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A low-volume Nordic hamstring curl programme improves change of direction ability, despite no architectural, strength or speed adaptations in elite youth soccer players

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ABSTRACT

Nordic hamstring curls (NHC) are a commonly used injury intervention method in amateur team sports. Seventeen elite male academy soccer players performed an 8-week low volume NHC programme. Pre-post intervention measures of isokinetic eccentric knee flexor (KF) strength, linear speed, COD performance, hamstring muscle thickness, pennation angle and fascicle length were recorded. No significant main effects were observed for measures of isokinetic KF strength ($P \geq 0.19$), linear sprint speed ($P \geq 0.47$) or hamstring muscle architecture ($P \geq 0.30$). However, significance was noted for improved COD performance ($P < 0.01$; mean difference, −0.06, $p = 0.001$, 95% CI = 0.03 to 0.09; $d = 0.80$), exceeding the minimal detectable difference (MDD = 0.05 s). A low-volume NHC intervention may contribute to significant improvements in COD ability, independent of no significant changes in eccentric KF strength, linear sprint speed or muscle architectural properties in elite youth soccer players.

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Nordics; performance soccer; youth

Introduction

Hamstring injuries (HSI) are the most common injury observed in soccer (Ekstrand et al., 2016), displaying high recurrence rates resulting in time lost from training and match-play, potentially leading to financial and physical and performance detriments (Hägglund et al., 2013). Previous research has documented HSI risk factors including muscle strength deficiencies and shorter muscle fascicle lengths (Bourne et al., 2018), highlighting the need for successful injury reduction strategies to be implemented in soccer clubs (Buckthorpe et al., 2019). Elite-level soccer is characterized by rapid accelerations, decelerations, and changes of directions (CODs) that involve high mechanical and metabolic demands (Harper et al., 2019). Consequently, these high-intensity actions can increase the risk of HSI due to heightened eccentric forces sustained within the hamstring biarticular musculature (Bishop and Girard, 2013) and often precede injury occurrence in professional soccer match play (Carling et al., 2010).

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Previous research has documented specific risk factors provoking HSI, including hamstring muscle strength deficiencies and imbalances, and shorter muscle fascicle lengths (Bourne et al., 2018).

The Nordic hamstring curl (NHC) is an eccentric exercise often incorporated in HSI reduction programmes (Bahr et al., 2015; Mjølsnes et al., 2004). Efficacy of high volume NHC intervention adaptations have been reported in measures of eccentric knee flexor (KF) strength and muscle architecture for sub-elite (Alonso-Fernandez et al., 2018; Ishø et al., 2018; Siddle et al., 2019) and elite (Mendiguchia et al., 2020; Suarez-Arrones et al., 2019) male soccer players. However, elite soccer players have raised concerns regarding, fatigue, impaired performance, and injury risk because of high volume NHC training (Bahr et al., 2015). Acknowledging issues in compliance and implementation, a low volume NHC was equally effective as equivalent high-volume protocols for achieving significant increases in eccentric KF strength and fascicle lengths in recreational males, thus potentially advocating a "micro-dosing" strategy (Presland et al., 2018). However, currently no studies have examined the influence of low volume NHC training on concurrent gains in markers of injury risk and performance enhancement within elite youth soccer populations, which could help to inform NHC programming prescriptions at the elite level. As such, this study aimed to investigate the effects of an 8-week low volume NHC intervention on functional and structural performance in elite male academy soccer players. The authors hypothesized that a low-volume NHC programme would result in concurrent gains in functional performance and HSI risk factors.

Material and methods

Study design

All participants partook in testing procedures at 0-weeks (pre-test) and 8-weeks (post-test) in addition to their normal soccer training and match-play. The elite soccer context negates use of a randomized controlled trial as players could not be allocated to a control group where performance gains and injury risk might be compromised (Lacome et al., 2019; Severo-Silveira et al., 2018). Participants were instructed to refrain from vigorous physical activity 48 hours prior to testing and wore similar apparel and the same exercise shoes for each testing session. All participants conducted a pre-testing session where they were familiarized with all outcome measures to be recorded.

