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**Acute adaptations and subsequent preservation of strength and speed measures  
following a Nordic hamstring curl intervention: a randomised controlled trial**

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## **Abstract**

This randomised controlled trial investigated changes in eccentric hamstring strength, 10 m sprint speed, and change-of-direction (COD) performance immediately post Nordic hamstring curl (NHC) intervention and following a 3-week detraining period.

Fourteen male team sports athletes were randomised to a do-as-usual control group (CG;  $n = 7$ ) or to a NHC intervention group (NHC;  $n = 7$ ). Isokinetic dynamometry at  $180^\circ/\text{s}$  evaluated eccentric hamstring strength immediately post-intervention as the primary outcome measure. Secondary outcomes included 10 m sprint time and COD. Each outcome was measured, pre, immediately post-intervention and following a 3-week detraining period.

Immediately post-intervention significant group differences were observed in the NHC group for eccentric hamstring strength ( $31.81 \text{ Nm}^{-1}$  vs.  $6.44 \text{ Nm}^{-1}$ ,  $P = 0.001$ ), COD ( $-0.12 \text{ s}$  vs.  $0.20 \text{ s}$ ;  $P = 0.003$ ) and sprint ( $-0.06 \text{ s}$  vs.  $0.05 \text{ s}$ ;  $P = 0.024$ ) performance. Performance improvements were maintained following a detraining period for COD ( $-0.11 \text{ s}$  vs.  $0.20 \text{ s}$ ;  $P = 0.014$ ) and sprint ( $-0.05 \text{ s}$  vs.  $0.03 \text{ s}$ ,  $P = 0.031$ ) but not eccentric hamstring strength ( $15.67 \text{ Nm}^{-1}$  vs.  $6.44 \text{ Nm}^{-1}$ ,  $P = 0.145$ )

These findings have important implications for training programmes designed to reduce hamstring injury incidence, whilst enhancing physical qualities critical to sport.

## **Keywords**

Change-of-direction; Eccentric strength; Hamstring; Performance; Resistance training

## 1 **Introduction**

2 Hamstring strain injuries (HSI) are the most prevalent non-contact injury in intermittent team  
3 sports (Brooks, Fuller, Kemp and Reddin, 2006; Ekstrand, Walden and Hagglund 2016; Feeley  
4 et al., 2007; Hickey, Shield, Williams and Opar, 2014), with incidence up to 37% (Brooks et  
5 al., 2006; Orchard, Seward & Orchard, 2013; Ekstrand et al., 2016). HSI causes considerable  
6 time lost from both match – play and training, with financial (Ekstrand et al., 2013) and  
7 performance (Hagglund et al., 2013) implications. Team sports are characterised by  
8 accelerations and quick changes of direction (Gabbett, King and Jenkins, 2008; Stolen,  
9 Chamari, Castanga & Wisloff, 2005), increasing the risk for HSI due to enhanced eccentric  
10 forces applied to the hamstring musculature (Barnes et al., 2014; Taylor et al., 2017). Despite  
11 a focus on HSI prevention (Al Attar, Soomro, Sinclair, Pappas & Sanders, 2017; Bourne et al.,  
12 2018; van der Horst et al., 2017), recurrence rates remain high with incidence in soccer  
13 increasing annually by approximately 2.3% between 2001 and 2014 (Ekstrand et al., 2016).  
14 Injury management programmes have subsequently been considered ineffective (Ekstrand,  
15 Hägglund, Kristenson, Magnusson & Waldén, 2013) or contradictory (Gambetta & Benton,  
16 2006) in relation to injury prevention and performance.

17  
18 Eccentric hamstring strength represents a modifiable risk factor for HSI (Croisier et al., 2008;  
19 Timmins et al., 2016). Eccentric strength training has been shown to reduce HSI incidence by  
20 ~ 70% when Nordic hamstring curl (NHC) exercises are adopted as part of an injury prevention  
21 programme (Petersen, Thorborg, Nielsen, Budtz-Jørgensen & Hölmich, 2011; van der Horst,  
22 Smits, Petersen, Goedhart & Backx, 2015). Despite this decrease in HSI, elite sports medical  
23 staff highlight the NHC as only the 5<sup>th</sup> most commonly used injury prevention exercise (McCall  
24 et al., 2014), with concerns cited in relation to delayed onset of muscle soreness (DOMS) and  
25 performance inhibition (Bahr, Thorborg, & Ekstrand, 2015; Van Hooren & Bosch, 2017).

26

27 The influence of the NHC exercise and associated gains in eccentric hamstring strength on  
28 important high-intensity movement actions such as sprint and change-of-direction (COD)  
29 speed, critical to sports performance, has received little consideration, with only a few previous  
30 studies (Ishoi et al., 2017; Mendiguchia et al., 2015) quantifying improvements in linear speed  
31 over distances < 20 m. However, intermittent team sports are also characterised by their multi-  
32 directional demands (Bishop & Girard, 2013; Taylor, Wright, Dischiavi, Townsend &  
33 Marmon, 2017), arguably placing greater emphasis on agility and COD speed. Furthermore, a  
34 hierarchical model of factors influencing COD performance has highlighted the influence of  
35 eccentric hamstring strength (Naylor and Greig, 2015), thus emphasising the necessity to  
36 understand whether eccentric exercises such as the NHC help improve COD performance.

37

38 Gains in sprint performance (Ishoi et al., 2017; Mendiguchia et al., 2015) have been the result  
39 of 7 – 10-week NHC interventions (Delahunt et al., 2016; Seymore et al., 2017), with improved  
40 eccentric hamstring strength observed after intervention periods of 6-weeks. Consequently, the  
41 aim of the current study was to evaluate the influence of a six-week NHC intervention on  
42 immediately post-intervention measures of isokinetic eccentric hamstring strength, linear and  
43 COD speed in male intermittent team sports players. A secondary aim was to investigate the  
44 residual training effect of the NHC intervention by assessing if speed, COD and eccentric  
45 hamstring strength was retained following a 3-week detraining period. This time period has  
46 relevance with respect to the off-season and the mid-season break employed in European soccer  
47 leagues (Funten, Faude, Lensch & Meyer, 2014).

48

49

50

## 51 **Materials and Methods**

### 52 *Trial Design*

53 A single assessor-blinded randomised controlled superiority study was conducted as a repeated  
54 measures design whereby participants partook in a pre-test (0-weeks), immediately post-  
55 intervention (6-weeks), and following a 3-week detraining period (9-weeks). The independent  
56 variable within the study is treatment in the form of Nordic hamstring exercises. The NHC  
57 group performed NHCs in addition to their normal training and match-play, whereas, the CG  
58 performed their regular training and matches only. The primary outcome measure was pre-post  
59 intervention differences in eccentric hamstring strength, recorded immediately post-  
60 intervention. Secondary outcome measures included COD and 10-m sprint time. Ethical  
61 approval was obtained from the institutional ethics committee, in accordance with the Helsinki  
62 declaration.

63

### 64 *Participants*

65 To prospectively consider participant drop-out, sixteen amateur intermittent team sports  
66 (Soccer,  $n = 8$ ; Rugby League,  $n = 8$ ) athletes from the North-West region of the United  
67 Kingdom were recruited for the study. Upon completion of baseline testing, a staff member not  
68 involved in the study randomly allocated participants into an NHC group ( $n = 8$ , age:  $20.13 \pm$   
69  $1.55$  years, height:  $180.88 \pm 7.88$  cm, mass:  $75.38 \pm 7.10$  kg) or a CG ( $n = 8$ , age:  $20.86 \pm$   
70  $1.57$  years, height:  $178.00 \pm 8.41$  cm, mass:  $77.14 \pm 7.39$  kg). Eligibility criteria required  
71 participants to be male, 18-25 years old with no previous lower limb injury in the past 6 months  
72 and team sports players completing a minimum of two intermittent team training sessions per  
73 week and one match. To maximise balance across groups for variables such as age, height,  
74 mass, strength and speed, randomisation occurred using the minimisation process. A member  
75 of staff not involved in the study managed the randomisation process using sealed opaque

76 envelopes, which contained the name of a single participant. Starting with the intervention  
77 group, participants were alternately allocated to the relevant group. The randomisation  
78 procedure was concealed from all research personnel.

79

80 **\*Insert Figure 1 near here\***

81

## 82 *Study Settings*

83 The current study was conducted between October – December, 2017. During this period,  
84 participants generally had two intermittent team sport training sessions (~ 4 h) and one match  
85 per week. All testing procedures were conducted in a laboratory-controlled environment at the  
86 same time of day to control for possible diurnal variation (Thun, Bjorvatn, Flo, Harris &  
87 Pallesen, 2015). Participants were instructed to refrain from vigorous physical activity 48 h  
88 prior to testing.

