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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 Nm^{-1} vs. 6.44 Nm^{-1} , $P = 0.001$), COD (-0.12 s vs. 0.20 s ; $P = 0.003$) and sprint (-0.06 s vs. 0.05 s ; $P = 0.024$) performance. Performance improvements were maintained following a detraining period for COD (-0.11 s vs. 0.20 s ; $P = 0.014$) and sprint (-0.05 s vs. 0.03 s , $P = 0.031$) but not eccentric hamstring strength (15.67 Nm^{-1} vs. 6.44 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 5th 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 ± 7.88 cm, mass: 75.38 ± 7.10 kg) or a CG ($n = 8$, age: $20.86 \pm$
70 1.57 years, height: 178.00 ± 8.41 cm, mass: 77.14 ± 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⁺ 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°s^{-1} . This speed was selected as
129 being representative of the average angular velocity exhibited during the 180° 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 (Mjøl̄snes 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 ± 1.32 years, height: 179.81 ± 7.45 cm,
195 mass: 75.54 ± 7.14 kg), CG ($n = 7$, age: 21.01 ± 1.64 years, height: 178.12 ± 8.49 cm, mass:
196 77.64 ± 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⁻¹ vs. 6.44 Nm⁻¹; mean difference,
203 29.46 Nm⁻¹, 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⁻¹). No significant group main effects
205 for mean change were observed following the three-week detraining period (15.67 Nm⁻¹ vs.
206 6.44 Nm⁻¹; mean difference 8.73 Nm⁻¹, 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⁻¹ 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 ≤ 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⁻¹ 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⁻¹ (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.

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

Week	Frequency per week	No. of sets per training	Repetitions per set
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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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
COD (s)	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]
10 m Sprint (s)	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]
IKD Nm⁻¹	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