Participants

A convenience sample of 17 elite male academy soccer players (age: 16.65 ± 0.61 years, height: 178.29 ± 8.13 cm, mass: 71.50 ± 6.83 kg) contracted to the same team were recruited. Participants trained four times per week, accumulating ~14 training hours, in addition to weekly matches. Exclusion criteria included history of HSI or accompanying injury in the previous 6 months. Ethical approval (SPA-REC-2019-259R1) was granted from the university institution review board in accord with the spirit of the Helsinki Declaration, whilst written informed parental consent was provided.

Training Intervention

The NHC intervention was conducted at the club's facilities prior to training under the supervision of trained staff. All participants had 12 months previous experience performing the NHC. The NHC was initiated with the participant in a kneeling position on a cushioned pad with their torso maintained up-right. A partner was advised to apply pressure to the participant's heels/ankles, to ensure the participant's feet remained in contact with the ground. To perform the exercise, participants were instructed to slowly lower their torso towards the ground at constant cadence (~3 s per repetition), maintain a straight back, and resist the effects of gravity for as long as possible. The participant's hands were used to break the forward fall, followed by a push to return to the initial position, minimizing concentric loading.

The 8-week low volume NHC intervention commenced with a standardized 2-week training period comprising of 24 NHE repetitions across four sets, twice per week (96 reps total). For the remaining six weeks, participants conducted 8 NHE repetitions per week, across two sets during one training session (48 reps total; Presland et al., 2018). Each participant was supplied with a weekly completion chart, with compliance of NHE repetitions set as >80%. A minimum of 48 hours recovery was provided between strenuous activity and each testing session. Prior to each testing session, a warm-up was performed consisting of 5 min of static cycling, followed by 5 min of dynamic stretching. After each testing procedure, a 3-min rest period was adhered to.

Procedures

Eccentric knee flexor strength

Unilateral eccentric KF strength was assessed on the dominant leg of the participant, defined as their preferred kicking leg, using an Isokinetic Dynamometer (Biodex Medical System 2, Shirley, New York) at speeds of $60°{\cdot}s^{-1}$, $180°{\cdot}s^{-1}$ and $270°{\cdot}s^{-1}$, conducted in a randomized order. Three warm-up repetitions were performed at each speed. The dynamometer was set-up in accordance with previous literature (Siddle et al., 2019). Five maximal efforts were performed at each speed, with passive concentric knee flexion performed at $60°{\cdot}s^{-1}$ between repetitions, and 60 s rest between each set. The isokinetic phase was defined as angular velocity ± 1%, with analysis of peak torque (PT) and angle of peak torque (APT) applied to the repetition demonstrating the highest PT. PT and APT displayed ICC values of 0.84–0.89, thus highlighting excellent levels or reliability.

Muscle architecture

Muscle architecture characteristics, muscle thickness (MT), pennation angle (PA) and fascicle length (FL) of the biceps femoris long head (BF^{lh}), semimembranosus (SM) and semitendinosus (ST) were assessed using two-dimensional B-mode ultrasound images (GE Healthcare, LOGIQ e R7, Wauwatosa, USA) taken along the longitudinal axis of each muscle belly (frequency 12 MHz; depth 8 cm; field of view 12.7 × 47 mm, probe L4-12 t) on the dominant limb. The participant lay in prone, with hip in a neutral position and the knee extended. The scanning site was determined as the mid-point between the ischial tuberosity and popliteal crease, along the line of the BF^{lh}, SM and ST. Three ultrasound images were recorded and stored for analysis using ImageJ software. MT was determined as the distance between the intermediate and superficial aponeuroses, whilst PA was defined as the angle between a fascicle of interest and the inferior aponeuroses (Timmins et al., 2021). FL were reported in absolute terms relative to each measured muscle's length. As the entire fascicle was not visible in the probe's field of view, its length was estimated using the following equation (Kellis et al., 2009) (AA = aponeuroses angle):

$$FL = sin(AA + 90^{\circ}) x\, MT / sin(180^{\circ} - (AA + 180^{\circ} - PA))$$

The same ultrasound practitioner collected and analysed all scans, with ICC values for outcome measures ranging from 0.82 to 0.86.

