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BRIEF REPORT

WILEY

The dose–response of pain throughout a Nordic hamstring exercise intervention

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The Nordic hamstring exercise (NHE) reduces hamstring injury incidence. Compliance to large exercise volumes of the NHE is poor, with exercise related soreness often seen as a contributing factor. We investigated the dose–response of NHE exposure with delayed onset muscle soreness (DOMS) and non-DOMS pain. Forty males were randomized to a 6-week intervention of four different NHE dosages: Group 1: very low volume; Group 2: low volume; Group 3: initial high to low volume; Group 4: low to high volume. Group 4 experienced more DOMS ($p < 0.05$) and non-DOMS pain ($p = 0.030$) than other groups. High volumes of NHE increase DOMS and non-DOMS pain while lower volume protocols have lesser DOMS and non-DOMS pain responses.

KEYWORDS
delayed onset muscle soreness, eccentric exercise, hamstring strain injuries, injury prevention

1 | INTRODUCTION

Hamstring strain injuries (HSIs) are the primary injury sustained by footballers across Europe.[1] The Nordic hamstring exercise (NHE) reduces the incidence of HSI.[2] However, the compliance to large exercise volumes of the NHE is poor,[3] with exercise related soreness seen as a potential contributing factor.[3] Delayed onset muscle soreness (DOMS) has been reported in response to the NHE,[4] but non-DOMS musculoskeletal pain (e.g., knee pain) associated with this exercise has received minimal attention, despite potentially contributing towards poor adherence levels.

A reduced exercise dosage of NHE (8 repetitions per week from week 3),[5] compared to protocols employed in prevention RCTs (progressing to 90 repetitions per week),[2] is effective for altering biceps femoris long head (BFlh) muscle architecture and eccentric strength,[5] both previously linked to HSI risk,[6] although not consistently.[7] Recently, an even lower volume of NHE was found to be effective for increasing strength (8 weekly repetitions from week 1), while a higher dose was found to be effective

for architectural changes.[8] However, the pain response (DOMS and non-DOMS) to different levels of NHE dosage has not been investigated; this may be useful for guiding exercise prescription and providing insight on adherence. Therefore, this study aimed to determine if there is a dose–response relationship between NHE exposure with DOMS and non-DOMS pain.

2 | METHODS

2.1 | Participants

Forty recreationally active males (32.0 ± 4.3 years, 180.0 ± 6.6 cm, 82.5 ± 9.5 kg) were recruited for this study (Figure S1). Participants were recruited from within the Aspire Zone in Doha, Qatar through email communication and word of mouth. All participants provided written informed consent prior to participation in the study, which was approved by the Anti-Doping Laboratory of Qatar. Inclusion criteria consisted of healthy, active males, aged between 18 and 40 years of age who were not concurrently resistance training and had no history of HSI in the last year.

2.2 | NHE training intervention

Participants were block randomized by a random number generator to a 6-week intervention of four different NHE dosages: Group 1 ($n = 10$): very low volume; Group 2 ($n = 10$): low volume; Group 3 ($n = 10$): initial high to low volume; Group 4 ($n = 10$): low to high volume (Table 1). NHE training was supervised on a commercially available device (Nordbord, Vald Performance, QLD, Australia). Participants knelt on a padded board, with their arms across their chest and hips extended, and were instructed to lean forward, lower their body and slow their descent as much and as far through range as possible.[5,8] Verbal encouragement was given throughout training. When participants developed enough strength to stop their movement in the final 10–20°, they held a weight plate to their chest to maintain intensity (weight range: 5–20 kg).[5,8]

2.2.1 | Pain Assessment

Delayed onset muscle soreness was assessed at the start of each session using a verbal numeric rating scale (vNRS) of 0–10. Weekly peak DOMS was utilized for analysis where weeks had multiple sessions and scores from non-training weeks in Group 1 were obtained in their subsequent training session. Non-DOMS related musculoskeletal pain was assessed upon completion of the programme, using a binary outcome (yes/no for non-DOMS related pain due to NHE at any point throughout the intervention; vNRS and area of pain was also recorded (Table S1)). To compare the effects of different NHE dosages on DOMS related pain, linear mixed models analyses were conducted with participants as random factors and fixed factors of: group allocation and week of intervention. Post-hoc pairwise analyses (with Tukey HSD adjustment for multiple comparison) were conducted for all pairwise comparisons. To compare the effects of different dosages on non-DOMS pain, a Fisher's exact test was undertaken. A sample size calculation using G*Power with power set at 80%, an alpha level of <0.05, and accounting for a 10% drop-out rate, found 40 participants to be sufficient.[5]

3 | RESULTS

Delayed onset muscle soreness analyses showed a significant effect of time (week) ($p < 0.0001$) and a time by group interaction effect ($p < 0.0001$), with group 4 experiencing more DOMS than all other groups ($p < 0.05$, Figure 1). All groups experienced a significant decrease in DOMS over 6 weeks except group 4 ($p < 0.01$, Figure 1). In week 1, group 4 had median DOMS of 3.5, group 3 had 4.5, group 2 had 1, and group 1 had 0. However, all groups dropped to a median of 0 from week 2 onwards apart from group 4, who had median DOMS of 2, 2, 2, 1.5 and 0 for the remaining weeks.

