

TITLE

Eccentric knee flexor strength profiles of 341 elite male academy and senior Gaelic football players: Do body mass and previous hamstring injury impact performance?

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1 **Eccentric knee flexor strength profiles of 341 elite male academy and senior Gaelic**
2 **football players: do body mass and previous hamstring injury impact performance?**

3

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15

16 **Abstract**

17 **Objective**

18 Report eccentric knee flexor strength values of elite Gaelic football players from underage to
19 adult level whilst examining the influence of body mass and previous hamstring injury.

20 **Design**

21 Cross-sectional study.

22 **Setting**

23 Team's training facility.

24 **Participants**

25 Elite Gaelic football players (n=341) from under 14 years to senior age-grades were recruited
26 from twelve teams.

27 **Main Outcome Measures**

28 Absolute (N) and relative ($N \cdot kg^{-1}$) eccentric hamstring strength as well as corresponding
29 between-limb imbalances (%) were calculated for all players.

30 **Results**

31 Mean maximum force was 329.4N (95% CI 319.5 – 340.2) per limb. No statistically
32 significant differences were observed in relative force values ($4.4 N \cdot kg^{-1}$, 4.2 – 4.5) between
33 age-groups. **Body mass had moderate-to-large and weak associations with maximum
34 force in youth ($r=.597$) and adult ($r=.159$) players, respectively.** Overall 40% (95 CI 31.4
35 – 48.7) presented with a maximum strength between-limb imbalance >10%. Players with a
36 hamstring injury had greater relative maximum force (9.3%, 95% CI 7.0 – 11.8; $p>0.05$) and
37 a 28% (95% CI 10.0 – 38.0) higher prevalence of between-limb imbalances $\geq 15\%$ compared
38 to their uninjured counterparts.

39 **Conclusions**

40 Overlapping strength profiles across age-groups, combined with greater strength in
41 previously injured players, suggests difficulties for establishing cut-off thresholds associated
42 with hamstring injury risk.

43 **Keywords**

44 Gaelic football; eccentric hamstring strength

45 **Highlights**

46 1. The mean strength value of elite senior Gaelic football players was 22% greater than all
47 other elite players. However, when standardised to body mass ($N.kg^{-1}$), senior players
48 were 15% weaker than younger age-groups.

49 2. Players with a history of hamstring injury in the 12 months prior to testing had relative
50 strength values 9% stronger than uninjured players.

51 3. Overall 40% of elite Gaelic football players presented had absolute strength imbalances
52 >10% with quartiles revealing overlaps in metrics across the age-groups.

53

54 Introduction

55 Gaelic football is a multidirectional, running-based field sport that originated in Ireland. Since
56 1884, Gaelic football has been governed by the Gaelic Athletic Association (GAA). Presently,
57 there are over 334,000 players with 2600 registered clubs (GAA, 2014). Community clubs
58 represent sub-elite levels of Gaelic football, while select players aged 14 years and upwards
59 are chosen to participate with their county team, representing the elite levels of Gaelic
60 games.

61 During match-play two opposing teams of 14 outfield players and a goalkeeper play on a
62 grass pitch 145 m long by 90 m wide. The aim is to outscore the opposition at H-shaped goal
63 posts by kicking or striking a round ball over (1 point) or under (1 goal equating to 3 points) a
64 crossbar. Match-play consists of two 30 minute periods **separated** by a 10 minute interval,
65 however, at the elite senior level two 35 minute periods are played. Shoulder-to-shoulder
66 contact is permitted, yet 68% of injuries are incited by non-contact mechanisms (Murphy et
67 al., 2012).

68 Elite underage players (15 ± 0.7 years) run on average 5700 m or $93 \text{ m}\cdot\text{min}^{-1}$ during match-
69 play, with 15% of the total distance performed at high-speed ($>17 \text{ km}\cdot\text{h}^{-1}$) (Reilly et al., 2015).
70 Additionally, elite senior players run on average 9200 m ($131 \text{ m}\cdot\text{min}^{-1}$) with 18% of the total
71 distance performed at high-speed (Malone et al., 2016). It has been hypothesised that these
72 workrates may contribute to the high incidence of non-contact lower limb injuries in Gaelic
73 football and field sports with similar demands (Roe et al. 2017). For instance, elite Australian
74 football players covering $>653 \text{ m}$ at $\geq 24 \text{ km}\cdot\text{h}^{-1}$ each week are 3.3 times more likely to sustain
75 a hamstring injury compared to their peers (Ruddy et al., 2016).

76 Hamstring injuries are the most common injury in elite Gaelic football affecting 21% of
77 players per 32 week season (Roe et al., 2016). An elite Gaelic football squad of 38 players
78 can expect to sustain 9 hamstring injuries per season, each resulting in an average of 26
79 time-loss days (Roe et al., 2016). Furthermore, following return to sport players with a
80 previous hamstring injury are 230% more likely to sustain a future hamstring injury in
81 comparison to their uninjured peers (Roe et al., 2016). Hamstring injury incidence have been
82 illustrated to be greater among elite Gaelic football players aged 18-20 and ≥ 30 years
83 identifying the need for modifiable risk factors and characteristics across age groups (Roe et
84 al., 2016).

