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Effects of sprint vs. strength training on risk factors for hamstring injury in football players

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Running head: Training to reduce the risk of hamstring injury

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ABSTRACT

BACKGROUND: This study aimed to compare the effects of in-season sprint training *vs.* Nordic hamstring exercise (NHE) training on risk factors for hamstring strain injuries (HSI). **METHODS:** Eighteen male university football players (20.9±2.5 years; 181±7 cm; 75.8±9.1 kg; 15.2±3.5% of body fat) were randomly allocated to a sprint group or NHE group. They completed baseline isokinetic strength and sprint mechanics assessments prior to their assigned intervention performed twice weekly for 4-weeks, before post-testing. A mixed design ANOVA with repeated maesures assessed time, group and interaction effects for all risk factors. **RESULTS:** There were significant increases in hamstring eccentric peak torque at $60°\cdot s^{-1}$ (+8% - 9.9%), the torque produced at 20° (+15%) and 10° (+21% - 31%), as well as a rightward shift in angle of peak torque towards knee extension (-27% - -36%) in both groups ($p<0.05$). We also observed a significant increase (+24.5%) in hamstring eccentric peak torque at $180°\cdot s^{-1}$ in the strength group only and significant improvements (+29.4%) in the rate of torque development of the dominant leg at $60°\cdot s^{-1}$ in the sprint group only ($p<0.05$). No significant effect were noted on sprint performance or sprint mechanics ($p>0.05$). **CONCLUSIONS:** These findings suggest that both training programmes can be effective to mitigate the risk of HSI, but through different mechanisms.

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Key words: rate of torque development, angle of peak torque, sprint mechanics, eccentric strength

Introduction

Hamstring strain injury (HSI) is the most commonly reported injury in professional (25.4% of all injuries)[1] and amateur football (13% of all injuries).[2] Player careers and team performances can be negatively affected as a result of HSI, with a previous study revealing that 4-6 hamstring injuries are expected per 25-player squad, resulting in 14 matches missed per season.[3] These statistics and the high HSI re-injury rates (12.5 to 22.7%)[1] highlight the need to optimise HSI prevention strategies for footballers.

Hamstring eccentric strengthening is one exercise modality that has received the greatest attention to date in the literature, with, in particular, the Nordic hamstring exercise (NHE) showing large decreases (-51%) in HSI incidence in recent systematic reviews and meta-analyses.[4-5] However, the recent UEFA Elite Club Injury Study showed that, unlike other injuries, HSI have not decreased in the past 18 years.[6] More recently, sprint training has been mentioned as a potential solution, not merely a mechanism, for HSI.[7] Hamstring injuries often occur during the late swing and early stance phases of sprinting when the hamstrings contract forcefully while reaching their maximum length.[7] Therefore, maximal speed running could represent a more appropriate stimulus for hamstring activation compared to isolated eccentric strengthening exercises, as it elicits greater levels of hamstring activity,[8] while capturing the unique nature of this cyclic activity, i.e. elastic energy transfer, reflexes, hip-knee kinematics, intra- and inter-muscles coordination.[7,9]

Only two intervention studies have been published to date comparing the effects of sprint training and NHE on factors associated with HSI. Freeman et al.[10] showed that two 4-week training programmes based on NHE *vs.* sprint training, respectively, significantly improved hamstring eccentric strength (+6.2-9.8%) but sprint training resulted in greater improvements (+8.6% *vs.* 0%) in maximal speed in secondary school athletes. More

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recently, Mendiguchia et al.[9] compared the effects of 6 weeks of sprint training (loaded and unloaded) with those of NHE and football only training during the pre-season in elite footballers. Their results showed that compared to the other types of training, sprint training resulted in a greater increase in the fascicle length of the biceps femoris (+16% *vs.* +7% and -0.1%, respectively for the sprint vs. NHE and football groups) and greater improvement in sprinting performance and sprinting mechanics, in particular the maximal theoretical horizontal force (F_0, +7% *vs.* -3% and +1.6%, respectively for the sprint vs. NHE and football groups). While these results are promising, they were not all from footballers and some were obtained in pre-season, when improvements following training are more likely. In addition, only a small range of parameters associated with HSI were considered in these studies, while it is well-established that HSI mechanisms are multifactorial.[11]

