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EFFECTS OF NORDIC HAMSTRING EXERCISE SET CONFIGURATION ON ECCENTRIC HAMSTRING STRENGTH CHANGES IN YOUTH FEMALE ATHLETES

Running Head: Eccentric hamstring training in youth female athletes

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ABSTRACT

Anterior Cruciate Ligament injury poses a significant risk in youth female athletes. The Nordic hamstring exercise (NHE) can improve eccentric hamstring strength (EHS), a key factor related to ACL injury risk, yet limited research exists in this population. This study compared two NHE set configurations - Traditional Sets (TS) and Rest Redistribution (RR) - on EHS in youth female athletes. Subjects (age: 13.93 ± 1.58 years; Body Mass: 48.95 kg ± 11.15 kg; Percentage of Predicted Adult Height: 96.50% ± 4.30%) were randomly assigned to TS (n =17) or RR (n = 18) groups. Both groups performed a six-week NHE program, increasing weekly volume from 6 to 18 repetitions. Pre- and post-tests assessed EHS changes using the NordBord and isokinetic testing at 60°/s and 180°/s, assessing peak torque, angle of peak torque and torque at 20°, 40°, 60°, and 80° of knee flexion. Both TS and RR significantly increased NordBord EHS (g = 0.34-0.98). Isokinetic data at 60°/s and 180°/s revealed significant small increases in peak torque and torque at 40°, 60° and 80° (g = 0.22-0.46). Yet, no changes were observed in torque at 20° (g = 0.01-0.23) and the angle of peak torque increased (g = 0.33-0.83). No between-group differences were observed for any measure. These findings suggest that either TS or RR set configurations can effectively enhance EHS in youth female athletes. However, to target EHS at longer muscle lengths, practitioners should include additional exercises beyond the NHE.

KEYWORDS: ACL, Youth Female Athletes, Nordic, Eccentric Hamstring, Injury Prevention

INTRODUCTION

Anterior cruciate ligament (ACL) injuries are prevalent among youth female athletes with an increasing number of injuries being reported in recent years (1). The ACL, located within the tibiofemoral joint, stabilizes the knee joint by limiting excessive anterior tibial translation and internal tibial rotation (17). This ligament is especially crucial during deceleration and landing maneuvers (9). Although males have a higher overall ACL injury rate due to greater participation in contact sports, women are 3 to 8 times more likely to experience an ACL injury (35). Further, high-school female athletes (13-18 years) exhibited a 1.6-fold higher rate of ACL tears per exposure than males (25). The elevated ACL injury occurrence in female athletes may impose significant long-term consequences, with youth female soccer players at nearly a 5-fold higher rate of suffering a new ACL injury as well as quitting soccer to a higher degree (22). Therefore, training programs that specifically target ACL risk factors in youth female athletes is essential.

Biomechanically, as youth females mature, they exhibit lower relative peak vertical ground reaction forces as well as higher knee abductor and internal rotation moments when landing which may increase their risk of sustaining ACL tears (38). However, high eccentric hamstring strength (EHS) can decrease ground reaction forces and knee-valgus moments during landing, thus reducing ACL injury risk (15). In female adolescents, those with higher hamstring strength were reported to have lower ACL loading during landing compared to their weaker counterparts (45). This may be explained by the hamstring muscles decreasing ACL loading by reducing tibial internal rotation, decreasing anterior shear forces, and increasing hamstrings-quadriceps co-activation (8,41). Alarmingly though, hamstring strength development in youth females has been reported to plateau by age 11 years (5). Accordingly, the consequences of ACL injuries in female athletes means the targeting of modifiable risk factors such as EHS through training is crucial (26).

To prevent ACL injuries in youth female athletes, including the Nordic hamstring exercise (NHE) in preventive programs is recommended (37). However, to date, only two studies have reported the effects NHE training in youth female athletes (<18 years) compared to approximately 10 studies in male youth. In youth female handball players (15.9 ± 0.2 years), an eight-week NHE program significantly improved sprint, vertical jump, and change-of-direction performance (13). However, a direct assessment of hamstring strength was not included. Conversely, in pre-pubertal female athletes (11.3 ± 0.5 years), a 20-week NHE program resulted in significant improvements in eccentric hamstring peak torque. (44). It is important to note that in these studies, peak weekly NHE volumes were 108 and 90 repetitions, respectively. Yet, in youth male soccer players, a low volume of 10 repetitions per week of eccentric hamstring training for six weeks increased eccentric knee flexor strength (32). Subsequently, a better approach of prescribing the NHE for youth female soccer players may be possible and more feasible for implementing in practice.

Typically, the NHE is prescribed using traditional sets (TS) in which all repetitions are completed prior to a rest period (18). Alternatively, a rest redistribution (RR) method has been advocated which involves shorter but more frequent rest periods, whilst still completing the desired volume (43). Whilst the total rest time and training volume is the same as TS, RR can reduce mechanical fatigue, perceptual exertion, and metabolic stress (29). Since peak force during the NHE significantly reduces after only four repetitions in youth athletes, the use of RR may offer benefits to this population (19). Therefore, the inclusion of more frequent inter-repetition rest periods may maintain performance and technique of the NHE, translating to greater increases in hamstring strength. Accordingly, the purpose of this study was to investigate the effects of a low volume, six-week NHE program, applying two different set distributions (TS vs RR), on changes in EHS in youth female athletes. It was hypothesized that whilst NHE programs would increase EHS, greater changes would be observed following RR training.

METHODS

Experimental Approach to the Problem

A repeated measures, randomized control trial with two parallel groups was undertaken to compare the effects of performing weekly volume matched NHE training using either TS or RR in youth female soccer players. The training program took place during the 2023-2024 season (April-May 2024). Apparatus to measures eccentric hamstring strength included the NordBord and isokinetic dynamometer which were taken both pre and post the six-week program to assess changes in eccentric hamstring strength.

Subjects

A sample size calculation using GPower (version 3.1.9.6) determined the minimum required sample size. A sample of 12 subjects per group was required based on a type I error rate of 0.05, 95% statistical power and an estimated effect size of Cohen's *d* = 0.73.

