, therefore potentially requiring a greater touchdown distance (i.e. foot
399 positioned further forward of the CM). Additionally, the block start already positions
400 the sprinter's CM ahead of their feet (Mero, Luhtanen, & Komi, 1983) and the effect of
401 both running shoe worn and surface may also provide different opportunities for a
402 sprinter's maintenance of balance. The range of different constraints imposed on rugby
403 players (e.g. greater mass (performer constraint), standing start (task constraint), grass
404 surface (environmental constraint)) suggest that expecting them to touch down posterior
405 to their CM in the same manner as sprinters during the initial steps may not be feasible.
406 It may also be possible to manipulate GRF orientation through other technical
407 adjustments which combine to not affect the overall touchdown distance (Bezodis,
408 North, & Razavet, 2017). Further investigations of segmental and joint angular
409 kinematics during the initial steps of rugby players and how these are influenced by
410 performer constraints such as physical qualities (e.g. strength, anthropometrics), as well
411 as how they influence GRF orientation, may provide further insight into factors which
412 influence rugby players' sprint acceleration technique and performance.

413 Whilst touchdown distance was not related to sprint performance for any of the
414 groups, toe-off distance consistently was ($r = -0.44$ to -0.58). Having the stance toe
415 further behind the CM at toe-off was associated with increased NAHEP in all three
416 groups, and therefore appeared to be reflective of an effective push-off. A more
417 negative toe-off distance was also evident in sprinters compared with backs, who in turn
418 achieved more negative toe-off distances compared with forwards. The importance of
419 this technical feature does appear to transfer between sprinters and rugby players and a
420 CM further forward relative to the point of contact at toe-off during the first step has
421 previously been associated with higher propulsive impulse (Kugler & Janshen, 2010).

422 Toe-off distance, and the body segment rotations used to achieve a greater toe-off
423 distance may be representative of an effective ‘push-off’ and therefore a function of
424 GRF orientation characteristics (Rabita et al., 2015), therefore warranting further
425 investigation. In the current study, sprinters produced longer contact times relative to
426 backs and may have used this to achieve a greater toe-off distance as a result (Kugler &
427 Janshen, 2010). While start position and footwear may again play roles in the ability to
428 achieve such a forward lean position, performer constraints may also be an important
429 consideration. For example, Lee and Piazza (2009) demonstrated, through computer
430 simulation, that the longer toes of sprinters (compared with non-sprinters) prolonged the
431 time of contact during a ‘push-off’ giving greater time for forward acceleration by
432 producing greater propulsive forces. However, it is possible to have a high impulse by
433 pushing-off for longer, but low acceleration if the magnitude of the impulse (and thus
434 change in velocity) is achieved primarily through spending a longer time generating
435 GRF rather than by generating greater GRF magnitudes. This may account for the
436 strategy of backs to produce higher step rates through shorter contact times whilst still
437 achieving superior sprint performance compared with forwards.

438 This study aimed to quantify the differences in step characteristics and linear
439 kinematics between professional rugby players and sprinters during the initial steps of
440 acceleration, and determine how each technique variable related to the initial sprint
441 performance of each group. Although we did not experimentally test each different
442 ecological constraint independently, the groups were observed in representative settings
443 to determine between group differences in their habitual environments. Therefore the
444 findings are relevant to practitioners working with rugby players to enhance initial
445 sprint acceleration performance. There were clear differences in touchdown and toe-off
446 kinematics between groups which are likely to have emerged, at least in part, as a result

447 of inherent differences in task, environment and performer constraints. Toe-off distance
448 was the only technical feature to differ between the groups which was also consistently
449 related to sprint performance within each group, and thus may be an important
450 consideration which can transfer to the sprint training practices of rugby players. Other
451 features of technique identified as potentially important for sprint acceleration
452 performance from the existing literature on sprint-trained athletes may not transfer
453 directly to rugby players.