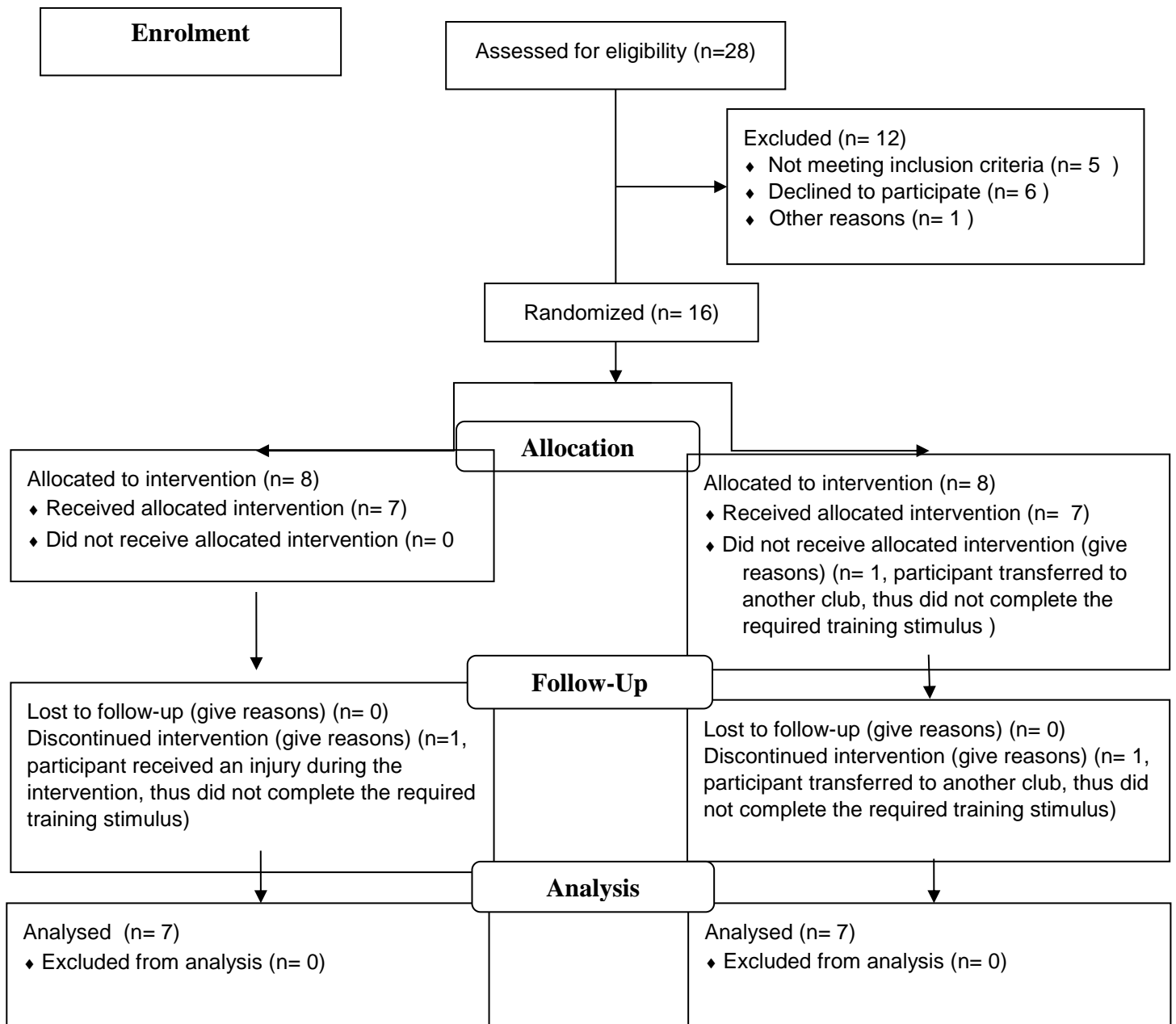


Figure 1: Flow diagram of participant enrolment, allocation, follow-up, and analyses.

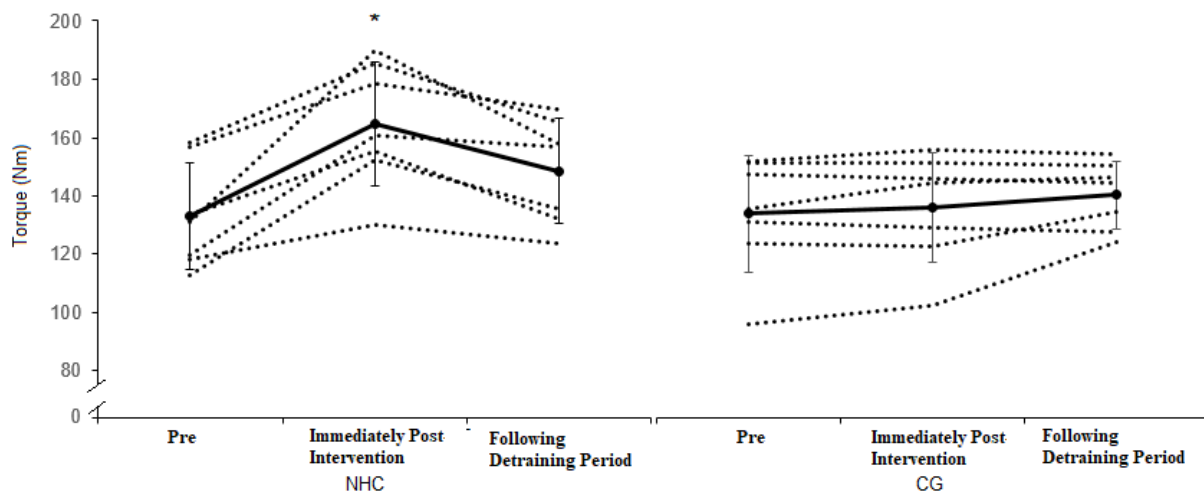


Figure 2: Individual participant response for eccentric hamstring strength, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. * denotes a significant ($P \leq 0.05$) between group difference for that particular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

