

1 **TITLE**

2 The impact of previous hamstring strain injury on the change in eccentric hamstring strength
3 during pre-season training in elite Australian footballers.

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20 **ABSTRACT**

21 **Background:** Hamstring strain injuries (HSIs) are the most common injury type in Australian football
22 and the rate of recurrence has been consistently high for a number of years. Long lasting
23 neuromuscular inhibition has been noted in previously injured athletes but it is not known if this
24 influences athletes adaptive response to training. **Purpose:** To determine if elite Australian footballers
25 with a prior unilateral HSI (previously injured group) display lesser improvements in eccentric
26 hamstring strength during pre-season training compared to athletes without a history of HSI (control
27 group). **Study design:** Prospective cohort study. **Methods:** Ninety-nine elite Australian footballers
28 participated (17 with a history of unilateral HSI in the previous 12 month period). Eccentric hamstring
29 strength was assessed at the start and end of pre-season training using an instrumented Nordic
30 hamstring device. Change in eccentric strength across preseason was determine in absolute terms and
31 normalised to start of preseason strength. Start of preseason strength was used as a covariate to control
32 for differences in starting strength. **Results:** The left and right limbs in the control group showed no
33 difference in absolute or relative change (left limb absolute change, $60.7 \pm 72.9\text{N}$; relative change,
34 1.28 ± 0.34 ; right limb absolute change, $48.6 \pm 83.8\text{N}$; relative change, 1.24 ± 0.43). Similarly, the
35 injured and uninjured limbs from the previously injured group showed no difference for either
36 absolute or relative measures of change (injured limb absolute change, $13.1 \pm 57.7\text{N}$; relative change,
37 1.07 ± 0.18 ; uninjured limb absolute change, $14.7 \pm 54.0\text{N}$; relative change, $1.07 \pm 0.22\text{N}$). The
38 previously injured group displayed a significantly lesser increase in eccentric hamstring strength
39 across the preseason (absolute change, 13.9 ± 55.0 ; relative change, 1.07 ± 0.20) compared to the control
40 group (absolute change, 54.6 ± 78.5 ; relative change, 1.26 ± 0.39) for both absolute and relative
41 measures ($p < 0.001$), even after controlling for differences in start of pre-season eccentric hamstring
42 strength, which had a significant effect on strength improvement. **Conclusion:** Elite Australian
43 footballers with a unilateral HSI history displayed lesser improvements in eccentric hamstring
44 strength across preseason training. The smaller improvements were not restricted to the previously
45 injured limb as the contralateral limb also displayed similarly small improvements in eccentric
46 strength. Whether this is the cause of or the result of injury remains to be seen, but it has the potential
47 to contribute to the risk of hamstring strain re-injury.

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49 **Key terms:** Hamstring, muscle injury, eccentric strength, Nordic hamstring exercise.

50 **What is known about the subject:** The rate of recurrence of hamstring strain injuries in elite
51 Australian footballers has been high for a number of years, however the reason for this remains
52 largely unknown. There is an increasing evidence base of prolonged deficits in neuromuscular
53 function in previously injured hamstrings. What remains to be seen is whether previously injured
54 athletes exhibit a muted adaptive response to training interventions.

55 **What this study adds to the existing knowledge:** This study looked specifically at changes in
56 eccentric hamstring strength across preseason training, due to the important role of eccentric strength
57 in preventing hamstring strain injury. Previously injured Australian footballers with a history of
58 hamstring strain injury displayed smaller improvements in eccentric hamstring strength across
59 preseason compared to uninjured controls. This study draws to attention the possibility that previously
60 injured athletes may have long term restrictions in strength improvements even after ‘successful’
61 rehabilitation and return to play.

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67 **INTRODUCTION**

68 Over the past 20 seasons hamstring strain injuries (HSIs) have been the most prevalent injury in
69 Australian football¹⁸ and they impose a significant financial burden on athletes and their associated
70 clubs.⁹ Whilst the rate of recurrent HSIs in the elite Australian Football League has fallen in recent
71 years,¹⁷ it still remains one of the most common types of injury for recurrence.¹⁸ In Australian
72 football, much like other sports,¹⁸ history of HSI is repeatedly identified as the primary risk factor for
73 future injury^{6,25} and is often considered a non-modifiable risk factor (i.e. it cannot be changed).¹⁴