The main modifiable risk factors for HSI reported in prospective studies are low eccentric hamstrings strength,[12] excessive imbalance between eccentric hamstrings and concentric quadriceps strength (H_{ecc}:Q_{con}),[13] interlimb asymmetry in hamstring strength above 15%,[12] shorter fascicle length of the biceps femoris,[14] and low horizontal force production capacity during sprinting (F_0).[15] Other variables suggested as potential risk factors for HSI from comparisons of injured and uninjured athletes include an angle of eccentric hamstring peak torque (APT) closer to knee flexion,[14,16] and a smaller rate of eccentric hamstring torque development.[17]

Within this context, the aim of the present study was to investigate the effects of an in-season sprint training programme compared to a NHE-based training programme on a variety of risk factors for HSI in amateur football players.

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Materials and Methods

Participants

Eighteen participants were recruited for this study. This sample size was calculated from a power analysis based on Freeman et al.[10]'s study (effect size: 0.49; expected power: 0.80, alpha level: 0.05). At the time of the study, the team was involved in two football practice sessions, one match and two strength and conditioning sessions weekly. Participants were randomly allocated, while controlling for playing position, to a sprint training group (n = 9; 20.6 ± 1.3 years; 179.9 ± 6.8 cm; 74.6 ± 7.8 kg; 15.2 ± 4.0 % of body fat) or a NHE training group (final n = 7 after two drop-outs due to ankle and shoulder injuries, 21.3 ± 2.7 years; 182.4 ± 7.4 cm; 77.4 ± 10.3 kg; 15.2 ± 2.1 % of body fat). Exclusion criteria were any current injury or a hamstring injury sustained within the past 12 months, as well as any current medical treatment or nutritional supplements that could affect muscular performance. Participants gave written informed consent and the study was approved by the local University ethics committee in accordance with the principles set forth in the Helsinki declaration (Oxford Brookes university Research Ethics Committee, Chair: Dr David Evans, approval number 191305, date: 27/09/2022).

Procedures

Participants were assessed before and immediately after a 4-week training intervention period.

Baseline and post-intervention strength testing

After a 10 min standardised warm-up on an ergocycle (Monark 874E; Monark, Varberg, Sweden) at 100W with 6 s intermittent sprints in the last 4 min, participants completed isokinetic dynamometer strength testing (Biodex system 4; Biodex, Shirley, NY). Participants position and dynamometer settings has been described elsewhere.[18]

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Strength testing was performed on both the dominant (leg used to kick a ball) and non-dominant legs and at two angular velocities, $60°\cdot s^{-1}$ and $180°\cdot s^{-1}$, with all these conditions randomised. These velocities are characterised by excellent test-retest reliability (Intraclass correlation coefficients of 0.95-0.98).[19] The range of motion was from 0° (full knee extension) to 90° of knee flexion and participants were given verbal encouragement to provide maximal effort throughout the range. The test consisted of concentric contractions of the quadriceps and hamstrings and eccentric contraction of the hamstrings at $60°\cdot s^{-1}$ (three repetitions) and $180°\cdot s^{-1}$ (five repetitions). Each condition was preceded by a familiarisation set.

The following variables were calculated as the average of the two best contractions at $60°\cdot s^{-1}$ and the three best contractions at $180°\cdot s^{-1}$:

- Concentric peak torque of the quadriceps (Q_{con}, N.m)
- Eccentric peak torque of the hamstrings (H_{ecc}, N.m)
- H_{ecc}:Q_{con}
- Rate of torque development for H_{ecc} (RTD_{200}, $N\cdot m\cdot s^{-1}$), calculated as the ratio between the change in torque and the corresponding change in time, over a rolling window of 200 ms intervals.[20]
- H_{ecc} at angles of 30°, 20° and 10°
- APT
- Asymmetry for all parameters: = ([(dominant-non dominant)/dominant] x 100.

