1 **Sprint acceleration technique is associated with lower-limb injury epidemiology in**

2 **professional male Rugby Union players: a seven-season analysis**

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Objectives: To investigate whether sprint acceleration technique is associated with the epidemiology of non-contact lower-limb running-based injuries in professional male Rugby Union players.

Design: Retrospective analysis of prospectively collected cohort data.

Methods: Eighty-five professional male rugby players were monitored across seven seasons, comprising 63,786 total hours of training and match exposure. Players were classified into four sprint acceleration strategy groups based on their spatiotemporal characteristics obtained during quantitative sprint acceleration testing. Non-contact lower-limb running-based injuries were prospectively recorded using standardised injury surveillance methods. Injury incidence, severity, and burden were calculated per 1,000 player hours. Poisson regression models were used to determine relative risks for index injuries by acceleration strategy group, adjusting for exposure and age.

Results: Sixty-two players sustained 123 non-contact lower-limb running-based injuries. Calf injuries had the highest incidence, while hamstring injuries imposed the greatest burden. Players adopting a high step-rate and short flight time strategy were over 2.5 times more likely to sustain hamstring injuries, whereas those adopting a longer step length and longer flight time strategy were over 2.5 times more likely to sustain calf injuries. Conversely, the high step-rate and short flight time strategy was associated with a substantially lower risk of calf injury.

Conclusions: Sprint acceleration technique is associated with site-specific non-contact lower-limb injury risk in professional male rugby players. Acceleration strategy-specific injury profiles highlight the importance of incorporating individual sprint mechanics into multifactorial injury prevention and monitoring practices.

Keywords: athletic injuries; risk factors; biomechanical phenomena; running; team sports; sports medicine

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55 **1. Introduction**

56 Injuries are a relatively frequent occurrence in Rugby Union.[1-3] Non-contact lower limb
57 injuries, specifically those occurring during linear running-based activities, constitute the

58 second highest incidence of rugby injuries during matches and the highest incidence during
59 training.[2-4] These non-contact running-based injuries therefore present a considerable
60 challenge for teams as they impact player availability, and therefore team performance, and
61 ultimately match outcome.[5] Beyond this direct impact on the pitch these running-based
62 injuries also carry substantial costs for rugby organisations, requiring investments in
63 resources and personnel related to aspects such as medical treatment, rehabilitation, and
64 preventive measures.

65 Sprint accelerations are frequently performed in rugby and comprise a large proportion of the
66 linear running activities that players undertake during training and competition.[6,7] Therefore,
67 the repetitive nature of these accelerations not only poses a direct risk of non-contact lower
68 limb injuries but also contributes to cumulative loading[8], which may increase injury risk
69 during other linear running tasks, such as constant velocity running at maximum or sub-
70 maximal speeds. The repeated mechanical stresses placed on the lower limb tissues during
71 accelerations can induce neuromuscular fatigue[8], characterised by task-specific reductions
72 in force-producing capacity and alterations in motor control, which may compromise the
73 capacity to effectively attenuate and distribute mechanical loads, thereby increasing
74 susceptibility to strain or overload during subsequent linear running-based activities.

75 Different sprint acceleration technical strategies with varying biomechanical features are
76 exhibited by professional rugby players[9]. The technical strategy that a given player adopts
77 when accelerating will likely influence the specific nature of the lower limb mechanical
78 stresses and is therefore important to consider as it may ultimately influence the potential
79 injury risk during linear running-based activities. For example, the ankle plantarflexors are
80 the primary contributor of the lower limb muscles to the vertical impulse produced during
81 sprint acceleration.[10,11] Given that vertical impulse is the primary determinant of step length
82 relative to step rate across acceleration,[12] players that employ longer step lengths relative to
83 their step rate during acceleration may therefore experience greater plantarflexor loading
84 compared to those favouring a higher step rate. In contrast, for those favouring higher step

85 rates, greater demand is likely placed on the hip-spanning muscles[13-15] as this requires the
86 generation and absorption of higher energy for both propulsion (hip extensors) and/or rapid
87 limb repositioning (hip flexors).[11] Because each acceleration strategy is associated with
88 varied technical demands that likely induce different musculoskeletal demands on the lower
89 extremity, we hypothesise that the specific injury occurrence will differ between players that
90 exhibit different sprint acceleration strategies.

91 An individual's sprint acceleration strategy can be quantified through the use of a whole-
92 body kinematic approach.[9] This enables classification according to combined normalised
93 spatiotemporal variables, namely the ratios between step length / step rate and between
94 contact time / flight time. This holistic level representation of their system behaviour during
95 acceleration reflects the outcome of a complex interaction between various kinematic and
96 kinetic factors and has been well established in professional rugby players,[9] including to
97 inform individual-specific acceleration performance training programmes.[7]

98 If the adoption of different sprint acceleration strategies is associated with specific injury
99 epidemiology, this would provide highly valuable evidence to inform tailored injury prevention
100 programmes, ultimately enhancing player availability and team success in rugby. This study
101 therefore used a robust and comprehensive seven-season dataset of sprint acceleration and
102 injury epidemiology data from a male professional rugby team with the aim of investigating
103 the associations between different whole-body sprint acceleration strategies and the
104 incidence, severity, burden and relative risk of running-based lower-limb injuries.

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109 **2. Methods**

110 *2.1. Study design and participants*

111 A retrospective analysis of prospectively collected cohort data was conducted. The study
112 involved male senior squad members of a professional rugby club competing in the English
113 Rugby Premiership league over seven seasons (Table 1). From the beginning of the 2017-18
114 pre-season until the conclusion of the 2023-24 season (i.e., seven full seasons with pre- and
115 in-season phases), match and training exposure, along with detailed records of all time-loss
116 injuries sustained, were documented daily by the club's athletic development and medical staff
117 as part of the club's injury surveillance processes. The whole-body sprint acceleration
118 strategies of players,[9] were also prospectively determined at multiple timepoints each season
119 throughout the entire observation period during which injuries and exposure were recorded.
120 Across the seven seasons, 174 different players, all injury-free at the start of their individual
121 observation periods, were initially eligible for inclusion. Following exclusions due to completing
122 less than one complete season, insufficient sprint acceleration data, or a change in their sprint
123 acceleration strategies over the observation period (Table 1), 85 players were included in the
124 final analysis. These players had a total exposure of 63,786 player hours across the seven
125 studied seasons.

126 Injury surveillance, exposure data and sprint acceleration testing were collected prospectively
127 as part of routine performance monitoring within the club. The analysis of these pre-existing
128 data was undertaken retrospectively as these data appropriately quantified the necessary
129 constructs in order to address the specific aim of this study. All exposure, injury, and sprint
130 acceleration data were accessed by the lead researcher using anonymised unique player
131 identifiers, with re-identification only possible within the club's secure systems by authorised
132 club personnel. As the data were collected as part of the players' normal training, match, and
133 medical monitoring; no additional testing or deviation from standard practice was undertaken.
134 At the start of each season, players were issued with a privacy notice through which they
135 provided written informed consent permitting the use of their anonymised performance and
136 medical data for research purposes. The study protocol was approved by the University of
137 Surrey Ethics Committee (Ethics RM ref: 0726).

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139 *2.2. Data collection*

140 *2.2.1. Exposure and injury data*

141 Individual player exposure was captured throughout the observation period for all on-field
142 sessions (rugby training, matches, running-based conditioning, and speed training) using
143 global positioning system data (Vector S7, Catapult, Melbourne, Australia), to the nearest
144 minute. Attendance registers were also used to log exposure during gym-based sessions, to
145 the nearest 15 minutes. These data were cross-referenced with attendance registers
146 completed at the end of each day by the athletic development staff, which included manual
147 recordings of live modifications to training and match participation, ensuring the verification of
148 exposure records and actual time-loss reported due to injury. The total minutes per player per
149 season were determined and rounded to the nearest hour for the final analysis.