89

## 90 *Intervention*

91 The NHC exercise was initiated in a kneeling position with the torso maintained up-right (van  
92 der Horst et al., 2015). The partner then applies pressure to the participant's heels/ankles to  
93 maintain feet contact with the ground (van der Horst et al., 2015). Performing the exercise  
94 involves the participant slowly lowering their torso to the ground, whilst maintaining a straight  
95 back, and resisting the effects of gravity using their hamstring muscles for as long as possible  
96 (Bourne, Opar, Williams & Shield, 2016). The player's hands are used to break the forward  
97 fall, followed by a push to return to the initial kneeling position, and minimize concentric  
98 loading (Mjølsnes et al., 2004; van der Horst et al., 2015).

99

100 Each participant was trained individually by the principal investigator and supplied with a  
101 weekly completion chart (Table 1) to ensure that participants adhered to the correct  
102 performance (van der Horst et al., 2015). The participants completed two sessions per week  
103 with the number of sets and repetitions gradually progressed throughout the programme  
104 (Mjølsnes et al., 2004; Sebelien et al., 2014). The NHC intervention was delivered prior to the  
105 training sessions as they are advocated as a component of the Federation Internationale de  
106 Football Association (FIFA) 11<sup>+</sup> warm-up routine (Bizzini, Junge & Dvorak, 2013), which has  
107 been shown to reduce overall injury incidence (Owoeye, Akinbo, Tella & Olawale, 2014;  
108 Silvers et al., 2015).

109

110 **\*Insert Table 1 near here\***

111

112 ***Outcomes***

113 Each testing session was conducted by a blind assessor. A minimum of 48 h recovery was  
114 provided between strenuous exercise and each testing session. Prior to each testing session, a  
115 warm-up was performed, consisting of 5-minutes jogging, progressing to sprinting, followed  
116 by 5-minutes of dynamic stretches (Sebelien et al. 2014). After each testing procedure, a 5-  
117 minute rest period was adhered to. Participants had an initial briefing period at the first testing  
118 session, and three trial tests until familiar with each procedure and NHC exercise performance  
119 (Mjølsnes et al., 2004). Participants were asked to wear similar apparel and the same exercise  
120 shoes for each testing session to reduce the influence of shoe properties on sports performance  
121 (Malisoux, Gette, Urhausen, Bomfim & Theisen, 2017). To provide a consistent and  
122 standardised testing environment, no verbal feedback nor motivation was provided during any  
123 of the testing sessions.

124



### 125 *Eccentric Isokinetic Hamstring Strength*

126 Unilateral eccentric hamstring strength was assessed using the participant's dominant limb,  
127 defined by their preferred kicking leg (Mjølsnes et al., 2004), using an isokinetic dynamometer  
128 (IKD) (Biodex Medical System 2, Shirley, New York) at  $180^{\circ}\text{s}^{-1}$ . This speed was selected as  
129 being representative of the average angular velocity exhibited during the  $180^{\circ}$  COD task used  
130 in the current study (Greig, 2009). Prior to each isokinetic test, participants were provided with  
131 three familiarisations trials followed by three warm-up repetitions (Mjølsnes et al., 2004). The  
132 dynamometer set-up was adjusted for each individual participant in accordance with  
133 manufacturer guidelines. Participants were seated securely in  $\sim 90^{\circ}$  of hip flexion, with  
134 restraints applied proximally to the knee joint, thigh, waist, and ankle and across the chest. The  
135 lever arm was then visually aligned with the knee joint's axis of rotation (Eustace, Page and  
136 Greig, 2017). No verbal feedback nor motivation was provided during the IKD trials. Three  
137 maximal efforts were performed, with the best effort utilized for determining peak torque (Nm).

138

### 139 *10 m Sprint*

140 10-m sprints were assessed using two single-beam timing gates (SmartSpeed, Fusion Sport,  
141 Australia), set at a standing torso height. A 10 m distance was chosen as the number of maximal  
142 short distance  $< 10$  m sprints has increased in professional soccer in recent years (Barnes et al.,  
143 2014). Participants were required to perform 3 maximal sprints from a standing position with  
144 the front foot placed in line with the first timing gate (Ishøi et al., 2017). Timing started when  
145 the participants passed the first timing gate at 0-m and was recorded when they passed the  
146 second timing gate at 10-m. Only the best attempt (least time taken to complete the 10 m  
147 distance) was considered for analysis. Participants adhered to a 3-minute passive rest period  
148 following completion of each sprint (Marques & Izquierdo, 2014).

149

## 150 **COD**

151 Change-of-direction (COD) was assessed via a linear 20-m, 180° COD test, adapted from  
152 previous research (Sasaki, Nagano, Kaneko, Sakurai & Fukubayashi, 2011; Lockie, Schultz,  
153 Callaghan, Jeffries & Berry, 2013), using one single-beam timing gate (SmartSpeed, Fusion  
154 Sport, Australia) positioned at the start line. Each test was performed from a standing position  
155 with the foot placed on the 0-m start line. Participants were instructed to run as fast as they  
156 could to the 10-m line, where they were then required to perform a 180° turn and sprint back  
157 to the starting point. A 180° turn was utilised to elicit a rapid deceleration, as such requiring an  
158 eccentric overload of the hamstring musculature. Participants performed three familiarisation  
159 trials (Mjølsnes et al., 2004) followed by three recorded trials, with the best trial used for data  
160 analysis. A passive rest period of 3 minutes was allocated after each trial.

161

## 162 **Statistical Methods**

163 Post hoc power analyses were completed using G\*Power software (v.3.1, Heinrich-Heine-  
164 Universitat, Dusseldorf, Germany), with the statistical analyses performed using the primary  
165 outcome measure, eccentric strength. The partial eta squared values generated for the between  
166 group differences at 6 weeks was used to generate effect size  $f$  values to subsequently calculate  
167 statistical power. The power analyses identified that the current sample size ( $n = 14$ ) elicited  
168 an observed statistical power for pre to post difference of 0.997.

169

170 Data was checked for normality *a priori*, using histograms, q-q plots, skewness and kurtosis,  
171 and a Shapiro-Wilk test. Mauchly's test of Sphericity was performed for the dependent  
172 variables, with a Greenhouse Geisser correction included if test significance was indicated. For  
173 the analysis of the primary (eccentric hamstring strength) and secondary (10 m sprint, COD)  
174 outcomes, an analysis of covariance (ANCOVA) using the baseline score as the covariate was

175 performed to examine differences in the physical response between the two groups (NHC and  
176 CG) over the intervention period. Where significant main effects or interactions were observed,  
177 post-hoc pairwise comparisons with a Bonferonni correction factor was applied, with 95%  
178 confidence intervals (CI) for differences also reported. Cohen's *d* effect sizes were calculated  
179 using pooled SD data and were classified as trivial (< 0.20 – 0.49), moderate (0.50-0.79) and  
180 large (> 0.80) (Cohen, 1992). Between session reliability was assessed using intraclass  
181 correlation coefficients (ICC), from which standard error of measurement (SEM) and minimal  
182 detectable difference were calculated. SEM was calculated using the formula:  $SD\ Pooled \times$   
183  $(\sqrt{1 - ICC})$  (Thomas, Nelson & Silverman, 2005), whilst MDD was calculated using the  
184 formula:  $MDD = SEM \times 1.96 \times \sqrt{2}$  (Weir, 2005)

185

186 The fragility index (Walsh et al., 2014) was calculated for the primary outcome measure to  
187 determine the robustness of statistically significant results. All statistical analysis was  
188 completed using PASW Statistics Editor 22.0 for Windows (SPSS Inc, Chicago, USA), with  
189 statistical significance set at  $P \leq 0.05$ . All data is reported as mean  $\pm$  standard deviation unless  
190 otherwise stated.

191

## 192 **Results**

### 193 *Participants*

194 14 participants completed the study ( $n = 7$ , age:  $20.47 \pm 1.32$  years, height:  $179.81 \pm 7.45$  cm,  
195 mass:  $75.54 \pm 7.14$  kg), CG ( $n = 7$ , age:  $21.01 \pm 1.64$  years, height:  $178.12 \pm 8.49$  cm, mass:  
196  $77.64 \pm 7.48$  kg), with two participants lost due to injury unrelated to the NHE and/or team  
197 transfer. The intervention group had a mean compliance of 94.05%.

