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°/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

Introduction

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

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

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

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

Materials and Methods

Trial Design

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

Participants

To prospectively consider participant drop-out, sixteen amateur intermittent team sports (Soccer, n = 8; Rugby League, n = 8) athletes from the North-West region of the United Kingdom were recruited for the study. Upon completion of baseline testing, a staff member not involved in the study randomly allocated participants into an NHC group (n = 8, age: 20.13 ± 1.55 years, height: 180.88 ± 7.88 cm, mass: 75.38 ± 7.10 kg) or a CG (n = 8, age: 20.86 ± 1.57 years, height: 178.00 ± 8.41 cm, mass: 77.14 ± 7.39 kg). Eligibility criteria required participants to be male, 18-25 years old with no previous lower limb injury in the past 6 months and team sports players completing a minimum of two intermittent team training sessions per week and one match. To maximise balance across groups for variables such as age, height, mass, strength and speed, randomisation occurred using the minimisation process. A member of staff not involved in the study managed the randomisation process using sealed opaque envelopes, which contained the name of a single participant. Starting with the intervention group, participants were alternately allocated to the relevant group. The randomisation procedure was concealed from all research personnel.

Insert Figure 1 near here

Study Settings

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

Intervention

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

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

Insert Table 1 near here

Outcomes

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

Eccentric Isokinetic Hamstring Strength

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

10 m Sprint

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

COD

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

Statistical Methods

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

Data was checked for normality *a priori*, using histograms, q-q plots, skewness and kurtosis, and a Shapiro-Wilk test. Mauchly's test of Sphericity was performed for the dependent variables, with a Greenhouse Geisser correction included if test significance was indicated. For the analysis of the primary (eccentric hamstring strength) and secondary (10 m sprint, COD) outcomes, an analysis of covariance (ANCOVA) using the baseline score as the covariate was performed to examine differences in the physical response between the two groups (NHC and CG) over the intervention period. Where significant main effects or interactions were observed, post-hoc pairwise comparisons with a Bonferonni correction factor was applied, with 95% confidence intervals (CI) for differences also reported. Cohen's *d* effect sizes were calculated using pooled SD data and were classified as trivial (< 0.20 – 0.49), moderate (0.50-0.79) and large (> 0.80) (Cohen, 1992). Between session reliability was assessed using intraclass correlation coefficients (ICC), from which standard error of measurement (SEM) and minimal detectable difference were calculated. SEM was calculated using the formula: $SD\ Pooled \times (\sqrt{1} - ICC))$ (Thomas, Nelson & Silverman, 2005), whilst MDD was calculated using the formula: $MDD = SEM \times 1.96 \times \sqrt{2}$ (Weir, 2005)

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

Results

Participants

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

Primary Outcome Measure

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

Insert Figure 2 here

Secondary Outcome Measures

As highlighted in table 2, the NHC group demonstrated significantly greater mean changes in COD (-0.12 s vs. 0.20 s; mean difference, -0.332 s, P = 0.003, *d* = 2.17) when compared to the CG immediately post-intervention. The same observation was observed following the detraining period, with significantly greater mean changes observed in COD (-0.11 s vs. 0.20 s; mean difference, - 0.235 s, P = 0.014, *d* = 1.38) when compared to the CG. The mean change for the NHC group surpassed and equalled the minimal detectable difference (MDD = 0.11 s) for the immediately post-intervention (-0.12 s) and following detraining (-0.11 s) periods respectively. Figure 3 highlights the individual responses for each participant across the three time points, in addition to the mean group response.

Insert Figure 3 here

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

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

Insert Figure 4 here

Insert Table 2 near here

Harms

No harms were observed during the execution of the NHC.

Discussion

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

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

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

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

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

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

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

However, it should be acknowledged that maintained improvements in COD and sprint performance were observed despite an approximately 10% decrease in eccentric hamstring strength when comparing the detraining period results to the immediately post-intervention testing session. This suggests that the maintenance of COD and sprint performance may be a result of other adaptations associated with NHC mechanical stimulus, such as: hypertrophic effects of type II muscle fibre cross-sectional area (Alt, Nodler, Severin, Knicker & Struder, 2017), knee flexor/extensor muscle balance (Alt et al., 2017), increased fascicle length (Alonso-Fernandez Docampo-Blanco & Martinez-Fernandez, 2018; Bourne et al., 2016) and enhanced neuromuscular parameters (Delahunt et al., 2016). However, these measures were beyond the scope of the current study and future research may wish to investigate this area. An alternative thought could suggest that the NHC group maintained an 11% increase in eccentric hamstring strength, when compared to baseline levels. Consequently, it may be possible that a maintained increase of this magnitude is sufficient to preserve improvements in COD and sprint performance. The decrease in eccentric hamstring strength observed following the detraining period also has potential implications for injury risk. These results suggest that removing the NHC stimulus can, within a period of three weeks, reduce the strength benefits gained from training. Consequently, this may have implications for practitioners regarding the scheduling and frequency of NHC when used in an attempt to reduce HSI incidence. However, it should be noted that although not significantly different, eccentric hamstring strength was increased by 11% in NHC group when compared to baseline.