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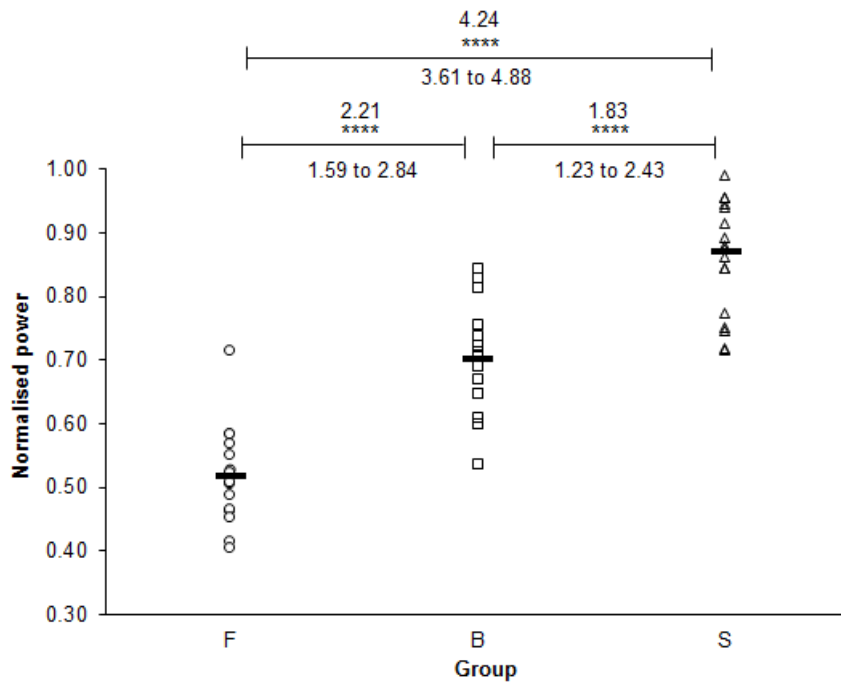
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Table I. Effect sizes^a (and their 90% confidence limits) for spatiotemporal step characteristics in each step between rugby backs and forwards, sprinters and rugby forwards, and sprinters and rugby backs.

Spatiotemporal step characteristics	Backs vs. forwards					
	Step 1		Step 2		Step 3	
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	1.08	0.52 to 1.65	0.92	0.43 to 1.41	0.76	0.22 to 1.31
Step rate (Hz)	0.64	0.11 to 1.17	1.45	0.52 to 2.38	1.16	0.51 to 1.81
Contact time (s)	-1.00	-1.54 to -0.46	-2.67	-3.37 to -1.97	-1.69	-2.21 to -1.16
Flight time (s)	0.37	-0.27 to 1.02	0.63	-0.11 to 1.38	0.81	0.03 to 1.58
Step length ^b	0.70	0.03 to 1.38	0.75	0.20 to 1.31	0.51	-0.08 to 1.11
Contact length ^b	-0.25	-0.80 to 0.30	0.12	-0.44 to 0.68	-0.33	-0.84 to 0.18
Flight length ^b	0.87	0.20 to 1.54	1.06	0.28 to 1.83	1.63	0.82 to 2.43
Touchdown distance ^b	-0.57	-1.10 to -0.03	-1.04	-1.74 to -0.34	-1.19	-1.76 to -0.61
Toe-off distance ^b	-0.56	-1.14 to 0.02	-1.22	-1.72 to -0.72	-0.42	-0.91 to 0.08
	Sprinters vs. forwards					
	Step 1		Step 2		Step 3	
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	1.18	0.54 to 1.83	0.95	0.40 to 1.51	1.18	0.65 to 1.71
Step rate (Hz)	0.28	-0.21 to 0.77	0.71	0.06 to 1.37	0.77	0.21 to 1.34
Contact time (s)	-0.47	-0.97 to 0.03	-1.89	-2.87 to -0.92	-1.31	-1.81 to -0.81
Flight time (s)	0.37	-0.27 to 1.02	0.70	0.10 to 1.30	0.76	0.20 to 1.32
Step length ^b	1.36	0.78 to 1.94	1.41	0.85 to 1.96	1.46	0.87 to 2.04
Contact length ^b	-0.4	-0.89 to 0.08	0.02	-0.61 to 0.64	0.09	-0.42 to 0.61
Flight length ^b	1.41	0.71 to 2.10	1.64	1.04 to 2.23	2.45	1.80 to 3.10
Touchdown distance ^b	-1.92	-2.40 to -1.44	-2.64	-3.41 to -1.87	-2.03	-2.66 to -1.41
Toe-off distance ^b	-2.53	-3.12 to -1.94	-2.62	-3.20 to -2.05	-2.05	-2.67 to -1.43
	Sprinters vs. backs					
	Step 1		Step 2		Step 3	
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	0.11	-0.57 to 0.78	0.06	-0.68 to 0.80	0.49	-0.07 to 1.05
Step rate (Hz)	-0.46	-0.99 to 0.07	-0.38	-0.87 to 0.12	-0.32	-0.85 to 0.20
Contact time (s)	0.63	0.10 to 1.16	0.58	-0.19 to 1.34	0.50	-0.05 to 1.05
Flight time (s)	-0.21	-0.80 to 0.39	0.04	-0.47 to 0.55	-0.03	-0.51 to 0.46
Step length ^b	0.52	-0.01 to 1.04	0.76	0.17 to 1.36	0.92	0.35 to 1.50
Contact length ^b	-0.18	-0.69 to 0.33	-0.11	-0.78 to 0.56	0.59	0.00 to 1.18
Flight length ^b	0.42	-0.18 to 1.03	0.38	-0.13 to 0.88	0.48	-0.03 to 0.99
Touchdown distance ^b	-1.69	-2.20 to -1.18	-1.18	-1.82 to -0.55	-0.89	-1.53 to -0.25
Toe-off distance ^b	-2	-2.60 to -1.41	-2.16	-2.90 to -1.42	-1.71	-2.21 to -1.20