198

199

### 200 *Primary Outcome Measure*

201 The NHC group demonstrated significant immediately post-intervention mean change  
202 improvements in eccentric hamstring strength (31.81 Nm<sup>-1</sup> vs. 6.44 Nm<sup>-1</sup>; mean difference,  
203 29.46 Nm<sup>-1</sup>, P = 0.001, *d* = 2.55) when compared to the CG. Additionally, the mean change at  
204 the same testing session, exceeded the MDD (16.93 Nm<sup>-1</sup>). No significant group main effects  
205 for mean change were observed following the three-week detraining period (15.67 Nm<sup>-1</sup> vs.  
206 6.44 Nm<sup>-1</sup>; mean difference 8.73 Nm<sup>-1</sup>, P = 0.145, *d* = 0.73). There were 7 and 0 responders in  
207 the NHC and CG respectively. The immediately post-intervention eccentric hamstring strength  
208 became non-significant when the P value was recalculated using the Fishers exact test and one  
209 participant was converted from not having the primary endpoint to having the primary endpoint  
210 (P ≥ 0.05), thus providing a fragility index of 2, equating to ~ 28% of the participants. Figure  
211 2 highlights the individual responses for each participant across the three time points, in  
212 addition to the mean group response.

213

214 **\*Insert Figure 2 here\***

215

### 216 *Secondary Outcome Measures*

217 As highlighted in table 2, the NHC group demonstrated significantly greater mean changes in  
218 COD (-0.12 s vs. 0.20 s; mean difference, -0.332 s, P = 0.003, *d* = 2.17) when compared to the  
219 CG immediately post-intervention. The same observation was observed following the  
220 detraining period, with significantly greater mean changes observed in COD (-0.11 s vs. 0.20  
221 s; mean difference, - 0.235 s, P = 0.014, *d* = 1.38) when compared to the CG. The mean change  
222 for the NHC group surpassed and equalled the minimal detectable difference (MDD = 0.11 s)  
223 for the immediately post-intervention (-0.12 s) and following detraining (-0.11 s) periods

224 respectively. Figure 3 highlights the individual responses for each participant across the three  
225 time points, in addition to the mean group response.

226

227 **\*Insert Figure 3 here\***

228

229 Between group differences in mean change analyses highlighted a significant improvement in  
230 10 m sprint performance for the NHC group (- 0.06 s vs. 0.05 s; mean difference, - 0.115 s, P  
231 = 0.024,  $d = 1.78$ ) immediately post-intervention testing session when compared to the CG. An  
232 identical response was also observed the following the detraining period, with enhanced mean  
233 changes observed in the NHC group (-0.05 s vs. 0.03 s; mean difference, -0.105 s, P = 0.031,  
234  $d = 1.17$ ) when compared to the CG. The mean change for the NHC group exceeded the MDD  
235 (0.03 s) immediately post-intervention (- 0.06 s) and following the three-week detraining  
236 period (-0.05 s).

237

238 Figure 4 highlights the individual responses for each participant across the three time points,  
239 in addition to the mean group response.

240

241 **\*Insert Figure 4 here\***

242 **\*Insert Table 2 near here\***

243 ***Harms***

244 No harms were observed during the execution of the NHC.

245

246 **Discussion**

247 The purpose of this study was to investigate the effects of a 6-week NHC programme on  
248 primary outcome measures of eccentric strength, and secondary outcome measures of COD

249 and 10-m sprint performance immediately post-intervention, whilst also investigating the  
250 effects of a 3-week detraining period. The key findings demonstrate that immediately post-  
251 intervention, a 6-week NHC intervention programme significantly improved COD and 10 m  
252 sprint performance, concomitantly with improvements observed in measures of eccentric  
253 hamstring strength. Furthermore, performance gains in 10 m sprint and COD direction speed  
254 were maintained following a 3-week detraining period. This suggests players who have  
255 completed a sustained period of NHC training may retain performance of important high-  
256 intensity movement qualities for a short-term period of up to 3 weeks. These findings have  
257 important implications for training programme design and scheduled or enforced rest periods  
258 (such as the winter break in European soccer).

259

260 Improvements (19.29%) in eccentric knee flexor torque were observed immediately post-  
261 intervention within the NHC group, whereas only negligible (1.61%) enhancements were  
262 observed within the CG. These enhancements are similar to the 11 – 17% improvements  
263 observed using various measures of eccentric hamstring strength following a 10-week NHC  
264 programme (Mjølsnes et al., 2004; Ishøi et al., 2017). It has been demonstrated that shorter and  
265 longer programme durations both demonstrate improvements in eccentric hamstring strength,  
266 as strength enhancements initially result in neural adaptations after 3 – 4 weeks, followed by  
267 architectural changes (Seynnes, de Boer & Narici, 2007; Douglas, Pearson, Ross, & McGuigan,  
268 2017). With sport-specific fatigue highlighted as a potential risk factor for HSI (Woods et al.,  
269 2003; Page, Marrin, Brogden and Greig, 2017; Timmins et al., 2014), improvements in  
270 eccentric hamstring strength could help to reduce HSI rates (Mjølsnes et al., 2004; Petersen et  
271 al., 2011; van der Horst et al., 2015; Timmins et al., 2016). In fact, it has been suggested that  
272 an increase in strength capacity provides an enhanced force threshold, thereby increasing the  
273 margin to which elevated HSI risk may occur (Timmins et al., 2016).

274

275 Improvements in performance were observed in the COD task, with a 2.77% decrease in 20-m  
276 180° COD time highlighted in the NHC group. This is the first study to observe the individual  
277 contribution of an NHC intervention on COD performance. Alternative studies have reported  
278 positive effects in COD speed from eccentric training in soccer (de Hoyo et al., 2016; Tous-  
279 Fajardo, Gonzalo-Skok). Tous-Fajardo et al. (2016) observed that eleven weeks of eccentric  
280 exercises alongside vibration training improved 45° COD performance by 5.5%. However,  
281 NHC were one of eight exercises performed, making it difficult to conclude that NHC was  
282 directly responsible for enhanced COD speed. Additionally, kinematic parameters, such as  
283 braking and propulsive forces, significantly improved during 45° and 60° COD performances  
284 following a ten-week eccentric overload programme (de Hoyo et al., 2016). Fast changes of  
285 direction are critical for success in team sports (Gabbett, King and Jenkins, 2008; Stolen,  
286 Chamari, Castanga & Wisloff, 2005), requiring players to perform 3-dimensional  
287 accelerations, decelerations and rapid changes of direction that are high in mechanical load  
288 (Abdelkrim, Chouachi, Chamari, Chtara & Castagana, 2010; Stolen et al., 2005). The  
289 improvements in COD performance may be a result of enhancements in eccentric hamstring  
290 strength achieving greater braking forces, helping to maintain hip extensor torque, assist in  
291 dynamic trunk stabilisation (Jones, Bampouras & Marrin, 2009) and contribute to the storage  
292 and utilisation of elastic energy (Spiteri, Cochrane, Hart, Haff, & Nimphius, 2013; de Hoyo et  
293 al., 2016). Furthermore, Greig and Naylor (2017) reported that eccentric hamstring strength at  
294 the same 180°s<sup>-1</sup> used in the current study was the primary predictor of linear 10m sprint and  
295 T-test performance, accounting for 61% of the variation observed in T-test performance.

296

297 Improvements in eccentric hamstring strength may have facilitated the 3.5% reduction in 10-  
298 m sprint speed time, compared to a 2.6% increase in the CG. Ishøi et al. (2017) reported a 2.6%

299 decrease in sprint time over the same distance following a ten-week NHC programme in  
300 amateur soccer players. The results of the current study support two further studies, which  
301 observed 1.6 - 2.4% improvements in 5 - 10 m sprint performance in soccer players on  
302 completion of NHC training, in isolation or in conjunction with other exercises (Askling,  
303 Karlsson & Thorstensson, 2003; Mendiguchia et al., 2015). Whilst not of the same relative  
304 magnitude as the gains in eccentric hamstring strength, it has been suggested that a ~ 0.8%  
305 impairment in sprinting performance has a substantial negative effect on the likelihood of an  
306 athlete losing possession of ball against an opponent (Paton, Hopkins, & Vollebregt, 2001).  
307 With shorter sprint distances (< 10 m) increasing in soccer match-play frequency (Barnes et  
308 al., 2014), this further highlights the potential performance benefits of NHC intervention.  
309 Improvements in sprint performance reported may be due to the superior eccentric hamstring  
310 strength peak torque which has been demonstrated to be critical for producing greater  
311 magnitude of horizontal force production (Mendiguchia et al., 2015; Morin et al., 2015). The  
312 possible increase in horizontal force production may be due to enhanced efficiency of the  
313 stretch-shortening cycle (Cormie, McGuigan, & Newton, 2010), potentially improving neural  
314 adaptations, such as, rate of force development (Aagaard, 2003). Thus, in turn this may increase  
315 hamstring muscle activation, producing greater hip extensor force on ground contact, thereby  
316 increasing horizontal force production during propulsion and improving sprint performance  
317 (Mendiguchia et al., 2015; Morin et al., 2015).