Linear sprint speed

Sprint speed was assessed using timing gates (Brower TCi Timing System, United States of America) initiated at 0 m and recording time splits of 5 m, 10 m and 20 m. Each timing gate was positioned at average standing torso height. Participants performed three maximal sprints from a standing position, with a 3-min passive rest period between trials. The trial eliciting the fastest 20 m split was used for statistical analysis, with ICC of 0.89–0.93.

Change of direction

Change of direction (COD) speed was measured using the same timing gates, with each trial initiated from a standing position. Participants were instructed to run as fast as possible to the 5 m line, where they were then required to perform a 180° turn and sprint back to the starting point. Three maximal efforts were performed on the dominant leg for the 5-0-5 test, with a 3-min passive rest period between trials. The quickest trial was selected for analysis, with ICC = 0.91.

Statistical analysis

Data was assessed for normality *a priori*, whilst a paired samples T-test was used to examine pre-post intervention outcome measures. Statistical analyses were conducted using PASW Statistics Editor 25.0 for Mac (SPSS, Inc, Chicago, IL, USA), with significance set at $P \leq 0.05$. Data is presented as mean $\pm$ standard deviation. For significant findings, 95% confidence intervals and Cohen's d effect size were calculated using pooled SD data and categorized as small (<0.20–0.49), moderate (0.50–0.79) and large (>0.80). Relative reliability between trials was determined using a 2-way random effects model intraclass correlation coefficients (ICC). These ICC values were interpreted as >0.8 = almost perfect reliability. From this, standard error of measurement (SEM) was calculated using the formula $SD\ pooled \times (\sqrt{1} - ICC)$ whilst minimal detectable differences (MDD) were determined using the formula $MDD = SEM\, x\, 1.96\, x\, \sqrt{2}$.

Results

Sixteen elite male youth soccer players completed the study (age: 16.63 ± 0.62 years, height: 178.31 ± 8.40 cm, mass: 71.10 ± 6.84 kg) with one participant removed due to injury unrelated to the NHC intervention. The participants had a mean compliance of 93% for completion of the NHE repetitions.

Eccentric knee flexor strength

Table 1 highlights no significant improvements post intervention in PT ($P \geq 0.19$) or APT ($P \geq 0.45$), irrespective of test speed. Figure 1 highlight the individual pre-post response for PT at 60°·s^{-1}, 180°·s^{-1} and 270°·s^{-1}, respectively.