The effect size was based on a previous study in youth female athletes which reported changes in eccentric hamstring strength following 10 weeks of NHE training (44). A total of 45 female athletes, aged between 10 and 16 years, were recruited from a regional talent center. Subjects were randomly allocated to either the TS *(n* = 23*)* or RR *(n* =22*)* groups using a free online number randomizer (46). Since maturation and body mass can influence strength and NHE performance, respectively, stratified randomization was employed to ensure homogeneous group distribution. The Percentage of Predicted Adult Height (PAH%) method was used to estimate biological maturation (30). Figure 1 displays a CONSORT diagram of the levels of reporting and subject flow. Subjects typically performed two on-field technical sessions (60-90 mins) and one resistance training session (60 mins) per week in addition to a weekly game. Within their weekly resistance training program, subjects performed 1 x 3 repetitions of the NHE as part of their injury prevention warm up. Subjects were required to complete 100% of the NHE training program to be included in the analysis. Written subject and parental informed consent were obtained before the start of the study along with a health history questionnaire. Subjects were required to be free from lower-limb injury for a period of six months. All experimental procedures were approved by the Institutional Ethics Committee (ETHICS2023-113).

Figure 1 About Here

Procedures

All subjects were familiar with the NHE due its inclusion within their weekly resistance training session. However, subjects also performed the NHE on the NordBord on three separate occasions separated by at least one week prior to the commencement of the training intervention to determine between-session reliability of their eccentric knee flexor strength. Subjects were familiarized to the isokinetic dynamometer during their first testing session. Prior to all testing and training sessions, subjects were asked to refrain from participating in intensive training sessions for a minimum of 24 hours. For each testing and training session, subjects performed the same warm up including activation and mobilization exercises for the lower body. All testing and training sessions were conducted in the institutions Performance Gym and Human Performance Laboratory. Training sessions took place at the same time of day throughout the study (6pm-8pm).

Anthropometry and Biological Maturation

Subjects' height (cm) and body mass (kg) were measured using a wall-mounted stadiometer (seca 217, Hamburg, Germany) and electronic scales (seca Model 813, Birmingham, England). Two readings were taken for each subject, with a third if differences exceeded 0.1 cm or 0.1 kg for height and body mass, respectively. Biological maturation was estimated using Percentage of Predicted Adult Height (PAH%) via a self-reported online portal and adjusted using the Epstein equation to correct overestimation (20). To help standardize the process, parents were given a tape measure and provided a link to a short online video explaining how to accurately record parental height to minimize error of measurement. Subjects' maturity status was then expressed as a percentage of their predicted adult height.

NordBord

The NordBord (Vald Performance, Newstead, QLD, Australia) testing protocol was based on a previous study completed in youth athletes (23). Subjects kneeled on the cushioned surface of the apparatus and secured their ankles to the padded hooks, which were connected to load cells, before performing the NHE (see Video, Supplemental Digital Content 1, which demonstrates the NordBord test). Each subject completed three repetitions with a rest period of 60 seconds between each. A fourth repetition was completed if there was a difference in peak eccentric force between repetitions in any limb of more than 30N (23). The NordBord recorded peak forces (N) for each limb at a frequency of 50 Hz in which data were recorded in real time on a laptop and uploaded to the manufacturer's proprietary software before being exported to a Microsoft Excel spreadsheet. The average of the three trials was used for data analysis. Each limb's peak force was divided by the subject's body mass at both pre- and post- testing sessions to establish relative peak eccentric force ($N.kg^{-1}$). A pilot study conducted with the same population showed a between-session Typical Error of Measurement (TEM) for peak force of 0.39 $N.kg^{-1}$ (CV% = 7.93%) and 0.35 $N.kg^{-1}$ (CV% = 7.43%) for the left and right leg, respectively between sessions two and three.

Isokinetic Dynamometer

An isokinetic dynamometer (HumacNorm, Cybex, Massachusetts, USA) was used to assess eccentric hamstring torque and angular measures (see Video, Supplemental Digital Content 2, which demonstrates the isokinetic test). The testing protocol was based on a previous study on youth female athletes (44). Following the previously described warm up, subjects then performed 10 sub-maximal repetitions at 120°/s on both limbs to familiarize themselves with the system. Following a short rest period, subjects next completed 5 maximal repetitions, on both legs, for each speed (60°/s and 180°/s) in a randomized and counterbalanced order with one minute of rest between limbs. All testing was completed in a seated position. Thighs were secured with straps to the seat, the lateral epicondyle of the femur aligned with the center of rotation of the lever arm, the hip flexion angle was set at 90° and the resistance pad was adjusted to face a point 3 cm above the malleoli. The knee range of motion was set at 5° to 90° and a gravity correction procedure was performed before all testing. To motivate the subjects, both real-time visual and verbal feedback during the testing was provided. The average of the three repetitions with the highest peak eccentric torque values were analyzed for Peak Torque (PT), Angle of Peak Torque (°PT) and torque at 20 (T20°), 40 (T40°), 60 (T60°), and 80 (T80°).

Nordic Hamstring Exercise Training Programs

The intervention was a six-week progressive program of NHE performed during subjects' weekly supervised resistance training session in the evening. The exercise was performed using a fixed device (BLK BOX Hip Thruster Floor GHD Bench, United

Kingdom) with ankles secured by a padded ankle bar to prevent compensation, and an elevated foam pad placed under the knees to allow full knee extension (see Video, Supplemental Digital Content 3, which shows the NHE exercise being performed). The same technique for the NHE was used as per the NordBord testing. To standardize the verbal coaching cues, the instructor advised subjects to control the descent slowly aiming for approximately five seconds to achieve a consistent knee angular velocity (12). The training program progressively increased from 6 repetitions per week (week 1) to 18 repetitions by the last week of training (week 6). The inter-set rest for TS was 180 seconds to enable sufficient recovery between sets (19). Both TS and RR had the same total rest time per session but with different set distributions (Table 1).