74 However, a growing body of evidence indicates that neuromuscular maladaptations associated with
75 previous HSI may be responsible for the elevation of future injury risk, despite return to play and
76 ‘successful’ rehabilitation.^{15 16 21 22} Most notably, hamstrings which have previously sustained a strain
77 injury display signs of neuromuscular inhibition during eccentric contractions, when compared to the
78 contralateral uninjured hamstring.^{15 16 22} The resultant deficits in eccentric knee flexor strength might
79 reasonably be expected to increase the likelihood of future HSI in this limb, given lower levels of
80 eccentric hamstring strength increases the risk of future injury.^{4 23}

81 A recent review⁵ proposed a novel framework suggesting that persistent neuromuscular inhibition
82 during eccentric contraction following HSI^{15 16 22} could lead to continued eccentric weakness and thus
83 elevated risk of re-injury.¹⁴ Based on the proposed framework, it would be expected that this
84 inhibition has the potential to limit the extent of muscular adaptations in response to rehabilitative and
85 prophylactic exercises, given the need for high levels of activation to drive adaptation.^{5 14} If this were
86 the case, athletes with a previous HSI might not only show deficits in eccentric hamstring strength in
87 the previously injured limb but may also show a suppressed response to eccentric training
88 interventions that are commonly utilised in prophylactic programs. The impact of a prior HSI on the
89 adaptive capacity of a previously injured athlete is, however, yet to be examined.

90 In the elite Australian Football League the pre-season training period spans up to 4 months between
91 November and February.²⁴ It is a time in the training cycle where teams focus on increasing physical
92 fitness with an aim to improve performance and avoid injury.²⁴ From the perspective of preventing
93 HSI, it is common to target gains in eccentric hamstring strength as one of the major outcomes during
94 the pre-season period. Much of this philosophy is based on evidence showing the preventative
95 benefits of eccentric hamstring strengthening during pre-season in other sports.^{2 4 19} There is currently
96 no work which examines the improvements in eccentric hamstring strength throughout the pre-season
97 training period in elite Australian footballers and whether previous HSI impacts upon the athlete’s
98 ability to improve eccentric hamstring strength.

99 The purpose of this investigation was to assess eccentric hamstring strength changes during the pre-
100 season training period in elite Australian footballers with and without a history of unilateral HSI. We
101 hypothesised that athletes with a history of HSI would exhibit a minimal increase in eccentric
102 hamstring strength during the pre-season training period compared to the uninjured athletes.

103 **MATERIALS & METHODS**

104 **Sample size calculations**

105 Based on a previous study,²² that used a similar research design, a priori sample size of 15 for the
106 previously injured group and 75 for the control group was determined using G*Power (version 3.1.7).
107 The input parameters for the power analysis were: independent t-test; effect size (d) = 0.8; α = 0.05; β
108 = 0.20 and allocation ratio 5:1. An independent t-test was selected since the change in eccentric
109 hamstring strength for both limbs was expected to be averaged and then compared between groups, as
110 performed previously,²² given that the adaptive capacity would be centrally impaired and not limb
111 specific.⁵ A large effect size was anticipated based on Rhea et al.,²⁰ and the 5:1 sample ratio was
112 based on typical hamstring injury rates at 15-20%.¹⁴

113 **Participants**

114 A total of 99 Australian footballers from five elite teams were eligible to participate (from an overall
115 pool of 210) in the study, of which 17 had a history of unilateral HSI (previously injured group),
116 confirmed by magnetic resonance imaging (MRI), in the previous 12 month period. All participants
117 were free of injury to the lower limbs (able to participate fully in training) that would be expected to
118 influence knee flexor strength at the time of testing. Exclusion criteria included: any athlete with a
119 history of bilateral HSI in the prior 12 months, any athlete with a history of clinical diagnosed HSI
120 that was negative on MRI in the prior 12 months, any athlete who sustained a HSI during pre-season,
121 any athlete who had sustained an anterior cruciate ligament rupture previously or who had sustained
122 an injury to the quadriceps, calf or groin/hip in the prior 12 months. All testing procedures were
123 approved by the University Human Research Ethics Committee and participants gave informed
124 written consent prior to testing after having all procedures explained to them.