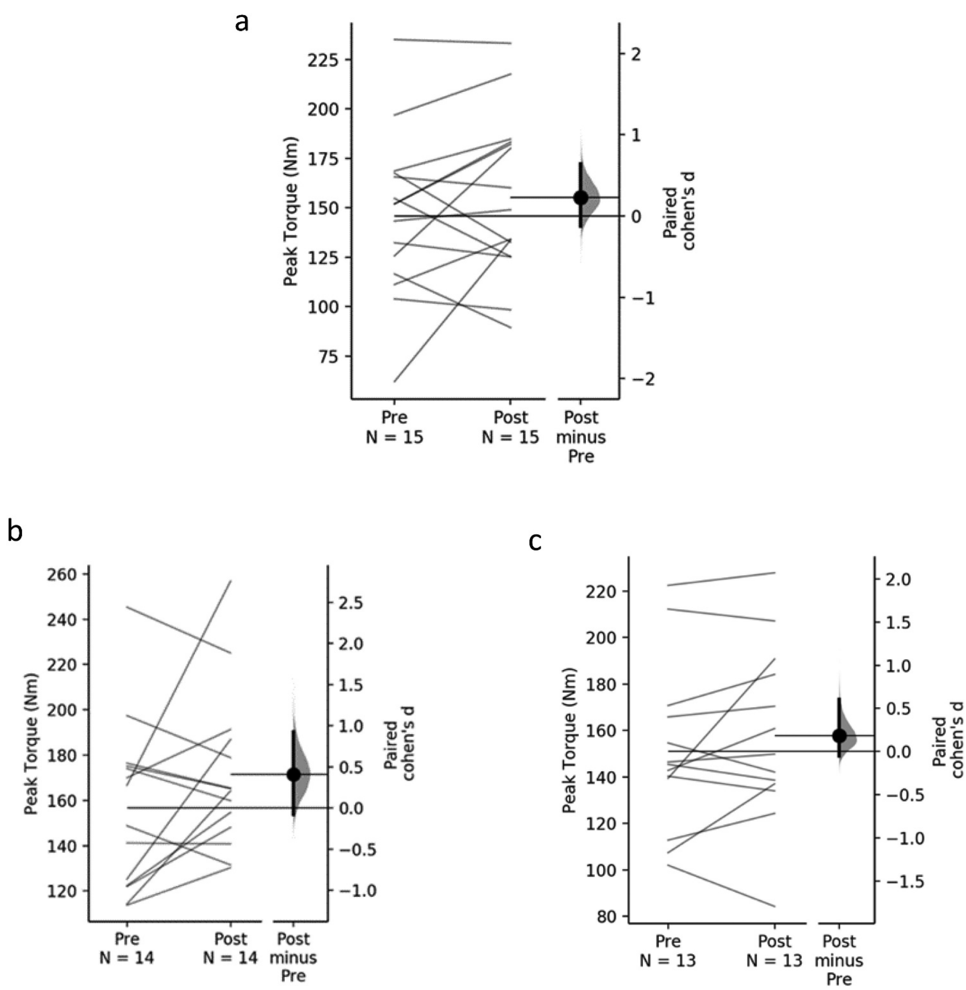

Figure 1. Individual participant response for eccentric hamstring strength peak torque at 60°s^{-1} (A), 180°s^{-1} (B) and 270°s^{-1} (C).

Table 1. Overview of primary, secondary and performance outcome measures from pre and post testing sessions. Data presented as mean SD unless otherwise stated.

METRIC	PRE	POST	MEAN DIFFERENCE	INFERENCE	SEM	MDD
IKD PT 60°s-1 (Nm−1)	145.82 ± 40.99	155.25 ± 41.24	9.43	Small	16.45	45.59
IKD PT 180°s-1 (Nm−1)	156.62 ± 37.33	171.34 ± 35.27	14.72	Small	14.27	39.56
IKD PT 270°s-1 (Nm−1)	150.94 ± 36.05	157.77 ± 38.17	6.83	Trivial	15.87	44.00
IKD APT 60°s-1 (°)	42.00 ± 11.90	40.93 ± 10.19	-1.07	Trivial	4.36	12.07
IKD APT 180°s-1 (°)	37.80 ± 5.22	35.90 ± 3.54	-1.90	Trivial	1.96	5.42
IKD APT 270°s-1 (°)	56.50 ± 16.48	52.92 ± 20.78	-3.58	Small	7.76	21.52
BFlh MT (cm)	2.28 ± 0.41	2.23 ± 0.26	-0.05	Trivial	0.15	0.43
SM MT (cm)	2.89 ± 0.45	3.02 ± 0.42	0.13	Small	0.20	0.54
ST MT (cm)	2.73 ± 0.49	2.84 ± 0.38	0.11	Small	0.19	0.52
BFlh FL (cm)	7.61 ± 1.27	7.82 ± 1.06	0.21	Trivial	0.49	1.35
BFlh PA (°)	17.94 ± 3.96	17.33 ± 3.12	-0.61	Trivial	1.43	3.97
Mean COD (s)	2.49 ± 0.07	2.43 ± 0.08*	-0.06	Large	0.02	0.05
Sprint 5m (s)	0.97 ± 0.04	0.96 ± 0.05	-0.01	Small	0.02	0.04
Sprint 10m (s)	1.67 ± 0.06	1.68 ± 0.06	0.01	Trivial	0.02	0.05
Sprint 20m (s)	2.92 ± 0.09	2.93 ± 0.11	0.01	Trivial	0.03	0.08

IKD, isokinetic dynamometer; PT, peak torque; APT, angle of peak torque; BFlh, biceps femoris long head; MT, muscle thickness; SM, semimembranosus; ST, semitendinosus; FL, fascicle length; PA, pennation angle; SEM, standard error of measurement; MDD, minimal detectable difference. * Denotes a significant difference between pre and post intervention

Muscle architecture

As highlighted in Table 1, hamstring MT failed to display significant findings post-intervention for BFlh (P = 0.44), SM (P = 0.30), or ST (P = 0.48). Similarly, there was no significant main effect post-intervention for BFlh PA (P = 0.56) or BFlh FL (P = 0.57). Figure 2 demonstrates the individual pre-post response for BFlh FL and BFlh PA, respectively.