318

319 Acute improvements in performance immediately post-intervention programme suggest that  
320 the intervention is successful. However, team sports are often subjected to periods of fixture  
321 congestion (Carling, Gregson, McCall, Moreira, Wong & Bradley, 2015), resulting in  
322 intervention programmes often being discarded (McCall et al., 2014) to allow players to  
323 prepare or compete in the subsequent match, potentially resulting in a detraining effect



324 (Gabbett, 2005). Consequently, it is imperative to determine whether these adaptations are  
325 maintained after the programme has ceased. The current study suggests that following a 3-  
326 week detraining period involving no NHC training stimulus, players maintained improvements  
327 in 10 m sprint and COD speed. The retention of improvements in key motor abilities is often  
328 referred to as residual training effects and could be a result of the repeated bout effect, which  
329 has been shown to last between several weeks and possibly up to six months (Nosaka,  
330 Sakamoto, Newton & Sacco, 2001). Sprinting and agility are highlighted as essential  
331 components of soccer performance (Barnes, Archer, Hogg, Bush & Bradley, 2014),  
332 consequently the ability to maintain improvements in 10 m sprint speed and COD ability  
333 following a 3-week detraining period should be of interest to sports coaches, players and  
334 medical staff alike.

335

336 However, it should be acknowledged that maintained improvements in COD and sprint  
337 performance were observed despite an approximately 10% decrease in eccentric hamstring  
338 strength when comparing the detraining period results to the immediately post-intervention  
339 testing session. This suggests that the maintenance of COD and sprint performance may be a  
340 result of other adaptations associated with NHC mechanical stimulus, such as: hypertrophic  
341 effects of type II muscle fibre cross-sectional area (Alt, Nodler, Severin, Knicker & Struder,  
342 2017), knee flexor/extensor muscle balance (Alt et al., 2017), increased fascicle length  
343 (Alonso-Fernandez Docampo-Blanco & Martinez-Fernandez, 2018; Bourne et al., 2016) and  
344 enhanced neuromuscular parameters (Delahunt et al., 2016). However, these measures were  
345 beyond the scope of the current study and future research may wish to investigate this area. An  
346 alternative thought could suggest that the NHC group maintained an 11% increase in eccentric  
347 hamstring strength, when compared to baseline levels. Consequently, it may be possible that a  
348 maintained increase of this magnitude is sufficient to preserve improvements in COD and sprint

349 performance. The decrease in eccentric hamstring strength observed following the detraining  
350 period also has potential implications for injury risk. These results suggest that removing the  
351 NHC stimulus can, within a period of three weeks, reduce the strength benefits gained from  
352 training. Consequently, this may have implications for practitioners regarding the scheduling  
353 and frequency of NHC when used in an attempt to reduce HSI incidence. However, it should  
354 be noted that although not significantly different, eccentric hamstring strength was increased  
355 by 11% in NHC group when compared to baseline.

356

357 Maintenance of sprint speed and COD ability were observed despite a non-significant reduction  
358 (9.79%) in eccentric knee flexor torque in the NHC group. These results are similar to previous  
359 research (Alonso-Fernandez, Docampo-Blanco & Martinez-Fernandez, 2018; Izquierdo et al.  
360 2007), which highlighted decreases in muscular strength and biceps femoris long head fascicle  
361 length. The reduction in eccentric knee flexor peak torque may lead to a decrease in strength  
362 and increase injury likelihood, as longer fascicles are often correlated with improvements in  
363 eccentric hamstring strength and reductions in injury rates (Bosquet et al., 2013; Guex,  
364 Degache, Morisod, Saily, & Millet, 2016).

365

366 NHC have recently been suggested to be ineffective (Ekstrand et al., 2013) or even  
367 contradictory (Gambetta & Benton, 2006) with regards to injury prevention and performance  
368 due to low adherence and implementation rates (McCall et al., 2014; Bahr, Thorborg, &  
369 Ekstrand, 2015). However, this study provides evidence suggesting that NHCs can improve  
370 important high-intensity movement actions critical to sports performance in addition to  
371 enhancing eccentric hamstring strength, which has been postulated to reduce HSI. Furthermore,  
372 recent research (Lovell et al., 2018) has suggested that performing injury prevention exercises,  
373 including NHC, on match day + 24 hours, reduces muscle damage and soreness when  
374 compared to match day + 72 hours. This is in conjunction with previous research (Presland et

375 al., 2017), which demonstrates that low volume NHC programs produce the same structural  
376 and functional changes as high volume programs. This suggests that sports teams could  
377 implement NHC as part of a complete holistic intervention program (Buckthorpe, Gimpel,  
378 Wright, Sturdy & Stride, 2018), including multi-joint exercises early in the typical training  
379 micro-cycle, to ensure that the exercise stimulus is not hindered during periods of fixture  
380 congestion (Lovell et al., 2018). Consequently, the current study suggests that medical staff  
381 may be able to remove or reduce the intervention for periods of up to 3 weeks during fixture  
382 congested periods and still maintain beneficial improvements in functional performance. This  
383 has implications for scheduled (e.g. training periodization) and enforced (e.g. winter break)  
384 breaks.

385

386 Caution should be taken when attempting to generalise the findings of this study beyond the  
387 amateur population and experimental design used. The current participants comprised a  
388 combination of both rugby league and soccer players. Although both sports share similar  
389 fundamental characteristics, there are distinct differences in the conditioning practices adopted  
390 by both sports and, as such, this could have influenced some elements of the data. However, in  
391 an attempt to reduce the influence of the aforementioned limitation, an equal number of soccer  
392 and rugby athletes were assigned to each group. Although achieving appropriate statistical  
393 power, the relatively small sample size should be noted, producing larger confidence intervals  
394 as a direct result, consequently the magnitude of association may be overestimated. Future  
395 studies should aim to investigate a similar study design with an increased sample size in elite  
396 populations comprising a singular intermittent team sport where hamstring injury incidence is  
397 problematic. Furthermore, the fragility index for the primary outcome measure (immediately  
398 post-intervention eccentric strength) was 2, indicating that two patients from the control group  
399 would need to be converted from not having the primary endpoint to having the primary

400 endpoint, at which point the primary outcome would lose statistical significance. A small  
401 number of studies (Khan et al., 2016; Walsh et al., 2014) have analysed the results of ~ 450  
402 randomised controlled trials, indicating the fragility index to be  $\leq 3$  in 25-30% of all outcomes  
403 analysed. Despite this, the fragility index of the primary outcome measure in the current study  
404 should be noted and results as such treated with caution.

405

406 Although each testing protocol was designed to replicate aspects of high-intensity movement  
407 actions critical to functional performance in team sports match play, these features vary in  
408 relation to competition level, player position and sport (Haugen et al., 2014). The 20 m 180°  
409 COD task was designed to elicit a rapid deceleration, as such requiring an eccentric overload  
410 of the hamstring musculature, however the authors acknowledge that the validity of this  
411 measure with regards to match-play in both rugby and soccer is yet to be investigated.  
412 Eccentric hamstring strength was tested at 180°s<sup>-1</sup> based on hierarchical modelling of factors  
413 influencing speed and agility (Greig and Naylor, 2017), and the average knee angular velocity  
414 observed during a 180° turn (Greig, 2009). Knee angular velocity during sprinting and kicking  
415 a ball can reach 840-1720°s<sup>-1</sup> (Kivi, Maraj, & Gervais, 2002; Kellis & Katis, 2007), and thus  
416 the impact of the NHC intervention on eccentric hamstring strength at different speeds might  
417 also be warranted. Furthermore, only the compliance of the NHC intervention was recorded,  
418 no other methods of lower-limb strength training were noted during the intervention period.  
419 However, the effects of such other lower-limb strength exercises were thought to be equally  
420 distributed between the groups (Moher et al., 2010). Finally, sensitivity analyses might also be  
421 applied to the duration of the training intervention and subsequent cessation period, and  
422 additional measures of sporting performance.

423

424

**425 Conclusions**

426 The 6-week NHC intervention programme resulted in significant improvements in eccentric  
427 hamstring strength and performance in 10 m sprint and COD speed immediately post-  
428 intervention, which was maintained following a 3-week detraining period. Consequently, it  
429 may be possible to manipulate the implementation of the NHC as both an injury prevention  
430 exercise whilst simultaneously improving functional performance.

431

432 **Disclosure of Interest:** The authors report no conflict of interest

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450 **References**

451 Aagaard, P. (2003). Training-Induced Changes in Neural Function. *Exercise and Sport Science*  
452 *Reviews*, 31(2), 61-67.

453 Abdelkrim, N. B., Chaouachi, A., Chamari, K., Chtara, M., & Castagna, C. (2010). Positional  
454 role and competitive-level differences in elite-level men's basketball players. *Journal of*  
455 *Strength and Conditioning Research*, 24(5), 1346-1355.