125 **Experimental design**

126 The current study employed a prospective cohort design. All athletes reported for testing during the
127 first and final weeks of preseason training (November through February). On each occasion all
128 athletes completed a submaximal warm up set of the Nordic hamstring exercise, followed by a single
129 set of three maximal repetitions of the Nordic hamstring exercise, during which left and right limb
130 eccentric knee flexor forces were recorded using a custom made device. All testing was performed
131 following similar levels (duration and intensity) of training completed in the days prior.

132 **Eccentric knee flexor strength assessment**

133 The device, used to determine eccentric knee flexor strength during the Nordic hamstring exercise,
134 and its reliability, have been described previously, and can be seen in Figures 1 and 2.¹³ Participants
135 knelt on a padded board, with the ankles secured immediately superior to the lateral malleolus by
136 individual ankle braces which were attached to custom made uniaxial load cells (Delphi Force
137 Measurement, Gold Coast, Australia) with wireless data acquisition capabilities (Mantracourt, Devon,
138 UK). The ankle braces and load cells were secured to a pivot which allowed the force to always be
139 measured through the long axis of the load cells, with an individual load cell for both the left and right
140 limb allowing for separate measures from each limb. Following a warm up set, participants performed
141 one set of three maximal repetitions of the bilateral Nordic hamstring exercises. Instructions to players
142 were to gradually lean forward at the slowest possible speed while maximally resisting this movement
143 with both limbs while keeping the trunk and hips held in a neutral position throughout, and the hands
144 held across the chest.¹³ Participants were loudly exhorted to provide maximal effort throughout each
145 repetition. A trial was deemed acceptable when the force output reached a distinct peak (indicative of
146 maximal eccentric strength), followed by a rapid decline in force which occurred when the athlete was
147 no longer able to resist the effects of gravity acting on the segment above the knee joint.

148 **Injury histories**

149 For all athletes recruited who had sustained a unilateral HSI in the 12 months prior to the first testing
150 session, details of their injury history was obtained from their club clinician. Details obtained included

151 which limb was injured (dominant/non dominant limb), muscle injured (biceps femoris long
152 head/biceps femoris short head/semimembranosus/semitendinosus), location of injury
153 (proximal/distal, muscle belly/muscle-tendon junction), activity type performed at time of injury (i.e.
154 running/kicking etc.) and grade of injury (I, II or III). Importantly, all diagnoses were confirmed by
155 MRI performed 48-72 hours after the insult.

156 **Pre-season training programs**

157 With regards to prophylactic programs for the prevention of HSIs all clubs utilised the Nordic
158 hamstring exercise and stiff legged (or Romanian) deadlift as part of their training regimen. Typical
159 set and repetition ranges for the Nordic hamstring exercise were 2-4 sets for 6-10 repetitions. These
160 prophylactic exercises were completed at least on a weekly basis by all teams included in the study. In
161 addition there was a strong focus on exercises that aimed to increase eccentric hamstring strength
162 using a combination of bilateral and unilateral movements. Often athletes with a history of previous
163 HSI were prescribed additional eccentric exercise as part of efforts to further reduce their risk of re-
164 injury.

165 **Data analysis**

166 Force data for both limbs during the Nordic hamstring exercise was logged to a personal computer at
167 100 Hz through a wireless USB base station receiver (Mantracourt, Devon, UK). For both limbs
168 (left/right for the control group or injured/uninjured for the previously injured group) peak force for
169 each contraction was determined and maximal force generating capacity was expressed as an average
170 of the peak from three contractions (average peak force). This method of analysis was chosen because
171 it has displayed high test-retest reliability (intraclass correlation coefficients, 0.85 to 0.89).¹³ The
172 change in eccentric strength across pre-season was expressed in absolute units (Newtons) as well as
173 relative to the early preseason strength measure by taking the quotient of late preseason and early
174 preseason strength.

175 **Statistical analysis**

176 Data were screened and all test assumptions assessed to confirm the appropriateness of the analyses.
177 The change in eccentric hamstring strength across preseason was compared between the left and right
178 limbs of the control group and between the retrospectively injured and uninjured limbs in the
179 previously injured group using a two-tailed paired samples t-test. As no within group differences were
180 noted, the two limbs for each group were averaged. To compare between the control and previously
181 injured groups a univariate general linear model was employed with eccentric knee flexor strength at
182 the start of preseason used as a covariate to control for differences in baseline strength since it was
183 different between groups. Statistical significance was set at $p < 0.05$ and Cohen's d used to assess the
184 magnitude of the effect. Data are reported as mean differences \pm standard deviations or, if stated,
185 95% confidence interval (95%CI). All statistical analyses and assumption testing was performed using
186 SPSS version 19.0.0.1 (IBM Corporation).