Baseline and post-Intervention sprint mechanics testing

After a 10 min standardised warm-up consisting of jogs, changes in direction, accelerations and dynamic stretching, participants performed two 30 m sprints, separated by 5 min, from a three-point start position (crouched position with one hand on the ground). They were performed on the usual football pitch (3G artificial grass) used

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for the team practice sessions. Sprint time and sprint mechanics were measured with MySprint application for iPhone, using the method validated by Samozino et al. (2015).[21] The following parameters were calculated, using the fastest of the two sprints performed:

- 30 m sprint time (s)
- Theoretical maximal horizontal force (F_0, N·kg^{-1})
- Theoretical maximal velocity (V_0, m·s$^{-1)}$
- Maximal power output (P_{max}, W·kg^{-1})
- Maximal value of the ratio of the horizontal force and resultant force (RF_{peak}, %)

Training interventions

Both training interventions were performed at the end of football practice sessions. This timing is not likely to affect strength gains as mentioned by Lovell et al.[22] A total of two sessions per week were completed by both groups. Progression to the exercise for both groups over the 4 weeks is displayed in Table 1. The NHE was performed using the technique described by Delextrat et al.[18] Sprints were undertaken from a standing start, with 5 min rest between repetitions.

Statistical analyses

All data are presented as mean ± standard deviation with 95% confidence interval (CI) Statistical analyses were conducted using SPSS statistical software (version 27.0, IBM Corp., Armonk, NY, USA). Initial tests were performed to check the normality of all variables using the Shapiro-Wilk test, while homogeneity of variances was evaluated using the Levene's test. A mixed design two-way analysis of variance (ANOVA) with repeated measures was performed to assess the effect of time, group and their interaction on all outcome variables described above. Student T-tests were undertaken as post-hoc tests in case of significant interactions. A p-value < 0.05 was considered significant. Effect sizes were calculated as Partial Eta Squared $\left(\eta_p^2\right)$ for the ANOVA and

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interpreted as no effect (0-0.05), minimum effect (0.05-0.26), and strong effect (0.26-0.64), while Cohen's *d* represented the effect size for post-hoc tests, and were interpreted as small (>0.2), medium (>0.5) and large (>0.8).[23]

Results

The compliance rate for all completed training sessions was 84.4%.

Quadriceps Concentric Peak Torque (Q_{con})

There was no significant effect of time ($p = 0.169$ to 0.668), group ($p = 0.439$ to 0.948), or time × group interaction ($p = 0.076$ to 0.545) on Q_{con} for either legs or angular velocities (Table 2).

Hamstrings Eccentric Peak Torque (H_{ecc})

There was a significant increase in H_{ecc} between pre and post-tests in the non-dominant leg (+9.9%, $F(1,14) = 4.829$, $p = 0.045$) and the dominant leg (+8.1%, $F(1,14) = 4.651$, $p = 0.049$) at $60°\cdot s^{-1}$. There was also a significant interaction between group and time for the non-dominant leg at $180°\cdot s^{-1}$ ($F(1.14) = 6.390$, $p = 0.024$). The post-hoc test revealed a significant increase in H_{ecc} between pre and post-test within the NHE group (+24.5%, $t(1) = -2.209$, $p = 0.035$, $d=0.89$), whereas the sprint group showed no variation between these time points ($t(1) = 1.169$, $p = 0.139$, Table 2).

Functional Hamstrings to Quadriceps Ratio (H_{ecc}:Q_{con})

There was no significant effect of time ($p = 0.075$ to 0.993), group ($p = 0.208$ to 0.880), or time × group interaction ($p = 0.185$ to 0.362), on $H_{ecc}:Q_{con}$ for either legs or angular velocities (Table 2).

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Rate of Torque Development (RTD_{200}) for Hamstrings Eccentric Contractions

There was a significant time x group interaction for the dominant leg at 60°·s^{-1} (F(1,14) = 5.475, p = 0.035, d = 1.01). A significant increase between pre- and post-tests was highlighted by the post-hoc test in the sprint group (+29.4%, t(1) = -3.473, p = .004), while no significant difference between these time points was shown in the strength group (t(1) = 0.522, p = 0.310), (Table 3).

