TITLE
Effect of a 6-week Nordic hamstring intervention on athletic performance measures in rugby academy players: a randomised controlled trial

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Effect of a 6-week Nordic hamstring intervention on athletic performance measures in rugby academy players: a randomised controlled trial

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ABSTRACT

The lack of eccentric strength and its effect on injury has been thoroughly researched however the improvement of eccentric hamstring strength and its implications for athletic performance has been minimally investigated among a junior elite population. This parallel design randomised controlled trial aim was to assess a 6-week Nordic hamstring exercise (NHE) intervention and its effect on speed and jump performance. There were 50 young male rugby academy athletes allocated into two groups using non-blinded block randomisation: NHE training (n=25), or no NHE training (control) (n=25). Eccentric hamstring strength was assessed before and after the intervention using a NordBord. Sprint tests over 10m, 20m and 30m were assessed using Brower speed gates. Counter movement jump (CMJ) and squat jump (SJ) were assessed using a Kistler force plate. Confidence interval set at 95%. The NHE group showed significant 10% improvement in eccentric hamstring strength. Significant improvement in 10m, 20m and 30m was observed with significant differences from the control group in eccentric hamstring strength, 10m and 30m. The intervention group pre to post measure effect size for eccentric hamstring strength (Cohen's d=0.64) was medium but the 10m (Cohen's d=-0.02), 20m (Cohen's d=-0.17) and 30m (Cohen's d=-0.24) results were small. This NHE protocol is an appropriate short-term intervention to improve eccentric hamstring in junior elite athletes. Small improvements were made in sprint results with a greater improvement in 30m compared to 10m and 20m results. The improved eccentric strength could have architectural and neural adaptations to the hamstring that infers an improvement in speed.

Keywords: Jump, Speed, eccentric, strength

INTRODUCTION

It has been observed that during sprinting (96) and jumping tasks (19), the hamstring is under high eccentric demand (62,69). During running tasks, the hamstring plays a key role in preserving joint stiffness and stability during the deceleration phase, which occurs towards the terminal stage of the knee extension movement (53). This stiffness aids faster running speeds through improved stretch reflexes and therefore an increase in muscle force (56). During high running speeds the biceps femoris long head, semitendinosus and semimembranosus have shown high EMG activity (44), peak musculotendon strain and produced peak musculotendon force during terminal swing (81). This highlights the important role the hamstring has in the generation of forward propulsive force (39,89). This has been attributed to the release of elastic energy, which is stored during the flight phase when they work eccentrically (53,86). Furthermore, higher peak activation for the biceps femoris long head at terminal swing and for semitendinosus during mid swing has been observed (53). This shows the complex neuromuscular coordination patterns the hamstring muscle group undergoes during high speed running.

Recent research has shown the major role the hamstring plays in sprint acceleration mechanics. The horizontal aspect of the total ground reaction force during acceleration has been show to be a highly important aspect for peak performance and a major difference between elite sprinters and non-elite (62). Morin et al. (62) showed that athletes who produced more horizontal force had a better activation of hamstrings before ground contact and higher hamstring eccentric peak torque capability. Furthermore, hamstring force production and hamstring force absorption increases by 1.4 fold and 1.9 fold, respectively, when running speed increases from 80% to maximal speed (23). Studies looking at players returning from injury showed a substantially lower sprint score than the uninjured group (58,59). The authors attributed it to the lower horizontal power due to it being significantly different to the uninjured group compared to the velocity component. This lower horizontal force output can be attributed to the strength deficits in the previously injured hamstring of the athlete (66,68). This suggests an improvement in eccentric strength of the hamstring muscles has the potential to maximise forward propulsive force, consequently improving sprint speed.

The hamstring has been observed as a key contributor to the transfer of force from knees to the hip (45) during jumping tasks. Primarily, the activity of the hamstring muscle group in the downward phase of a dynamic jumping activity has been recognised as an important contributor to jump height (69). The hamstrings work eccentrically during the downward phase to control the descent, consequently maximising the stretch shortening cycle (SSC) through an efficient transfer of power from knees to hip (4,46). Elastic energy storage has been found to be an important determinant of vertical velocity (76) and velocity has shown to be a highly important contributor to jump height (50). Therefore an improvement in eccentric hamstring strength could improve the SSC and elastic energy transfer (55). An observation on a group of soccer players showed a strong correlation between hamstring strength and counter-movement jump (CMJ) (21). This was predominantly attributed to the improved energy transfer from stronger hamstring muscle group to the distal segments of the body during the concentric phase of the jump causing higher take-off velocities (14). A study found similar results, concluding that the hamstring as a biarticular muscle has a function of transferring energy to other muscle groups through a coordinated pattern and to contribute to vertical acceleration (75).