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

NHC have recently been suggested to be ineffective (Ekstrand et al., 2013) or even contradictory (Gambetta & Benton, 2006) with regards to injury prevention and performance due to low adherence and implementation rates (McCall et al., 2014; Bahr, Thorborg, & Ekstrand, 2015). However, this study provides evidence suggesting that NHCs can improve important high-intensity movement actions critical to sports performance in addition to enhancing eccentric hamstring strength, which has been postulated to reduce HSI. Furthermore, recent research (Lovell et al., 2018) has suggested that performing injury prevention exercises, including NHC, on match day + 24 hours, reduces muscle damage and soreness when compared to match day + 72 hours. This is in conjunction with previous research (Presland et al., 2017), which demonstrates that low volume NHC programs produce the same structural and functional changes as high volume programs. This suggests that sports teams could implement NHC as part of a complete holistic intervention program (Buckthorpe, Gimpel, Wright, Sturdy & Stride, 2018), including multi-joint exercises early in the typical training micro-cycle, to ensure that the exercise stimulus is not hindered during periods of fixture congestion (Lovell et al., 2018). Consequently, the current study suggests that medical staff may be able to remove or reduce the intervention for periods of up to 3 weeks during fixture congested periods and still maintain beneficial improvements in functional performance. This has implications for scheduled (e.g. training periodization) and enforced (e.g. winter break) breaks.

Caution should be taken when attempting to generalise the findings of this study beyond the amateur population and experimental design used. The current participants comprised a combination of both rugby league and soccer players. Although both sports share similar fundamental characteristics, there are distinct differences in the conditioning practices adopted by both sports and, as such, this could have influenced some elements of the data. However, in an attempt to reduce the influence of the aforementioned limitation, an equal number of soccer and rugby athletes were assigned to each group. Although achieving appropriate statistical power, the relatively small sample size should be noted, producing larger confidence intervals as a direct result, consequently the magnitude of association may be overestimated. Future studies should aim to investigate a similar study design with an increased sample size in elite populations comprising a singular intermittent team sport where hamstring injury incidence is problematic. Furthermore, the fragility index for the primary outcome measure (immediately post-intervention eccentric strength) was 2, indicating that two patients from the control group would need to be converted from not having the primary endpoint to having the primary endpoint, at which point the primary outcome would lose statistical significance. A small number of studies (Khan et al., 2016; Walsh et al., 2014) have analysed the results of ~ 450 randomised controlled trials, indicating the fragility index to be ≤ 3 in 25-30% of all outcomes analysed. Despite this, the fragility index of the primary outcome measure in the current study should be noted and results as such treated with caution.

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

Conclusions

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

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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

(van der Horst et al., 2015)

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)						
	Pre	**Immediately post-intervention**	**Following detraining period**	**Within-group changes (95% CI)**		**Pre**	**Immediately post-intervention**	**Following detraining period**	**Within-group changes (95% CI)**		**Between group differences in mean change (95% CI), [Cohen's *d*]**	
				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

