

1 **Vertical jump testing in rugby league: a rationale for calculating**
2 **take-off momentum**

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33 **Abstract**

34 The purpose of this study was to determine the usefulness of calculating jump take-off
35 momentum in rugby league (RL), by exploring its relationship with sprint momentum, due to
36 the latter being an important attribute to this sport. Twenty-five male RL players performed
37 three maximal-effort countermovement jumps (CMJs) on a force platform and three maximal
38 effort 20 m sprints (with split times recorded). Jump take-off momentum and sprint momentum
39 (between 0-5 m, 5-10 m and 10-20 m) were calculated (mass multiplied by velocity) and their
40 relationship determined. There was a very large positive relationship between both jump take-
41 off and 0-5 m sprint momentum ($r = 0.781, p < .001$) and jump take-off and 5-10 m sprint
42 momentum ($r = 0.878, p < .001$). There was a nearly perfect positive relationship between jump
43 take-off and 10-20 m sprint momentum ($r = 0.920, p < .001$). Jump take-off and sprint
44 momentum demonstrated good-excellent reliability and very large-near perfect associations
45 (61-85% common variance) in a RL cohort, enabling prediction equations to be created. Thus,
46 it may be practically useful to calculate jump take-off momentum as part of routine CMJ testing
47 of RL players, and other collision-sport athletes, to enable indirect monitoring of sprint
48 momentum.

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51 **Keywords:** Countermovement Jump, Impulse, Sprinting, Velocity, Body Mass, Collision

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55 Introduction

56 The countermovement jump (CMJ) has been suggested to be an important test in rugby
57 league.²¹ The support for including the CMJ as part of rugby league physical testing batteries
58 is largely based on studies that have reported greater CMJ heights to be related to faster 5-, 10-
59 and 30 m sprint performances ($r = 0.56-0.62, p < .05$)⁴ and better tackling ability ($r = 0.38, p <$
60 $.05$)⁷ in high-level players. These attributes are considered important because rugby league
61 match play is comprised of many high-intensity running, collisions and tackling actions.⁸ Sprint
62 momentum (body mass \times velocity) has been suggested to be more important than sprint
63 velocity in collision-oriented sports.² These suggestions are due to research showing that
64 higher-level rugby league players attain similar sprint velocity to lower-level counterparts, but
65 greater momentum because of greater body mass.² In American footballers, however, CMJ
66 height was related to sprint velocity, but unrelated to sprint momentum, even across multiple
67 distances.¹⁰ The same authors also reported that body mass was positively correlated to sprint
68 momentum but negatively related to sprint velocity.¹⁰ This highlights that being heavier
69 impedes sprint velocity but can augment sprint momentum, with the latter being a more
70 important attribute for many collision sport athletes.² In rugby league, sprinting with greater
71 momentum should help to drive the opposition's defenders backwards and thereby facilitate
72 their own team's progression down field.²

73 Jump height attained from vertical jumping (not just the CMJ) depends on the velocity
74 with which the athlete leaves the ground (termed take-off velocity) and so, as when sprinting,
75 being heavier impedes jump take-off velocity. Indeed, any heavier athlete must push harder
76 (i.e. they must apply a larger net impulse) during the propulsion phase of a jump to attain the
77 same take-off velocity as a lighter athlete. Even if a heavier athlete does not attain the same
78 take-off velocity as a lighter athlete, they may have greater take-off momentum. Equally, a
79 heavier athlete could attain the same jump take-off momentum as a lighter athlete by producing

80 a lower take-off velocity (i.e. not jumping as high), providing that their mass is sufficiently
81 greater. For example, an athlete who weighs 110 kg and jumps 0.30 m would take-off with an
82 almost identical momentum to an athlete who weighs 90 kg and jumps 0.45 m (i.e. 267 kg·m/s).
83 It is important to note that change in momentum is equal to net impulse, thus the example
84 momentum values presented above would be identical to the jump propulsion net impulse
85 applied, although the unit of measurement is different (i.e. 267 Ns).