A difference was also found for non-DOMS related pain between groups ($p = 0.030$). Group 4 reporting the highest proportion of non-DOMS related musculoskeletal pain. Only 10% (1/10) of the lower volume groups (groups 1 and 2) reported non-DOMS related pain, while 50% (5/10) of group 3 and 60% (6/10) of group 4 reported non-DOMS pain episodes due to the NHE exercise. Of interest, 85% of pain reported was knee pain (Figure S1). DOMS or non-DOMS pain response did not alter compliance between groups, with 97% or above in all groups, and no dropouts. No formal diagnosis for pain was sought, and all participants fully recovered on assessment following the intervention and after a 2- and 4-week follow-up, with no ongoing interference to their recreational sports.

4 | DISCUSSION

Higher DOMS and non-DOMS related musculoskeletal pain is experienced by larger volume NHE prescriptions. Greater NHE volumes increases both strength and architecture adaptation[8] but appear to also increase the risk of DOMS and non-DOMS pain. 33% of the cohort

TABLE 1 Nordic hamstring exercise training prescription for all four groups

Group	Week	Frequency	Sets	Reps	Total weekly reps
Group 1: very low volume	1	1	2	4	8
	2	0	0	0	0
	3	1	2	4	8
	4	0	0	0	0
	5	1	2	4	8
	6	0	0	0	0
Total		3	6		24
Group 2: low volume	1	1	2	4	8
	2	1	2	4	8
	3	1	2	4	8
	4	1	2	4	8
	5	1	2	4	8
	6	1	2	4	8
Total		6	12		48
Group 3: initial high volume followed by low volume	1	3	4	6	72
	2	3	4	6	72
	3	1	2	4	8
	4	1	2	4	8
	5	1	2	4	8
	6	1	2	4	8
Total		10	32		176
Group 4: progressively increasing volume	1	1	2	5	10
	2	2	2	6	24
	3	3	3	7	63
	4	3	3	9	81
	5	3	3	12, 10, 8	90
	6	3	3	12, 10, 8	90
Total		15	42		358

Note: Group 1 ($n = 10$): Very low volume; Group 2 ($n = 10$): Low volume; Group 3 ($n = 10$): Initial high volume to low volume; Group 4 ($n = 10$): Progressively increasing volume.

experienced non-DOMS related pain, with 85% of these found in the higher volume groups. This may assist in explaining the poor adherence levels to high volume NHE protocols.[3] High rates of knee pain in the larger volume groups are noteworthy for prescribing practitioners and worthy of monitoring. No previous similar trials assessed pain response to NHE intervention other than DOMS,[4] thus to the authors' knowledge this is the first description of such non-DOMS musculoskeletal pain in response to the NHE in the literature. Participants in the current cohort are heavier than participants in previous research and this may have contributed to these findings,[5] but the mechanism seems largely speculative at present.

Low volume NHE prescription (Group 2: 2 sets of 4 repetitions once a week for 6 weeks) results in a low pain response (weekly median of 0 for DOMS, with only 10% experiencing non-DOMS pain): this volume has also been shown to be sufficient to increase strength.[8] Whether both strength and architectural changes are required to reduce prospective HSI risk has not yet been elucidated, and NHE volumes demonstrated to be effective in reducing HSI risk have involved high volume programmes.[2] Whether these lower volume protocols may also reduce HSI risk prospectively requires further investigation. The very low volume protocol (Group 1) results in low DOMS and non-DOMS pain response. However, this dosage has been found to be insufficient for strength and architectural adaptations.[8]

The current study was limited by a lack of longitudinal follow-up to assess any longer-term effects of the different dosages. The participants were recreationally active, and how this may translate to more highly trained athletes is unknown. The pain assessor was not blinded to