Angle of Peak Torque (APT) for Hamstrings Eccentric Contractions

The statistical analysis showed significant effects of time between pre and post-tests, with a reduction in APT towards a more extended leg position in the non-dominant leg (-36.3%, F(1,14) = 6.369, p = 0.024) and the dominant leg (-32.4%, F(1,14) = 8.742, p = 0.010) at 60°·s^{-1}. This was also the case for the dominant leg at 180°·s^{-1} (-26.8%, F(1,14) = 6.687, p = 0.022, Table 3).

Hamstring eccentric torque (H_{ecc}) at angles of 30°, 20° and 10°

A significant increase in H_{ecc} at 20° from pre to post-test was noted for the dominant leg at 60°·s^{-1} only (+15.0%, F(1,14) = 4.88, p = 0.044). At 10°, a significant increase in H_{ecc} from pre to post-tests was shown in both the non-dominant (+30.6%, F(1,14) = 5.015, p = 0.049) and dominant leg (+21.1%, F(1,14) = 5.685, p = 0.044) at 60°·s^{-1}, and in the non-dominant leg at 180°·s^{-1} (+27.3%, F(1,14) = 6.285, p = 0.033, Table 4).

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Asymmetry

There was no significant effect of time (p = 0.338 to 0.859), group (p = 0.444 to 0.782), or time × group interaction (p = 0.150 to 0.872) on asymmetry variables calculated for either legs or angular velocities.

Sprint performance and sprint mechanics

There was no significant effect of time (p = 0.335 to 0.524), group (p = 0.701 to 0.889), or time × group interaction (p = 0.144 to 0.883) on sprint performance (30 m time) and sprint mechanics variables ($p > 0.05$, Table 5).

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Discussion

Our main findings highlighted significant increases in peak H_{ecc} at $60°\cdot s^{-1}$ and H_{ecc} produced at 20° and 10°, as well as a shift in the APT towards leg extension in both groups after the 4-week intervention period. Group-specific changes included a significant increase (+24.5%) in H_{ecc} at $180°\cdot s^{-1}$ in the non-dominant leg in the strength group only and significant improvements (+29.4%) in RTD_{200} of the dominant leg at $60°\cdot s^{-1}$ in the sprint group only.

Peak torque

While the improvement in H_{ecc} following NHE in our study has been classically reported in the literature,[5] a relatively novel finding is the significant improvement in this variable in both legs at $60°\cdot s^{-1}$ following the sprint training programme (+7.5% to +7.7%). Freeman et al.[10] observed outcomes of this magnitude (+6.2%) with a comparable 4-week sprint training protocol. The main reason behind the effectiveness of sprint training is that it induces peak activation of the hamstrings to an even superior degree than any eccentric strength exercise,[8] hence stimulating a sufficient load to deliver specific eccentric strength adaptations. Nevertheless, the strength gains at both slow and fast velocities following NHE were greater in our present study as well as the study of Iga et al.[24]

Angle and peak torque (APT) and torque at 30°, 20°and 10°

The APT is a variable reflecting the length-tension relationship of the hamstring.[16,25] In the present study, both training interventions resulted in significant rightward shifts in APT (towards a more extended leg position) in both legs at 60°·s^{-1} (-32.4% to -36.3%,) and in the dominant leg at 180°.s^{-1} (-26.8%). Significant shifts from 14% to 42% in the APT in the direction of longer muscle lengths after eccentric strength training have been reported in previous studies.[18,25-26] The rather moderate changes in our study could be explained by our short intervention duration and the fact that the good strength level of our players.[18] The observed changes in APT in the present study are paralleled by significant increases (+10.1 to +37.1%, small to strong effect sizes) in the torque produced at angles of 20° (dominant leg at 60°·s^{-1} only) and 10° (both legs at 60°·s^{-1} and non-dominant leg at 180°·s^{-1}), which is similar to previous studies.[18,22] During sprinting, HSI most commonly occurs at knee extension angles less than 30°,[27] while peak H_{ecc} is often detected at shortened angles.[25] Therefore, it is proposed that a shift in APT towards angles of 0-30°, as measured in our study (20.0°-25.2°) at 60°·s^{-1} could provide a protective effect.[28] In favour of this hypothesis, van den Tillaar et al.[8] showed that the NHE elicits hamstring maximal activation at angles similar to sprinting, indicating that the both exercises could promote adaptations to occur at the optimal phase of the running cycle. Our results also refute concerns expressed in the literature over the NHE producing a low stimulus at extended knee positions,[25] and are in agreement with the

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findings of Iga et al.[24] demonstrating greater EMG activity of the hamstring at extended knee positions (0°-60°) compared to more flexed positions (61°-90°) during the NHE.