^aA positive/negative effect size depicts a greater/lesser magnitude of spatiotemporal step characteristics produced by the first group in their respective group comparison (e.g. a positive effect size under 'Backs vs. forwards' for step velocity would indicate that backs produced a higher step velocity compared with forwards in that step). The magnitude of differences (Cohen's *d*) were expressed as: <0.20, trivial; 0.20 to 0.59, small; 0.60 to 1.19, moderate; 1.20 to 1.99, large; 2.0 to 3.99, very large; ≥ 4.0 , extremely large.

^bNormalised to participant's stature.



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600 Figure 1. Normalised average horizontal external power^a for forwards (F), backs (B)
 601 and sprinters (S) from first touchdown until the end of the third contact phase of a
 602 sprint, and the effect sizes^b (and their 90% confidence limits^c) between each group.
 603 Individual participant means are plotted, and the black bars represent group means. The
 604 number of asterisks depict the quantitative chances of finding between group
 605 differences: * = possibly; ** = likely, *** = very likely, **** = most likely.
 606

607 ^aNormalised according to a modification of the equation presented by Hof (1996) as
 608 used by Bezodis et al. (2010).

609

610 ^bAbove the asterisks. A positive/negative effect size depicts a greater/lesser magnitude
 611 of normalised average horizontal external power produced by the first group in their
 612 respective group comparison (e.g. a positive effect size under 'Backs vs. forwards'
 613 would indicate that backs produced higher normalised average horizontal external
 614 power compared with forwards). The magnitude of differences (Cohen's d) were
 615 expressed as: <0.20, trivial; 0.20 to 0.59, small; 0.60 to 1.19, moderate; 1.20 to 1.99,
 616 large; 2.0 to 3.99, very large; ≥ 4.0, extremely large.