150 Injuries were defined as physical complaints requiring medical attention that rendered players
151 unable to participate in full rugby training or matches for more than 24 hours after sustaining
152 the injury, as per standard Rugby Union injury definitions for time-loss injuries.[16] All injuries
153 were diagnosed by qualified medical personnel and prospectively recorded at the time of injury
154 as part of routine medical surveillance in a central database, using the Orchard Sports Injury
155 Classification System,[17] specifying the injury mechanism, body region, and nature of the injury.
156 To identify the running-based lower-limb injuries required to address the current aim, injuries
157 were extracted when the prospectively recorded mechanism was classified as a non-contact
158 linear running-based event and the injury site was classified as the lower limb, with injuries
159 grouped into the following body sites (adapted from [1,4]): hip/groin, thigh, knee, calf, ankle, and
160 foot. Descriptive information for the thigh injuries was assessed to determine whether these
161 could be further sub-divided. However, no anterior thigh injuries occurred during non-contact
162 linear-based running events and thus the thigh category exclusively referred to hamstring
163 injuries and is named as such hereafter.

164 To verify the daily recorded injury information, all data were cross-referenced with daily training
165 lists produced by the club's athletic performance and medical team at the end of each week.
166 These training lists outlined player availability, current injury status, and planned modifications
167 to training or matches for that day. These records were then further checked against the
168 attendance registers, accounting for actual modifications made, completing the verification
169 process to carefully ensure the accuracy of all injury data included in the current study. The
170 procedures used in this research are aligned with the Olympic Committee (IOC) consensus
171 statement for injury epidemiology studies.[18]

172

173 [Insert Table 1 near here]

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175 Across the entire observation period, injury incidence was calculated as the number of injuries
176 per 1,000 player hours, while injury burden was defined as the total number of days lost per
177 1,000 player hours. Injury severity was expressed as the median number of days lost per
178 injury, as the data were not normally distributed. These calculations align with established
179 methods used in other rugby epidemiological studies.[1,3] The same calculations were applied
180 to assess incidence, burden, and severity when the injuries were grouped by the player's
181 acceleration strategy, and when they were grouped by injury site.

182

183 *2.2.2. Whole-body acceleration strategies*

184 The whole-body sprint acceleration strategies ('acceleration strategies' hereafter) of players
185 were individually determined using previously established methods.[7,9] Spatiotemporal data
186 (mean step length and step rate and contact and flight times, normalised according to the
187 convention of Hof[19]) were obtained from the first six steps of three to four maximal 10 m sprint
188 acceleration efforts from a two-point standing start, conducted as part of routine speed testing.
189 Testing was conducted on an outdoor 3G artificial surface, with players wearing rugby training

190 attire and moulded stud boots. Sprint assessments were performed under consistent applied
191 testing conditions, including similar times of day and weather conditions, and only when the
192 surface was dry. As part of the club's standard speed-testing procedures, testing was
193 undertaken when players were available for full training and not acutely affected by preceding
194 training.[7,9] Previous work using this framework has shown acceptable reliability and within-
195 player stability of these combined spatiotemporal characteristics across repeated
196 assessments in professional male rugby players.[7,9] Players were included if their acceleration
197 strategy was recorded a minimum of three times per season (at least once during the pre- and
198 in-season phases). As the studied seasons progressed, the number of players excluded for
199 not meeting this criterion typically decreased (Table 1) because the protocol became more
200 regular as a part of players' speed testing battery.

201 Players were then grouped according to their acceleration strategies. These were made using
202 a median split of the whole group step length/step rate (SL/SR) and contact time/flight time
203 (CT/FT) z-scores to yield four groups (Figure 1). Although SL/SR and CT/FT ratios exist on a
204 continuum, the median split approach was used to provide a practically interpretable
205 framework for categorising whole-body acceleration strategies in applied settings that can be
206 used as a fundamental starting point for understanding acceleration behaviour. This
207 framework was directly informed by previous work demonstrating that these combined
208 spatiotemporal characteristics provide a stable and informative representation of individual
209 acceleration behaviour in professional rugby players.[7,9] Each group was represented as a
210 compass bearing based on the mean spatial location of the group's whole-body strategy on a
211 Cartesian plane,[7] with distinct relative spatiotemporal differences evident between the groups.
212 Specifically, the North-West group displayed relatively longer step lengths and longer flight
213 times; the North-East group exhibited relatively longer step lengths and longer contact times;
214 the South-East group was characterised by relatively higher step rates and shorter flight times;
215 and the South-West group showed relatively higher step rates and shorter contact times.
216 Players whose acceleration strategies changed during the observation period (n = 6; Table 1)

217 were excluded from the analysis to avoid ambiguity or misclassification of acceleration
218 strategy. Consequently, the acceleration strategy assigned to each player was considered
219 representative of their typical acceleration behaviour across the entire observation period
220 during which their exposure and injuries were recorded. A change was defined if the centroid
221 of their acceleration strategy, determined during a testing session,[9] shifted to a different
222 strategy compared with the centroid location from a prior testing session, based on the above
223 median splits.

224

225 [Insert Figure 1 near here]

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228 *2.3. Statistical Analysis*

229 To address our hypothesis and determine whether there were significant differences in the
230 incidence and burden of injuries between injury sites and between the different acceleration
231 strategy groups, 95% Poisson confidence intervals were examined, consistent with previous
232 rugby epidemiology studies.[1,4] Differences were considered statistically significant if the
233 confidence intervals for two groups did not overlap.

234 Statistical differences in severity, calculated across all individual injuries within each injury site
235 and acceleration strategy, were assessed using the Kruskal-Wallis test. Additionally, for
236 severity, the 25th and 75th percentiles were reported. For illustrative purposes, bootstrapped
237 95% confidence intervals for the median severity were also used for acceleration strategies.

238 Poisson regression models were then employed to calculate relative risks,[20,21] providing
239 measures of the associations between acceleration strategies and the number of index injuries
240 per injury site. Total exposure per player and mean age per player within each acceleration
241 strategy group were included as covariates in the regression models to control for their
242 potential confounding effects. Poisson regression was chosen due to its suitability for

243 modelling count data, particularly when adjusting for exposure differences across
244 participants.[22] Model fit, including evaluation of deviance and Pearson Chi-Square statistics,
245 was also assessed to confirm the appropriateness of the Poisson distribution. Index injuries
246 were used to provide a conservative estimate of site-specific injury risk and reduce bias from
247 recurrent injuries. Robust standard errors were applied to adjust for potential violations of the
248 Poisson assumption of equal variance and mean, improving the accuracy of the relative risk
249 estimates. These models were restricted to the three main injury sites (hip/groin, hamstring,
250 and calf), and a combined measure of these sites (i.e., the sum of hip/groin, hamstring, and
251 calf injuries), due to the limited number of injuries at the other sites.

252 To determine whether the relative risks could be considered practically meaningful, two key
253 criteria were applied: 1) the 95% confidence intervals for the relative risks did not cross 1.0
254 (indicating statistical significance), and 2) the relative risk values exceeded internally derived
255 smallest association thresholds. These thresholds were established by examining the strength
256 of associations between the number of index injuries and variables for which no plausible
257 theoretical associations exist, similar to previous methods.[23] This approach was used as an
258 exploratory internal benchmark to help assess whether the observed associations were
259 stronger than those seen for theoretically unrelated variables, and therefore less likely to
260 reflect spurious patterning alone, rather than as a formal epidemiological cut-point. For these
261 theoretically unrelated variables, players were categorised into four groups according to hair
262 colour (bald/very short [n = 13], fair [n = 24], brown [n = 28], black [n = 20]), the first initial of
263 their first names (A-F [28], G-M [35], N-S [14], T-Z [n = 8]), and birth month (Q1 [n = 19], Q2
264 [n = 22], Q3 [n = 24], Q4 [n = 20]). Based on these analyses, the highest (1.85) and lowest
265 (0.38) relative risk values were set as exploratory upper and lower thresholds for interpreting
266 meaningfully higher or lower risk. Data analysis was conducted using SPSS (v26.0), with
267 statistical significance determined at $p < 0.05$. All methodological standards were aligned with
268 the CHAMP guidelines[24] to ensure valid exposure controls, precise risk estimates, and
269 transparent reporting of the analysis.

270

271 **3. Results**

272 *3.1. Incidence, severity and burden*

273 A total of 123 non-contact lower limb running-based injuries (including 82 index injuries) were
274 incurred during the seven-season observation period, with an incidence of 1.92 (95% CI: 1.60
275 – 2.29) injuries per 1000 player hours, a median severity of 15.0 (Q1 – Q3: 5.0 – 34.0) days,
276 and an overall burden of 47.5 (95% CI: 45.8 – 49.2) days lost per 1000 player hours.