Several mechanisms have been suggested in the literature to account for the aforementioned adaptations following NHE and/or sprint training. These include architectural modifications such as an increase in the biceps femoris fascicle length,[9] muscle hypertrophy,[22] and neural adaptations. The benefit of longer fascicles in the biceps femoris, evidenced with as little as 3 weeks of eccentric training,[29] is extensive as it prevents overstretching beyond the mechanical threshold that would cause excessive strain, from an increase of in-series sarcomeres and a reduced decline in excitation-contraction coupling.[30] This protective effect is essential during high-speed running where the hamstring must provide sufficient force in a lengthened state.

Rate of Torque Development (RTD_{200})

This variable has been suggested as a risk factor for HSI in retrospective studies, showing for example that previously injured hamstrings were characterised by significantly lower RTD compared to non–injured limbs.[17] Grazioli et al.[31] also reported that fatigue caused by a football match, known to be associated with a greater number of injuries,[32] led to greater decreases in RTD compared to other aspects, such as maximal voluntary strength. Interestingly, the present study showed a significant increase (+29.4%) in RTD_{200} in the dominant leg at $60°\cdot s^{-1}$ as a result of sprint training only. This result, similar to a previous study showing a greater maximal RTD after a period of resisted sprint training in sprinters,[33] suggests a potential protective effect of this type of training to decrease the risk of HSI. An increased RTD, usually resulting from a faster discharge rate of action potentials and the recruitment of a greater number of

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motor units at the start of resistance training[34] is likely to allow a faster development of hamstring eccentric force to ensure the attainment of the required torque to decelerate the swing of the limb.[17] Finally, the lack of changes in RTD_{200} at the faster angular velocity in the present study as well as the study of Opar et al.[17] may be due to the lower reliability of strength variables observed at higher compared to lower angular velocities.[19]

Sprint performance and sprint mechanics

Our results did not show any significant improvement in 30 m time after both interventions. This result is in agreement with the findings of Freeman et al.[10] following very similar training programmes to ours, suggesting that the duration, type or volume of these in-season trainings might not be sufficient to improve sprint performance. Regarding sprint mechanics, the theoretical maximal horizontal force (F_0) has been recently highlighted as a risk factor for HSI in two prospective studies on amateur and professional football players.[15,35] Our results show no effect of NHE on any of the sprint mechanics variables investigated, including F_0, which is in agreement with the study of Mendiguchia et al.[9] following 6 weeks of NHE training. This result was expected, in view of the differences between a complex whole-body movement as fast velocity (sprinting) and an isolated muscle strengthening exercise (NHE). For example, resistance training exercises elicit significantly lower activation of the hamstring muscles (from 18% to 75% of sprint values)[8] and the NHE does not address the elastic energy transfer, reflexes, hip-knee kinematics, or intra- and inter-muscles coordination taking place during sprinting.[7] Our results did not show any significant effect of sprint training on sprint mechanics, in agreement with Morin et al.[37]'s study, showing that very-heavy sled-resisted sprint training, but not unloaded sprint training, increased F_0 and mechanical effectiveness. This suggests that using some resistance in sprint training is essential to

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attend to the whole force-velocity spectrum and elicit positive adaptations in sprint mechanics that could potentially reduce the occurrence of HSI.[9]

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One limitation of the present study was the relatively small sample size. Despite a power calculation based on the main outcome variable of peak hamstring eccentric strength, our study might be slightly underpowered for some other factors investigated. The post-testing sessions were undertaken in December, combining high-levels of physical fatigue and busy academic schedule for our players, which may also have hindered some of the adaptations investigated. Finally, we could not measure some potential confounding variables known to affect HSI, such as hamstring flexibility or pelvis anterior tilt.