456 Al Attar, W. S. A., Soomro, N., Sinclair, P. J., Pappas, E., & Sanders, R. H. (2017). Effect of  
457 injury prevention programs that include the Nordic hamstring exercise on hamstring injury  
458 rates in soccer players: a systematic-review and meta-analysis. *Sports Medicine*, 47(5), 907-  
459 916.

460 Alonso-Fernandez, D., Docampo-Blanco, P., & Martinez-Fernandez, J. (2018). Changes in  
461 muscle architecture of biceps femoris induced by eccentric strength training with Nordic  
462 hamstring exercise. *Scandinavian Journal of Medicine & Science in Sports*, 28(1), 88-94.

463 Alt, T., Nodler, Y.T., Severin, J., Knicker, A.J., & Struder, H.K. (2018). Velocity-specific and  
464 time-dependent adaptations following standardised Nordic hamstring exercise training.  
465 *Scandinavian Journal of Medicine and Science in Sports*, 28, 65-76.

466 Askling, C., Karlsson, J., & Thorstensson, A. (2003). Hamstring injury occurrence in elite  
467 soccer players after pre-season strength training with eccentric overload. *Scandinavian Journal*  
468 *of Medicine & Science in Sports*, 13(4), 244-250.

469 Aus der Funten, M.D., Mchiro, M.D., Faude, O., Lensch, J., & Meyer, T. Injury characteristics  
470 in the German professional male soccer leagues after a shortened Winter break. *Journal of*  
471 *Athletic Training*, 49(6), 786 – 793.

- 472 Bahr, R., Thorborg, K., & Ekstrand, J. (2015). Evidence-based hamstring injury prevention is  
473 not adopted by the majority of Champions League or Norwegian Premier League football  
474 teams: the Nordic Hamstring survey. *British Journal of Sports Medicine*, 49(22), 1466-1471.
- 475 Barnes, C., Archer, D.T., Hogg, R.A., & Bradley, P.S. (2014). The evolution of physical and  
476 technical performance parameters in the English Premier League. *International Journal of*  
477 *Sports Medicine*, 35, 1 – 6.
- 478 Bishop, D. J. & Girard, O. (2013). Determinants of team-sport performance: implications for  
479 altitude training by team-sport athletes. *British Journal of Sports Medicine*, 47(1), 1 - 7.
- 480 Bizzini M., Junge A., & Dvorak J. (2013). Implementation of the FIFA 111 football warm up  
481 program: how to approach and convince the football associations to invest in prevention.  
482 *British Journal of Sports Medicine*, 47(12), 803-806.
- 483 Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). Physical demands of different positions  
484 in FA Premier League soccer. *Journal of Sports Science and Medicine*, 6(1), 63-70.
- 485 Bosquet, L., Berryman, N., Dupuy, O., Mekary, S., Arvisais, D., Bherer, L., & Mujika, I.  
486 (2013). Effect of Training Cessation on Muscular Performance: A Meta-Analysis.  
487 *Scandinavian Journal of Medicine and Science in Sports*, 23(3), 140 - 149.
- 488 Bourne, M. N., Opar, D. A., Williams, M. D., & Shield, A. J. (2016). Muscle activation patterns  
489 in the Nordic hamstring exercise: Impact of prior strain injury. *Scandinavian Journal of*  
490 *Medicine & Science in Sports*, 26(6), 666-674.
- 491 Bourne, M. N., Timmins, R. G., Opar, D. A., Pizzari, T., Ruddy, J. D., Sims, C., Williams, M.  
492 D., & Shield, A. J. (2018). An evidence-based framework for strengthening exercises to prevent  
493 hamstring injury. *Sports Medicine*, 48(2), 251-267.

- 494 Bourne, M.N., Duhig, S.J., Timmins, R.G., Williams, M.D., Opar, D.A., Al Najjar, A., ..... &  
495 Shield, A.J. (2016). Impact of the Nordic hamstring and hip extension exercises on hamstring  
496 architecture and morphology: implication for injury prevention. *British Journal of Sports*  
497 *Medicine*, 0, 1-9.
- 498 Brooks, J., Fuller, C. W., Kemp, S., & Reddin, D. B. (2006). Incidence, risk, and prevention of  
499 hamstring muscle injuries in professional rugby union. *The American Journal of Sports*  
500 *Medicine*, 34(8), 1297-1306.
- 501 Buckthorpe, M., Gimpel, M., Wright, S., Sturdy, T., & Stride, M. (2018). Hamstring muscle  
502 injuries in elite football: translating research into practice. *British Journal of Sports Medicine*,  
503 52(10), 628 – 629.
- 504 Carling, C., Gregson, W., McCall, A., Moreira, A., Wong, P., & Bradley, P.S. (2015). Match  
505 running performance during fixture congestion in elite soccer: Research issues and future  
506 directions. *Sports Medicine*, 45(5), 605 – 613.
- 507 Cohen, J. (1992). A power primer. *Psychological Bulletin*, 112(1), 155 – 159.
- 508 Croisier, J. L., Ganteaume, S., Binet, J., Genty, M., & Ferret, J. M. (2008). Strength imbalances  
509 and prevention of hamstring injury in professional soccer players. *The American Journal of*  
510 *Sports Medicine*, 36(8), 1469-1475.
- 511 De Hoya, M., Sañudo, B., Carrasco, L., Mateo-Cortes, J., Domínguez-Cobo, S., Fernandes, O.,  
512 Del Ojo, J. J., & Gonzalo-Skok, O. (2016). Effects of 10-week eccentric overload training on  
513 kinetic parameters during change-of-direction in football players. *Journal of Sports Sciences*,  
514 34(14), 1380-1387.



523 Delahunt, E., McGroarty M., de Vito, G., & Ditroilo, M. (2016). Nordic hamstring exercise  
524 training alters knee joint kinematics and hamstring activation patterns in young men. *European*  
525 *Journal of Applied Physiology*, 116, 663 – 672.

526 Delahunt, E., McGroarty, M., De Vito, G., & Ditrolio, M. (2016). Nordic hamstring exercise  
527 training alters knee joint kinematics and hamstring activation patterns in young men. *European*  
528 *Journal of Applied Physiology*. 116, 663 – 672.

529 Douglas, J., Pearson, S., Ross, A., & McGuigan, M. (2017). Chronic adaptations to eccentric  
530 training: a systematic review. *Sports Medicine*, 47(5), 917-941.

531 Ekstrand, J., Hägglund, M., Kristenson, K., Magnusson, H., & Waldén, M. (2013). Fewer  
532 Ligament Injuries but No Preventive Effect on Muscle Injuries and Severe Injuries: An 11-year  
533 follow-up of the UEFA Champions League Study. *British Journal of Sports Medicine*, 47(12),  
534 732-737.

535 Ekstrand, J., Waldén, M., & Hägglund, M. (2016). Hamstring injuries have increased by 4%  
536 annually in men's professional football, since 2001: a 13-year longitudinal analysis of the  
537 UEFA elite club injury study. *British Journal of Sports Medicine*, 50 (12), 731-737.

538 Eustace, S.J., Page, R.M., & Greig, M. (2017). Contemporary approaches to isokinetic strength  
539 assessments in professional football players. *Science and Medicine in Football*, 1(3), 251 –  
540 257.

547 Feeley, B.T., Kennelly, S., Barnes, R.P., Muller, M.S., Kelly, B.T., Rodeo, S.A., Warren, R.F.  
548 (2008). *American Journal of Sports Medicine*, 36(8), 1597-1603.

- 549 Gabbett, T., King, T., & Jenkins, D. (2008). Applied physiology of rugby league. *Sports*  
550 *Medicine*, 38(2), 119–138.
- 551 Gabbett, T.J. (2005). Changes in physiological and anthropometric characteristics of rugby  
552 league players during a competitive season. *Journal of Strength and Conditioning Research*,  
553 *19*(2), 400 - 408.
- 554 Gambetta, V., & Benton, D. (2006). A systematic approach to hamstring prevention and  
555 rehabilitation. *Sports Coach*, 28 (4), 1-6.
- 556 Greig, M (2009). The influence of soccer-specific activity on the kinematics of agility sprint.  
557 *European Journal of Sport Science*, 9(10), 23 - 30
- 558 Guex, K., Degache, F., Morisod, C., Saily, M. and Millet, G. P. (2016). Hamstring  
559 architectural and functional adaptations following long vs. short muscle length eccentric  
560 training. *Frontiers in Physiology*, 7(340), 1-9.
- 561 Hagglund, M., Wladen, M., Magnusson, H., Kristenson, K., Bengtsson, H., & Ekstrand, J.  
562 (2013). Injuries affect team performance negatively in professional football: an 11-year follow-  
563 up of the UEFA Champions League injury study. *British Journal of Sports Medicine*, 47(12),  
564 738 – 742.
- 565 Haugen, T., Tønnessen, E., Hisdal, J., & Seiler, S. (2014). The role and development of  
566 sprinting speed in soccer. *International Journal of Sports Physiology and Performance*, 9(3),  
567 432-441.
- 568 Hickey, J., Shield, A., Williams, M. D., & Opar, D. A. (2014). The financial cost of hamstring  
569 strain injuries in the Australian Football League. *British Journal of Sports Medicine*, 48(8),  
570 729-730.