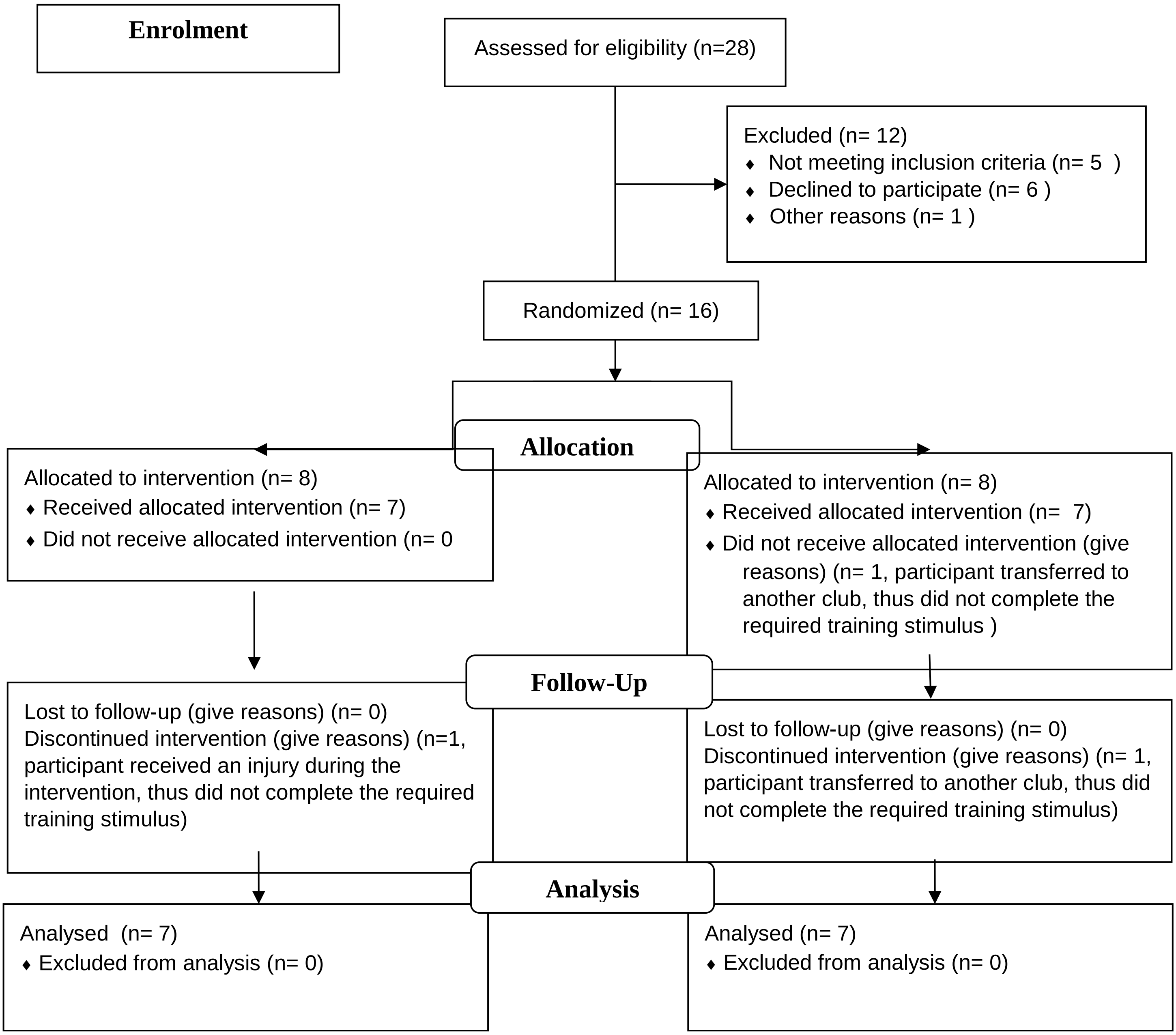

Figure 1: Flow diagram of participant enrolment, allocation, follow-up, and analyses.

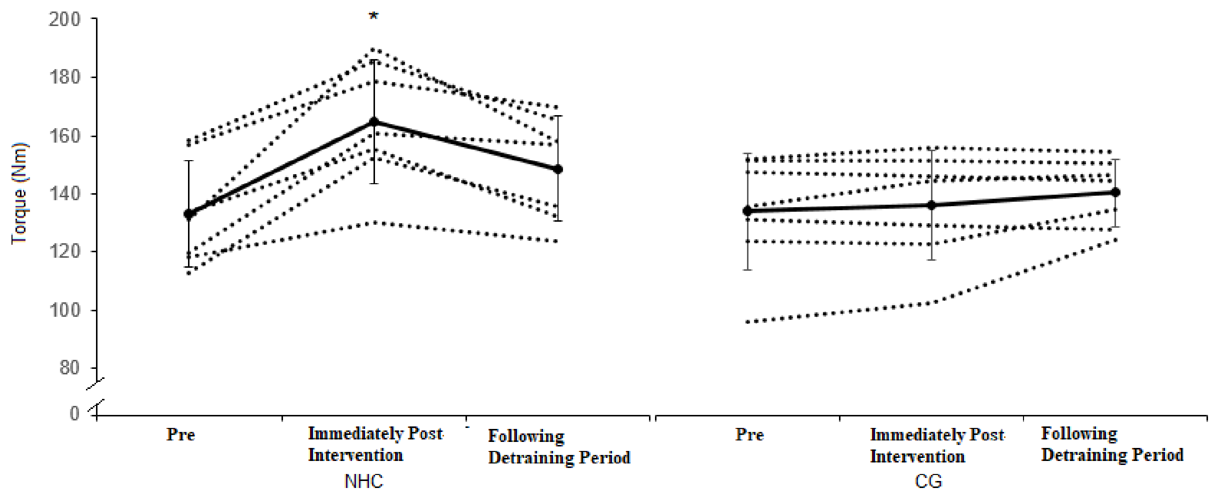

Figure 2: Individual participant response for eccentric hamstring strength, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. * denotes a significant (P ≤ 0.05) between group difference for that particular time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