Linear sprint performance

Table 1 highlights no significant main effect for linear sprint performance at 5 m (P = 0.46), 10 m (P = 0.29), or 20 m (P = 0.47). Figure 3 demonstrates the pre-post individual response for all linear sprint speed distances, with 5, 1 and 1 responders demonstrated to exceed the MDD, respectively, for 5, 10 and 20 m, respectively.

Change of direction speed

Table 1 identifies a significantly greater mean change in COD performance (pre = 2.49 s vs. post = 2.43 s; mean difference, −0.06, p = 0.001, 95% CI = 0.03 to 0.09; d = 0.80), with lower values identified post-intervention. Individual participant responses are highlighted in Figure 4, demonstrating nine responders to equal or exceed the MDD.

Discussion

The aim of the current study was to investigate the effects of an 8-week low volume NHC intervention programme on measures of HSI risk and functional performance in elite youth male soccer players. The NHC intervention elicited no significant improvements in eccentric KF strength or associated APT; architectural measures of MT, PA or FL; or linear sprint time over 5–20 m distances. However, time to complete the COD task was significantly reduced post intervention, with 9/16 players showing performance gains exceeding the MDD.

The non-significant changes observed in the current study, contrast previous literature assessing eccentric KF strength (Ishø et al., 2018; Suarez-Arrones et al., 2019) and muscle architecture (Bourne et al., 2017; Presland et al., 2018), however support associations between these metrics. Improvements in eccentric KF strength post intervention have often been attributed to a concurrent shift in the APT occurring at longer muscle lengths (Brockett et al., 2001). Changes in APT have been proposed to correlate with increases in FL due to addition of in-series sarcomeres causing a rightward alteration in a muscle's force length relationship (Reeves et al., 2009). However, APT measured within the current study was maintained across the intervention, indicative of no fundamental change in the strength curve. Post-intervention, only five participants exceeded the APT MDD. Consequently, the non-significant changes in muscle architecture observed in the current study (−2.20–4.50%) when compared to previous literature (7–23%; Bourne et al., 2017; Presland et al., 2018) may not have been sufficient to elicit significant improvements in eccentric KF strength (4.50–7.80%).

No consistent improvement or impairment to linear sprint performance was observed, contrasting previous research highlighting 3.5–9.4% reductions in sprint time, and associated gains in eccentric KF strength (Suarez-Arrones et al., 2019; Timmins et al., 2021). Individual responses highlighted 5 participants to exceed the MDD at 5 m. However, this was not maintained at 10 m and 20 m with only 1 participant exceeding the MDD. Hamstring muscle strength is a key contributor to sprinting with concurrent gains in speed and strength identified post-NHC interventions further supporting this association (Suarez-Arrones et al., 2019; Timmins et al., 2021).

The lack of significant change in eccentric KF strength and linear speed observed in the current study may therefore be due to the non-significant changes observed in hamstring muscle architecture. These concurrent findings and their inter-relationship might indicate that the intervention volume and/or intensity was not sufficient to elicit adaptations of a magnitude sufficient to cause architectural change in elite youth soccer players. These findings are in contrast with previous research, which demonstrated NHE interventions of varying duration (4–8 weeks), and volume (21–60 weekly NHE repetitions) result in significant hamstring architectural adaptations (Alonso-Fernandez et al., 2018; Presland et al., 2018). However, both studies utilized recreationally active populations, who may display a greater response to exercise and tendency to adaptation via neural pathways than elite soccer players who train (4–6 days per week) and play (1–2 games per week) full-time (Mendiguchia et al., 2020). As such, elite soccer players could be closer to their theoretical adaptive ceiling (Timmins et al., 2021). Additionally, within elite populations, players experienced at performing an exercise have fewer positive adaptations than those recently introduced to the stimulus (Suarez-Arrones et al., 2019), further complicating direct comparisons between playing status. As such, the low volume stimulus adopted within the current study in addition to other factors such as the intervention duration and extraneous variables including match and training load (Mendiguchia et al., 2020) may not have been sufficient to elicit hamstring architectural changes within