187 **RESULTS**

188 Of the 17 athletes with a history of unilateral HSI in the prior 12 months, the injuries were distributed
189 accordingly: dominant limb (53%), biceps femoris long head (76%) and the proximal muscle-tendon
190 junction (53%) (Table 1). Time since the most recent HSI ranged from 1.5 to 12 months (median time
191 since injury, 4.4 months/19 weeks), with the rehabilitation time ranging from 19 to 79 days (median
192 rehabilitation time, 31 days). The distribution of these 17 athletes at each of the five participating club
193 was five, four, four, three and one athlete/s respectively. All athletes (and associated medical staff)
194 reported a strong emphasis on eccentric conditioning and high speed running during late stage
195 rehabilitation and in the lead up to return to play.

196 Descriptive statistics for both groups with respect to demographic data and absolute levels of
197 eccentric hamstring strength at the start and end of preseason can be found in Table 2. Whilst the
198 previously injured athletes presented with generally higher level of eccentric strength compared to the
199 control group, the only significant differences was the left limb from the control group was weaker
200 than the uninjured limb in the previously injured limb ($p = 0.020$) With respect to the change in
201 eccentric hamstring strength across pre-season, the left and right limbs in the control group showed no

202 difference in either absolute or relative measures of change (left limb absolute change, $60.7 \pm 72.9\text{N}$;
203 relative change, 1.28 ± 0.34 ; right limb absolute change, $48.6 \pm 83.8\text{N}$; relative change, 1.24 ± 0.43)
204 (Table 3). Similarly, the injured and uninjured limbs from the previously injured group showed no
205 difference in either absolute or relative measures of change (injured limb absolute change,
206 $13.1 \pm 57.7\text{N}$; relative change, 1.07 ± 0.18 ; uninjured limb absolute change, $14.7 \pm 54.0\text{N}$; relative
207 change, $1.07 \pm 0.22\text{N}$) (Table 3).

208 Given that there were no differences in the change in eccentric hamstring strength between the left
209 and right limb in the control group (left vs right; absolute change $p = 0.06$, $d = 0.15$, relative change, p
210 $= 0.29$, $d = 0.10$) the responses of the two limbs were averaged to give a mean control group change
211 in eccentric hamstring strength. Similarly, for the previously injured group, as there was no difference
212 between limbs (injured vs uninjured; absolute change, $p = 0.88$, $d = 0.03$, relative change, $p = 0.93$, d
213 $= 0.00$) the responses of the injured and uninjured limbs were also averaged to give a mean injured
214 group change in eccentric hamstring strength. The previously injured group displayed a significantly
215 smaller increase in eccentric hamstring strength across the preseason (absolute change, 13.9 ± 55.0 ;
216 relative change, 1.07 ± 0.20) compared to the control group (absolute change, 54.6 ± 78.5 ; relative
217 change, 1.26 ± 0.39) for both absolute and relative measures, even after controlling for differences in
218 start of pre-season eccentric hamstring strength. Start of pre-season eccentric hamstring strength had a
219 significant effect ($p < 0.001$) on both change in absolute and relative strength changes (Table 4).

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221 **DISCUSSION**

222 The present study aimed to determine if elite Australian footballers with a history of unilateral HSI
223 (within the prior 12 months) would display a smaller increase in eccentric hamstring strength across
224 the pre-season training period compared to athletes without a history of HSI. The major finding was
225 that the previously injured athletes displayed smaller increases in eccentric hamstring strength
226 compared to the control group athletes, who had no history of HSI in the prior 12 months.

227 Interestingly, the smaller increase in eccentric strength across pre-season was not restricted to the

228 previously injured limb, as the injured and uninjured limb strength increases did not differ.

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230 This study is, to the authors' knowledge, the first to examine the change in eccentric hamstring
231 strength across the pre-season training period in elite Australian footballers. One paper, a randomised
232 control trial (RCT) in elite Swedish soccer players, has examined the impact of augmented eccentric
233 training, via flywheel ergometer, for the hamstrings across 10 weeks of preseason training and
234 reported a ~19% increase in eccentric hamstring torque.² The improvements in the control group in
235 the present study is similar in magnitude (15-20%) to those reported by Askling et al. (2003)² in the
236 training arm of their trial, however the impact of previous HSI on eccentric strength improvements
237 was not examined.