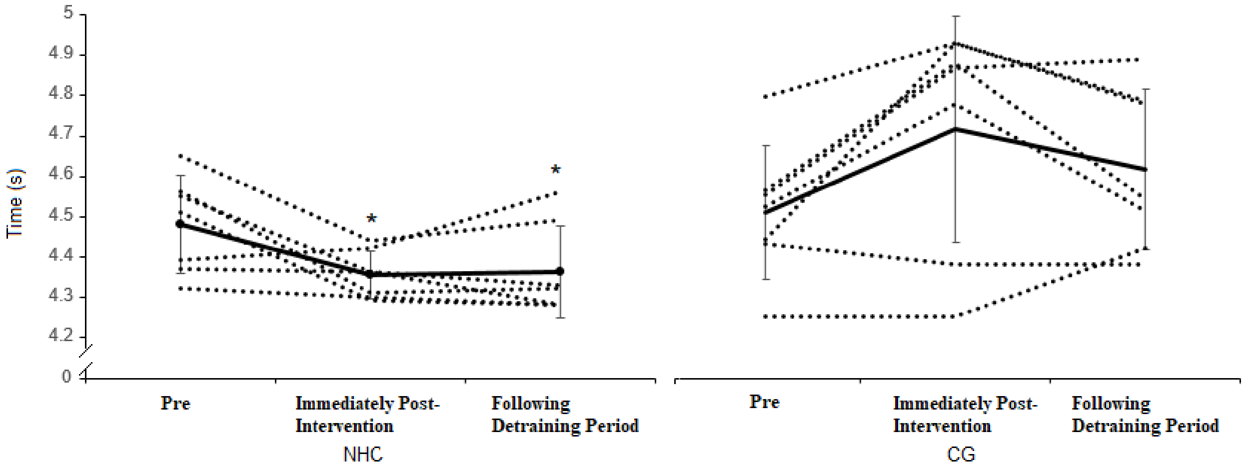

Figure 3: Individual participant response for COD, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. * denotes a significant (P ≤ 0.05) between group difference for that particular time point.

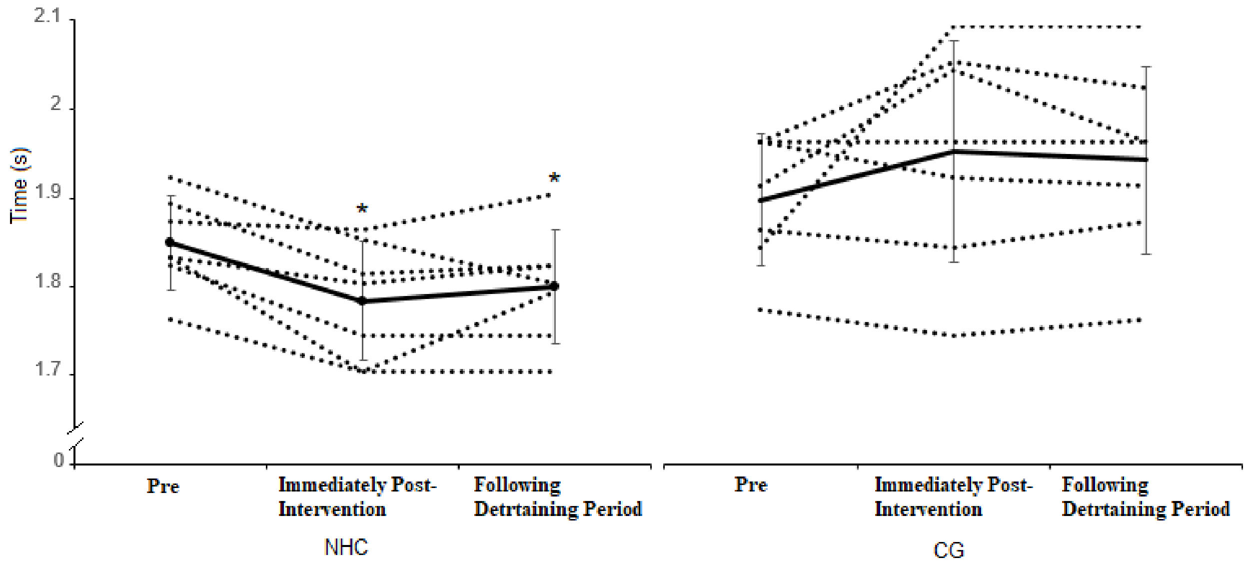

Figure 4: Individual participant response for 10 m sprint, across NHC and CG groups. The dashed line denotes an individual participant response, whereas the solid line represent the mean group response. * denotes a significant ($P \leq 0.05$) between group difference for that particular time point.