Table 1 About Here

Statistical Analysis

Normality was assessed through the Shapiro–Wilk test. Differences in anthropometric measures between groups were evaluated using independent samples *t*-tests. Within-session relative reliability was calculated for both pre- and post- measurements using the intraclass correlation coefficient (ICC), and absolute reliability was determined by calculating the typical error of measurement expressed as a coefficient of variation (CV%) ± 95% confidence limits using a customized Microsoft Excel spreadsheet (27). ICC values were interpreted as: >0.90 excellent, 0.90–0.75 good, 0.75–0.50 moderate, and <0.50 poor (31). CV% values below 5% were considered good, values between 5% and 10% were acceptable, and values above 10% were deemed poor (28). To evaluate pre-test to post-test performance following the NHE programs, paired sample t-tests was employed to assess within-group changes, and an analysis of covariance (ANCOVA) was carried out to detect between-group differences, assuming baseline values as covariates. Effect sizes (ES) for within-group changes and between-group differences were computed using Hedges' *g* with confidence intervals set at 95%. Effect sizes were interpreted based on pre-defined ranges: <0.19 = trivial, 0.20–0.59 = small, 0.60–1.19 = moderate, 1.20–1.99 = large, and 2.0–4.0 = very large (28). To ensure robust statistical analysis, outliers for each variable were evaluated independently using the Median Absolute Deviation (MAD) method with a threshold set at 2.5 times the MAD (34). Statistical analysis was conducted using JASP (version 13.1, University of Amsterdam, Amsterdam, Netherlands), with statistical significance set at $p < 0.05$.

RESULTS

All subjects received the training conditioning as allocated. Only players who participated in 100% of sessions were included for the final analyses, which resulted in a total of 35 subjects with five subjects not being included due to not completing all training sessions or not attending the post-testing session. As per Figure 1, four subjects were excluded due to injury. However, these injuries were independent of the training program (two knee sprains, one ankle sprain, and one hamstring strain before the intervention), indicating the safety of the program.

Anthropometry and Biological Maturation

Anthropometric characteristics and biological maturation of both groups are displayed in Table 2. No significant differences were observed between groups for any measures with the magnitude of the differences interpreted as *trivial.*

Table 2 About Here

Reliability

For NordBord relative peak eccentric force data, within-session reliability for both pre- and post- measurements on both limbs showed excellent relative reliability (ICC range = 0.96 to 0.99) and good absolute reliability (CV% = <5%). Regarding isokinetic data, pre- and post- test within-session reliability for both speeds and limbs for all measures was good-excellent (ICC > 0.75) except for °PT which was mostly poor-moderate (ICC range = 0.48 to 0.72). Absolute reliability was acceptable (<10%) for most measures but was poor for some measures within °PT (CV range = 12.51% to 42.75%), T20° (CV range = 5.84% to 21.21%), T40° (CV range = 3.97% to 18.73%), T60° (CV range = 4.12% to 13.38%) and T80° (CV range = 9.13 % to 17.73%). Details of all within-session relative and absolute reliability isokinetic data can be found within the supplementary materials (see Spreadsheet, Supplemental Digital Content 4).

NordBord

Pre- and post- test changes of EHS from the NordBord are displayed in Figure 2. TS group significantly increased relative EHS in both legs (Left: $p < 0.001$, 0.46 $N.kg^{-1}$, 11.39% ± 7.31%; Right: $p < 0.001$, 0.31 $N.kg^{-1}$, 7.20% ± 4.79%) to a moderate magnitude (Left: $g = {}^{0.22}\,0.98\,^{1.74}$; Right: $g = {}^{-0.07}\,0.69\,^{1.45}$). RR group showed a significant increase in the left leg ($p = 0.047$, 0.18 $N.kg^{-1}$, 4.20% ± 7.81%) but not in the right leg ($p = 0.161$, 0.09 $N.kg^{-1}$, 2.13% ± 5.18%), with small ($g = {}^{-0.32}\,0.34\,^{0.99}$) and trivial effects ($g = {}^{-0.53}\,0.16\,^{0.85}$) observed, respectively. ANCOVA analysis indicated no significant differences between groups (Left: $p = 0.100$; Right: $p = 0.053$), though the magnitude of the increases favored TS for both the left ($g = {}^{0.11}\,0.82\,^{1.53}$) and right ($g = {}^{0.21}\,0.96\,^{1.72}$) limbs.

Figure 2 About Here

Isokinetic Dynamometer

Pre- and post- test changes for the 60°/s and 180°/s isokinetic dynamometry tests are displayed in Tables 3 and 4, respectively. For the 60°/s test, PT significantly increased to a small magnitude in both legs for the RR group only. T40° significantly increased to a small magnitude in both legs for TS and the left leg for RR. T60° and T80° significantly increased to a small magnitude in both groups for the right leg only. Regarding the 180°/s test, significant increases were observed for the °PT in TS left leg (ES = small), TS right leg (ES = moderate) and RR left leg (ES = small). T40° significantly increased to a small magnitude in the right leg for TS. T60° and T80° significantly increased to a small magnitude in both TS and RR right legs. ANCOVA analysis indicated no statistical differences between groups for any variables.

Tables 3 and 4 About Here

DISCUSSION

This study is the first to examine the effects of two NHE programs on changes in EHS in youth female athletes. The results suggest, that both NHE training programs significantly increased EHS with small to moderate increases observed across the NordBord and isokinetic tests. However, the changes were not different between either TS or RR groups. Consequently, results from the current study suggest that practitioners can use both NHE training program types to increase EHS in youth female athletes.

The TS NordBord data revealed a significant, moderate increase in EHS for both the left and right legs. In contrast, the RR group demonstrated a significant, small increase in the left leg. These changes are similar to those previously published which have used the NordBord device in youth athletes. For example, small increases (*d* = 0.53; 10.23%) were reported in youth male soccer players (13.7 ± 1.0 years) following a six-week NHE training that included a total of 162 repetitions (18). Additionally, after a four-week NHE program with a total of 110 repetitions, Freeman et al. (24) reported small increases (*d* = 0.39; 9.80%) in student athletes (16.2 ± 1.3 years). While our study reported comparable improvements, it is noteworthy that in the current study we only prescribed a total training volume of 69 NHE repetitions. In adolescent male soccer players (17.5 ± 0.7 years), moderate improvements (*d* = 1.18; 11.30%) following a total of 60 repetitions (24 NHE and 36 modified stiff-leg deadlifts) completed over a 6-week period were observed (32). Further, similar significant small magnitude improvements (*d* = 0.31; 5.27%) in EHS were reported following an 8-week low vs high (144 vs 538 repetitions) NHE training in adult female soccer players (4). Therefore, a lower volume of NHE repetitions, compared to previous studies in youth female athletes, appears to be appropriate to increase EHS.