85 Modifiable risk factors for hamstring injuries have been identified in other elite field sports
86 using metrics derived from eccentric knee flexor strength assessment. For example, in elite

87 rugby union, between-limb imbalances of $\geq 15\%$ and $\geq 20\%$ were associated with a relative
88 risk ratio (RR) of 2.4 and 3.4 for future injury, respectively (Bourne et al., 2015). Similarly,
89 preseason eccentric knee flexor strength of < 256 N was associated with increased injury risk
90 in elite Australian football players (RR = 2.7) (Opar et al., 2015). Conversely, van Dyk et al.
91 (2017) found no association between knee flexor strength and hamstring injury risk in soccer
92 players. Although targeting interventions at players presenting with these characteristics may
93 mitigate hamstring injury risk, the absence of normative data makes it difficult for
94 practitioners to compare a player's characteristics to their peers to individualise interventions
95 (Fox et al., 2014; Chalker et al., 2016). Such data may guide clinical practise in performance-
96 orientated environments where stakeholders seek information for establishing intervention
97 targets (Roe et al., 2017).

98 Considering that 1-in-5 elite Gaelic football players will sustain a hamstring injury per season,
99 and that metrics derived from assessing eccentric knee flexor strength have been shown to
100 alter risk of injury, it is important that these mechanical characteristics are described.
101 Therefore, the primary aim of the current study was to describe eccentric knee flexor strength
102 in elite male Gaelic football players from under-age to senior level. The secondary aim was
103 to determine the influence of **body mass** and previous hamstring injury on eccentric knee
104 flexor strength.

105 **Methods**

106 A cross-sectional study was designed to measure eccentric knee flexor strength in elite
107 Gaelic football players from under 14 years to senior level.

108 **Participants**

109 Players (n=341; 20.8 yrs \pm 6.0; 75.3 kg \pm 13.1) were recruited from twelve inter-county male
110 teams. The number of participants varied between age groups: under 14 years (n=26; 13.6
111 years \pm 0.3; 55.0 kg \pm 11.2), under 15 years (n=33; 14.8 years \pm 0.3; 62.6 kg \pm 8.7), under 16
112 years (n=21; 15.5 years \pm 0.5; 68.6 kg \pm 8.4), under 17 years (n=25; 16.5 years \pm 0.5; 69.7
113 kg \pm 6.4), under 21 years (n=88; 20.2 years \pm 0.8; 81.6 kg \pm 6.7), and senior level (n=148;
114 26.6 years \pm 3.1; 84.0 kg \pm 7.1).

115 **Ethical Approval and Consent**

116 Ethical approval for this study was granted by the Human Research Ethics Committee at the
117 respective university.

118

119 **Procedures**

120 Players were required to complete a questionnaire prior to strength testing to establish their
121 dominant leg and previous injury history. Testing was completed during the preseason or
122 initial competitive cycle of the 2016/17 season. A prototype of the portable strength testing
123 device (Nordbord, Vald Performance, Australia) has previously shown high-to-moderate
124 reliability (intraclass correlation coefficient = 0.83-0.90; typical error, 21.7-27.5 N; typical error
125 as a coefficient of variation, 5.8%-8.5%) (Opar et al., 2013). A previously described protocol
126 was utilised for the current study (Opar et al., 2015). That is, following a warm-up set,
127 participants performed one set of three maximal repetitions of the Nordic hamstring exercise
128 on the device. Participants were instructed to gradually lean forward at the slowest possible
129 speed while maximally resisting the fall with both legs and maintaining an upright posture
130 with their spine and pelvis in a neutral position (“stay as tall as you can”, “imagine a straight
131 line from your knees to head”). The proprietary software provided instantaneous raw data
132 that were then exported into a customised Microsoft Excel spreadsheet (Microsoft,
133 Redmond, USA). Data relating to maximum force and average force for each leg, as well as
134 between-limb imbalances, were derived from the excel sheet.

135 **Analysis**

136 All data were analysed using SPSS (version 21.0; IBM, Inc., Chicago, IL, USA). Descriptive
137 statistics were used to report performance markers per age grade. Data are presented as
138 mean values with 95% confidence intervals (95% CI). The presented strength metrics are the
139 mean between left and right limbs. Quartiles were used to report performance markers
140 across 25th, 50th, and 75th percentile intervals. The maximum and average forces between
141 limbs across all three repetitions were compared to report percentage imbalances. Between-
142 limb imbalances were graded as <5%, ≥5% to <10%, ≥10% to <15%, or ≥15%. Strength
143 metrics were standardised to body mass to report the relative force ($N \cdot kg^{-1}$) for each player
144 and these were termed relative maximum and relative average force. To compare metrics
145 between age grades, data for each age grade were compared to the mean for all others
146 producing a relative strength ratio. Players with a previous hamstring injury within 12 months
147 prior to testing were compared to their uninjured peers using the mean values for maximum
148 and average force of both limbs. Previous hamstring injuries were stratified according to
149 severity based time-loss as mild (1-7 days), moderate (8-28 days), or severe (>28 days).
150 Return to sport was considered once medical clearance was obtained for full participation in
151 all team training and matches. Maximum force was also investigated following return to play
152 in previously injured players.