277 Among specific injury sites, the incidence was highest for calf injuries closely followed by
278 hamstring injuries, while the burden was highest for hamstring injuries closely followed by calf
279 injuries (Table 2). Both the incidence and burden for calf and hamstring injuries were
280 significantly higher than for all other injury sites. The incidence and burden of hip/groin injuries
281 was significantly greater than the incidence of foot, knee and ankle injuries, all of which had
282 relatively low incidence of < 0.10 per 1000 hours.

283 The median severity of injuries at sites involving joint- and bone-related tissues (i.e., knee,
284 ankle, and foot) was higher than at sites where muscle injuries predominated (i.e., hamstring
285 and calf) (Table 2 and Figure 2). However, these differences in injury severity between sites
286 were not statistically significant.

287

288 [Insert Table 2 near here]

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290

291 [Insert Figure 2 near here]

292

293 Between acceleration strategies, there were no statistical differences in incidence and severity
294 of all injuries. However, the injury burden for the North-West acceleration strategy

295 (characterised by relatively longer step lengths and longer flight times) was significantly
296 greater than all other acceleration strategies (Figure 3). The injury burden for the South-East
297 strategy (relatively higher step rates and shorter flight times) was significantly greater than that
298 observed for the North-East (relatively longer step lengths and longer contact times) and
299 South-West (relatively higher step rates and shorter contact times) acceleration strategies.

300

301 [Insert Figure 3 near here]

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304 *3.2. Relative risks*

305 There were no significant differences in the magnitude of relative risk when comparing
306 acceleration strategies for combined injuries (i.e., sum of hip/groin, hamstring, and calf).
307 However, when investigating specific injury sites, the North-West acceleration strategy
308 (relatively longer step lengths and longer flight times) was significantly associated with an
309 increased risk of calf injury, and the South-East strategy (relatively higher step rates and
310 shorter flight times) was significantly associated with an increased risk of hamstring injury,
311 both exceeding the pre-defined practically meaningful threshold (Figure 4). The relative risk of
312 players adopting these acceleration strategies sustaining such injuries was more than 2.5
313 times greater than for other acceleration strategies ($p \leq 0.002$). Additionally, for calf injuries,
314 the South-East acceleration strategy was associated with a 3.2-fold lower risk compared with
315 other strategies (RR = 0.309; $p = 0.02$).

316

317 [Insert Figure 4 near here]

318 **4. Discussion**

319 This study is the first to quantify the association between sprint acceleration strategies and
320 the epidemiology of non-contact lower-limb running-based injuries. A seven-season analysis
321 of 85 professional athletes provides robust findings in relation to the location, incidence,
322 severity, and burden of these injuries, and identifies associations between index injury counts
323 and acceleration strategies, supporting our hypothesis. This provides new and important
324 insight into links between specific injury profiles and the way someone accelerates. Those
325 who adopted the South-East (SE) acceleration strategy (characterised by relatively higher
326 step rates and shorter flight times) were more than 2.5 times as likely to sustain a hamstring
327 injury, whereas those adopting the North-West (NW) strategy (characterised by relatively
328 longer step lengths and longer flight times) were more than 2.5 times as likely to sustain a calf
329 injury. For ease of communication in applied settings, these strategies are sometimes referred
330 to as "*Spinners*" and "*Bounders*", respectively (Figure 1). Given the higher incidence and
331 burden of these non-contact lower-limb running-based injuries compared to other sites, these
332 findings provide useful information for practitioners to consider sprint acceleration technique
333 as one component of broader, individualised approaches to managing running-based injury
334 risk based. To aid interpretation and support applied dissemination, indicative visual
335 representations of these acceleration strategies at key events during the step cycle, and each
336 strategy's associated relative injury risk profile, are provided in Figure 5.

337

338 [Insert Figure 5 near here]

339

340 123 injuries were recorded over the seven-year period, accounting for 3,038 days lost.
341 Combined with previous evidence, this reinforces the importance of targeted approaches to
342 mitigate running-based injuries in rugby. For example, running has been reported to be the
343 most frequent cause of rugby training injury, with an incidence of 2.0 per 1000 hours.[4] This

344 aligns well with that observed across training and matches in the current study (1.92), and
345 suggests that nothing has been implemented to effectively change this incidence over almost
346 20 years. Running was the most common mechanism for training injury in the English
347 Premiership in 2022–2023,[2] and running has been identified as the second most common
348 cause of all match injuries, behind tackling.[3] The observed burden of 47.5 days lost per 1000
349 hours in the current study, which combines both training and match exposure, is between
350 values previously reported for training (40-45 days[4]) and matches (270 days[3]). While the
351 burden during matches is substantially higher, this reflects the disproportionately lower
352 exposure during match play, which inflates the burden value relative to training. Collectively,
353 these findings further highlight the need for effective strategies that focus on reducing the
354 prevalence of non-contact running-based lower limb injuries.

355 When considering injury measures across all lower-limb regions, no significant differences
356 existed in overall injury incidence or severity between the different acceleration strategy
357 groups (Figure 3). However, the NW group demonstrated the highest injury burden, which was
358 significantly greater than other groups. The SE group had the second-highest burden,
359 significantly exceeding that of the North-East (NE) and South-West (SW) groups, sometimes
360 referred to as "*Striders*" and "*Bouncers*" in applied settings). These findings support our
361 hypothesis by providing the first evidence that the adoption of certain technical strategies may
362 impose different levels of injury burden when running. Notably, due to the low number of knee,
363 ankle and foot injuries, these findings are most applicable to hip/groin, hamstring, and calf
364 injuries.

365 When assessing the relative risk of sustaining any non-contact lower limb injury (inclusive of
366 hip/groin, hamstring and calf injuries) during running, no single acceleration strategy was
367 found to pose a greater risk than others (Figure 4a). However, when examining injuries at
368 individual sites, distinct relationships were observed, highlighting significant associations
369 between specific acceleration strategies and particular injury locations, further supporting our
370 hypothesis as will now be discussed in turn.

371 Hamstring injuries had the second highest incidence and imposed the highest burden among
372 all injury sites (Table 2). Hamstring injuries have consistently ranked among the top three most
373 common and burdensome injuries in rugby for the past 20 years.[1,3,25] Since the majority (68%
374 - 85%) of hamstring injuries in rugby occur during running events,[25-27] this further strengthens
375 the current rationale for understanding how different acceleration strategies are related to
376 hamstring injury occurrence. 50% of all hamstring injuries occurred in the SE group, yielding
377 a significant and practically meaningful relative risk (> 2.5) of sustaining an index hamstring
378 injury for this specific acceleration strategy group (Figure 4c). In absolute terms, the SE group
379 sustained 0.84 index hamstring injuries per 1000 player-hours, compared with 0.30 across the
380 other acceleration strategy groups combined. This absolute difference is likely to be practically
381 meaningful in a professional rugby environment given the time-loss consequences of
382 hamstring injuries.[1,3,25] A primary feature of this strategy is a relatively high step rate, which
383 places greater demand on the hip-spanning muscles.[13,15] This includes increased loading of
384 the biceps femoris long head during the late swing phase,[14] which aligns with both the most
385 frequently injured hamstring muscle during running events in rugby,[25] and the phase of the
386 step in acceleration when hamstring injuries are most likely to occur.[28] Accordingly, the
387 increased hamstring injury risk observed in the SE group may be explained by the increased
388 demand on the biceps femoris long head to decelerate the more rapid forward swing of the
389 leg, increasing its energy absorption requirement as the knee extends during the late swing
390 phase. This interpretation is further supported by observations of increased hip extensor
391 moments and greater knee flexor power absorption during the late swing in hamstring-injured
392 professional rugby players.[29]

393 In the SE group, the high step rate is achieved primarily by short flight times, which may further
394 compound hamstring loading demands. Reduced flight time is associated with greater forward
395 trunk lean during acceleration,[30] and rugby players whose acceleration strategy most closely
396 resembled the SE strategy in the current study (i.e., high step rate and short flight time) have
397 previously been shown to display greater mean forward trunk lean at both touchdown and toe-

398 off compared to other acceleration strategies.[9] This forward trunk leaning posture could
399 increase hamstring injury risk, as a greater anterior pelvic tilt increases strain on the biceps
400 femoris long head during acceleration.[31] Together, these interacting features of the SE group
401 provide a potential injury mechanism to explain their observed higher relative risk of hamstring
402 injury. However, whilst these proposed mechanical factors provide plausible explanations for
403 the observed effects, they should be interpreted within a broader multifactorial context, as
404 factors such as strength capacity, fascicle length, prior injury history and workload fluctuations
405 may also have contributed to the observed injury patterns.