The effectiveness of the low-dose NHE programs used in this study may be attributed to the methodology employed rather than improvements resulting from the training program occurring due to the novelty of the stimulus. This is because our subjects were not only familiar with the NHE but also possessed pre-testing NordBord eccentric knee-flexor strength values above predicted values (11). Firstly, our subjects' ankles were fixed by pads rather than held by a training partner which likely enhanced force production at the ankle contact point due to greater stability. Indeed, recent research has reported a significantly better break point angle during the NHE when using a training device which allowed rigid heel-fixation compared to partner assistance (7). Next, only subjects who completed 100% of the sessions were included in the current study, while previous studies assessing changes in EHS following NHE training in youth have included compliance rates of >85% (18), 93.7% (44) and > 80% (42). Since compliance with neuromuscular training results in lower incidence of ACL injuries in female athletes (44), it seems likely that the high level of attending and completing the current NHE training programs positively influenced our results.

Concerning the isokinetic dynamometry results, the small increases in eccentric hamstring peak torque at 60°s^{-1} in both TS and RR programs are below those previously reported in youth female athletes following NHE training (44). However, the moderate increases reported by Vaczi et al. (42) occurred after a 10-week NHE program of 520 repetitions. Our changes, though, are comparable to the non-significant small improvements in eccentric peak torque at 60°/s reported in youth male soccer players following an 8-week NHE program of 144 repetitions (42), despite our total training volume being nearly 50% lower. In contrast, we observed non-significant, trivial changes in 180°s^{-1} eccentric hamstring peak torque for both NHE training programs. Since resistance training results in the greatest strength gains occurring at or near the training velocity (6), it is possible that the slow speed nature of the NHE did not transfer to faster speeds. In fact, a positive adaptation to NHE training is the decreased angular velocity of the knee during the exercise due to the ability of the hamstrings to decelerate the forward motion of the trunk (14). Yet, previous research has observed eccentric hamstring training at either slow (15°/s) or fast speeds (120°/s) to improve strength at fast (150°/s) and slow (60°/s) speeds, respectively (2,39). Therefore, further research is needed to better understand velocity-specific adaptations to NHE training in youth females.

Our findings corroborate those of Delahunt et al. (14) in which increases in PT occurred with no changes in °PT following NHE training. The authors suggested that this may be due to the subjects already possessing °PT near the end range of movement. Indeed, our subjects' baseline °PT values of ~26° align with the reported hamstring eccentric peak torque angle of 30° (10). Nevertheless, the trivial changes in T20° coupled with the small to moderate increases in °PT suggests the present NHE program did not challenge the hamstrings at longer muscle lengths. Improvements at longer muscle lengths might occur as athletes become stronger in the NHE and can increase the range of motion the knee experiences (3). Indeed, higher levels of eccentric hamstring peak torque are associated with an increased break point angle (33). Consequently, the increased break point angle would enable the hamstring muscles to be trained at longer muscle lengths (40). Accordingly, it would seem prudent that when initially prescribing the NHE, it may also be necessary to concomitantly include exercises that will specifically target end range eccentric hamstring strength (e.g., band assisted NHE, straight leg knee bridges).

Our hypothesis that RR would result in greater increases in EHS than TS was rejected. This may be explained by the rest interval we used for RR being long enough to facilitate recovery between sets. For example, although Drury et al. (19) observed greater maintenance of eccentric hamstring peak force when using a three-minute inter-set rest interval compared to a one-minute rest interval in young athletes (20.7 ± 2.3 years), the magnitude of the difference was small. Except for week 3 in the current RR program, all inter-set rest periods were typically between 60 to 90 seconds, and this may have enabled sufficient recovery in this population. This is because fatigue resistance during high-intensity intermittent exercise undergoes a gradual decline from childhood to adulthood (36). Indeed, Faigenbaum et al. (21) found during resistance training in children, teens, and adults, that whilst adults required 3-minutes rest to fully recover between sets, children and teens only required 1-2 minutes. Additionally, during 4 x 18 maximal knee flexions with 1-min rest, girls and female teens demonstrated greater fatigue resistance for peak torque than adult females (16). As a result, it is important for future research to determine the kinetic and kinematic changes during the NHE in children and adolescents.

This study is not without limitations. Firstly, subjects' match or training volume and intensity were not controlled. However, the results reflect real-world conditions with varying training loads and weekly training sessions and matches occurred at the same frequency. Additionally, all subjects except one were part of the same academy, minimizing variations in training load and ensuring greater consistency across the groups. Secondly, although subjects were familiar with the NordBord in which we reported its between-session reliability, familiarization for the isokinetic dynamometer testing only took place during the pre-test session as per previously published studies. However, it is evident from our reliability data that isokinetic measures can be highly variable. Thus, providing multiple familiarization trials prior may have enabled greater accuracy and confidence in these findings. Finally, to better understand the time-course of low volume NHE training program in youth female athletes, a longer training period would have been beneficial to enable comparisons with previous research. Indeed, such an approach would provide further insights as to whether the significant small-moderate improvements in EHS that occurred within 6-weeks by only performing 69 repetitions, would continue to increase in magnitude over a 10–20-week period as used in other studies.

PRACTICAL APPLICATIONS

Our findings provide coaches with numerous options for the effective implementation of the NHE exercise in youth female athletes. Importantly, both NHE training programs utilized in this study demonstrate that small, yet significant, increases in eccentric hamstring strength can occur with just 69 NHE repetitions completed in six weeks (~12 repetitions per week). Moreover, considering the minimal equipment required to perform the NHE, our training programs provide coaches with a low-cost, inclusive, and time-efficient approach for reducing ACL injury risk in youth females. However, since the NHE may initially target changes in strength at short to moderate muscle lengths, we recommend exercises that also target end-range hamstring strength.

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FIGURE LEGENDS

Figure 1: CONSORT diagram (Consolidated Standards of Reporting Trials) includes detailed information on the interventions received.

Figure 2: Gardner-Altman plots displaying pre-test (blue) and post-test (orange) changes in relative eccentric hamstring strength (EHS). Plots A and B represent the left and right legs, respectively, for the Traditional Set (TS) group. Plots C and D represent the left and right legs, respectively, for the Rest Redistribution (RR) group. Each individual is depicted as a data point on the left axes, and the mean difference is depicted as a data point on the floating axes on the right with the 95% confidence interval depicted by the ends of the vertical error bar.