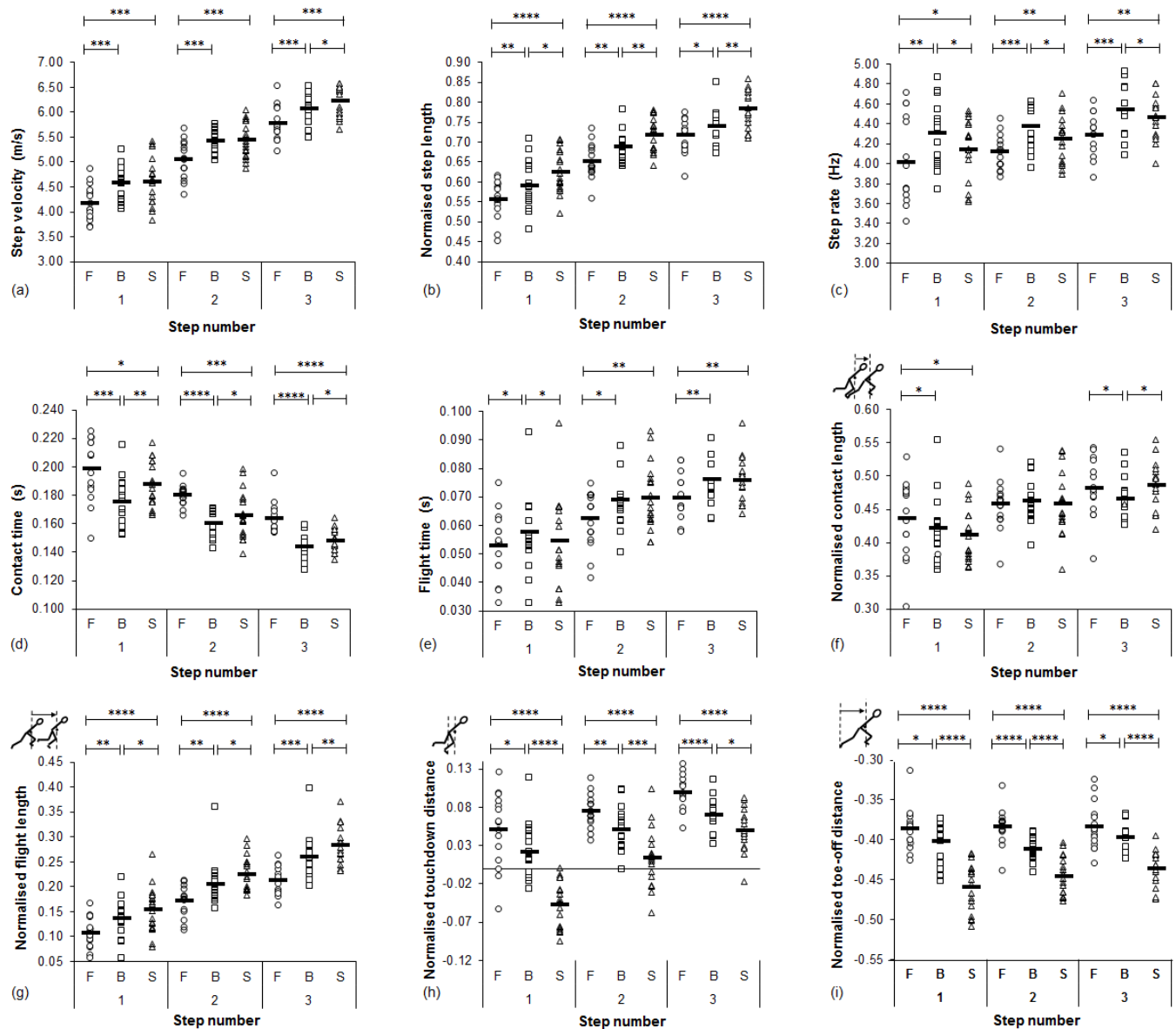
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618 ^cBelow the asterisks.

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623 Figure 2. Step characteristics and linear kinematic variables for rugby forwards (F) and
 624 backs (B), and sprinters (S) during the first three steps of a sprint. Individual participant
 625 means are plotted, and the black bars represent group means and each participant within
 626 each group is represented as an individual data point. The number of asterisks depict the
 627 quantitative chances of finding between group differences: * = possibly; ** = likely,
 628 *** = very likely, **** = most likely