Conclusions

Our findings showed significant increases in hamstring eccentric peak torque and the torque produced at 20° and 10°, as well as a shift in the APT towards leg extension in both groups. Furthermore, we showed a significant improvement in the rate of torque development in the sprint group only. These results suggest the possibility of personalised training for footballers (i.e. sprint training for players with low RTD, NHE training for those with low hamstring eccentric strength). The practicality of both the NHE and sprint training is of great benefit to sub-elite performers who may not have access to performance enhancing facilities. Further studies should investigate the mechanisms by which these adaptations occur, and consider the effectiveness of the combination of these training methods on HSI risk factors.

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Conflicts of interest

We do have any conflict of interest to report.

Authors' contribution

All authors read and approved the final version of the manuscript.

Individual authors' contribution are as follows:

AS: study design, implementation of training programme, testing, statistical analyses, write-up.

LT: study design, design of training programme, proof-reading of drafts.

GW: study design, statistical analyses, proof-reading of drafts.

EB: study design, statistical analyses, proof-reading of drafts.

AD: study design, testing, statistical analyses, write-up.

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TABLES

Table 1. Four-week progression of the training programme.

	Week 1	Week 2	Week 3	Week 4
NHE	2x 5 repetitions	2x 6 repetitions	3x 5 repetitions	3x 6 repetitions
Sprint	5x 30m	6x 30m	5x 40m	6x 40m

NHE: Nordic Hamstring Exercise.

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Table 2. Mean±standard deviation (95% confidence interval) for the concentric peak torque of the quadriceps (Q_{con}), eccentric peak torque of the hamstrings (H_{ecc}) and H_{ecc}:Q_{con} in the dominant (D) and non-dominant (ND) legs at 60°.s^{-1} (60) and 180°.s^{-1} (180).

	Pre training		Post training		η_p^2
	Sprint	NHE	Sprint	NHE	
Q_{con} D 60 (N.m)	210±37 (181-239)	206±50 (160-252)	192±45 (158-227)	216±44 (174-57)	T: 0.01, G: 0.02 I: 0.14
Q_{con} D 180 (N.m)	144±34 (117-170)	142±35 (110-174)	145±25 (126-165)	149±31 (120-177)	T: 0.06, G: 0.01 I: 0.03
Q_{con} ND 60 (N.m)	192±20 (177-207)	198±63 (140-255)	190±21 (174-205)	214±42 (175-25)	T: 0.13, G: 0.04 I: 0.21
Q_{con} ND 180 (N.m)	148±27 (128-169)	140±45 (99-182)	148±12 (139-157)	153±34 (121-184)	T: 0.10, G: 0.01 I: 0.10
H_{ecc} D 60 (N.m)	**167± 32*** (142-91)	**166± 53*** (117-215)	**180± 31*** (156-203)	**180± 36*** (147-213)	**T: 0.25**, G: 0.01 I: 0.01
H_{ecc} D 180 (N.m)	173±35 (146-199)	172±36 (139-206)	160±23 (142-178)	177±32 (147-206)	T: 0.03, G: 0.02 I: 0.10
H_{ecc} ND 60 (N.m)	**167± 31*** (143-190)	**157± 55*** (106-209)	**179±43*** (146-212)	**177± 51*** (129- 224)	**T: 0.26**, G: 0.01 I: 0.02
H_{ecc} ND 180 (N.m)	156±26 (136-176)	**135±40*** (98-171)	144± 26 (124-164)	**168±34*** (136-199)	T: 0.10, G: 0.01 **I: 0.31**
H_{ecc}:Q_{con} D 60	0.81±0.18 (0.67-0.95)	0.80±0.13 (0.68-0.92)	0.99±0.34 (0.73-1.25)	0.84±0.12 (0.73-0.95)	T: 0.21, G: 0.05 I: 0.09
H_{ecc}:Q_{con} D 180	1.27±0.44 (0.93-1.61)	1.23±0.19 (1.06-1.40)	1.14±0.30 (0.91-1.37)	1.22±0.29 (0.95-1.49)	T: 0.10, G: 0.01 I: 0.07
H_{ecc}:Q_{con} ND 60	0.87±0.14 (0.76-0.98)	0.81±0.20 (0.63-0.99)	0.95±0.22 (0.78-1.12)	0.81±0.09 (0.72-0.89)	T: 0.04, G: 0.11 I: 0.06
H_{ecc}:Q_{con} ND 180	1.08±0.31 (0.85-1.32)	1.01±0.31 (0.72-1.29)	0.98±0.20 (0.83-1.13)	1.12±0.19 (0.94-1.29)	T: 0.01, G: 0.01 I: 0.12