153 Cohen d was used to assess the magnitude of the effect (effect size, ES) between dominant
154 and non-dominant limbs, injured and non-injured limbs and players, as well as each age-
155 grade in comparison to all others. An ES of 0.2, 0.5, 0.8, or 1.3 was considered small,
156 moderate, large, or very large, respectively. A one-way between-groups analysis of variance
157 was used to compare mean differences between groups based on: age, and severity of
158 previous hamstring injury. Post-hoc Tukey tests were applied for pairwise comparisons. An
159 independent-samples t-test was used to compare means between players with and without a
160 previous hamstring injury. A paired-samples t-test was used to compare means between:
161 dominant and non-dominant limbs, and injured and uninjured limbs. Significance was set at a
162 $p < 0.05$. A linear regression was used to compute the equation representing the relationship
163 between the body mass (independent variable) and maximum force (dependent variable).
164 **Separate regressions were also computed following stratification of players to a**
165 **subgroup of youth (under 14 to 17 years) or adult (under 21 years to senior) levels.**

166 Results

167 Eccentric knee flexor strength scores are outlined in table 1 and table 2. A significant
168 difference in maximum ($p < 0.01$; $d = 0.7$) and average ($p < 0.02$; $d = 0.7$) strength was
169 recorded between under-14 years and all other age-groups, except under-15 players ($p =$
170 0.371). However, no statistically significant ($p=0.513$) differences were observed when
171 relative force values were analysed ($N \cdot \text{kg}^{-1}$). Data on the relative strength ratio comparing
172 metrics for each age group against all other player are outlined in table 3.

173 On average, relative maximum force was 5.0% (95% CI 3.2 – 6.9) greater in the dominant
174 limb when compared to the non-dominant limb. Similar findings were found for relative
175 average force (5.6%, 95% CI 3.3 – 8.1). Statistically significant differences between
176 dominant and nondominant limbs were found for relative maximum strength and relative
177 average strength in under-17 to senior players ($p < 0.02$, $d = 0.2$).

178 A moderate-large correlation was found between maximum force and body mass ($r = 0.47$)
179 **(figure 1)**. The linear regression **was found to be statistically significant ($r^2=.22$, $F(1,$
180 **$252)=92.0$, $p<0.001$) and** produced the following equation to describe the relationship
181 between maximum force and body mass: $3.54 \times \text{body mass (kg)} + 59.897$. **A statistically**
182 **significant linear regression was found among youth players (under 14 to 17 years)**
183 **($r=.59$, $r^2=.36$, $F(1, 98)=54.3$, $p<0.001$) with maximum force increasing 4.5N per 1kg**
184 **increase in body mass. A statistically significant linear regression was also found**
185 **among adult players (under 21 years to senior level) ($r=.16$, $r^2=.03$, $F(1, 152)=3.9$,**
186 **$p=0.049$) with maximum force increasing 1.9N per 1kg increase in body mass.****

187 Comparisons between injured and uninjured players were only completed on players from
188 under-16 years onwards as only one younger player reported a previous hamstring injury. A
189 total of 75 players (22.0%, 95% CI 17.9 – 26.7) reported a previous hamstring injury in the 12
190 months prior to testing. The proportion of previous hamstring injuries classified as mild,
191 moderate, and severe was 14.0% (95% CI 6.0 – 24.0), 56.0% (95% CI 42.0 – 70.0), and
192 30.0% (18.0 – 44.0), respectively (table 5). No statistically significant differences for
193 maximum force ($p = 0.234$), between limb difference ($p = 0.431$), or percentage between-limb
194 difference ($p = 0.779$) between previous injured and uninjured players when different periods
195 following return to sport were considered (table 6). Maximum force differed between
196 uninjured limbs and previously injured limbs at <2 months following return to play ($p = 0.04$; d
197 = 0.6) (table 6).

198 Statistically significant differences between injured and uninjured players were found for
199 absolute relative maximum ($p = 0.01$; $d = 0.4$) and relative average ($p = 0.02$; $d = 0.2$)
200 strength in under-21 years players. Statistically significant differences between injured and
201 uninjured players were found for relative maximum strength ($p = 0.01$, $d = 0.7$) and relative
202 average strength ($p = 0.02$, $d = 0.7$) in under-17. No statistically significant differences were
203 found between injured and uninjured limbs for relative maximum strength ($p = 0.46$, $d = 0.3$)
204 or relative average strength ($p = 0.46$, $d = 0.03$). The prevalence of imbalances $\geq 15\%$ was
205 1.28-times (95% CI 1.10 – 1.38) greater in players with a previous hamstring injury.

206 In total, 40.2% (95 CI 31.4 – 48.7) of players had a maximum force between-limb imbalance
207 >10% (table 4). Similarly, 38.5% (95% CI 20.2 – 46.6) of players had average force between-
208 limb imbalances >10%. No statistically significant differences were found between any age
209 groups for maximum ($p = 0.09$) or average strength ($p = 0.16$) imbalances. The percentage of
210 uninjured and previously injured players with a >10% maximum force between-limb
211 imbalance was 37.6% (95% CI 32.8 – 42.2) and 41.1% (95% CI 28.6 – 53.7), respectively.
212 Overall, 51.8% (39.3 – 63.3) of limbs with previous hamstring injury were weaker than the
213 uninjured contralateral limb. Furthermore, 23.2% (95% CI 12.5 – 33.9) of limbs with a
214 previous hamstring injury were >10% weaker than the uninjured contralateral limb.