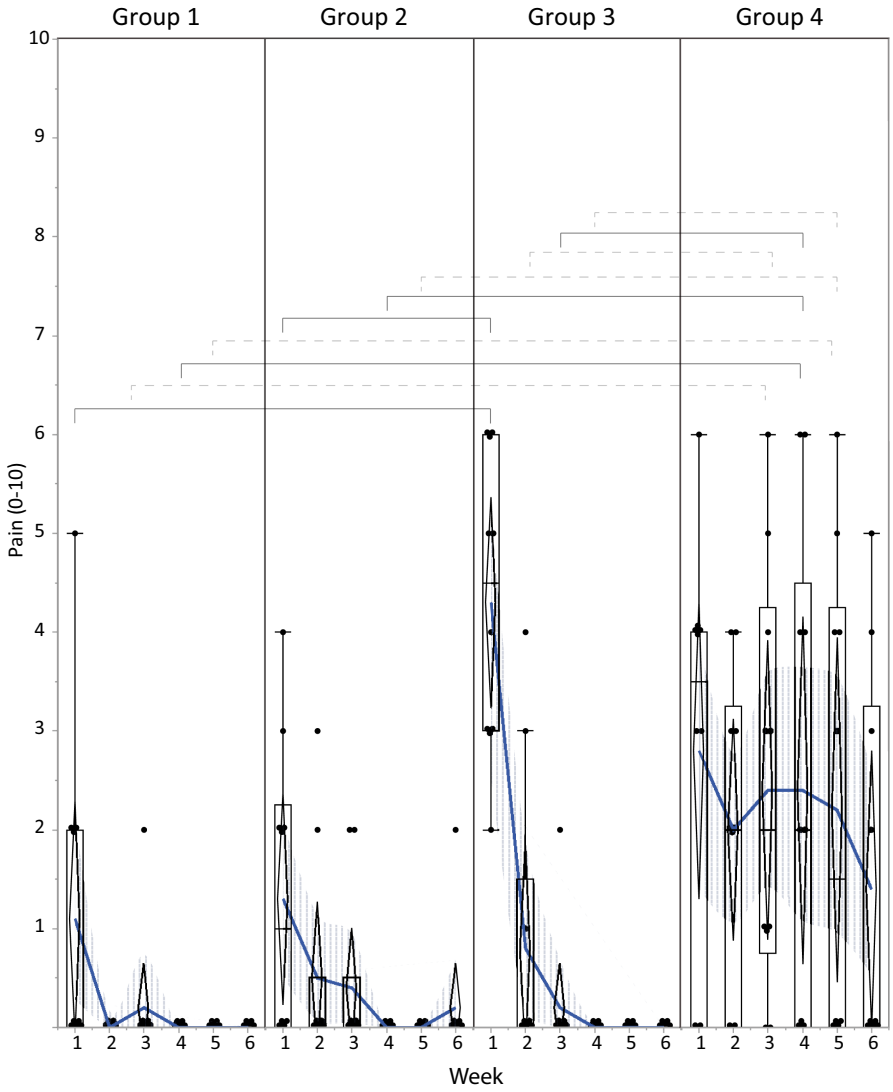

FIGURE 1 Delayed onset muscle soreness by week per group. Individual responses represented (dots) and box plots for the reported pain response for each group, for each week of the intervention. The confidence diamond within the box plot represents the bounds of the 95% confidence interval for the mean (for that group, for that week). Significant pairwise differences (for the same week, between different groups) are depicted by the brackets with the solid brackets denoting $p < 0.01$, and the dashed brackets $p < 0.05$. Within each group, a connecting line joins the group means with the shaded area representing the 95% confidence interval for this mean

group allocation. Furthermore, the generalizability of the findings may be limited by the sample size of each group. Finally, as it was an all-male cohort, these findings may not be as relevant for active females with further evidence required in this population.

To conclude, higher NHE volumes increase the risk of DOMS and non-DOMS related musculoskeletal pain, while also appearing to have large effects on both strength and architecture, and being the only dosage proven to reduce HSI.[2] These factors should all be considered by the responsible clinician when prescribing NHE dosage for injury prevention, and in addressing adherence to NHE programmes.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

1. Ekstrand J, Walden M, Hagglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA elite Club injury study. *Br J Sports Med*. 2016;50(12):731-737.

2. Petersen J, Thorborg K, Nielsen MB, Budtz-Jorgensen E, Holmich P. Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. *Am J Sports Med*. 2011;39(11):2296-2303.
3. Bahr R, Thorborg K, Ekstrand J. Evidence-based hamstring injury prevention is not adopted by the majority of champions league or Norwegian premier league football teams: the Nordic hamstring survey. *Br J Sports Med*. 2015;49(22):1466-1471.
4. Bourne MN, Duhig SJ, Timmins RG, et al. Impact of the Nordic hamstring and hip extension exercises on hamstring architecture and morphology: implications for injury prevention. *Br J Sports Med*. 2017;51(5):469-477.
5. Presland JD, Timmins RG, Bourne MN, Williams MD, Opar DA. The effect of Nordic hamstring exercise training volume on biceps femoris long head architectural adaptation. *Scand J Med Sci Sports*. 2018;28(7):1775-1783.
6. Timmins RG, Bourne MN, Shield AJ, Williams MD, Lorenzen C, Opar DA. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): a prospective cohort study. *Br J Sports Med*. 2016;50(24):1524-1535.
7. Opar DA, Timmins RG, Behan FP, et al. Is pre-season eccentric strength testing during the Nordic hamstring exercise associated with future hamstring strain injury? A systematic review and meta-analysis. *Sports Med*. 2021;51(9):1935-1945.
8. Behan FP, Vermeulen R, Whiteley R, Timmins RG, Ruddy JD, Opar DA. The dose-response of the Nordic hamstring exercise on biceps Femoris architecture and eccentric knee flexor strength: a randomized interventional trial. *Int J Sports Physiol Perform*. 2022;17(4):646-654.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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