406 Calf injuries had the highest incidence, representing 39% of all lower-limb running injuries and
407 imposing the second-highest burden among injury sites (Table 2). They have also frequently
408 ranked among the top five most common and burdensome injuries in professional rugby for
409 two decades.[1-3] 63% of all calf injuries occurred in the NW group, yielding a significant and
410 practically meaningful relative risk (> 2.5) of sustaining an index calf injury for players
411 exhibiting this specific sprint acceleration strategy (Figure 4d). In absolute terms, the NW
412 group sustained 0.58 index calf injuries per 1000 player-hours, compared with 0.29 across the
413 other acceleration strategy groups combined. This absolute is likely to be practically
414 meaningful in a professional rugby environment given the time-loss consequences of calf
415 injuries.[1,2,3] Producing a longer step length relative to step rate, characteristic of the NW
416 acceleration strategy, requires greater vertical ground reaction impulse.[12] This likely increases
417 plantarflexor loading, as the ankle plantarflexors generate most of the vertical impulse needed
418 to support body weight and propel the body forward.[10,11,13] However, it is important to note that
419 whilst the NE group produced similar step length / step rate ratios to the NW group (Figure 1),
420 they did not also show a significantly increased relative risk of calf injury (Figure 4b). This
421 suggests that relative step length alone may not lead to calf loading that predisposes a player
422 to calf injury.

423 The spatiotemporal features distinguishing the NW and NE groups' strategies are the
424 normalised contact and flight times, which define the spatial locations of their acceleration

425 strategies from "West" to "East" on the Cartesian plane, based on their contact/flight time ratios
426 (Figure 1). The NW group's longer step lengths were accompanied by relatively longer flight
427 times, which increases downwards whole-body velocity at touchdown. Such a profile would
428 lead to higher impact forces during early stance, when the plantarflexors act as energy
429 absorbers,[11] thereby increasing their load and likely the strain placed on the Achilles
430 tendon.[32,33] This is further compounded by the relatively shorter contact times produced by the
431 NW strategy, which requires greater force generation per unit time to achieve sufficient impulse
432 for propulsion. Collectively, these acute mechanical stressors may surpass the capacity of the
433 tissues involved, heightening the risk of sudden onset injuries, whilst the cumulative loading
434 during repetitive sprinting and running cycles may elevate the likelihood of overuse injuries
435 such as tendinopathy.[34] In contrast, the NE group likely experience lower impact forces, and
436 therefore less demand on the plantarflexors to absorb energy during early stance, due to their
437 relatively shorter flight times and longer contact times. Furthermore, strategies characterised
438 by long step lengths and contact times, and shorter flight times, like the NE group, are also
439 typically accompanied by longer contact lengths, primarily due to greater touchdown
440 distances.[9] This has been associated with increased braking forces[35] when the knee extensor
441 muscles play a significant role during early stance,[13] and thus individuals with an NE
442 acceleration strategy may rely more on knee extensors and less on plantarflexors for body lift
443 and forwards propulsion[10,11] compared to those employing an NW acceleration strategy.

444 The highest percentage (35%) of hip/groin injuries was sustained by players in the SW group,
445 and this group's relative risk exceeded 2 for hip/groin injuries (Figure 4b). Whilst the
446 overlapping confidence intervals indicate a lack of statistical significance, precluding any
447 definitive conclusions about increased risk of these injuries within the SW group, it is feasible
448 that this potentially elevated risk may again stem from their sprint acceleration strategy. The
449 high step rates and short contact times exhibited by the SW group require rapid limb
450 repositioning associated with a sharp spike in hip flexor force late in stance as the thigh
451 decelerates in preparation for the ensuing forwards swing.[11,13,15]

452 *4.1 Limitations*

453 This study analysed routinely collected longitudinal data from 174 professional rugby players
454 during their involvement with a single club that spanned some or all of the 7-year study period.
455 The within-club design ensured data integrity through consistent and rigorous data collection
456 methods. This included accurate sprint acceleration profiling, and the requirement for a
457 consistent sprint acceleration strategy for player inclusion,[7,9] as well as control of potentially
458 confounding factors such as playing style and medical practices. This consequently enabled
459 confidence in the outputs of a detailed longitudinal analysis of 63,786 player hours from a
460 sample of 85 players. However, it must be acknowledged that findings may be specific to the
461 unique context of this club, which could affect generalisability. Furthermore, when injuries were
462 separated by location and acceleration strategy, the sample size limits the statistical power
463 and the conclusions that could be drawn for some aspects, such as hip/groin injuries in the
464 SW group. Excluding the six players whose acceleration strategies changed over time was
465 intentional to ensure that every included player exhibited a consistent acceleration strategy
466 that aligned with one of the four previously identified strategies[7] throughout their entire
467 observation period in the current study. Whilst this was important for the validity of addressing
468 the current aim, it is possible that such changes reflected adaptation following injury or
469 physical development. Future studies could examine whether strategy transitions are
470 associated with injury occurrence, but clearly a larger sample of players transitioning between
471 strategies would be required. Relatedly, the whole-body sprint acceleration strategy
472 framework simplifies inherently continuous and multidimensional sprint behaviours into
473 categorical groups to aid interpretation in applied settings, and some players may have
474 displayed strategies close to group boundaries. However, this is not unique to the present
475 median-split approach but rather a broader feature of categorical classification methods.[9] The
476 internally derived smallest-association thresholds should also be interpreted cautiously, as
477 they were used as exploratory contextual benchmarks to assess whether observed
478 associations were stronger than those seen for theoretically unrelated variables, rather than

479 as formal epidemiological thresholds. It should also be acknowledged that players were
480 classified based on their acceleration strategies, but that injuries were recorded across all
481 linear running activities, not just those involving maximal acceleration. As with any applied
482 injury surveillance dataset, some degree of injury mechanism misclassification is possible, but
483 the prospective nature of documentation minimised this. There is also the potential for noise
484 in the exposure denominator given the integration of field- and gym-based exposure measures
485 collected through different monitoring processes. Again, these were documented
486 prospectively and are routinely measured with high accuracy in the environment. Finally,
487 although exposure and age were accounted for in the regression models, other potentially
488 relevant factors such as positional role, match-specific exposure, strength capacities, muscle
489 fascicle length, training load fluctuations and prior injury history were not modelled explicitly
490 and may also have influenced injury occurrence. Whilst these factors could limit direct links
491 between acceleration-specific biomechanics and injury occurrence, the observational design
492 also means that causal relationships cannot be established. Therefore, acceleration strategy
493 should be considered as one potential component within a multifactorial injury risk profile
494 rather than a direct cause of injury, even though maximal accelerations occur frequently in
495 rugby.[7]

496

497 *4.2 Practical Implications*

498 The current findings yield important new implications for the practical management of
499 hamstring and calf injuries in male professional rugby, and potentially in other similar
500 intermittent running-based team sports. Beyond addressing established clinical reasoning and
501 known modifiable risk factors such as load management and strength deficits[36], practitioners
502 may also consider technique-related interventions that take account of a player's acceleration
503 strategy alongside other established risk factors. The current findings should not be interpreted
504 as evidence that technique modification alone will prevent injury, but rather that acceleration

505 strategy may represent one modifiable factor within a broader multifactorial injury-
506 management framework.