215 **Discussion**

216 This study investigated eccentric knee flexor strength in elite Gaelic football players from
217 underage to senior level. Elite senior Gaelic football players have similar maximum eccentric
218 knee flexor strength (361.0 N, 95% CI 348.4 – 375.8) to elite (366.9 \pm 76.9), sub-elite (387.9
219 \pm 96.3), and under-19 (342.8 N \pm 81.5) elite rugby union players (Bourne et al., 2015).
220 Similarly, maximum eccentric knee flexor strength in elite Australian football, Australian

221 soccer, and French soccer players have been reported as $371.0 \text{ N} \pm 77.0$, 309.5 ± 73.4 , and
222 $411.0 \text{ N} \pm 66.0$, respectively (Timmins et al., 2015; Buchheit et al., 2016). It also appears
223 that age-matched Gaelic football players demonstrate greater eccentric knee flexor strength
224 than sub-elite cricket players aged 15-years ($285.0 \text{ N} \pm 68.0$) or 21-years ($308.0 \text{ N} \pm 77.0$),
225 and French academy soccer players at under-17 ($306.0 \text{ N} \pm 68.0$), under-19 ($301.0 \text{ N} \pm$
226 72.0), and under-21 ($299.0 \text{ N} \pm 52.0$) age-grades (Chalker et al., 2016; Buchheit et al., 2016).
227 These results suggest that elite Gaelic football players have similar or greater eccentric knee
228 flexor strength profiles when compared other field sport athletes.

229 Previous research reports increases of 4N in maximum eccentric knee flexor strength per
230 1kg increase in body mass (Buchheit et al., 2016). Although the current study found a
231 moderate-to-large **correlation** between these variables, **this was not universal across**
232 **age-groups. Previously the impact of maturation on aerobic capacity among Gaelic**
233 **football players transitioning across age-groups has been highlighted as being**
234 **potentially misleading when evaluating performance (Roe and Malone, 2016). Hence,**
235 **as the association between eccentric knee flexor strength and body mass is**
236 **moderate-to-large in youth players yet weak in adult players, it is plausible that the**
237 **timing of increases in strength may coincide, yet not be attributable, to increases in**
238 **known maturation-related outcomes such as body mass.** Thus, practitioners should
239 consider age, maturation, and relative strength measures when profiling player
240 characteristics.

241 In the current study, the mean relative eccentric knee flexor strength for elite Gaelic football
242 players was $4.4 \text{ N}\cdot\text{kg}^{-1}$ (95% CI 4.2 – 4.5). Such values are greater than reports from elite
243 senior soccer ($4.1 \pm 0.9 \text{ N}\cdot\text{kg}^{-1}$), Australian football ($3.2 \pm 1.3 \text{ N}\cdot\text{kg}^{-1}$), elite rugby union ($3.7 \pm$
244 $0.7 \text{ N}\cdot\text{kg}^{-1}$), sub-elite rugby union ($4.0 \pm 0.9 \text{ N}\cdot\text{kg}^{-1}$), elite cricket ($3.7 \pm 0.9 \text{ N}\cdot\text{kg}^{-1}$), and sub-
245 elite cricket ($3.7 \pm 1.0 \text{ N}\cdot\text{kg}^{-1}$) (Opar et al., 2015; Bourne et al., 2015; Chalker et al., 2016;
246 Timmins et al., 2016). These data indicate that relative eccentric knee flexor strength for age-
247 matched players is greater in elite Gaelic football than in other field sports.

248 The current study also observed that under-21 and senior players, the two older age levels
249 have similar relative strength profiles to their younger peers. Such findings may appear
250 counterintuitive as a greater emphasis on resistance training occurs at the senior level.
251 Although such trends have been described in other field sports, the reasons for this relative
252 decrement are unclear (Bourne et al., 2015; Chalker et al., 2016). As Gaelic football is a
253 contact sport, the development of musculature, including in the upper body, tends to be
254 prioritised in early career players transitioning to senior level. Thus, development of muscle
255 mass in different body regions may contribute to these reductions in relative strength.

256 However, senior players were 15% weaker, in relative mean force across 3 repetitions, than
257 all other age-groups tested. The use of a ratio to compare metrics between age-groups also
258 reveals that maximum force imbalances were 16% lower among senior players. Thus,
259 practitioners at the elite senior level may be prioritising symmetry and not relative strength.

260 Eccentric knee flexor strength was superior among limbs with a previous hamstring injury,
261 particularly at 8 weeks following return to sport. This is at odds with research in many field
262 sports, including an isokinetic dynamometer study in collegiate Gaelic football, reporting
263 decrements following return to sport (Croisier et al., 2008; De Vos et al., 2014; van Dyk et al.,
264 2016; O'Sullivan et al., 2008; Opar et al., 2015). However, the current study reported that the
265 likelihood that the injured limb was weaker after return to sport following a hamstring injury
266 was 51%, and that the likelihood that this weakness exceeded 10% was also 23%. Thus, this
267 likely contributes to no statistical relationship being found between previous hamstring injury
268 and maximum eccentric knee flexor strength. Furthermore, this indicates that secondary
269 injury risk management strategies are equally as effective as ineffective with regard to
270 developing comparable strength between limbs.