- 571 Ishøi, L., Hölmich, P., Aagaard, P., Thorborg, K., Bandholm, T., & Serner, A. (2017). Effects  
572 of the Nordic Hamstring exercise on sprint capacity in male football players: A randomized  
573 controlled trial. *Journal of Sports Sciences*, *1*(0), 1-10.
- 574 Izquierdo, M., Ibañez, J., González-Badillo, J. J., Ratamess, N. A., Kraemer, W. J., Häkkinen,  
575 K., Bonnabau, H., Granados, C., French, D. N., & Gorostiaga, E. M. (2007). Detraining and  
576 tapering effects on hormonal responses and strength performance. *Journal of Strength and*  
577 *Conditioning Research*, *21*(3), 768-775.
- 578 Jones, P., Bampouras, T.M., & Marrin K. (2009). An investigation into the physical  
579 determinants of change-of-direction speed. *Journal of Sports Medicine and Physical Fitness*,  
580 *49*(1), 97 -104.
- 581 Kellis, E., & Katis, A. (2007). Biomechanical characteristics and determinants of instep soccer  
582 kick. *Journal of Sports Science and Medicine*, *6*(2), 154-165.
- 583 Khan, M., Evaniew, N., Gichuru, M., Habib, A., Olufemi, A., Bedi, A., ... Bhandari, M. The  
584 fragility of statistically significant findings from randomized trials in sports surgery. A  
585 systematic survey. *American Journal of Sports Medicine*, *45*(9), 2164-2170.
- 586 Kivi, D. M. R., Maraj, B. K., & Gervais, P. (2002). A Kinematic Analysis of High-Speed  
587 Treadmill Sprinting Over a Range of Velocities. *Medicine and Science in Sports and Exercise*,  
588 *34*(4), 662-666.
- 589 Lockie, R. G., Schultz, A. B., Callaghan, S. J., Jeffriess, M. D., & Berry, S. P. (2013).  
590 Reliability and validity of a new test of change-of-direction speed for field-based sports: The  
591 Change-of-Direction and Acceleration Test (CODAT). *Journal of Sports Science and*  
592 *Medicine*, *12*(1), 88-96.

- 593 Lovell, R., Whalan, M., Marshall, P.W.M., Sampson, J.A., Siegler, J.C., & Bucheit, M. (2018).  
594 Scheduling of Eccentric Lower-limb Injury Prevention Exercises during the Soccer micro-  
595 cycle: Which day of the week? *Scandinavian Journal of Medicine & Science in Sports*.
- 596 Malisoux, L., Gette, P., Urhausen, A., Bomfim, J., & Theisen, D. (2017). Influence of sports  
597 flooring and shoes on impact forces and performance during jump tasks. *PloS One*, *12*(10), 1-  
598 12.
- 599 Marques, M.C., & Izquierdo, M. (2014). Kinetic and kinematic associations between vertical  
600 jump performance and 10-m sprint time. *Journal of Strength and Conditioning Research*,  
601 *28*(8), 2366 – 2371.
- 602 McCall, A., Carling, C., Nédélec, M., Davison, M., Le Gall, F., Berthoin, S., & Dupont, G.  
603 (2014). Risk factors, testing and preventative strategies for non-contact injuries in professional  
604 football: current perceptions and practices of 44 teams from various premier leagues. *British*  
605 *Journal of Sports Medicine*, *48*(18), 1352-1357.
- 606 Mendiguchia, J., Martinez-Ruiz, E., Morin, J. B., Samozino, P., Edouard, P., Alcaraz, P. E.,  
607 Esparza-Ros, F., & Mendez-Villanueva, A. (2015). Effects of hamstring-emphasized  
608 neuromuscular training on strength and sprinting mechanics in football players. *Scandinavian*  
609 *Journal of Medicine & Science in Sports*, *25*(6), 621- 629.
- 610 Mjølsnes, R., Arnason, A., Østhagen, T., Raastad, T., & Bahr, R. (2004). A 10-week  
611 randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained  
612 soccer players. *Scandinavian Journal of Medicine & Science in Sports*, *14*(5), 311-317.

- 613 Moher, D., Hopewell, S., Schulz, K.F., Montori, V., Cotzsche, P.C., Devereaux, P.J., ...  
614 Altman, D.G. (2010). CONSORT 2010 explanation and elaboration: Updated guidelines for  
615 reporting parallel group randomised trials. *British Medical Journal*, 340, c869.
- 616 Morin, J. B., Gimenez, P., Edouard, P., Arnal, P., Jiménez-Reyes, P., Samozino, P., Brughelli,  
617 M., & Mendiguchia, J. (2015). Sprint Acceleration Mechanics: The major role of hamstrings  
618 in horizontal force production. *Frontiers in Physiology*, 6(404), 1-14.
- 619 Naylor, J., & Greig, M. A hierarchical model of factors influencing a battery of agility tests  
620 (2015). *Journal of Sports Medicine and Physical Fitness*, 55(11), 1329 – 1335.
- 621 Nosaka, K., Newton, M., & Sacco, P. (2002). Responses of human elbow flexor muscles to  
622 electrically stimulated force lengthening exercise. *Acta Physiologica Scandinavica*, 174(2),  
623 137 – 145.
- 624 Orchard, J. W., & Seward, H. (2010). Injury report 2009: Australian Football League. *Sports*  
625 *Health*, 28(2), 10-19.
- 626 Owoeye O.B., Akinbo S.R., Tella B.A., & Olawale O.A. (2014). Efficacy of the FIFA 11+  
627 warm-up programme in male youth football: a cluster randomised controlled trial. *Journal of*  
628 *Sports Science and Medicine*, 13(2), 321-328
- 629 Page, R., Marrin, K., Brogden, C.M., & Greig, M. (2017). The biomechanical and  
630 physiological response to repeated soccer-specific simulation interspersed by 48 Or 72 h  
631 recovery. *Physical Therapy in Sport*, 22, 81 – 87.
- 632 Paton, C. D., Hopkins, W. G., & Vollebregt, L. (2001). Little effect of caffeine ingestion on  
633 repeated sprints in team-sport athletes. *Medicine and Science in Sports and Exercise*, 33(5),  
634 822-825.

- 635 Petersen, J., Thorborg, K., Nielsen, M. B., Budtz-Jørgensen, E., & Hölmich, P. (2011).  
636 Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-  
637 randomized controlled trial. *The American Journal of Sports Medicine*, 39(11), 2296-2303.
- 638 Presland, J., Timmins, R., Bourne, M., Williams, M., & Opar, D. (2018). The effect of Nordic  
639 hamstring exercise training volume on biceps femoris long head architectural adaptation.  
640 *Scandinavian Journal of Medicine & Science in Sports*, 28(7) 1775 - 1783.
- 641 Presland, J.D., Timmins, R.G., Bourne, M.N., Williams, M.D., & Opar, D.A. (2018).
- 642 Sasaki, S., Nagano, Y., Kaneko, S., Sakurai, T., & Fukubayashi, T. (2011). The relationship  
643 between performance and trunk movement during change of direction. *Journal of Sports*  
644 *Science and Medicine*, 10(1), 112-118.
- 645 Sebelien, C., Stiller, C. H., Maher, S. F., and Qu, X. (2014). Effects of implementing Nordic  
646 hamstring exercises for semi-professional soccer players in Akershus, Norway. *Orthopaedic*  
647 *Practice*, 26(2), 90-97.
- 648 Seymore, K.D., Domire, Z.J., De Vita, P., Rider, P.M., & Kulas, A.S. (2017). The effect of  
649 Nordic hamstring strength training on muscle architecture, stiffness, and strength. *European*  
650 *Journal of Applied Physiology*, 117, 943 – 953.
- 651 Seynnes, O. R., De Boer, M., & Narici, M. V. (2007). Early skeletal muscle hypertrophy and  
652 architectural changes in response to high-intensity resistance training. *Journal of Applied*  
653 *Physiology*, 102(1), 368-373.
- 654 Silvers-Granelli, H., Mandelbaum, B., Adeniji, O., Insler, S., Bizzini, M., Pohlig, R., ...  
655 Dvorak, J. (2015). Efficacy of the FIFA 11+ injury prevention program in the collegiate male  
656 soccer player. *American Journal of Sports Medicine*, 43(11), 2628-2637.