86 Given that the heavier body mass of collision sport athletes may be considered an asset,
87 it may be prudent to include body mass in rugby league players' CMJ metrics. This is
88 something that jump take-off momentum does but jump height and take-off velocity do not.
89 Unfortunately, in most previous rugby league studies, researchers have assessed CMJ
90 performance via field-based methods and reported jump height alone, although it has been
91 recommended recently that CMJ testing of this cohort should ideally be performed using a
92 force platform.^{15, 22} A shift towards testing rugby league player CMJ performance on force
93 platforms has been noted in more recently published studies, although the reported metrics
94 have still been biased towards lighter athletes/tasks that require acceleration of the athlete's
95 body mass alone.^{16, 18} Because force platform assessment of CMJs is being more routinely
96 conducted in rugby league, propulsion net impulse (and, therefore, take-off momentum) can be
97 readily calculated. The CMJ propulsion net impulse attained by rugby league players has,
98 indeed, been reported by McMahon et al.¹⁸ and was shown to be much larger for senior players
99 ($d = 1.56$) than for academy players owing to the heavier body mass of the former. However,
100 no researchers, to the authors' knowledge, have explored and reported the relationship between
101 CMJ propulsion net impulse/take-off momentum and sprint momentum in any athletic cohort,
102 not least rugby league players.

103 The purpose of this study was to explore the efficacy of calculating the CMJ propulsion
104 net impulse/take-off momentum from rugby league players by exploring its relationship with

105 sprint momentum across multiple distances. Based on previous research that showed the CMJ
106 height (which is determined by take-off velocity) of collision-sport athletes to be positively
107 associated with sprint velocity but unrelated to sprint momentum,¹⁰ it was hypothesized that
108 jump take-off momentum would be positively related to sprint momentum as body mass is
109 included in its calculation. As sprint momentum is considered to be important to rugby league
110 match performance,² identifying positive associations with jump take-off momentum would be
111 of interest to rugby league practitioners and researchers alike and provide a rationale for its
112 inclusion in vertical jump testing batteries. Despite jump take-off momentum being identical
113 to jump propulsion net impulse, it could be argued that momentum is a more widely understood
114 term among athletes and coaches within collision-sports. Therefore, if positive results emerge
115 from this study, it would be worthwhile adopting the former term (take-off momentum) going
116 forward to promote clearer understanding when reporting CMJ performance data to rugby
117 league athletes and coaches which could facilitate practitioners maximizing the use of their
118 CMJ force platform data.

119

120 **Methods**

121

122 Twenty-five rugby league players (age = 24.8 ± 3.1 years, height = 1.86 ± 0.06 m, body
123 mass = 98.1 ± 10.0 kg) who, at the time of testing, were competing in the English Rugby League
124 Championship agreed to participate in this study. Fourteen of the subjects regularly competed
125 in the global ‘forwards’ positional group (age = 25.8 ± 3.3 years, height = 1.85 ± 0.05 m, body
126 mass = 101.9 ± 10.4 kg) with the remainder regularly competing in the global ‘backs’ positional
127 group (age = 23.9 ± 2.8 years, height = 1.86 ± 0.07 m, body mass = 94.8 ± 8.6 kg). All subjects
128 were free from injury and engaged in a full-time strength and conditioning programme at the

129 time of testing (the start of the pre-season). Written informed consent was provided prior to
130 testing, the study was pre-approved by the institutional review board and conformed to the
131 World Medical Association's Declaration of Helsinki.

132

133 A within-session repeated measures design was adopted in this study, whereby subjects
134 performed multiple CMJs on a force platform and multiple 20 m sprints (with 5, 10 and 20 m
135 split times recorded) on an indoor running track, enabling jump take-off momentum and sprint
136 momentum to be calculated and their relationship to be determined.

137

138 Following a brief (~10 minutes) warm-up comprised of dynamic stretching and sub-
139 maximal jumping (5×1 sets of single effort and 2×5 repeated CMJs), subjects performed three
140 recorded maximal effort CMJs to their preferred countermovement depth, each interspersed by
141 ~1 minute.¹¹ The jumps were performed with the subjects instructed to “jump as fast and as
142 high as possible”, whilst keeping hands on hips.

143 Ground reaction forces during the maximal effort CMJs were sampled at 1000 Hz using
144 a Kistler type 9286AA force platform and Bioware 5.11 software (Kistler Instruments Inc.,
145 Amherst, NY, USA). Subjects stood still for the first second of data collection^{19, 20} to enable
146 body weight (N, calculated as vertical force averaged over 1 s) and body mass (kg, calculated
147 as body weight divided by gravitational acceleration) to be subsequently calculated. Raw
148 vertical force-time data were exported as text files and analyzed using a customized Microsoft
149 Excel spreadsheet (version 2016, Microsoft Corp., Redmond, WA, USA).