271 It remains unclear whether this observation, combined with reduced relative strength in
272 senior players, indicates that eccentric hamstring strength development is mainly prioritised
273 during rehabilitation periods only. The triad of reduced relative strength, greater strength
274 profiles in players with previous hamstring injury, and a known high incidence of hamstring
275 injury in the sport, requires examination of injury risk management practises in elite Gaelic
276 football. This is particularly true when the intense running-demands of elite Gaelic football
277 match-play are considered (Malone et al., 2017).

278 An important element of return to sport decision making is determining an acceptable level of
279 risk to tolerate (Creighton et al., 2010; Shier, 2015). Although the development of eccentric
280 hamstring strength is an important characteristic to reduce injury risk, identifying objective
281 and clear-cut 'at-risk' thresholds is difficult (Schmitt et al., 2012). Indeed, monitoring
282 development of mechanical properties during performance-oriented training programmes is
283 important for both primary and secondary injury prevention (Mendiguchia et al., 2017).
284 Monitoring strength levels in reference to preinjury levels or uninjured peers, whilst
285 considering pain and mental readiness for full participating in training and match-play, may
286 potentially inform return to sport decisions (van der Horst, 2017). Normative data may inform
287 criteria-based rehabilitation by providing information on desired performance levels (Adern et
288 al., 2015). However, this approach will be high risk if the comparison group (i.e. uninjured
289 player or preinjury level) are not consistently exposed to adequate training stimuli for
290 developing eccentric hamstring strength.

291 In addition to reducing hamstring injury incidence by 50% when compared to control groups
292 (0.4 v 0.7 per 1000 hours), the Nordic hamstring programme has been shown to increase
293 eccentric hamstring strength by 14% while increasing electromyographic activity after six
294 weeks (Al Alttar et al., 2016; Delahunt et al., 2014). A 45° hip extension exercise has also
295 been used to develop eccentric hamstring strength and fascicle length (Timmins et al., 2016).
296 Therefore, practitioners with limited time and access to facilities have evidence-based
297 methods for developing eccentric hamstring strength and managing injury risk.

298 Examinations of quartiles provides insight into the range in strength between players of the
299 same age, and the overlap of eccentric hamstring strength profiles across age-groups. The
300 similarities within, and between player-groups, has been considered a barrier to identifying
301 those at increased risk of sustaining injury when profiling player characteristics (Bahr, 2016).
302 Indeed, it has been shown that 20% of elite rugby union players with preseason maximum
303 strength imbalances $\geq 15\%$ sustained an inseason hamstring injury, and players with this
304 characteristic at 2.4-times more risk than those without (Bourne et al., 2015). The current
305 study reveals that 23.2% (95% CI 18.5 – 27.6) fall into this threshold which may contribute to
306 the higher incidence of hamstring injuries seen in the elite Gaelic football than rugby.
307 However, a prospective study needs to be undertaken before such inferences can be made.

308 Eccentric knee flexor strength varies across the season, with greater gains during preseason
309 reported among previously uninjured players (Opar et al., 2014). Other variables such as
310 age, fascicle length, fatigue, and high-speed running are also known to alter susceptibility to
311 hamstring injuries (Freckleton and Pizzari, 2012; Timmins et al., 2014; Roe et al., 2016;
312 Timmins et al., 2016; Duhig et al., 2016). The interaction between multiple intrinsic and
313 extrinsic variables influencing the emergence of injury needs to be considered in future
314 research (Bittencourt et al., 2017). For instance, hamstring injury incidence was 2.3-times
315 greater for elite Gaelic football players >30 years when compared to their younger peers
316 (Roe et al., 2016). Future reports of age-related changes in modifiable risk factors for
317 hamstring injury may guide development of prevention programmes for sub-groups of
318 players (Gabbe et al., 2006).

319 **Conclusion**

320 The reporting of normative eccentric knee flexor strength values provides unique insights for
321 monitoring a metric known to alter risk of injury. Firstly, senior players had mean strength
322 values 22% greater than all other players. However, when standardised to body mass ($N \cdot kg^{-1}$),
323 players at senior level were 15% weaker than younger age-groups. Thus, profiling metrics
324 should be standardised to player characteristics such as body mass. Secondly, players with

325 a history of hamstring injury in the 12 months prior to testing, had relative strength values 9%
326 stronger than uninjured players. We recommend practitioners to monitor strength
327 development following training cycles, although exposure to evidence-based interventions
328 such as Nordic hamstring exercise or hip extension would suffice. Thirdly, 40% of elite Gaelic
329 football players presented had maximum strength imbalances >10% with quartiles revealing
330 overlaps in metrics across the age-groups. As such, sole reliance on developing strength
331 profiles similar to uninjured players may be limited to assess risk of primary or secondary
332 hamstring injuries. Future research is needed to determine if specific eccentric hamstring
333 strength metrics influence injury risk in elite Gaelic football.