238 The finding that athletes, with a history of HSI, displayed a smaller increase in eccentric strength
239 during pre-season might have implications for recurrent injuries. Given the retrospective nature of
240 these observations it is impossible to determine whether a lesser increase in eccentric strength is the
241 result of injury and/or a predisposing factor that lead to the initial insult. It is also possible that a
242 heavy focus on eccentric exercise during the late stage of rehabilitation could influence the change in
243 eccentric hamstring strength during the subsequent preseason training period. Regardless, given the
244 established link between prior HSI and increased risk of future injury in elite Australian football,^{6,25}
245 characteristics of previously injured athletes can help to identify variables that warrant further
246 investigation. Of interest, from the current dataset, is the possibility that athletes display variable
247 increases in eccentric hamstring strength (i.e. high and low responders, respectively) across preseason
248 training. As eccentric strengthening interventions^{2,19} and smaller between limb eccentric strength
249 imbalances²³ appear to reduce the risk of HSI, individuals with a reduced ability to increase eccentric
250 hamstring strength might be predisposed to a greater likelihood of future HSI. Further work should
251 consider the implementation of a standard eccentric hamstring strengthening intervention across a
252 large participant pool to determine the spectrum of strength increases, with these participants followed
253 prospectively to establish if there is a causative relationship with HSI. It should also be acknowledged
254 that rehabilitation processes would likely play a critical role in the recovery of eccentric strength

255 following HSI and might also influence the adaptive response to eccentric exercise. It would be of
256 interest to examine increases in eccentric strength and adaptive capacity in previously injured athletes
257 who are exposed to standardised rehabilitation protocols, such as those reported previously.³ It is also
258 intriguing that the injured athletes displayed smaller increases in eccentric strength across preseason
259 but, there was no difference noted between the injured and uninjured limbs within this group. This
260 raises the possibility that the persistent neuromuscular inhibition noted during eccentric contraction
261 following unilateral HSI,^{15 16 22} may be mediated by central mechanisms and as such has bilateral
262 effects. Furthermore, it is possible that differences between the injured and control groups, with
263 respect to eccentric hamstring strength at the start of preseason (i.e. baseline strength), may have
264 impacted on the improvements seen in strength across preseason. It might be argued that the higher
265 starting strength in the injured group would limit their scope for improvement across pre-season,
266 however on-going subsequent work from our group suggests that ~340N is not close to a maximal
267 strength capacity of most elite Australian footballers, with scores well in excess of 400N noted in well
268 trained athletes. When start of preseason eccentric strength was controlled for, as a covariate in the
269 analysis, differences between the groups still persisted. .It should also be noted that when examining
270 the increase in eccentric hamstring strength in athletes from both groups in the bottom quartile for
271 eccentric strength at the start of preseason, the control group athletes (average start preseason strength
272 195N) displayed a ~55% increase in eccentric strength compared to the previously injured group
273 (average start preseason strength 194N) which increased ~20%.

274 The suppression of eccentric hamstring strength gains in the previously hamstring strain injured
275 athlete, as reported in the current study, is intriguing as a large RCT has shown that the
276 implementation of the Nordic hamstring exercise during preseason in soccer players resulted in a
277 significant reduction in the rate of reinjury.¹⁹ It would be reasonable to posit that the significant
278 reduction in reinjuries was conferred by an increase in eccentric hamstring strength following the
279 Nordic hamstring exercise intervention¹². The results from the current study suggest that eccentric
280 strength improvements may have been restricted in the previously injured athletes, however the cohort
281 from the RCT¹⁹ consisted of soccer players without a history of eccentric training of the hamstrings

282 prior to the intervention, which differs significantly from elite Australian footballers who employ
283 targeted eccentric exercise, as part of the late stages of rehabilitation and return to play, and generally
284 for prevention of HSI. It remains to be seen if greater magnitudes of, or larger improvements in,
285 eccentric hamstring strength, assessed during the performance of the Nordic hamstring exercise,
286 reduces risk of future HSI.