- 657 Spiteri, T., Cochrane, J. L., Hart, N. H., Haff, G. G., & Nimphius, S. (2013). Effect of strength  
658 on plant foot kinetics and kinematics during a change of direction task. *European Journal of*  
659 *Sports Science*, 13(6), 646-652.
- 660 Stock, M. S., Olinghouse, K.D., Drusch, A.S., Mota, J.A., Hernandez, J.M., Akalonu, C.C., ...  
661 Thompson, B.J. (2015). Evidence of muscular adaptations within four weeks of barbell training  
662 in women. *Human Movement Science*, 45, 7-22.
- 663 Stølen, T., Chamari, K., Castagna, C., & Wisloff, U (2005). Physiology of soccer: an update.  
664 *Sports Medicine*, 35, 501–536.
- 665 Taylor, J. B., Wright, A. A., Dischiavi, S. L., Townsend, A. M. & Marmon, A. R. (2017).  
666 Activity demands during multi-directional team sports: A systematic review. *Sports Medicine*,  
667 47(12), 2533-2551.
- 668 Thomas, J.R., Nelson, J.K. & Silverman, S.J. (2005) *Research methods in physical activity* (3<sup>rd</sup>  
669 ed) Champaign, IL: Human Kinetics.
- 670 Thun, E., Bjorvatn, B., Flo, E., Harris, A., & Pallesen, S. (2015). Sleep, circadian rhythms, and  
671 athletic performance. *Sleep Medicine Reviews*, 23(0), 1-9.
- 672 Timmins, R. G., Bourne, M. N., Shield, A. J., Williams, M. D. Lorenzen, C., & Opar, D. A.  
673 (2015). Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of  
674 hamstring injury in elite football (soccer): A Prospective Cohort Study. *British Journal of*  
675 *Sports Medicine*, 50(24), 1524-1535.
- 676 Timmins, R.G., Opar, D.A., Williams, M.D., Schache, A.G., Dear, N.M., & Shield, A.J. (2014).  
677 Reduced biceps femoris myoelectrical activity influences eccentric knee flexor weakness after  
678 repeat sprint running. *Scandinavian Journal of Medicine & Science in Sports*, 24(4), 299 – 304.

- 687 Tous-Fajardo, J., Gonzalo-Skok, O., Arjol-Serrano, J. L., & Tesch, P. (2016). Enhancing  
688 change-of-direction speed in soccer players by functional inertial eccentric overload and  
689 vibration training. *International Journal of Sports Physiology and Performance*, 11 (1), 66-73.
- 690 Turner, A. N., Cree, J., Comfort, P., Jones, L., Chavda, S., Bishop, C., & Reynolds, A. (2014).  
691 Hamstring strain prevention in elite soccer players. *Strength and Conditioning Journal*, 36(5),  
692 10-20.
- 693 Van Der Horst, N., Backx, F., Goedhart, E. A., & Huisstede, B. M. (2017). Return to play after  
694 hamstring injuries in football (soccer): A worldwide Delphi procedure regarding definition,  
695 medical criteria and decision-making. *British Journal of Sports Medicine*, 51 (22), 1583-1591.
- 696 Van Der Horst, N., Smits, D. W., Petersen, J., Goedhart, E. A., & Backx, F. J. G. (2015). The  
697 preventive effect of the Nordic hamstring exercise on hamstring injuries in amateur soccer  
698 players: a randomized controlled trial. *American Journal of Sports Medicine*, 43(6), 1316-  
699 1323.
- 700 Van Hooren, B., & Bosch, F. (2017). Is there really an eccentric action of the hamstrings during  
701 the swing phase of high-speed running? Part 2: Implications for exercise. *Journal of Sports*  
702 *Sciences*, 35 (23), 2322-2333.
- 703 Walsh, M., Srinathan, S.K., McAuley, D.F., Mrkobrada, M., Levine, O., Ribic, C., ...  
704 Devereaux (2014). The statistical significance of randomized controlled trial results is  
705 frequently fragile: a case for a fragility index. *Journal of Clinical Epidemiology*, 67(6), 622-  
706 628.
- 707 Weir, J.P. (2012). Quantifying the test-retest reliability using the intraclass correlation  
708 coefficient and the SEM. *Journal of Strength and Conditioning Research*, 19(1): 153-164.



709 Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The  
710 Football Association Medical Research Programme: An audit of injuries in professional  
711 football – analysis of hamstring injuries. *British Journal of Sports Medicine*, 38(1), 36-41.

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727 **Table 1: Nordic Hamstring Exercise Protocol**

<b>Week</b>	<b>Frequency per week</b>	<b>No. of sets per training</b>	<b>Repetitions per set</b>
1	1	2	5
2	2	2	6
3	2	3	6
4	2	3	6, 7, 8
5	2	3	8, 9, 10
6	2	3	10, 9, 8

728 (van der Horst et al., 2015)

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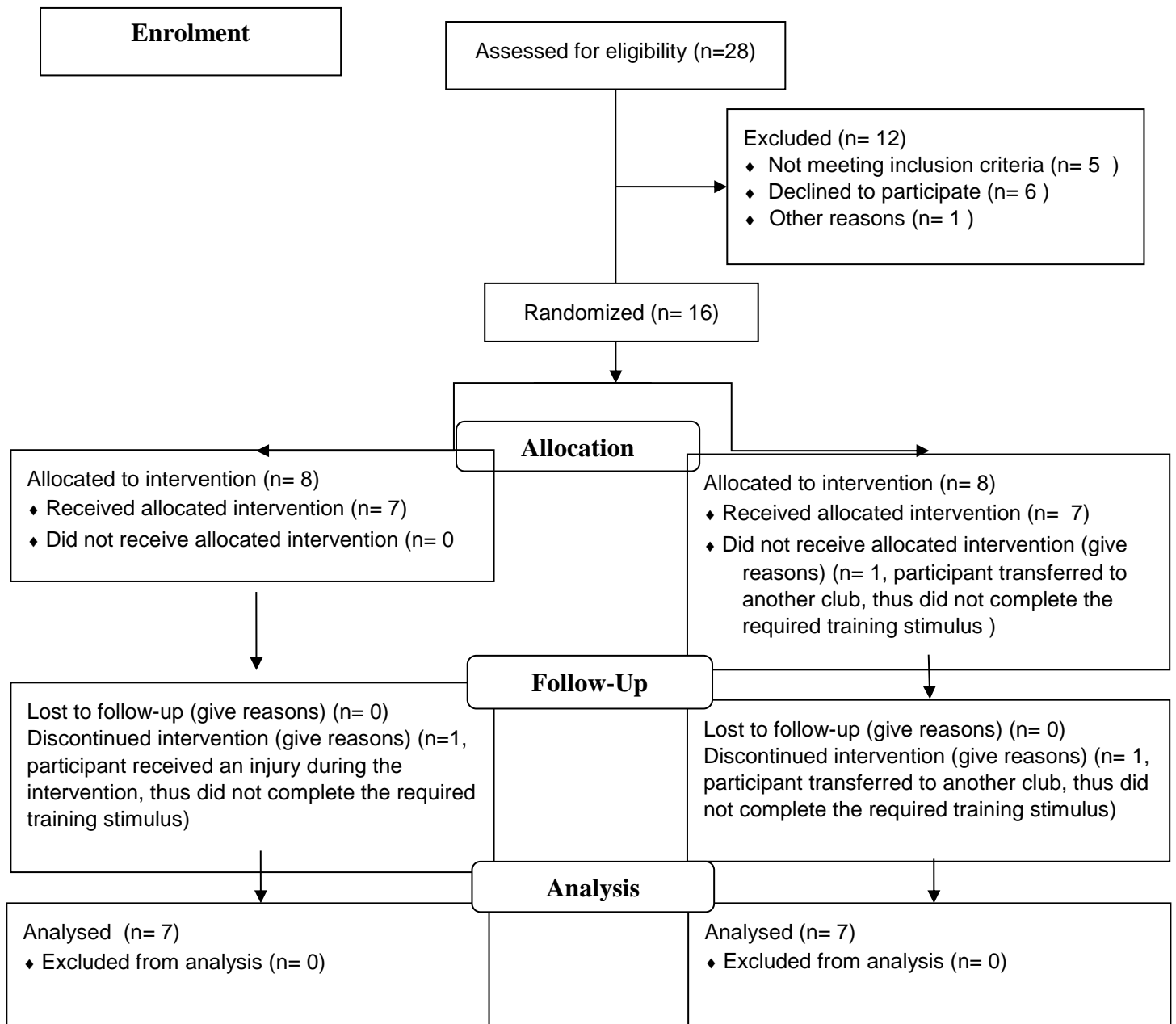
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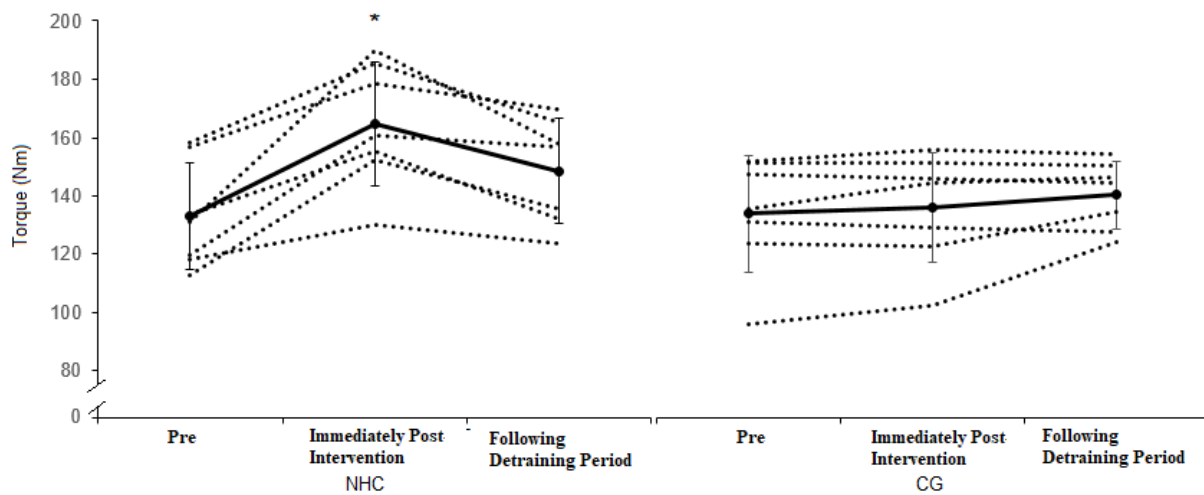
Table 2: Overview of the primary and secondary outcome measures across groups and times points. Data presented as mean (SD) unless otherwise stated