507 Firstly, this could involve supporting a player's existing strategy by strengthening tissues to
508 tolerate the repeated stresses associated with that strategy. For instance, elevated hamstring
509 strength targets may be appropriate for players adopting the SE acceleration strategy,
510 whereas enhanced plantarflexor strength may benefit those using the NW acceleration
511 strategy. Secondly, attention to kinematic aspects of technique may also help address
512 sprinting-related injury risk at specific sites alongside acceleration strategy-specific
513 intervention. For instance, enhancing aspects of lumbo-pelvic control during sprinting which
514 have been linked to hamstring injury risk[37] may be more important for players adopting the SE
515 acceleration strategy. For those using the NW acceleration strategy, intralimb foot-shank
516 coordination during stance may warrant attention as foot and ankle kinematics that increase
517 dorsiflexion toward toe-off - particularly when combined with knee extension - resemble those
518 observed during Achilles tendon ruptures.[38] In addition, a more pronounced forefoot strike
519 pattern may be associated with greater lower-leg mechanical demands and reliance on
520 plantarflexor–Achilles elastic loading.[39]

521 Thirdly, practitioners may also implement interventions aimed at modifying an individual's
522 acceleration strategy in some cases. For instance, players adopting the NW acceleration
523 strategy who sustain recurrent calf injuries may benefit from moving towards a more balanced
524 step length/step rate and contact/flight time ratio to reduce plantarflexor and Achilles tendon
525 loading. This may warrant strengthening the muscles spanning the hip to support this change,
526 given the greater loading at the hip joint associated with the higher step rates that would be
527 required for a more balanced strategy. Individual-specific technique or strength-focussed
528 interventions have previously been shown to be successful in moving acceleration strategies
529 in the intended direction in professional male rugby players.[7] However, caution is warranted,
530 as a substantial change in strategy that crosses into another category may introduce new
531 risks. For example, transitioning from the NW to the SE acceleration strategy may redistribute

532 load more proximally from the plantarflexors and Achilles tendon, potentially lowering calf
533 injury risk but increasing susceptibility to hamstring injury.

534 From a monitoring perspective, total running volume should be managed for players using the
535 NW acceleration strategy due to the high calf loading across all running intensities (e.g.,
536 acceleration, submaximal, and maximal speeds) and similar tendon strain magnitudes across
537 these forms.[40] For SE strategy players, high-speed running warrants particular attention, as
538 hamstring injuries are more frequent during these activities.[41]

539 For practitioners working with smaller squads where deriving meaningful group reference
540 values may not be feasible, the representative step length/step rate and contact time/flight
541 time ratios presented here (Figure 1) may provide useful reference points for interpreting
542 individual athletes' acceleration strategies in similar populations. Alternatively, practitioners
543 may monitor each player's acceleration strategy longitudinally and evaluate how changes in
544 these ratios relate to changes in performance[7] or injury occurrence.

545

546 **5. Conclusion**

547 This study provides the first evidence linking the technique that individuals exhibit during sprint
548 acceleration to non-contact lower limb running-based injury profiles. Certain sprint
549 acceleration technical strategies were found to be associated with elevated injury risk to
550 specific sites such as the hamstrings and calf. These results emphasise the importance of
551 tailoring intervention and monitoring strategies to individual acceleration profiles as part of a
552 multi-factorial approach to the reduction of running-based injuries in professional male rugby.

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Declaration of interest statement

The authors declare no competing interests.

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584 **References**

585 1. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Epidemiology of injuries in English
586 professional rugby union: part 1 match injuries. Br J Sports Med.
587 2005;39(10):757–766. doi:10.1136/bjsm.2005.018135
588
589 2. England Rugby. England Rugby professional injury surveillance project season
590 report 2022–23. 2023. Available at: https://rfu.widen.net/s/9jjsz8xskn/prisp-22-23-
591 report
592
593 3. West SW, Starling L, Kemp S, Williams S, Cross M, Taylor A, Brooks JHM,
594 Stokes KA. Trends in match injury risk in professional male rugby union: a 16-
595 season review of 10 851 match injuries in the English Premiership (2002–2019):
596 the Professional Rugby Injury Surveillance Project. Br J Sports Med.
597 2021;55(12):676–682. doi:10.1136/bjsports-2020-102529
598
599 4. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Epidemiology of injuries in English
600 professional rugby union: part 2 training injuries. Br J Sports Med.
601 2005;39(10):767–775. doi:10.1136/bjsm.2005.018408
602
603 5. Williams S, Trewartha G, Kemp SP, Brooks JH, Fuller CW, Taylor AE, Cross MJ,
604 Stokes KA. Time-loss injuries compromise team success in elite rugby union: a 7-
605 year prospective study. Br J Sports Med. 2016;50(11):651–656.
606 doi:10.1136/bjsports-2015-094798
607
608 6. Tee JC, Lambert MI, Coopoo Y. GPS comparison of training activities and game
609 demands of professional rugby union. Int J Sports Sci Coach. 2016;11(2):200–
610 211. doi:10.1177/1747954116637153
611
612 7. Wild JJ, Bezodis IN, North JS, Bezodis NE. Enhancing the initial acceleration
613 performance of elite rugby backs. Part II: insights from multiple longitudinal
614 individual-specific case-study interventions. Int J Sports Physiol Perform.
615 2023;18(9):1019–1029. doi:10.1123/ijspp.2023-0091
616
617 8. Enoka RM, Duchateau J. Muscle fatigue: what, why and how it influences muscle
618 function. J Physiol. 2008;586(1):11–23. doi:10.1113/jphysiol.2007.139477
619
620 9. Wild JJ, Bezodis IN, North JS, Bezodis NE. Characterising initial sprint
621 acceleration strategies using a whole-body kinematics approach. J Sports Sci.
622 2022;40(2):203–214. doi:10.1080/02640414.2021.1985759
623
624 10. Debaere S, Delecluse C, Aerenhouts D, Hagman F, Jonkers I. Control of
625 propulsion and body lift during the first two stances of sprint running: a simulation
626 study. J Sports Sci. 2015;33(19):2016–2024.
627 doi:10.1080/02640414.2015.1026375
628

11. Pandy MG, Lai AKM, Schache AG, Lin YC. How muscles maximize performance in accelerated sprinting. Scand J Med Sci Sports. 2021;31(10):1882–1896. doi:10.1111/sms.14021

12. Nagahara R, Takai Y, Kanehisa H, Fukunaga T. Vertical impulse as a determinant of the combination of step length and frequency during sprinting. Int J Sports Med. 2018. doi:10.1055/s-0043-122739

13. Dorn TW, Schache AG, Pandy MG. Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance. J Exp Biol. 2012;215(Pt 11):1944–1956. doi:10.1242/jeb.064527

14. Lenhart R, Thelen D, Heiderscheit B. Hip muscle loads during running at various step rates. J Orthop Sports Phys Ther. 2014;44(10):766–774. doi:10.2519/jospt.2014.5575

15. Willer J, Allen SJ, Burden RJ, Folland JP. How humans run faster: the neuromechanical contributions of functional muscle groups to running at different speeds. Scand J Med Sci Sports. 2024;34(8):e14690. doi:10.1111/sms.14690

16. Fuller CW, Molloy MG, Bagate C, et al. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. Br J Sports Med. 2007;41(5):328–331. doi:10.1136/bjsm.2006.033282

17. Rae K, Orchard J. The Orchard Sports Injury Classification System (OSICS) version 10. Clin J Sport Med. 2007;17(3):201–204. doi:10.1097/JSM.0b013e318059b536

18. Bahr R, Clarsen B, Derman W, et al. International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sports 2020 (STROBE-SIIS). Orthop J Sports Med. 2020;8(2):2325967120902908. doi:10.1177/2325967120902908

19. Hof AL. Scaling gait data to body size. Gait Posture. 1996;4(3):222–223. doi:10.1016/0966-6362(95)01057-2

20. Ruddy JD, Cormack SJ, Whiteley R, Williams MD, Timmins RG, Opar DA. Modeling the risk of team sport injuries: a narrative review of different statistical approaches. Front Physiol. 2019;10:829. doi:10.3389/fphys.2019.00829

21. Hopkins WG, Marshall SW, Quarrie KL, Hume PA. Risk factors and risk statistics for sports injuries. Clin J Sport Med. 2007;17(3):208–210. doi:10.1097/JSM.0b013e3180592a68