LIST OF SUPPLEMENTAL DIGITAL CONTENT

Supplemental Digital Content 1 - NordBord. MP4

Supplemental Digital Content 2 - Isokinetic. MP4

Supplemental Digital Content 3 - Nordic. MP4

Supplemental Digital Content 4 – ISK Reliability. XLSX

Figure 1 - CONSORT Diagram

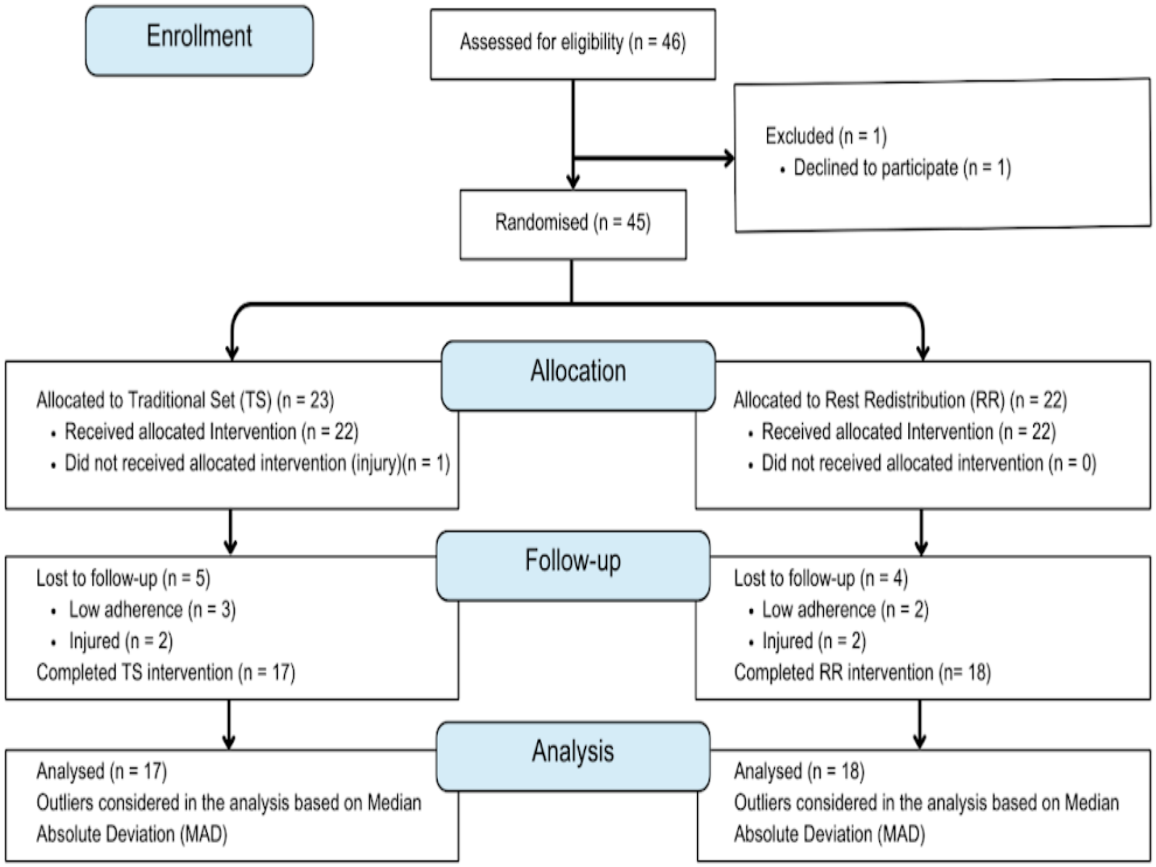
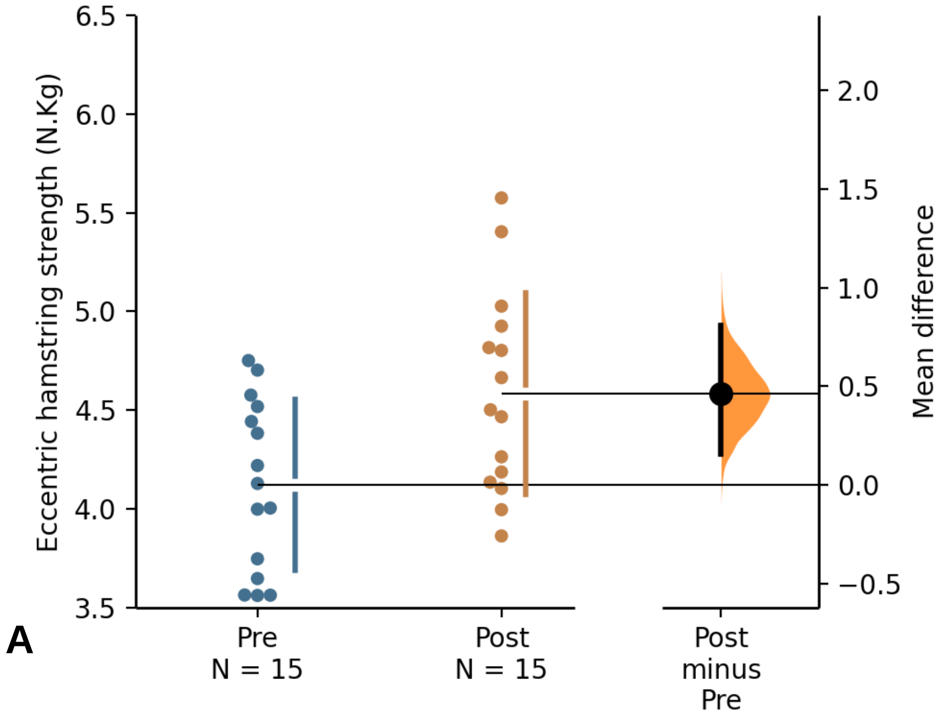
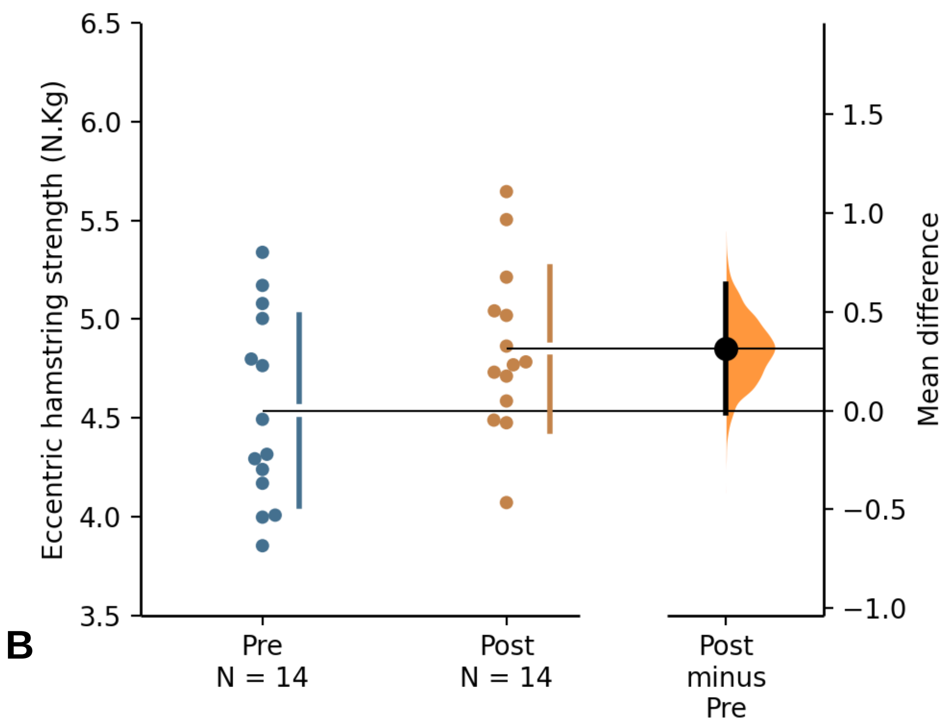
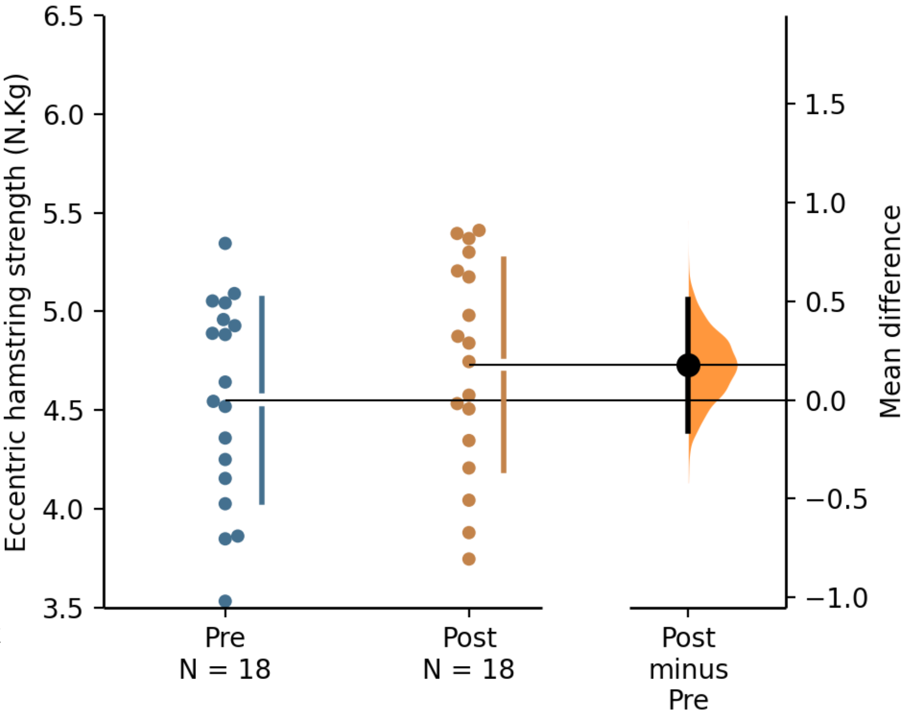