150 Center of mass velocity was determined by dividing net force by body mass on a
151 sample-by-sample basis and then integrating the product using the trapezoid rule.¹⁹ The instant
152 of take-off was identified when force fell below a threshold equal to five times the standard

153 deviation of the flight phase force.^{13, 14} The standard deviation of the flight phase force was
154 calculated across the middle 50% of the flight phase duration (i.e., force during the mid-portion
155 of when the force platform was unloaded and the subjects were airborne).^{13, 14} Take-off velocity
156 was calculated as the center of mass velocity at the instant of take-off. Jump take-off
157 momentum was calculated by multiplying take-off velocity by the subject's body mass. The
158 authors would like to note that this method of calculating jump take-off momentum yielded
159 identical values to the propulsion net impulse attained based on the impulse-momentum
160 relation.

161 Approximately five minutes after completing the CMJs, two 20 m practice sprints at 50
162 and 75% of perceived maximum intensity were performed followed by three maximum effort
163 trials of the 20 m sprint, interspersed by two minutes of rest.^{3, 5, 17} Subjects initiated the sprint
164 from a stationary two point, split start³ and were instructed to sprint as fast as possible through
165 the full 20 m course marked out on the running track. Any sprint trials that were initiated with
166 a countermovement or included deceleration before completing the 20 m course were discarded
167 and supplementary sprint trials were recorded after two minutes of rest.

168 Brower single-photocell electronic timing gates (ETGs) (Draper, Utah, USA) were
169 placed at 0-, 5-, 10-, and 20 m increments along an indoor running track, with each emitter and
170 reflector spaced 2 m apart⁶ at approximately hip height.²³ Specifically, the average hip height
171 (taken as the highest point of the iliac crest when in a standing position) of the subjects was
172 used to set the timing gate height (~1 m) and this was not adjusted for the smallest or tallest
173 subjects tested.¹⁷ Although the initial pair of ETGs were placed at 0 m, the subjects started 0.3
174 m behind this point in line with previous recommendations.¹

175 Sprint times for each distance (5-, 10-, and 20 m) and trial were automatically recorded
176 via a handheld computer and manually entered into a Microsoft Excel spreadsheet (version

177 2016, Microsoft Corp., Redmond, WA, USA) for further analysis. The 5-10 m and 10-20 m
178 split times for each trial were calculated by subtracting the 10 m time from the 5 time and the
179 20 m time from the 10 m time, respectively. Momentum was then calculated by firstly
180 calculating the average velocity (horizontal displacement divided by time) between each timing
181 gate (e.g. between 0-5 m, 5-10 m and 10-20 m) and then multiplying this by the subject's body
182 mass.²

183 A two-way mixed-effects model (average measures) intraclass correlation coefficient
184 (ICC), along with the upper and lower 95% confidence interval (CI₉₅), was used to determine
185 the relative between-trial reliability of each variable. Based on the CI₉₅ of the ICC estimate,
186 values between 0.75 and 0.90 and greater than 0.90 were indicative of good and excellent
187 relative reliability, respectively.¹² Absolute between-trial reliability of each variable was
188 calculated using the coefficient of variation percentage (CV%, calculated in this study as the
189 standard deviation divided by the mean which was then expressed as a percentage), along with
190 the upper and lower CI₉₅. A CV of $\leq 10\%$ and $\leq 5\%$ (based on the CI₉₅ of the CV% estimate)
191 was considered to represent good and excellent reliability, respectively.¹⁶

192 All momentum calculations met parametric assumptions, therefore, relationships
193 between sprint momentum (at all distances) and jump take-off momentum were explored using
194 the Pearson correlation coefficient and CI₉₅ via SPSS software (version 25; SPSS Inc., Chicago,
195 IL, USA) with the alpha level set at $p \leq .05$. Correlation coefficients were interpreted as very
196 large (0.7-0.9) and nearly perfect (0.9-1.0).⁹ Linear regression equations were subsequently
197 produced to enable the prediction of sprint momentum (for each distance) from jump take-off
198 momentum in future work and in applied practice.