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*: significant differences between pre-and post-tests, p<0.05 (η_p^2: partial eta squared, T: Time, G: group, I: time × group interaction). NHE: Nordic Hamstring Exercise.

Table 3. Mean±standard deviation (95% confidence interval) for the angle of peak torque (APT) and the rate of torque development (RTD$_{200}$) of the eccentric torque of the hamstrings in the dominant (D) and non-dominant (ND) legs at 60°.s^{-1} (60) and 180°.s^{-1} (180).

	Pre-training		Post-training		η_p^2
	Sprint	NHE	Sprint	NHE	
APT D 60 (°)	**34.9±9.3*** (27.8-42.1)	**32.0±8.1*** (24.5-39.6)	**20.0±19.4*** (5.1-34.9)	**25.2±11.6*** (14.4-35.9)	**T: 0.38,** G: 0.01 I: 0.08
APT D 180 (°)	**40.4±8.8*** (33.6-47.1)	**37.7±7.4*** (30.9-44.5)	**24.1±16.2*** (11.7-36.5)	**33.1±17.2*** (17.1-49.0)	**T: 0.32,** G: 0.03 I: 0.13
APT ND 60 (°)	**35.2±11.6*** (26.3-44.1)	**33.6±16.4*** (18.4-48.8)	**23.5±18.4*** (9.4-37.6)	**20.3 ± 24.3*** (-2.1-42.7)	**T: 0.31,** G: 0.01 I: 0.01
APT ND 180 (°)	39.7±14.3 (28.8-50.7)	40.0±18.1 (23.2-56.7)	30.9±19.3 (16.1-45.8)	37.0±26.0 (13.0-61.1)	T: 0.05, G: 0.01 I: 0.01
RTD$_{200}$ D 60 (N.m.s^{-1})	**222 ± 52*** (182-261)	236±105 (138-333)	**287± 75*** (229-344)	219±78 (148-291)	T: 0.12, G: 0.04 **I: 0.28**
RTD$_{200}$ D 180 (N.m.s^{-1})	310±73 (254-366)	305±74 (237-373)	278±27 (257-299)	298±72 (232-364)	T: 0.08, G: 0.01 I: 0.03
RTD$_{200}$ ND 60 (N.m.s^{-1})	187±49 (149-225)	214±55 (163-265)	177±26 (157-197)	222±48 (179-266)	T: 0.01, G: 0.26 I: 0.26
RTD$_{200}$ ND 180 (N.m.s^{-1})	264±44 (229-298)	293±98 (203-384)	259±70 (205-313)	278±59 (224-333)	T: 0.01, G: 0.08 I: 0.01

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*: significant differences between pre-and post-tests, p<0.05 (η_p^2: partial eta squared, T: Time, G: group, I: time × group interaction). NHE: Nordic Hamstring Exercise.

Table 4. Mean±standard deviation (95% confidence interval) for the eccentric hamstring torque produced at 30°, 20° and 10° of leg extension in the dominant (D) and non-dominant (ND) legs at 60°.s^{-1} (60) and 180°.s^{-1} (180).