334

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Table 1 – Eccentric Knee Flexor Strength Profiles in Elite Gaelic Football Players

	Maximum Force (N)	Average Force (N)	Relative Maximum Force (N•kg⁻¹)	Relative Average Force (N•kg⁻¹)	Maximum Force Imbalance (%)	Average Force Imbalance (%)
All Players	329 (320 - 340)	306 (296 - 316)	4.4 (4.2 - 4.5)	4.0 (3.9 - 4.2)	9.4% (8.5 - 10.3)	8.9% (8.1 - 9.8)
Under 14 Years	236 (211 - 260)*#	212 (201 - 241)*#	4.3 (3.8 – 4.7)	4.0 (3.6 – 4.4)	8.4% (6.4 - 10.9)	7.2% (5.4 - 9.0)
Under 15 Years	276 (258 - 296)	256 (237 - 274)	4.4 (4.1 - 4.6)	4.0 (3.8 - 4.3)	12.6% (9.4 - 16.2)	11.5% (8.2 - 15.3)
Under 16 Years	314 (291 - 342)	290 (268 - 313)	4.6 (4.3 - 4.9)	4.3 (4.1 - 4.6)	9.1% (6.2 - 12.3)	9.2% (6.5 - 11.7)
Under 17 Years	321 (299 - 342)	297 (274 - 321)	4.6 (4.3 - 5.0)	4.3 (4.0 - 4.6)	10.5% (7.6 - 13.8)	9.8% (7.2 - 12.7)
Under 21 Years	351 (331 - 368)	319 (301 - 335)	4.3 (4.1 - 4.5)	3.9 (3.7 - 4.1)	10.4% (9.0 - 12.0)	10.0% (8.6 - 11.5)
Senior	361 (348 - 376)	336 (323 - 350)	4.3 (4.1 - 4.5)	3.5 (3.0 - 4.0)	8.6% (7.6 - 9.8)	8.4% (7.3 - 9.6)

Legend: * indicates p<0.05, # indicates moderate to large effect size (>0.5 – <0.8). All other statistical outputs were insignificant or showed small effect size.

Table 2 – Quartile Ranges Per Eccentric Knee Flexor Strength Metric in Elite Gaelic Football Players

	Under 14 Years			Under 15 Years			Under 16 Years			Under 17 Years			Under 21 Years			Senior		
	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th	25th	50th	75th
Maximum Force	195	236	284	239	275	296	262	298	342	271	322	374	279	356	421	298	360	425
Average Force	184	220	258	214	256	277	247	270	312	244	289	347	256	325	361	269	329	392
Maximum Imbalance	14.3%	7.0%	3.0%	17.5%	9.0%	4.5%	13.5%	7.0%	3.5%	13.5%	9.0%	5.5%	16.5%	8.1%	4.0%	12.0%	7.0%	3.0%
Average Imbalance	11.5%	6.0%	3.0%	19.0%	7.0%	2.5%	14.0%	9.0%	2.5%	13.5%	8.0%	4.0%	14.1%	8.8%	4.5%	12.0%	6.3%	3.3%
Maximum Force Between Limb Difference	32.3	16.5	7.8	47.5	28.0	12.5	44.5	24.0	12.0	42.5	28.0	14.0	56.0	30.5	14.3	47.8	26.0	11.0
Average Force Between Limb Difference	27.3	14.5	8.8	51.0	23.0	7.5	40.0	29.0	7.5	43.0	30.0	11.5	46.8	28.5	14.0	39.0	24.5	11.3
Maximum Relative Force	3.6	4.3	5.2	3.9	4.5	4.8	4.0	4.6	5.3	4.0	4.9	5.3	3.4	4.3	5.2	3.5	4.2	5.1
Average Relative Force	3.4	4.0	4.7	3.6	4.0	4.5	3.8	4.3	4.7	3.6	4.4	4.6	3.2	3.9	4.4	3.2	3.9	4.8

Table 3 – Eccentric Knee Flexor Strength Metrics Per Age Group as a Ratio Relative to All Other Players

	Maximum Force (N)	Maximum Force Between Limb Difference	Average Force Between Limb Difference	Average Force (N)	Relative Maximum Force (N·kg ⁻¹)	Relative Average Force (N·kg ⁻¹)	Maximum Force Imbalance (%)	Average Force Imbalance (%)
Under 14 Years	0.73 (0.69 - 0.75)	0.60 (0.56 - 0.62)	0.53 (0.52 - 0.53)	0.73 (0.71 - 0.76)	0.97 (0.92 - 1.00)	1.00 (0.97 - 1.01)	0.82 (0.80 - 0.85)	0.74 (0.71 - 0.76)
Under 15 Years	0.87 (0.86 - 0.88)	1.13 (1.10 - 1.18)	1.12 (1.01 - 1.19)	0.88 (0.86 - 0.88)	1.00 (0.97 - 1.03)	1.00 (0.99 - 1.03)	1.34 (1.28 - 1.38)	1.29 (1.17 - 1.40)
Under 16 Years	1.02 (1.00 - 1.04)	0.88 (0.76 - 0.97)	0.97 (0.86 - 1.03)	1.02 (1.00 - 1.03)	1.05 (1.03 - 1.07)	1.09 (1.08 - 1.13)	0.90 (0.78 - 0.98)	0.98 (0.89 - 1.01)
Under 17 Years	1.04 (1.01 - 1.06)	1.13 (1.08 - 1.19)	1.12 (1.06 - 1.20)	1.04 (1.03 - 1.06)	1.05 (1.04 - 1.08)	1.09 (1.08 - 1.10)	1.07 (0.98 - 1.13)	1.06 (1.00 - 1.11)
Under 21 Years	1.16 (1.14 - 1.17)	1.30 (1.20 - 1.43)	1.27 (1.18 - 1.43)	1.14 (1.12 - 1.16)	0.97 (0.95 - 0.99)	0.97 (0.94 - 1.00)	1.06 (0.95 - 1.21)	1.08 (0.99 - 1.24)
Senior	1.21 (1.17 - 1.25)	1.01 (0.89 - 1.15)	1.04 (0.93 - 1.19)	1.22 (1.18 - 1.26)	0.97 (0.95 - 0.99)	0.85 (0.78 - 0.91)	0.84 (0.75 - 0.98)	0.88 (0.80 - 1.02)