287 Besides a history of unilateral HSI, other factors may be responsible for the divergent responses
288 between the two groups. Firstly, the strong focus on eccentric exercise during the late stages of
289 rehabilitation has the potential to influence eccentric strength and the change in strength across the
290 preseason period. Indeed, the lack of a between limb strength imbalance in the previously injured
291 group at the start of preseason (1.3%), which was much lesser than previous reports using the current
292 strength assessment device (15%)¹³, is suggestive that rehabilitation in this cohort aimed to minimise
293 any deficits in eccentric strength. The influence of rehabilitation procedures, across the spectrum of
294 HSI severities, on long-lasting deficits in function and response to training stimulus is an area of great
295 interest for future investigations. Secondly, the physiological demands of Australian football require
296 athletes at the elite level to possess high aerobic and anaerobic fitness, maximal sprint speed, repeat-
297 sprint performance and strength and power qualities.⁷ These diverse demands require an intense
298 training load for athletes, particularly during preseason training. However speculative, it is possible
299 that the multiple physiological demands of preseason training might minimise improvements in
300 certain performance markers in some athletes.¹⁰ If some athletes struggle to improve strength/power
301 qualities (such as eccentric hamstring strength), then it would be reasonable to suggest that their risk
302 of HSI would be greater.⁴ It is possible, that the athletes from the previously injured group in the
303 current work had, in prior seasons, improved eccentric hamstring strength minimally due to the
304 competing demands of preseason training, predisposing them to injury, and that phenomena (a low
305 responder to strength training) was measured here more so than the impact of prior injury. The
306 complex interaction of the numerous factors that can impact on strength gains during preseason
307 training in elite athletes certainly requires greater focus, particularly given the important role strength
308 plays in injury prevention.¹¹

309 There are some limitations inherent to this study. The investigators had no control over the pre-season
310 training programs of any team involved (as is to be expected in an elite sporting environment), as this
311 study was purely observational. Whilst we were able to report general details of the pre-season HSI
312 prophylactic program, we are not able to make comment as to whether differing training programs
313 between individuals and/or teams may have influenced the findings. In spite of this, these
314 observations were made on 99 athletes across five elite Australian football teams, suggesting that the
315 results may be generalisable within this sport. Furthermore, HSI history was confined to the previous
316 12 months to minimise reporting error and this neglects HSIs which occurred prior to this time period.
317 Severe HSIs sustained more than 12 months ago may have confounded the current findings.
318 Importantly, however, all HSIs were confirmed by MRI to eliminate the inclusion of athletes suffering
319 referred pain posterior thigh injury and this is a strength of the current investigation.²⁵ Finally, whilst
320 the study was sufficiently powered to detect between group differences, given the relatively small
321 sample of previously injured athletes, it was underpowered to explore the possible impact of time
322 since injury, the number and severity of previous HSIs, rehabilitation type and length and the possible
323 role of other lower limb injuries on improvements in eccentric hamstring strength across preseason. A
324 larger study examining a more homogenous sample of HSIs, powered to include additional covariates
325 is warranted in future. A larger sample would also allow for analysis to control for cluster effects by
326 team, which was not possible with the current sample size.

327 In conclusion, elite Australian footballers with a unilateral history of HSI within the previous 12
328 months display a greater baseline level of and a smaller increase in eccentric hamstring strength
329 through the pre-season training period, compared to their control group counterparts. Interestingly,
330 this diminished response was not confined to the previously injured limb but was also observed in the
331 contralateral uninjured limb, which might suggest that the effects of prior HSI may be centrally
332 mediated. The existence of high and low responders to eccentric exercise and the impact on future
333 HSI risk is worthy of further examination.

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431 **FIGURE CAPTIONS**

432 **Figure 1. Performing the Nordic hamstring exercise using the novel device (progressing from**
433 **left to right). The participant controls the speed of the fall by forceful eccentric contraction of**
434 **the knee flexors. After the completion of the exercise, the participant slowly returns to the**
435 **starting position by pushing back up with both hands (not shown). The ankles are secured**
436 **independently in individual custom-made braces.**

437 **Figure 2. Close up view of the ankle brace and load cell organisation with participant limb in**
438 **position during Nordic hamstring exercise.**