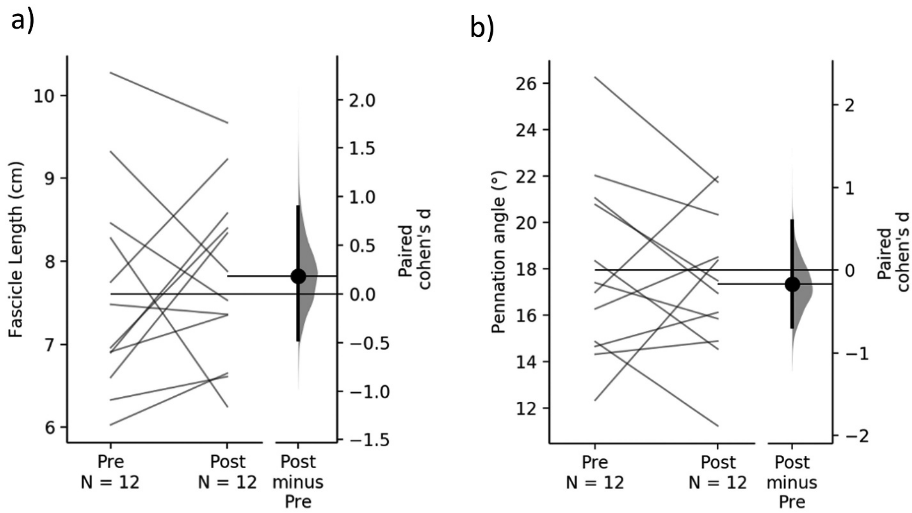

Figure 2. (a) Individual participant response for fascicle length of biceps femoris long head muscle. (b) Individual participant response for pennation angle of biceps femoris long head muscle.

this study population. These findings further highlight the need for future research, as playing status may influence data interpretation with potential implications for subsequent programme design (Medeiros et al., 2020).

Fourteen (of 16) participants improved their COD performance post-intervention, 9 of which exceeded the MDD. These findings are consistent with previous research highlighting a 2.7–5.5% decrease in COD time following isolated (Siddle et al., 2019) and combined NHC programmes (Tous-Fajardo et al., 2016) in sub-elite and elite male youth soccer players. Rapid changes of direction are vital for success in soccer, with players required to perform directional and speed changes that impose high metabolic and mechanical load demands (Tous-Fajardo et al., 2016), whilst a strong correlation has been identified between eccentric KF strength and COD performance (Paul et al., 2016). In the current study, there was a non-significant 4.5–7.8% gain in eccentric KF strength. When braking, eccentric KF strength helps to maintain hip extensor torque, assists dynamic knee and trunk stabilization, and contributes to the storage and utilization of elastic energy during the final foot contact of COD tasks (Dos Santos et al., 2017). This is in contrast to linear sprinting, where concentric muscle actions of the lower limbs have been identified as the primary agonists (Johnson & Buckley, 2001). It should be noted that COD tasks are commonplace in popular soccer training methods such as small-sided games. As such, improvements in COD ability observed could potentially be due to a combination of the NHC intervention and a player's normal everyday soccer-specific training and conditioning.

The lack of a control group limits the potential to evaluate the impact of the concurrent training load, but in liaison with club staff it was considered unethical and counterproductive to the club to impose a control group where some players would be excluded from potential benefit in performance and injury risk (Lacome et al., 2019; Severo-Silveira et al., 2018). Furthermore, the duration of the protocol,