Table 4 – Imbalances Associated with Maximum Eccentric Knee Flexor Strength in Elite Gaelic Football Players

	Maximum Force Between-Limb Percentage Imbalance				Maximum Force Between-Limb Force (N) Difference			
	0 to 5% Imbalance	5 to 10% Imbalance	10 to 15% Imbalance	>15% Imbalance	0 to 5% Imbalance	5 to 10% Imbalance	10 to 15% Imbalance	>15% Imbalance
All Players	30.8% (26.1 to 36.1)	29.0% (24.3 to 33.7)	17.0% (12.9 to 21.1)	23.2% (18.5 to 27.6)	8.3 (7.3 - 9.4)	25.8 (24.1 - 27.5)	40.3 (37.4 - 43.3)	72.8 (67.3 - 78.6)
Under 14 Years	34.6% (19.2 to 52.8)	26.9% (11.5 to 42.3)	15.4% (3.8 to 30.8)	23.1% (7.7 to 42.3)	6.2 (4.0 - 7.9)	17.9 (14.3 - 22.0)	24.8 (16.8 - 34.8)	42.8 (37.3 - 48.3)
Under 15 Years	24.2% (12.1 to 39.4)	27.3% (12.1 to 42.4)	9.1% (0.0 to 18.2)	39.4% (24.2 to 57.6)	9.0 (5.5 - 13.6)	22.4 (16.1 - 29.8)	36.0 (28.0 - 41.0)	61.3 (45.9 - 78.2)
Under 16 Years	33.3% (14.3 to 52.3)	23.8% (4.8 to 42.9)	23.8% (9.5 to 42.9)	19.0% (4.8 to 38.1)	8.0 (4.7 - 11.0)	19.2 (15.4 - 23.0)	37.2 (31.6 - 43.8)	68.0 (54.3 - 82.3)
Under 17 Years	24.0% (8.0 to 40.0)	28.0% (12.0 to 44.0)	28.0% (12.0 to 44.0)	20.0% (4.0 to 40.0)	8.8 (6.2 - 11.3)	25.1 (20.4 - 30.7)	38.3 (34.3 - 41.6)	78.4 (65.8 - 93.8)
Under 21 Years	26.1% (17.0 to 36.4)	29.5% (20.5 to 40.9)	15.9% (9.1 to 23.9)	28.4% (19.3 to 38.6)	9.0 (23.9 - 30.6)	27.2 (23.9 - 30.6)	40.6 (33.6 - 48.1)	80.7 (70.4 - 91.7)
Senior	35.1% (27.0 to 42.6)	30.4% (23.6 to 37.8)	16.9% (10.8 to 23.0)	17.6% (12.2 to 23.6)	8.3 (6.8 - 9.9)	27.6 (25.2 - 30.3)	44.4 (40.3 - 48.6)	77.5 (70.1 - 85.2)

Table 5 – Eccentric Knee Flexor Strength Between Uninjured and Previously Injured Limbs Based on Severity

	No Hamstring Injury	No Hamstring Injury Senior & U21	Hamstring Injury in Last 12 Months	Mild Injury (1-7 Days)	Moderate Injury (8-28 Days)	Severe Injury (>28 Days)
Sample Size	265	176	76	11	43	23
Maximum Force	325 (315 - 336)	350 (338 - 362)	367 (347 - 387)	375 (275 - 475)	397 (362 - 431)	357 (315 - 400)
Average Force	299 (290 - 309)	321 (309 - 333)	343 (323 - 363)	346 (241 - 450)	375 (340 - 410)	332 (289 - 375)
Maximum Imbalance	9.4% (8.5 - 10.3)	8.8% (7.8 - 9.8)	10.3% (8.4 - 12.1)	7.1% (3.4 - 10.8)	10.8% (7.8 - 13.8)	12.8% (7.9 - 17.7)
Average Imbalance	9.0% (8.1 - 9.8)	8.6% (7.7 - 9.6)	10.0% (8.2 - 11.7)	5.1% (1.0% - 9.2)	10.2% (7.2 - 13.2)	12.4% (7.2 - 17.8)
Maximum Force Difference	27.3 (28.8 - 35.4)	32.8 (28.6 - 37.1)	39.7 (32.9 - 46.5)	21.0 (7.6 - 46.4)	45.0 (33.6 - 56.4)	47.7 (30.0 - 65.5)
Average Force Difference	28.4 (25.5 - 31.4)	29.5 (25.8 - 33.3)	35.8 (29.6 - 41.9)	19.1 (5.7 - 40.8)	40.3 (29.7 - 50.8)	38.0 (29.9 - 46.2)
Reduced Maximum Force on Injured Limb			51.8% (37.5 - 64.3)	80.0% (40.0 - 100)	50.0% (30.8 - 69.2)	60.0% (33.3 - 86.7)