673 22. Rothman KJ. Epidemiology: an introduction to measures of effect. In: Rothman
674 KJ, Greenland S, Lash TL, eds. Modern Epidemiology. 3rd ed. Philadelphia, PA:
675 Lippincott Williams & Wilkins; 2008:51–70.
676
677 23. Birchall M, Drummond A, Williams MN. Antecedents of bullying victimisation in
678 adolescents: a fresh look at Aotearoa New Zealand. Kōtuitui. 2025;20(4):528–
679 541. doi:10.1080/1177083X.2024.2385427
680
681 24. Mansournia MA, Collins GS, Nielsen RO, et al. A checklist for statistical
682 assessment of medical papers (the CHAMP statement): explanation and
683 elaboration. Br J Sports Med. 2021;55(18):1009–1017. doi:10.1136/bjsports-
684 2020-103652
685
686 25. Kenneally-Dabrowski C, Serpell BG, Spratford W, et al. A retrospective analysis
687 of hamstring injuries in elite rugby athletes: more severe injuries are likely to
688 occur at the distal myofascial junction. Phys Ther Sport. 2019;38:192–198.
689 doi:10.1016/j.ptsp.2019.05.009
690
691 26. Bourne MN, Opar DA, Williams MD, Shield AJ. Eccentric knee flexor strength and
692 risk of hamstring injuries in rugby union: a prospective study. Am J Sports Med.
693 2015;43(11):2663–2670. doi:10.1177/0363546515599633
694
695 27. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Incidence, risk, and prevention of
696 hamstring muscle injuries in professional rugby union. Am J Sports Med.
697 2006;34(8):1297–1306. doi:10.1177/0363546505286022
698
699 28. Le VT, Kikuchi Y, Takabayashi T, et al. Kinematics and activation of hamstring
700 muscles during the initial acceleration phase of sprinting in soccer players: a
701 biomechanical investigation. J Sci Sport Exerc. 2024. doi:10.1007/s42978-024-
702 00292-x
703
704 29. Kenneally-Dabrowski C, Brown NAT, Warmenhoven J, et al. Late swing running
705 mechanics influence hamstring injury susceptibility in elite rugby athletes: a
706 prospective exploratory analysis. J Biomech. 2019;92:112–119.
707 doi:10.1016/j.jbiomech.2019.05.037
708
709 30. Higashihara A, Nagano Y, Takahashi K, Fukubayashi T. Effects of forward trunk
710 lean on hamstring muscle kinematics during sprinting. J Sports Sci.
711 2015;33(13):1366–1375. doi:10.1080/02640414.2014.990483
712
713 31. Astrella A, Iordanov D, De Caro D, et al. Biceps femoris muscle-tendon strain
714 during an entire overground sprint acceleration: a biomechanical explanation for
715 hamstring injuries in the acceleration phase. Sports Biomech. 2025;24(6):1725–
716 1738. doi:10.1080/14763141.2024.2353233
717

718 32. Adam NC, Smith CR, Herzog W, et al. In vivo strain patterns in the Achilles
719 tendon during dynamic activities: a comprehensive survey of the literature. Sports
720 Med Open. 2023;9(1):60. doi:10.1186/s40798-023-00604-5
721
722 33. Devaprakash D, Graham DF, Barrett RS, et al. Free Achilles tendon strain during
723 selected rehabilitation, locomotor, jumping, and landing tasks. J Appl Physiol
724 (1985). 2022;132(4):956–965. doi:10.1152/japplphysiol.00662.2021
725
726 34. Cardoso TB, Pizzari T, Kinsella R, Hope D, Cook JL. Current trends in
727 tendinopathy management. Best Pract Res Clin Rheumatol. 2019;33(1):122–140.
728 doi:10.1016/j.berh.2019.02.001
729
730 35. Hunter J, Marshall R, McNair P. Relationships between ground reaction force
731 impulse and kinematics of sprint-running acceleration. J Appl Biomech.
732 2005;21(1):31–43.
733
734 36. Wing C, Bishop C. Hamstring strain injuries: incidence, mechanisms, risk factors,
735 and training recommendations. Strength Cond J. 2020;42(3):40–57.
736
737 37. Mendiguchia J, Castaño-Zambudio A, Jiménez-Reyes P, et al. Can we modify
738 maximal speed running posture? Implications for performance and hamstring
739 injury management. Int J Sports Physiol Perform. 2022;17(3):374–383.
740 doi:10.1123/ijspp.2021-0107
741
742 38. Hoenig T, Gronwald T, Hollander K, et al. Video analysis of Achilles tendon
743 ruptures in professional male football reveals underlying injury patterns and
744 provides strategies for injury prevention. Knee Surg Sports Traumatol Arthrosc.
745 2023;31(6):2236–2245. doi:10.1007/s00167-023-07384-1
746
747 39. Ardigò LP, Lafortuna C, Minetti AE, Mognoni P, Saibene F. Metabolic and
748 mechanical aspects of foot landing type, forefoot and rearfoot strike, in human
749 running. Acta Physiol Scand. 1995;155(1):17–22. doi:10.1111/j.1748-
750 1716.1995.tb09943.x
751
752 40. Lai A, Schache AG, Brown NAT, Pandy MG. Human ankle plantar flexor muscle-
753 tendon mechanics and energetics during maximum acceleration sprinting. J R
754 Soc Interface. 2016;13(121):20160391. doi:10.1098/rsif.2016.0391
755
756 41. Chavarro-Nieto C, Beaven M, Gill N, Hébert-Losier K. Hamstrings injury
757 incidence, risk factors, and prevention in rugby union players: a systematic
758 review. Phys Sportsmed. 2023;51(1):1–19. doi:10.1080/00913847.2021.1992601

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Tables

Table 1. Details of player inclusion and characteristics of those included in the study

Inclusion/exclusion								
Season		1	2	3	4	5	6	7
Players eligible for inclusion (n)		49	52	56	49	55	50	54
Exclusions made	< 1 season's observation[a]	-	1	-	-	-	-	-
	Insufficient WBS testing[b]	22	19	25	8	7	2	-
	Change in WBS[c]	-	-	1	1	2	1	-
Players included in final analysis								
Players per season (n)		27	32	30	40	46	47	54
Number of players each season according to their year of observation	1st	27	6	8	15	10	6	13
	2nd	-	26	6	8	14	10	6
	3rd	-	-	16	6	7	12	9
	4th	-	-	-	11	5	6	9
	5th	-	-	-	-	10	3	6
	6th	-	-	-	-	-	10	4
	7th	-	-	-	-	-	-	7
Total exposure (hours)		6685	7883	7063	9749	10923	9666	11817

Player characteristics

Total (n)	**Backs / forwards (%)**	**Age (years) (mean ± SD)**	**Total exposure (hours) (mean ± SD)**
85	64 / 36	24.9 ± 3.9	753 ± 465

WBS = whole-body sprint acceleration strategy

Players were excluded from the final analysis if [a]they completed less than one complete season due to early contract release; [b]their WBS was assessed less than three times in each season; [c]their WBS changed to another strategy during their observation period. Age represents the average of players' mean age across their respective observation period.

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Table 2. Non-contact linear running-based injury measures per lower limb site

Injury site	Total / index injuries (n)	Incidence (95% CI)	Median injury severity (Q1-Q3)	Burden (95% CI)
A. Hip/groin	22 / 17	0.34 (0.22 - 0.52)$^{C, E, F}$	8.5 (4.5 – 20.0)	5.4 (4.9 – 6.0)$^{C, E, F}$
B. Hamstring	42 / 29	0.66 (0.47 – 0.89)$^{A, C, E, F}$	18.0 (4.0 – 43.0)	17.4 (16.4 - 18.5)$^{A, C, E, F}$
C. Knee	3 / 3	0.05 (0.01 - 0.14)	42.0 (2.0 - 63.0)†	1.7 (1.4 – 2.0)
D. Calf	48 / 25	0.75 (0.55 - 0.99)$^{A, C, E, F}$	14.5 (5.3 – 30.0)	17.0 (16.0 – 18.1)$^{A, C, E, F}$
E. Ankle	3 / 3	0.05 (0.01 - 0.14)	46.0 (2.0 - 66.0)†	1.8 (1.5 – 2.1)
F. Foot	5 / 5	0.08 (0.03 - 0.18)	41.0 (14.0 – 100.0)	4.2 (3.7 – 4.7)

Superscript capital letters next to incidence and burden indicate that these measures are significantly greater (based on non-overlapping 95% confidence intervals) for the corresponding injury site compared to other sites. The capital letters align with the injury site listed in the "Injury Site" column.

†numbers in brackets represent the minimum and maximum values rather than Q1-Q3 since only three injuries for each of these sites occurred.