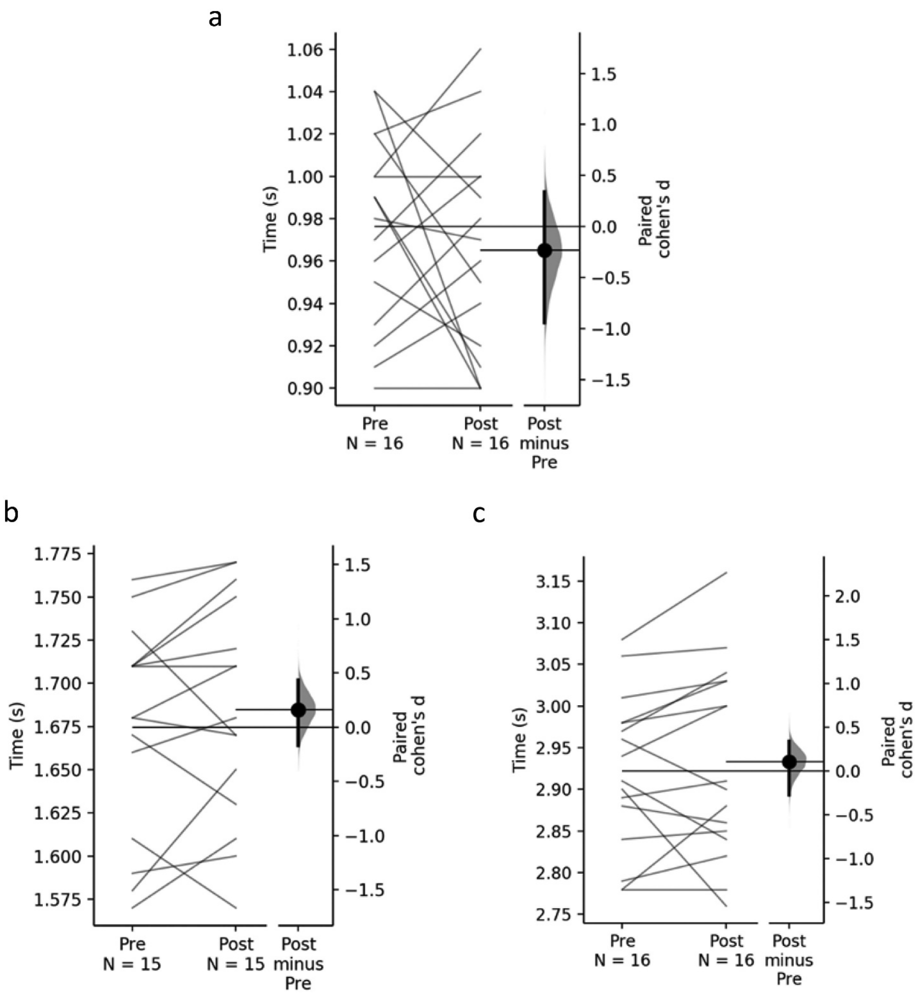

Figure 3. Individual participant response for linear sprint speed.

training volume and methodology of exercise should be noted before making direct comparisons with literature of a similar nature, as improvements associated with the NHC are largely mode and intensity specific (Lacome et al., 2019), as such findings should not be generalized beyond the current population. It should also be noted that the use of two-dimensional B-mode ultrasound to estimate muscle architectural changes, although considered reliable, has some associated methodological limitations (Franchi et al., 2018).

Future research is required to determine whether manipulation of intervention duration, exercise mode in the form of assisted vs unassisted NHC and training volume would provide more beneficial improvements in both performance and structural adaptations in elite youth soccer populations, with implications for performance and injury risk.

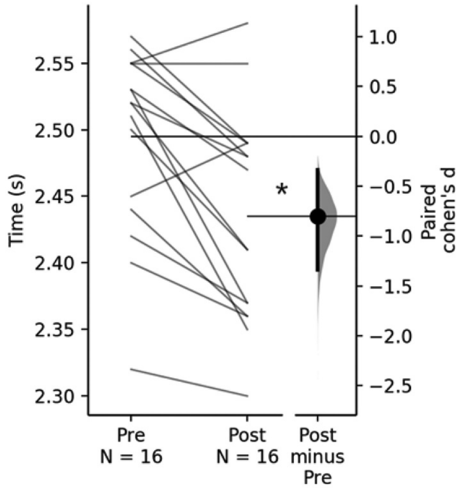

Figure 4. Individual participant response for mean change-of-direction speed. *Denotes statistical significance ($p < 0.05$).

Conclusions

An 8-week low volume NHC intervention programme resulted in significant improvements in COD performance in elite male youth soccer players, despite non-significant changes in hamstring muscle architecture, eccentric KF strength and linear sprint times. These results highlight the association between adaptation in muscle architecture, strength and performance, but also the specific differentiation between linear and change of direction speed. Consequently, it is suggested that NHC adaptations are potentially specific to participant, multi-modal exercise mode and study design.

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