Table 6 – Eccentric Knee Flexor Strength Between Uninjured and Previously Injured Limbs Following Return to Play

Group	Mean Maximum Force Between-Limbs	Difference Between-Limbs	Percentage Difference Between-Limbs	Maximum Force Per Limb
No Previous Hamstring Injury	351 (338 - 364)	33.8 (29.3 - 38.3)	9.8% (8.6 - 11.2)	357 (315 - 400)
<u>Time Following Return to Play</u>				
<2 Months	378 (335 - 421)	33.7 (23.7 - 59.6)	11.9% (7.1 - 18.2)	405 (364 - 445)*#
3-6 Months	413 (342 - 479)	49.1 (20.0 - 78.3)	11.8% (7.4 - 16.9)	399 (349 - 449)
7-12 Months	391 (339 - 447)	46.8 (26.2 - 67.3)	12.3% (8.4 - 16.4)	388 (335 - 442)
12-24 Months	370 (330 - 412)	25.3 (24.7 - 50.7)	10.7% (7.1 - 14.4)	371 (334 - 407)
>24 Months	349 (318 - 381)	29.6 (17.4 - 41.8)	8.5% (5.4 - 11.8)	365 (336 - 395)

Legend: * indicates p<0.05, # indicates moderate to large effect size (>0.5 – <0.8). All other statistical outputs were insignificant or showed small effect size.

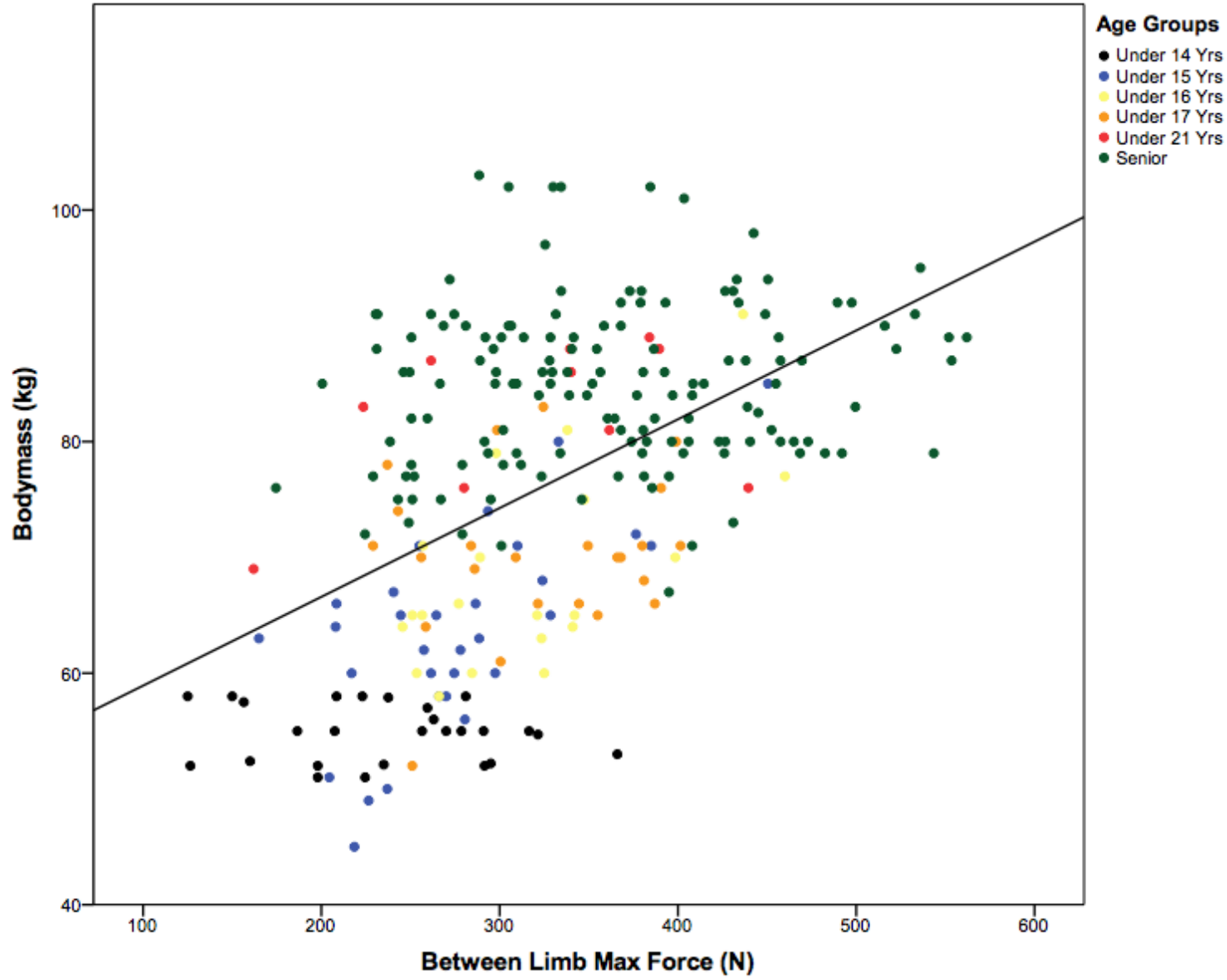


Fig. 1. Relationship between body mass and maximum eccentric knee flexor strength (between-limbs).