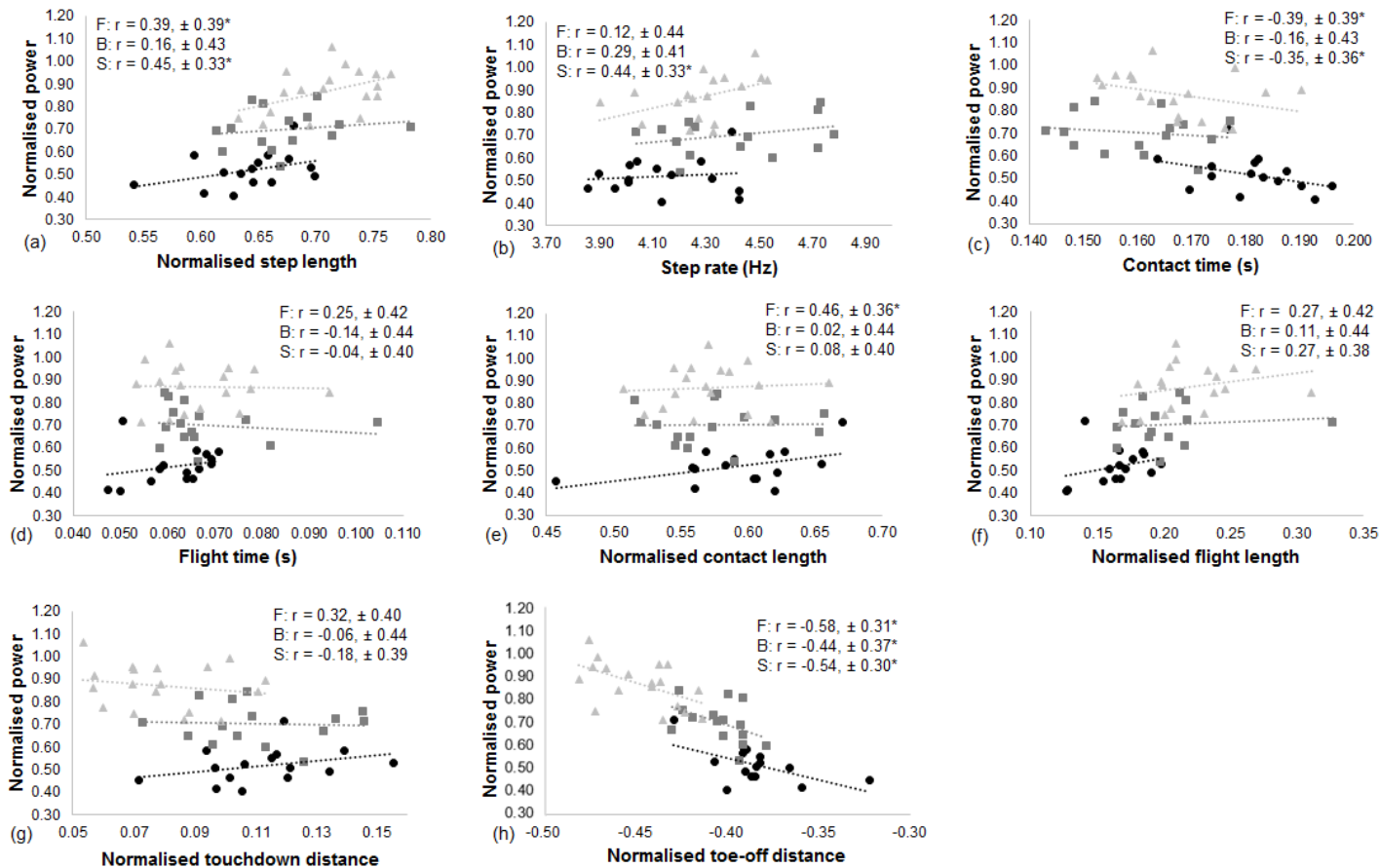
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655 Figure 3. Relationships (Pearson's correlation coefficients and their 90% confidence intervals) of step characteristics and linear kinematic
656 variables with average normalised average horizontal external power for forwards (F), backs (B) and sprinters (S) from first touchdown until the
657 end of the third contact phase of a sprint. Black circles = rugby forwards; dark grey squares = rugby backs and light grey triangles = sprinters.
658 Asterisks indicate clear relationships where confidence limits do not overlap substantial positive and negative values (i.e. $r = \pm 0.1$; Hopkins,
659 2002).