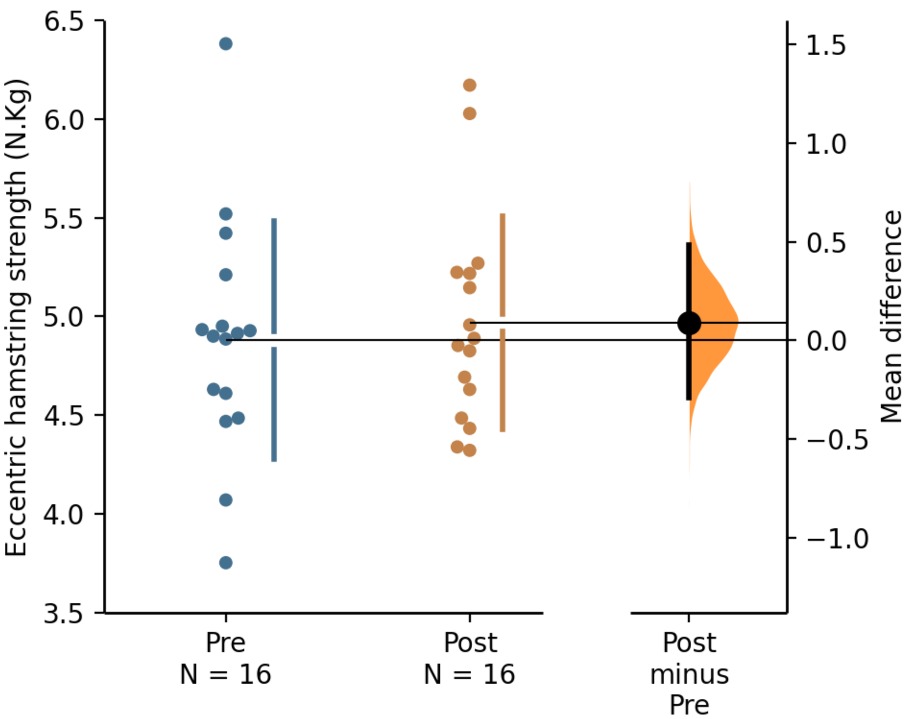
Figure 2 - NordBord Pre-Post Changes






6.5
6.0
5.5
5.0
4.5
4.0
3.5
Eccentric hamstring strength (N.Kg)
1.5
1.0
0.5
0.0
−0.5
−1.0
Mean difference
Pre
N = 18
Post
N = 18
Post
minus
Pre

C


6.5
6.0
5.5
5.0
4.5
4.0
3.5
Eccentric hamstring strength (N.Kg)
1.5
1.0
0.5
0.0
−0.5
−1.0
Mean difference
Pre
N = 16
Post
N = 16
Post
minus
Pre

D

Table 1: Details of the NHE training programmes for both groups over the 6-week training period.