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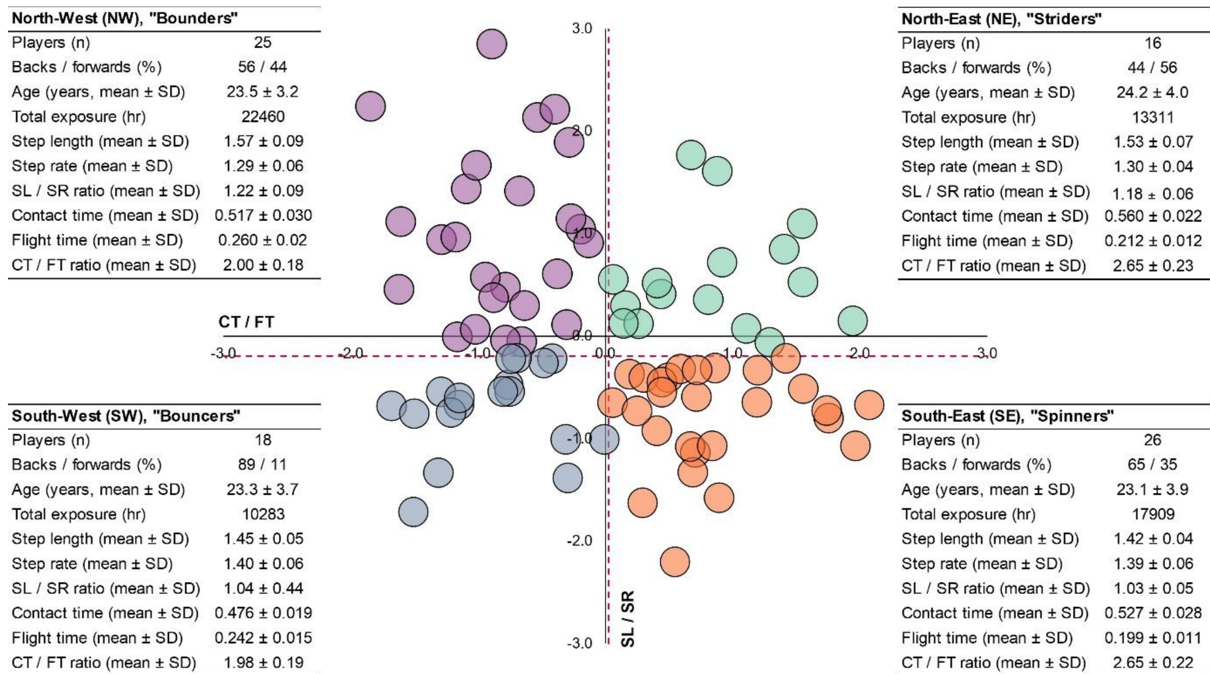
Figures



North-West (NW), "Bounders"	
Players (n)	25
Backs / forwards (%)	56 / 44
Age (years, mean ± SD)	23.5 ± 3.2
Total exposure (hr)	22460
Step length (mean ± SD)	1.57 ± 0.09
Step rate (mean ± SD)	1.29 ± 0.06
SL / SR ratio (mean ± SD)	1.22 ± 0.09
Contact time (mean ± SD)	0.517 ± 0.030
Flight time (mean ± SD)	0.260 ± 0.02
CT / FT ratio (mean ± SD)	2.00 ± 0.18

North-East (NE), "Striders"	
Players (n)	16
Backs / forwards (%)	44 / 56
Age (years, mean ± SD)	24.2 ± 4.0
Total exposure (hr)	13311
Step length (mean ± SD)	1.53 ± 0.07
Step rate (mean ± SD)	1.30 ± 0.04
SL / SR ratio (mean ± SD)	1.18 ± 0.06
Contact time (mean ± SD)	0.560 ± 0.022
Flight time (mean ± SD)	0.212 ± 0.012
CT / FT ratio (mean ± SD)	2.65 ± 0.23

South-West (SW), "Bouncers"	
Players (n)	18
Backs / forwards (%)	89 / 11
Age (years, mean ± SD)	23.3 ± 3.7
Total exposure (hr)	10283
Step length (mean ± SD)	1.45 ± 0.05
Step rate (mean ± SD)	1.40 ± 0.06
SL / SR ratio (mean ± SD)	1.04 ± 0.44
Contact time (mean ± SD)	0.476 ± 0.019
Flight time (mean ± SD)	0.242 ± 0.015
CT / FT ratio (mean ± SD)	1.98 ± 0.19

South-East (SE), "Spinners"	
Players (n)	26
Backs / forwards (%)	65 / 35
Age (years, mean ± SD)	23.1 ± 3.9
Total exposure (hr)	17909
Step length (mean ± SD)	1.42 ± 0.04
Step rate (mean ± SD)	1.39 ± 0.06
SL / SR ratio (mean ± SD)	1.03 ± 0.05
Contact time (mean ± SD)	0.527 ± 0.028
Flight time (mean ± SD)	0.199 ± 0.011
CT / FT ratio (mean ± SD)	2.65 ± 0.22

Figure 1. Whole-body acceleration strategy groupings, player characteristics and exposure.

Dashed red lines depict the whole group median split of the x- and y-axes values. Age represents the average of the mean age of players within each group across the observation period. Terms used in inverted commas represent names for the different acceleration strategy groups for ease of communication in practical settings. Spatiotemporal variables in the tables are in their dimensionless form.[19] Values on the figure are Z scores for each of the step length (SL)/step rate (SR) ratios (vertical axis) and contact time (CT)/flight time (FT) ratios (horizontal axis).

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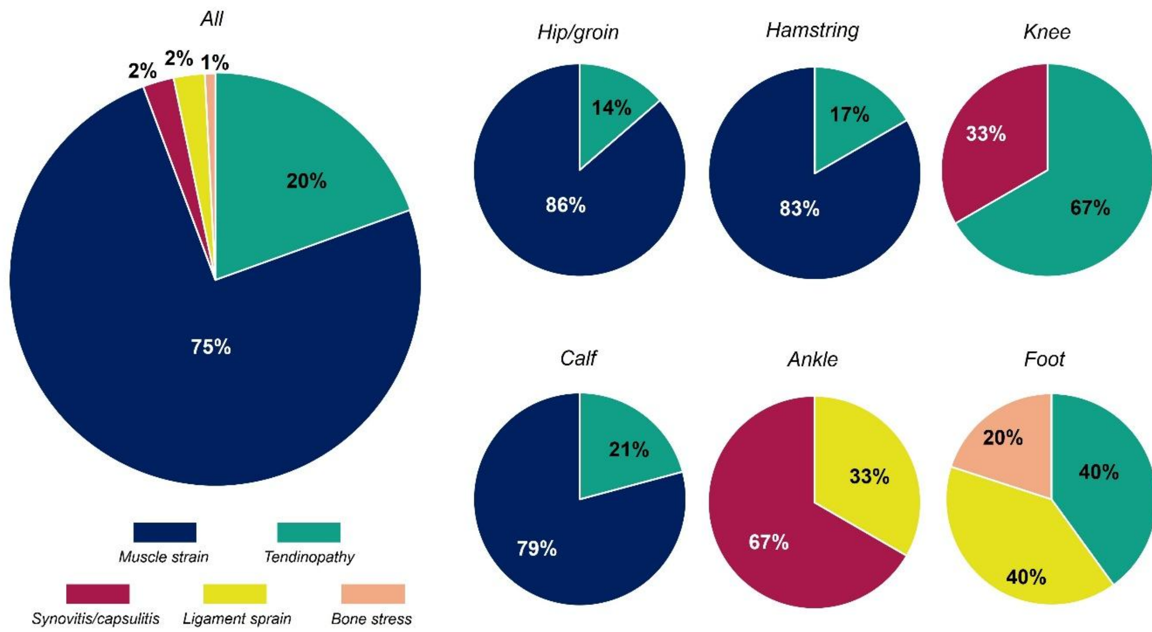

805 **Figure 2**. Distribution of lower limb injury pathology types as a percentage of all injuries

806 sustained, and per injury site across the 7-season observation period.