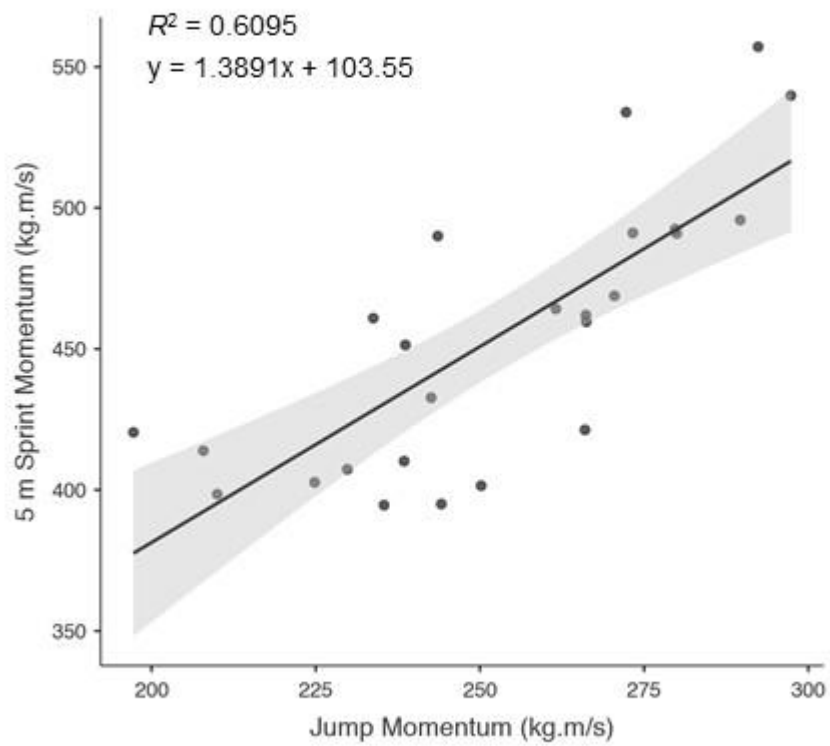
199

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201 **Results**

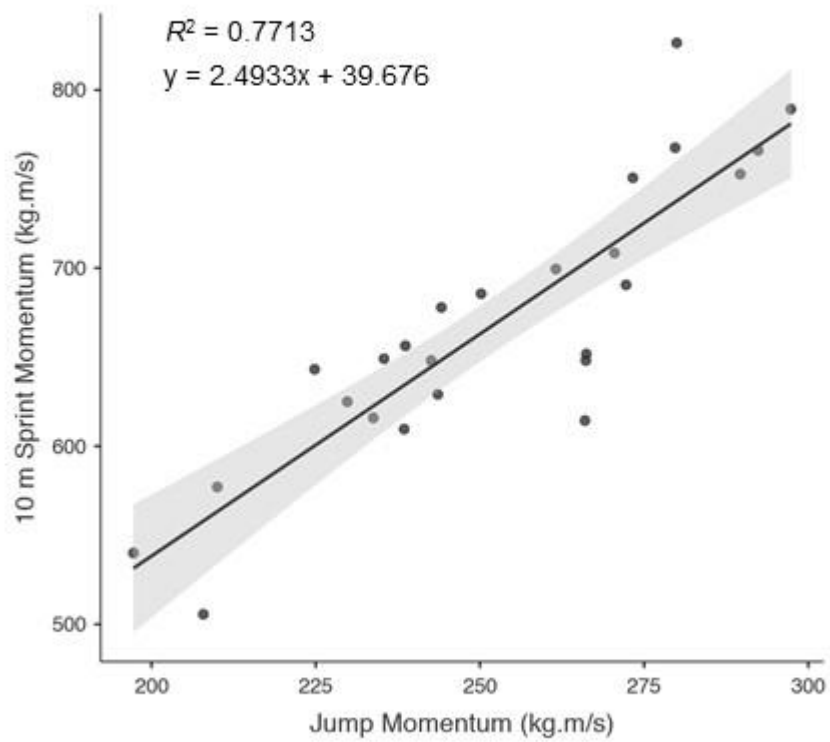
202 The jump take-off momentum (ICC = 0.988 [CI₉₅ = 0.977-0.994], CV% 1.7 [CI₉₅ = 1.3-
203 2.2]) 0-5 m sprint momentum (ICC = 0.953 [CI₉₅ = 0.908-0.977], CV% 2.7 [CI₉₅ = 1.5-3.8]),
204 and 5-10 m sprint momentum (ICC = 0.964 [CI₉₅ = 0.930-0.983], CV% 3.0 [CI₉₅ = 2.1-3.9])
205 demonstrated excellent reliability. The 10-20 m sprint momentum demonstrated good-
206 excellent reliability (ICC = 0.897 [CI₉₅ = 0.795-0.952], CV% 4.0 [CI₉₅ = 2.6-5.3]).