Week	Traditional Sets (TS)		Rest Redistribution (RR)	
	Sets x Reps	Rest	Sets x Reps	Rest
1	2 x 3 (6)	180s	3 x 2 (6)	90s
2	2 x 4 (8)	180s	4 x 2 (8)	60s
3	2 x 5 (10)	180s	5 x 2 (10)	45s
4	2 x 6 (12)	180s	4 x 3 (12)	60s
5	3 x 5 (15)	180s	5 x 3 (15)	90s
6	3 x 6 (18)	180s	6 x 3 (18)	72s

*Number in brackets indicates total training volume (reps x sets); s = seconds; Reps = repetitions.

Table 2 - Anthropometric Data

Table 2: Differences in anthropometric and biological maturation measures between traditional set (TS) and rest redistribution (RR) groups.

	TS (*n* = 17)	RR (*n* = 18)		
	Mean ± SD	Mean ± SD	*p*-value	Hedges *g*
Age (Years)	13.85 ± 1.67	14.00 ± 1.54	0.788	$^{-0.75}$ -0.09 $^{0.57}$
PAH% (%)	96.13 ± 3.89	96.84 ± 4.66	0.626	$^{-0.83}$ -0.16 $^{0.50}$
Height (cm)	157.36 ± 8.58	158.58 ± 8.47	0.675	$^{-0.80}$ -0.14 $^{0.52}$
Pre-Test Body-Mass (kg)	48.01 ± 11.30	49.84 ± 11.01	0.630	$^{-0.82}$ -0.16 $^{0.50}$
Post-Test Body Mass (kg)	48.67 ± 11.13	50.50 ± 10.84	0.626	$^{-0.83}$ -0.16 $^{0.50}$

*SD = standard deviation; PAH% = percentage of predicted adult height; kg = kilogram; 95% confidence intervals of the Hedges *g* effect size are shown as: $^{\text{Lower limit}}$ Effect size $^{\text{Upper limit}}$

Table 3: Within-group changes and between-group differences in eccentric hamstring strength for the 60°/s isokinetic dynamometer test.

	Traditional (TS)				Rest Redistribution (RR)				Between Group	
	Pre-Test	**Post-Test**	***p-value***	**Hedges *g***	**Pre-Test**	**Post-Test**	***p*-value**	**Hedges *g***	**ANCOVA**	**Hedges *g***
PT_L	65.75 ± 16.46	69.72 ± 16.17	0.188	$^{-0.48}$ 0.24 $^{0.96}$	74.11 ± 23.1	82.07 ± 22.50	<0.001	$^{-0.32}$ 0.34 $^{1.00}$	0.141	$^{-0.29}$ 0.40 $^{01.09\ (RR)}$
PT_R	70.57 ± 20.63	74.84 ± 20.92	0.081	$^{-0.47}$ 0.20 $^{0.87}$	70.15 ± 24.72	76.11 ± 27.36	0.002	$^{-0.52}$ 0.22 $^{0.97}$	0.573	$^{-0.51}$ 0.20 $^{0.91\ (RR)}$
°PT_L	24.54 ± 13.49	29.13 ± 10.27	0.232	$^{-0.35}$ 0.37 $^{1.09}$	26.54 ± 9.82	27.82 ± 7.02	0.530	$^{-0.55}$ 0.15 $^{0.84}$	0.519	$^{-0.43}$ 0.28 $^{0.99\ (TS)}$
°PT_R	26.33 ± 12.26	30.84 ± 11.99	0.091	$^{-0.34}$ 0.36 $^{1.06}$	23.42 ± 10.29	27.81 ± 9.80	0.061	$^{-0.23}$ 0.43 $^{1.09}$	0.672	$^{-0.66}$ 0.01 $^{0.69\ (TS)}$
$T20°_L$	58.15 ± 23.97	61.40 ± 19.10	0.440	$^{-0.53}$ 0.15 $^{0.82}$	66.47 ± 21.98	71.84 ± 23.20	0.105	$^{-0.44}$ 0.23 $^{0.91}$	0.355	$^{-0.54}$ 0.14 $^{0.81\ (RR)}$
$T20°_R$	65.22 ± 23.28	69.37 ± 18.97	0.238	$^{-0.50}$ 0.19 $^{0.88}$	70.66 ± 24.70	71.07 ± 25.91	0.911	$^{-0.66}$ 0.02 $^{0.69}$	0.593	$^{-0.43}$ 0.26 $^{0.94\ (TS)}$
$T40°_L$	59.43 ± 18.43	65.10 ± 15.10	0.042	$^{-0.37}$ 0.33 $^{1.03}$	67.11 ± 23.13	75.67 ± 23.33	<0.001	$^{-0.30}$ 0.36 $^{1.02}$	0.200	$^{-0.37}$ 0.30 $^{0.98\ (RR)}$
$T40°_R$	60.29 ± 23.67	69.08 ± 19.37	<0.001	$^{-0.30}$ 0.40 $^{1.10}$	67.55 ± 23.59	72.93 ± 24.83	0.066	$^{-0.46}$ 0.22 $^{0.89}$	0.501	$^{-0.36}$ 0.33 $^{1.01\ (TS)}$
$T60°_L$	49.50 ± 19.17	53.41 ± 14.82	0.099	$^{-0.45}$ 0.22 $^{0.90}$	57.71 ± 22.33	61.19 ± 21.98	0.059	$^{-0.52}$ 0.15 $^{0.83}$	0.709	$^{-0.62}$ 0.05 $^{0.72\ (TS)}$
$T60°_R$	51.50 ± 19.58	57.90 ± 17.31	0.003	$^{-0.34}$ 0.34 $^{1.01}$	56.40 ± 19.38	63.32 ± 22.23	0.002	$^{-0.33}$ 0.32 $^{0.98}$	0.769	$^{-0.60}$ 0.07 $^{0.73\ (RR)}$
$T80°_L$	33.19 ± 15.73	36.27 ± 13.14	0.160	$^{-0.51}$ 0.21 $^{0.92}$	37.64 ± 16.84	39.23 ± 16.95	0.370	$^{-0.58}$ 0.09 $^{0.76}$	0.773	$^{-0.50}$ 0.19 $^{0.89\ (TS)}$
$T80°_R$	31.35 ± 13.72	37.75 ± 14.60	<0.001	$^{-0.28}$ 0.44 $^{1.16}$	35.91 ± 13.43	42.50 ± 16.68	0.013	$^{-0.23}$ 0.43 $^{1.09}$	0.953	$^{-0.66}$ 0.02 $^{0.71\ (RR)}$