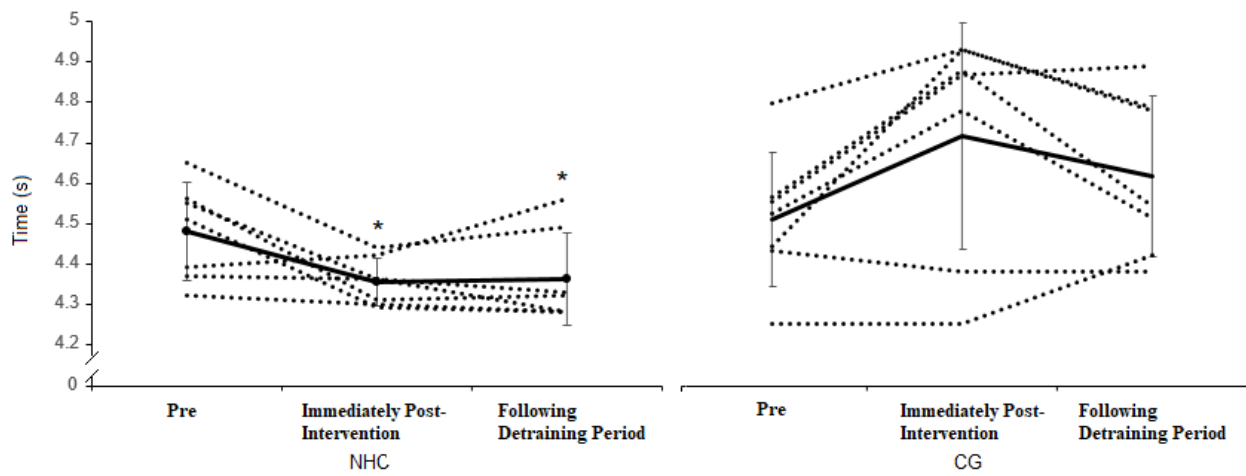


Figure 3: Individual participant response for COD, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. * denotes a significant ($P \leq 0.05$) between group difference for that particular time point.

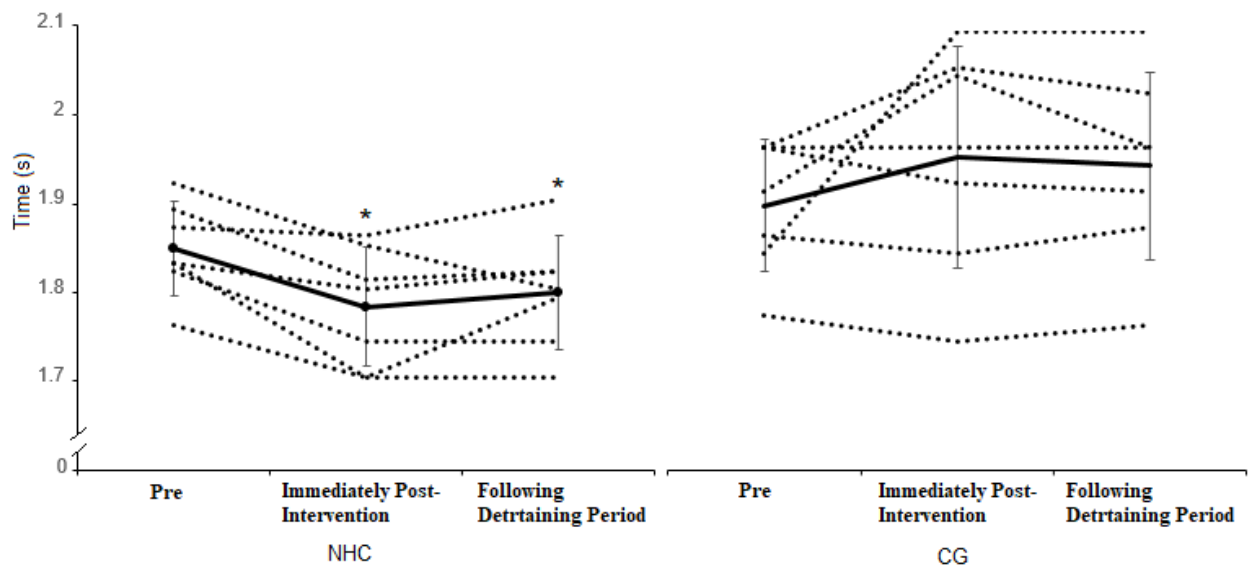


Figure 4: Individual participant response for 10 m sprint, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. * denotes a significant ($P \leq 0.05$) between group difference for that particular time point.