207 There was a very large positive relationship between both jump take-off and 0-5 m
208 sprint momentum ($r = 0.781, p < .001$) and jump take-off and 5-10 m sprint momentum ($r =$
209 $0.878, p < .001$). There was a nearly perfect positive relationship between jump take-off and
210 10-20 m sprint momentum ($r = 0.920, p < .001$). The scatter plots that illustrate these
211 associations, including the corresponding CI₉₅, coefficient of determination (R^2), and linear
212 regression equation, are presented in Figures 1-3.



213

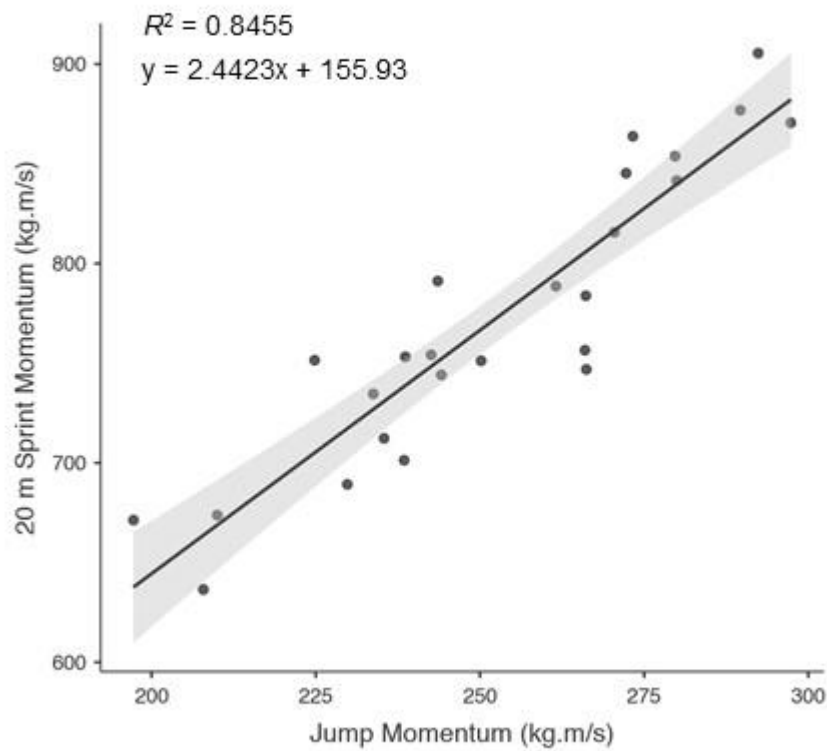
214 **Figure 1:** Relationship between jump take-off momentum and 0-5 m sprint momentum. The
215 grey shaded area represents the 95% confidence interval.



216

217 **Figure 2:** Relationship between jump take-off momentum and 5-10 m sprint momentum. The
218 grey shaded area represents the 95% confidence interval.

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220

221 **Figure 3:** Relationship between jump take-off momentum and 10-20 m sprint momentum. The
222 grey shaded area represents the 95% confidence interval.

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224

225

226 Discussion

227 The purpose of this study was to explore the efficacy of calculating the jump take-off
228 momentum (via CMJ testing) of rugby league players by exploring its relationship with sprint
229 momentum across multiple distances (0-5 m, 5-10 m and 10-20 m). The results of this study
230 show that jump take-off momentum is positively correlated with sprint momentum, as shown
231 by the very large-nearly perfect correlation coefficients, with the strength of the relationship
232 being largest with longer sprint distances (Figures 1-3). These high associations enabled
233 prediction equations to be produced. The hypothesis of the study was, therefore, accepted.

234 This is the first study, to the authors' knowledge, to explore relationships between jump
235 take-off momentum and sprint momentum in any collision sport athletes. The strength of the
236 relationships shown in Figures 1-3, illustrate that 61-85% of the variance in 5-20 m sprint
237 momentum can be explained by jump take-off momentum. The magnitude of these
238 relationships is much larger than those reported for the CMJ height and 5-30 m sprint velocities
239 (~32-38% common variance) attained by rugby league athletes.⁴ As explained earlier,
240 possessing a larger body mass will impede jump height and sprint velocity attainment. Indeed,
241 a previous study involving American footballers, who, like rugby league players, present with
242 a large range of body masses, reported body mass to be negatively related to sprint velocity.¹⁰
243 Thus, the much lower relationships between jump height and sprint velocity reported for a
244 sample of rugby league players of varying body masses⁴ is unsurprising. However, momentum
245 is the product of velocity and body mass and so the very large to nearly perfect associations
246 between the jump take-off and sprint momentum are likely due to body mass being accounted
247 for by momentum. The previously discussed study involving American footballers also
248 reported that body mass alone was positively correlated to sprint momentum.¹⁰ However, the
249 finding that jump take-off momentum became a stronger correlate of sprint momentum at

250 longer sprint distances illustrates the positive influence of being able to sprint at a higher
251 velocity on the associations reported in the present study (Figures 1-3).