*PT = peak torque (Nm); °PT = angle of peak torque (°); T20° = torque at 20° (Nm); T40° = torque at 40° (Nm); T60° = torque at 60° (Nm); T80° = Torque at 80° (Nm); $_L$ = left leg; $_R$ = right leg; 95% confidence intervals of the effect size are shown as $^{Lower\ limit}$ Effect size $^{Upper\ limit}$; initials in brackets for between-group Hedges *g* data indicates which direction the effect size favoured.

Table 4: Within-group changes and between-group differences in eccentric hamstring strength for the 180°/s isokinetic dynamometer test.

	Traditional (TS)				**Rest Redistribution (RR)**				**Between Group**	
	Pre-Test	**Post-Test**	***p-value***	**Hedges *g***	**Pre-Test**	**Post-Test**	***p*-value**	**Hedges *g***	**ANCOVA**	**Hedges *g***
PT$_L$	69.97 ± 17.80	70.55 ± 18.83	0.837	$^{-0.66}$ 0.03 $^{0.72}$	77.46 ± 22.12	81.72 ± 25.32	0.154	$^{-0.50}$ 0.17 $^{0.85}$	0.339	$^{-0.37}$ 0.31 $^{1.00}$ (RR)
PT$_R$	72.11 ± 20.89	75.08 ± 19.95	0.244	$^{-0.53}$ 0.14 $^{0.81}$	79.63 ± 23.61	81.12 ± 25.26	0.490	$^{-0.61}$ 0.06 $^{0.73}$	0.773	$^{-0.52}$ 0.15 $^{0.83}$ (TS)
°PT$_L$	30.55 ± 16.13	38.38 ± 13.52	0.021	$^{-0.19}$ 0.51 $^{1.22}$	29.81 ± 10.95	34.12 ± 14.25	0.022	$^{-0.35}$ 0.33 $^{1.01}$	0.269	$^{-0.34}$ 0.35 $^{1.04}$ (TS)
°PT$_R$	28.94 ± 10.36	40.01 ± 15.18	0.008	$^{0.11}$ 0.83 $^{1.55}$	28.68 ± 12.04	32.50 ± 9.42	0.245	$^{-0.35}$ 0.34 $^{1.04}$	0.091	$^{-0.18}$ 0.52 $^{1.23}$ (TS)
T20°$_L$	58.58 ± 27.32	62.53 ± 23.46	0.192	$^{-0.52}$ 0.15 $^{0.82}$	73.41 ± 20.40	73.60 ± 26.75	0.958	$^{-0.65}$ 0.01 $^{0.66}$	0.662	$^{-0.40}$ 0.27 $^{0.94}$ (TS)
T20°$_R$	64.65 ± 24.36	66.12 ± 24.35	0.688	$^{-0.63}$ 0.06 $^{0.75}$	76.47 ± 25.08	77.20 ± 25.72	0.798	$^{-0.63}$ 0.03 $^{0.68}$	0.867	$^{-0.62}$ 0.05 $^{0.73}$ (TS)
T40°$_L$	63.39 ± 16.81	66.53 ± 19.73	0.280	$^{-0.53}$ 0.17 $^{0.86}$	73.16 ± 21.91	77.60 ± 24.87	0.202	$^{-0.47}$ 0.18 $^{0.84}$	0.696	$^{-0.58}$ 0.10 $^{0.77}$ (RR)
T40°$_R$	66.69 ± 20.52	72.08 ± 17.97	0.022	$^{-0.42}$ 0.27 $^{0.97}$	74.64 ± 22.43	79.85 ± 27.63	0.055	$^{-0.45}$ 0.20 $^{0.86}$	0.963	$^{-0.66}$ 0.02 $^{0.69}$ (TS)
T60°$_L$	58.01 ± 17.63	61.87 ± 17.62	0.167	$^{-0.48}$ 0.21 $^{0.91}$	64.08 ± 23.51	68.71 ± 23.10	0.032	$^{-0.50}$ 0.19 $^{0.89}$	0.662	$^{-0.61}$ 0.08 $^{0.77}$ (RR)
T60°$_R$	58.92 ± 17.77	64.99 ± 16.85	<0.001	$^{-0.33}$ 0.34 $^{1.02}$	66.79 ± 22.06	72.46 ± 25.34	0.016	$^{-0.42}$ 0.23 $^{0.89}$	0.851	$^{-0.61}$ 0.05 $^{0.72}$ (TS)
T80°$_L$	39.67 ± 15.49	42.26 ± 17.95	0.461	$^{-0.59}$ 0.15 $^{0.89}$	44.90 ± 22.25	46.98 ± 19.21	0.331	$^{-0.60}$ 0.10 $^{0.79}$	0.901	$^{-0.67}$ 0.05 $^{0.76}$ (TS)
T80°$_R$	35.55 ± 15.46	43.18 ± 16.89	<0.001	$^{-0.24}$ 0.46 $^{1.16}$	44.75 ± 18.95	52.67 ± 21.21	<0.001	$^{-0.29}$ 0.38 $^{1.06}$	0.984	$^{-0.64}$ 0.04 $^{0.72}$ (RR)

*PT = peak torque (Nm); °PT = angle of peak torque (°); T20° = torque at 20° (Nm); T40° = torque at 40° (Nm); T60° = torque at 60° (Nm); T80° = torque at 80° (Nm); $_L$ = left leg; $_R$ = right leg; 95% confidence intervals of the effect size are shown as $^{\text{Lower limit}}$ Effect size $^{\text{Upper limit}}$; initials in brackets for between-group Hedges *g* data indicates which direction the effect size favoured.