	Pre-training		Post-training		η_p^2
	Sprint	NHE	Sprint	NHE	
Torque 30° D 60 (N.m)	152±32 (128-176)	152±52 (104-200)	154±32 (130-179)	161±34 (130-192)	T:0.04, G: 0.01 I: 0.02
Torque 30° D 180 (N.m)	141±35 (114-167)	152±27 (127-177)	137±30 (114-160)	145±37 (110-179)	T: 0.03, G: 0.03 I: 0.01
Torque 30° ND 60 (N.m)	150±34 (123-176)	130±54 (80-180)	157±39 (127-188)	133±62 (76-190)	T: 0.03, G: 0.07 I: 0.01
Torque 30° ND 180 (N.m)	134±31 (110-158)	117±34 (86-148)	132±27 (111-153)	128±31 (100-157)	T: 0.02, G: 0.04 I: 0.04
Torque 20° D 60 (N.m)	**140±41*** (108-171)	**145± 57*** (93-198)	**154±40*** (123-174)	**174±44*** (133-215)	**T: 0.26,** G: 0.03 I: 0.04
Torque 20° D 180 (N.m)	118±41 (86-149)	138±37 (104-172)	133±41 (102-165)	140±48 (96-185)	T: 0.06, G: 0.04 I: 0.03
Torque 20° ND 60 (N.m)	135±37 (106-164)	125±59 (70-179)	157±50 (119-195)	126±53 (77-127)	T: 0.08, G: 0.06 I: 0.06
Torque 20° ND 180 (N.m)	122± 33 (97-148)	113±31 (85-142)	123±42 (91-155)	118±45 (77-160)	T: 0.01, G: 0.02 I: 0.01
Torque 10° D 60 (N.m)	**139± 35*** (102-176)	**135± 76*** (14-256)	**173± 23*** (149-198)	**159± 49*** (81-237)	**T: 0.42,** G: 0.01 I: 0.02
Torque 10° D 180 (N.m)	116±30 (68-164)	134±47 (56-226)	150±58 (57-242)	176±44 (45-268)	T: 0.35, G: 0.12 I: 0.01
Torque 10° ND 60 (N.m)	**110±46*** (62-159)	**107± 46*** (59-155)	**151±70*** (78-224)	**132± 52*** (78-187)	**T: 0.33,** G: 0 .02 I: 0 .03
Torque 10° ND 180 (N.m)	**96± 38*** (50-143)	**106±37*** (68-145)	**117±36*** (73-162)	**141± 43*** (95-186)	**T: 0.41,** G: 0.07 I-:0.04

*: significant differences between pre-and post-tests, p<0.05 (η_p^2: partial eta squared, T: Time, G: group, I: time × group interaction). NHE: Nordic Hamstring Exercise.

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Table 5. Mean±standard deviation (95% confidence interval) for sprint mechanics variables

	Pre-training		Post-training		η_p^2
	Sprint	NHE	Sprint	NHE	
30-m time (s)	4.70±0.16 (4.56-4.85)	4.61±0.16 (4.44-4.78)	4.67±0.22 (4.47-4.87)	4.73±0.18 (4.54-4.92)	T: 0.04, G: 0.01 I: 0.14
F_0 ($N.kg^{-1}$)	7.63±0.44 (7.22-8.04)	8.08±0.77 (7.28-8.90)	7.78±0.90 (6.95-8.61)	7.25±0.80 (6.41-8.09)	T: 0.09, G: 0.01 I: 0.16
V_0 ($m.s^{-1}$)	8.42±0.48 (7.97-8.86)	8.55±0.30 (8.23-8.87)	8.61±0.69 (7.97-9.26)	8.70±0.75 (7.91-9.41)	T: 0.08, G: 0.01 I: 0.01
P_{max} ($W.kg^{-1}$)	16.1±1.4 (14.8-17.3)	17.3±1.8 (15.4-19.2)	16.7±2.1 (14.8-18.6)	15.7±1.6 (14.0-17.3)	T: 0.04, G: 0.01 I: 0.18
RF_{max} (%)	51.4±1.7 (49.8-53.0)	53.1±2.9 (50.1-56.1)	52.0±3.2 (49.0-55.9)	50.1±28.0 (47.1-53.0)	T: 0.08, G: 0.01 I: 0.16

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*: significant differences between pre-and post-tests, $p<0.05$ (η_p^2: partial eta squared, T: Time, G: group, I: time × group interaction). NHE: Nordic Hamstring Exercise.

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