252 The rationale for exploring the efficacy of calculating the jump take-off momentum of
253 rugby league players by exploring its relationship with sprint momentum is due to the former
254 already being established as an important attribute in collision-oriented sports.² As there were
255 such high associations between the two momentum variables (Figures 1-3), it is reasonable to
256 state that calculating jump take-off momentum, following a CMJ test, provides insight into
257 rugby players' sprint momentum capabilities. Therefore, even though the CMJ is not a
258 movement that is readily performed in rugby league or in other collision sports, jump take-off
259 momentum appears to be a valuable metric that would likely be of interest to rugby league
260 researchers and practitioners due to its ability to indirectly inform sprint momentum. It is also
261 very useful to learn that jump take-off momentum yielded a very low typical error between
262 trials (CV% 1.7 [CI₉₅ = 1.3-2.2]), meaning that it should demonstrate suitable sensitivity to
263 change with respect to rugby league training. This, of course, needs to be verified by future
264 research. For example, future research into the test-retest reliability of the jump take-off
265 momentum of rugby league players is encouraged to inform the typical error of this metric
266 between days. Work is also required to determine whether training induced changes in both
267 jump and sprint momentum are related, as we explored these associations in a cross-sectional
268 manner alone.

269 Anecdotally, sprint testing is less likely to be performed early in the rugby league
270 preseason due to perceived potential risk of injury which may be associated with detraining
271 over the off-season. It may be possible, therefore, that jump take-off momentum could be
272 calculated during early preseason instead, due to it posing a reduced injury risk, and used to
273 indirectly inform the sprint momentum capability of players via the prediction equations
274 presented in Figures 1-3. It is also not essential for researchers and practitioners to have access

275 to the force platform, as jump take-off momentum can be estimated from CMJ height values
276 that have been recorded via alternative means, such as from mobile phone applications, contact
277 mats or optoelectronic systems, by calculating the square root of jump height (in meters)
278 multiplied by 19.62 (which represents two times gravitational acceleration) and then
279 multiplying this answer by body mass. For example, if an athlete's body mass is 90 kg and they
280 jump 0.42 m their take-off momentum is 258 kg·m/s. It is important to note, however, that
281 athletes should be coached to avoid tucking their legs during flight when assessing the CMJ
282 via alternative means, otherwise the estimated jump height, and, therefore, take-off momentum,
283 will be inaccurate. Based on the above example of an athlete attaining a jump take-off
284 momentum of 258 kg·m/s, their predicted sprint momentum over 0-5 m, 5-10 m and 10-20 m
285 is 462 kg·m/s, 683 kg·m/s and 786 kg·m/s, respectively.

286 We would like to emphasize that being able to accelerate body mass alone is still an
287 important attribute in rugby league.² For example, a higher absolute sprint velocity is required
288 to beat an opponent to the ball or to accelerate away from them when carrying the ball. We
289 merely suggest that jump take-off momentum may be of interest to rugby league (and other
290 collision sports) researchers and practitioners for the reasons discussed above and do not want
291 to devalue the importance of absolute sprint velocity. Based on the results of this study, the
292 potential utility of calculating the jump take-off momentum of collision sport athletes, with
293 respect to within-athlete monitoring and talent identification, is promising but does require the
294 research avenues mentioned earlier to be explored fully.

295 In conclusion, jump take-off and sprint momentum (calculated between 0-5 m, 5-10 m
296 and 10-20 m) demonstrated good-excellent reliability and very large-near perfect associations
297 ($r = 0.781-0.920$, $P < 0.001$) in a rugby league cohort. It seems, therefore, to be efficacious to
298 calculate jump take-off momentum as part of routine CMJ testing of rugby league players.
299 Sprint momentum is deemed to be an important attribute within rugby league as it should

300 facilitate a backwards drive of the opposition's defenders thus facilitating a team's progression
301 down field.² The calculation of jump take-off momentum following routine CMJ testing of
302 rugby league players is, therefore, recommended because it could enable prediction of sprint
303 momentum (see equations in Figures 1-3) without the potential risks associated with maximum
304 sprint testing, particularly at the beginning of new seasons.

305

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