	Intervention (n = 7)					Control Group (n = 7)					Between group differences in mean change (95% CI), [Cohen's <i>d</i> ]	
	Pre	Immediately post-intervention	Following detraining period	Within-group changes (95% CI)		Pre	Immediately post-intervention	Following detraining period	Within-group changes (95% CI)			
				Immediately post-intervention	Following detraining period				Immediately post-intervention	Following detraining period	Immediately post-intervention	Following detraining period
<b>COD (s)</b>	4.48 (0.12)	4.36 (0.06)	4.37 (0.11)	- 0.12 (-0.26; 0.10)	- 0.11 (-0.24;0.02)	4.52 (0.16)	4.72 (0.28)	4.62 (0.20)	0.20 (0.07; 0.30)	0.11 (0.01; 0.20)	- 0.332 * (-0.53; -0.14) [- 2.17]	- 0.235 * (-0.41;-0.06) [- 1.38]
<b>10 m Sprint (s)</b>	1.85 (0.05)	1.79 (0.07)	1.81 (0.06)	- 0.06 (- 0.13; 0.01)	- 0.05 (-0.12; 0.01)	1.90 (0.07)	1.95 (0.12)	1.94 (0.10)	0.05 (0.02; 0.11)	0.03 (0.02; 0.12)	- 0.115 * (-0.21; -0.02) [- 1.78]	- 0.105 * (-0.20; -0.01) [-1.17]
<b>IKD Nm<sup>-1</sup></b>	133.13 (18.34)	164.94 (21.29)	148.80 (17.96)	31.81 (21.90; 41.57)	15.67 (6.77; 24.07)	134.37 (19.93)	136.57 (19.03)	140.81 (11.71)	2.20 (-7.56; 12.12)	6.44 (-1.96; 15.34)	29.46 * (15.54; 43.37) [2.55]	8.73 (-3.51;20.96) [0.73]

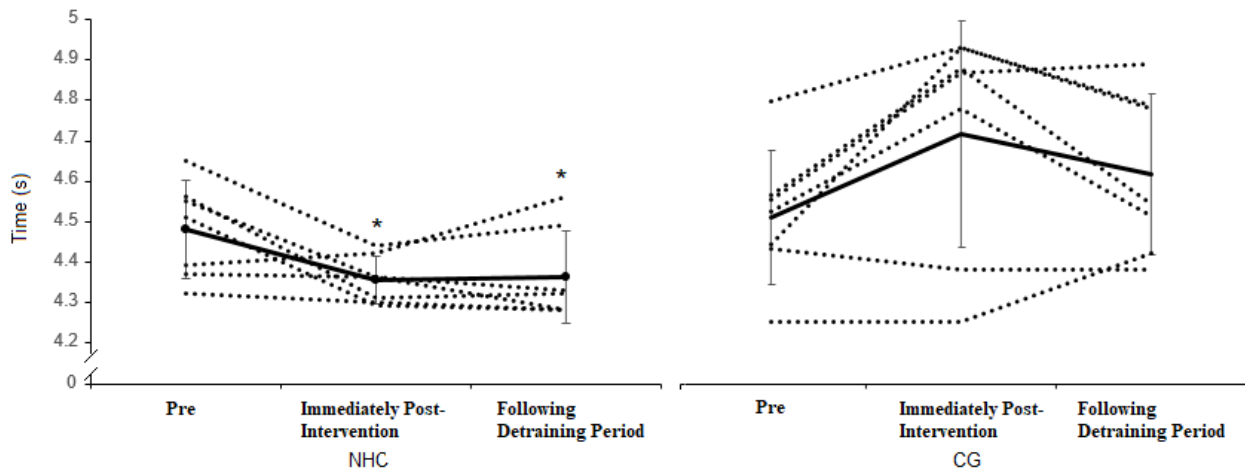
\*Denotes a significant group difference



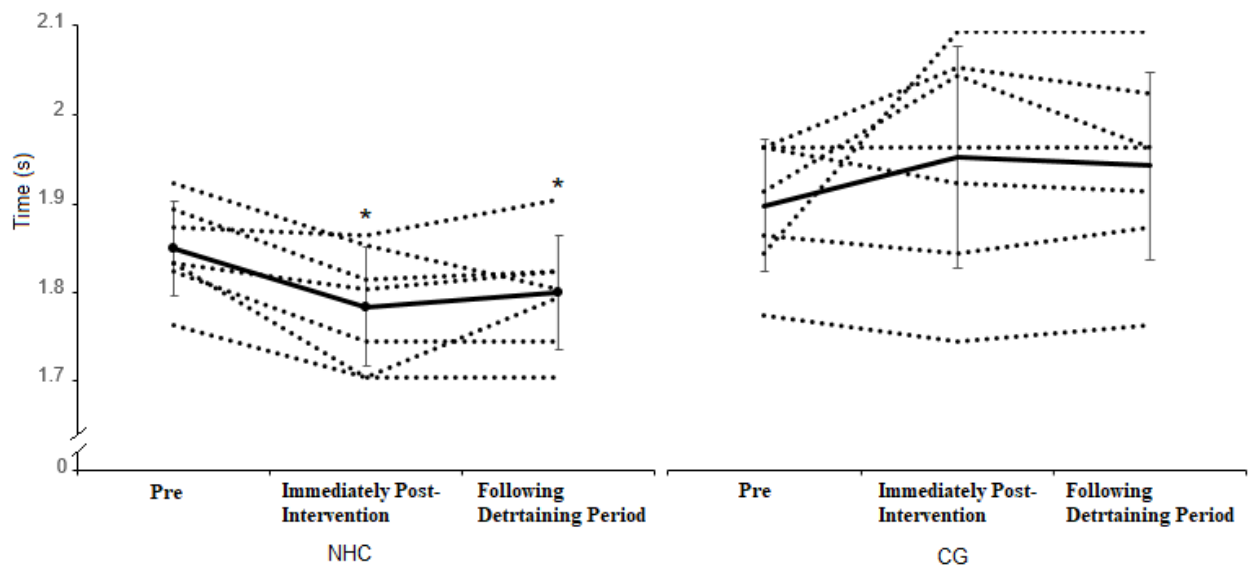
**Figure 1: Flow diagram of participant enrolment, allocation, follow-up, and analyses.**



**Figure 2: Individual participant response for eccentric hamstring strength, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. \* denotes a significant ( $P \leq 0.05$ ) between group difference for that particular time point.**



**Figure 3: Individual participant response for COD, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. \* denotes a significant ( $P \leq 0.05$ ) between group difference for that particular time point.**



**Figure 4: Individual participant response for 10 m sprint, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. \* denotes a significant ( $P \leq 0.05$ ) between group difference for that particular time point.**