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452 **TABLES**

453 Table 1: Details of prior hamstring strain injuries sustained by athletes from the injured group

Participant number	Limb injured	Muscle injured	Location of injury	Activity type at time of injury	Rehabilitation time for most recent injury (days)	Time betw recent inj strength t (weeks)
1	D	SM	Proximal MTJ	Running	62	14
2	D	BFlh	Distal MTJ	Running	31	17
3	D	BFlh	Proximal MTJ	Kicking	76	31
4	ND	ST	Muscle Belly	Running	25	24
5	ND	BFlh	Proximal MTJ	Running	19	9
6	ND	SM	Proximal tendon	Bending forward	79	30
7	D	ST	Distal MTJ	Running	21	52
8	D	BFlh	Proximal MTJ	Running	72	32
9	D	BFlh	Muscle belly	Running/kicking	32	15
10	D	BFlh	Muscle belly	Running	23	40
11	ND	BFlh	Muscle belly	Not defined	26	25
12	ND	BFlh	Proximal MTJ	Running	33	35
13	ND	BFlh	Proximal MTJ	Running	60	16
14	ND	BFlh	Distal MTJ	Running	23	19
15	D	BFlh	Proximal MTJ	Bending forward	35	6
16	ND	BFlh	Proximal MTJ	Running	21	12
17	D	BFlh	Proximal MTJ	Running	19	13

454 D, dominant; ND, non-dominant; SM, semimembranosus; BFlh, biceps femoris long head; ST,
 455 semitendinosus; MTJ, muscle-tendon junction.

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470 Table 2: Demographic and eccentric knee flexor strength data for athletes with (n=17) and without
 471 (n=82) a history of hamstring strain injury in the prior 12 months.

Uninjured group						
Age (years)	Height (cm)	Weight (kg)	Early preseason eccentric strength (N)		Late preseason eccentric strength (N)	
			Left limb	Right limb	Left limb	Right limb
22.6 ± 3.3	188.3 ± 7.6	87.8 ± 7.6	271.9 ± 74.8	290.8 ± 84.4	327.7 ± 73.5	336.9 ± 71.0
Previously injured group						
Age (years)	Height (cm)	Weight (kg)	Early preseason eccentric strength (N)		Late preseason eccentric strength (N)	
			Injured limb	Uninjured limb	Injured limb	Uninjured limb
23.3 ± 2.6	186.2 ± 6.5	85.9 ± 6.6	309.3 ± 91.2	319.8 ± 82.4	311.2 ± 78.1	326.9 ± 77.8

472 Data presented as mean ± standard deviation.

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Table 3: Absolute and relative change in eccentric knee flexor strength across preseason for athletes with (n=17) and without (n=82) a history of hamstring strain injury in the prior 12 months.

Group	Limb	Absolute change in eccentric strength (N) ±SD	Between limb difference (N) (95%CI)	p	Effect size [^]	Relative change [#] in eccentric strength ±SD	Between limb difference (95%CI)	p	Effect size [^]
Previously injured	Uninjured	14.7 ± 54.0	1.6			1.07 ± 0.22			
	Injured	13.1 ± 57.7	(-37.4 to 40.6)	0.88	0.03	1.07 ± 0.18	0.00 (-0.14 to 0.14)	0.934	0.00
Uninjured	Left	60.7 ± 72.9				1.28 ± 0.34			
	Right	48.6 ± 83.8	12.1 (-12.1 to 36.3)	0.06	0.15	1.24 ± 0.43	0.04 (-0.08 to 0.16)	0.291	0.10

[#]Change determined as the quotient of the late over early pre-season eccentric hamstring strength. [^]Cohen's *d* used to determine effect size. SD, standard deviation; 95%CI, 95% confidence interval.

Table 4: Average absolute and relative change of both limbs in eccentric knee flexor strength across preseason for the athletes with (n=17) and without (n=82) a history of hamstring strain injury in the prior 12 months.

Group	Absolute change in eccentric strength (N) ±SD	Between group difference (N) (95%CI)	p	Effect size [^]	Relative change [#] in eccentric strength ±SD	Between group difference (95%CI)	p	Effect size [~]
Previously injured	13.9 ± 55.0				1.07 ± 0.20			
Uninjured	54.6 ± 78.5	40.7 (1.0 to 80.4)	0.012*	0.60	1.26 ± 0.39	0.19 (0.0 to 0.38)	0.015*	0.73
Covariate effect (early pre-season eccentric strength)			<0.001 [~]				<0.001 [~]	

[#]Change determined as the quotient of the late over early pre-season eccentric hamstring strength. [^]Cohen's *d* used to determine effect size. SD, standard deviation; 95%CI, 95% confidence interval.

*Significant set at p<0.05 with start of preseason eccentric strength employed as a covariate in general linear model.

[~]Early pre-season strength had a significant effect as a covariate.