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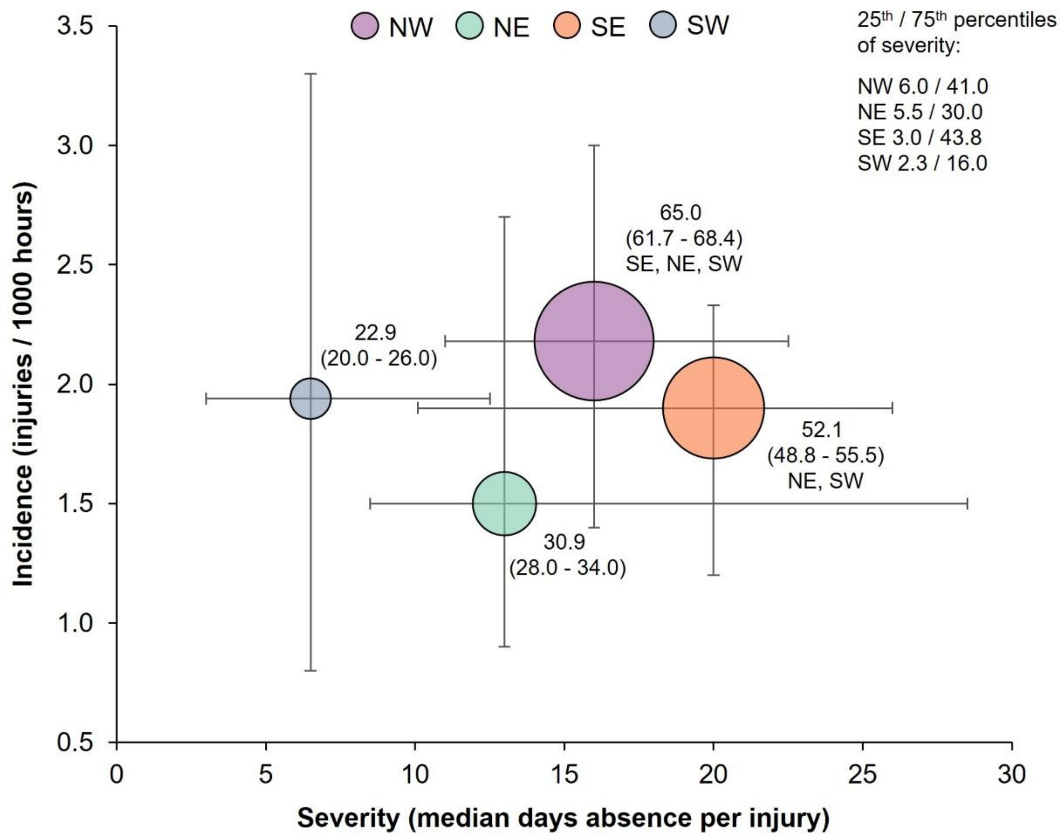

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810 **Figure 3.** Injury incidence, severity and burden by acceleration strategy.

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812 Vertical error bars represent the lower and upper bounds of the 95% Poisson confidence interval for the
813 incidence rate and horizontal error bars represent the lower and upper bounds of the bootstrapped 95%
814 confidence interval for the median severity. Data points are scaled, with larger markers representing
815 greater burden magnitude. Burden values, along with the lower and upper bounds of their 95% Poisson
816 confidence intervals, are displayed next to each data point. Stated compass bearings next to each data
817 point indicate whether the corresponding acceleration strategy imposed a significantly greater burden
818 than other strategies.

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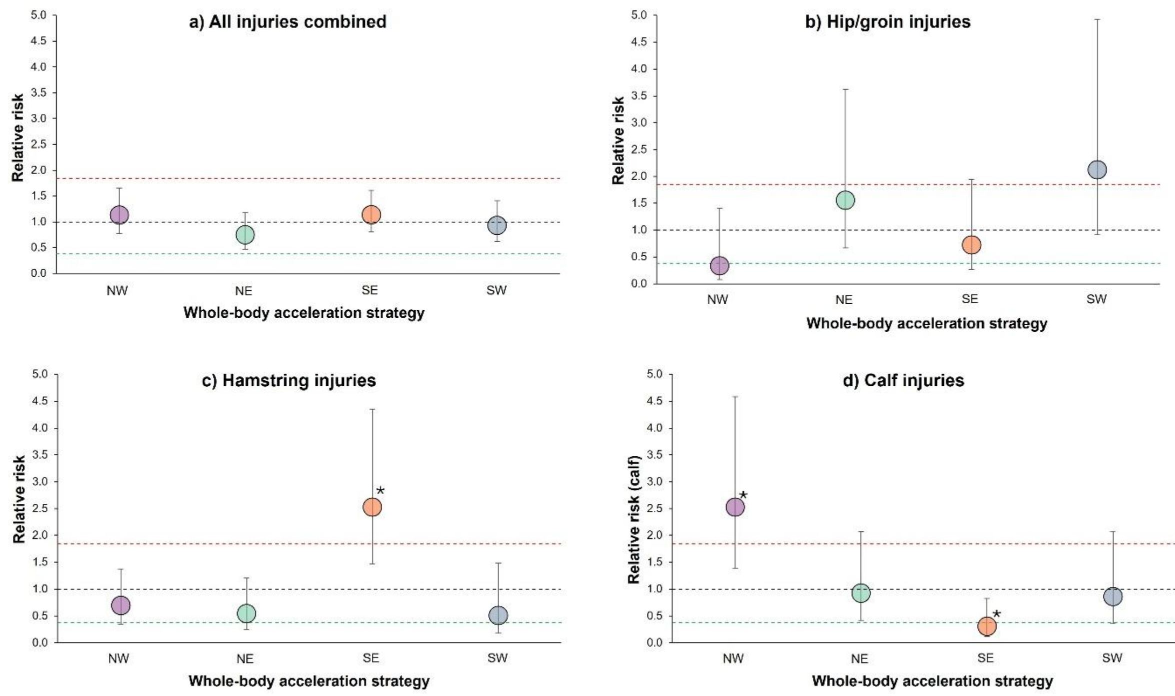

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822 **Figure 4.** Relative risk of injury across each of the four different whole-body acceleration
823 strategy groups for a) all injuries combined, b) hip/groin injuries, c) hamstring injuries and d)
824 calf injuries.

825 Asterisks denotes associations are statistically significant and the red and green dashed lines
826 represent the smallest association thresholds

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828

BOUNDERS (NW)

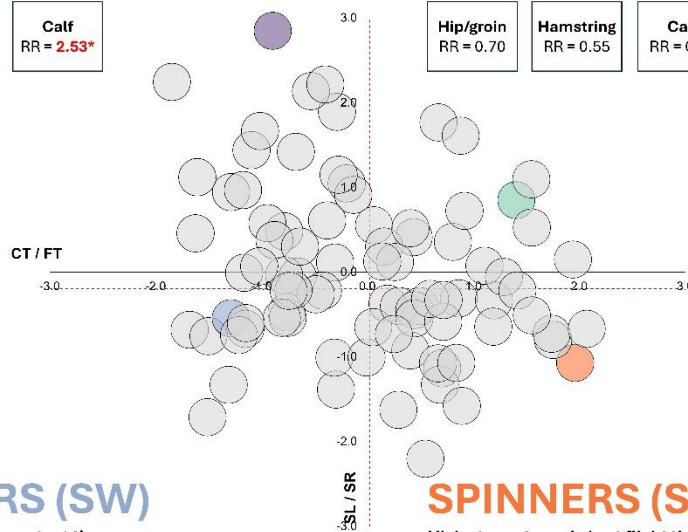
Long step length and long flight time

Hip/groin	Hamstring	Calf
RR = **0.34**	RR = 0.70	RR = **2.53***

STRIDERS (NE)

Long step length and long contact time

Hip/groin	Hamstring	Calf
RR = 0.70	RR = 0.55	RR = 0.93



BOUNCERS (SW)

High step rate and short contact time

Hip/groin	Hamstring	Calf
RR = **2.12**	RR = 0.51	RR = 0.86

SPINNERS (SE)

High step rate and short flight time

Hip/groin	Hamstring	Calf
RR = 0.72	RR = **2.53***	RR = **0.31***

829

830 **Figure 5.** Visual representation of whole-body sprint acceleration strategies and their

831 associated site-specific relative injury risks.

832 Silhouettes are from one player in each strategy group. The data points corresponding to these

833 players are highlighted in colour on the Cartesian plane, and they were selected because they all had

834 identical sprint acceleration performance. The silhouettes illustrate a single step cycle (step 3) at

835 touchdown, mid-stance, toe-off, mid-flight, and subsequent touchdown. Relative risks (RR) for

836 hip/groin, hamstring, and calf injuries are shown for each strategy group. Bold values exceed the

837 predefined smallest association threshold for increased (red front) and decreased (green) relative

838 injury risk, and asterisks indicate statistical significance.