Several studies place emphasis on strengthening of the biceps femoris, rectus femoris and tibialis anterior, corroborating their importance in the phases of a CMJ (4,22,81,95). Additionally, component analysis research identifies the semitendinosus and biceps femoris long head as muscle groups utilised during a CMJ (22). The semitendinosus muscle has been found to have an important contribution to muscle work and jump height due to its large moment arm at the knee. It is suggested the knee extensors build force before shortening through a downward forward acceleration of the center of mass, stimulated by the semitendinosus (13). During the concentric phase of a jumping activity the role of the hamstring is less, however, the role in hip extension has been observed as being quite significant (8,15,22,91). Considering the role the hamstring has in the storage and release of elastic energy, it is suggested that the hamstrings would have little involvement in a concentric only movement such as the squat jump (SJ).

The Nordic hamstring exercise (NHE) exercise has been postulated as a superior exercise for hamstring injury prevention (37) but little work has been produced to understand its implications for performance among the junior elite population (56). The reason for its suitability to improve overall hamstring strength is due to its bilateral and supramaximal nature. This causes muscle damage, causing more sarcomeres to be produced, consequently, improving the optimum length of the hamstrings for torque generation (18). Therefore, the hamstring is better equipped to absorb and produce force at high speeds and long muscle lengths. The large moment arm at the knee would give reason for the semitendinosus showing maximal activation during the NHE shown through EMG analysis (92). In MRI studies the semitendinosus, the biceps femoris short and biceps femoris long head have shown to be preferentially activated, respectively, during the NHE (35,57,63).

Many studies have shown a reduction in injury rate utilising a NHE intervention (9,60,72). Additionally, NHE intervention studies have been shown to improve cross sectional area (64,84), fascicle length (28,16,6), increase in muscle volume (6,16,84) and increase in peak torque at longer muscle lengths (18,20,63). Eccentric strength improvement in NHE intervention studies have ranged from 10 to 29.9% measured via various testing equipment (24,29,43,60,78,79,80). However, there are a few studies to find no improvement in hamstring strength and morphology after a NHE intervention (33,83,84).

Recent studies investigating the implications of NHE interventions found primarily positive athletic performance related results. Studies of varying lengths and populations have found improvement in 5m (33,51,88), 10m (51,88), 15m (33), 20m (88) and CMJ (7,24, 51,90). However, there are a few studies that have shown no improvement (84) or negative effect (83) on various athletic performance measures. These studies show a trend that the NHE intervention, and the muscle architectural and strength benefits associated with the exercise, can infer a positive athletic impact. However, many of these studies use a non-athletic population that has minimal use of informing practice of athletes with previous resistance training (29,79,80,84). Furthermore, the volume of the NHE is very high with the majority of studies. This leads to lack of compliance due to muscle soreness and therefore not completing the exercise maximally (9,36,72,83). It is questionable whether a high volume of NHE is possible in an elite population due to additional training units during the day and preparation for matches. Muscle soreness could cause performance impairment of subsequent sessions (83). Additionally, recent evidence suggests that a low volume of NHE is more beneficial than high volume for architectural adaptations (74). This suggests that eccentric strength can be improved with a lower volume of NHE and minimal associated muscle soreness and consequently minimal or no affect on subsequent training units during the day.

The purpose of this study will be to assess whether a short-term NHE intervention improves eccentric strength and athletic performance measures among a junior elite population. Therefore, providing evidence of the NHE inclusion in a resistance training programme with an appropriate volume. The hypothesis being that the intervention group will show a statistically significant improvement in sprint speed, CMJ measurements, eccentric strength and no improvement in SJ measurements. Secondly, the control group will show no improvement in any strength or athletic performance measures.

METHODS

Experimental Approach to the Problem

This randomised controlled trial analysed the effect a 6-week NHE intervention on eccentric hamstring strength, 10m, 20m, 30m, CMJ and SJ. The participants were tested two days before and after the 6-week intervention. Participants were instructed to maintain their habitual lifestyle and normal dietary intake during the intervention.

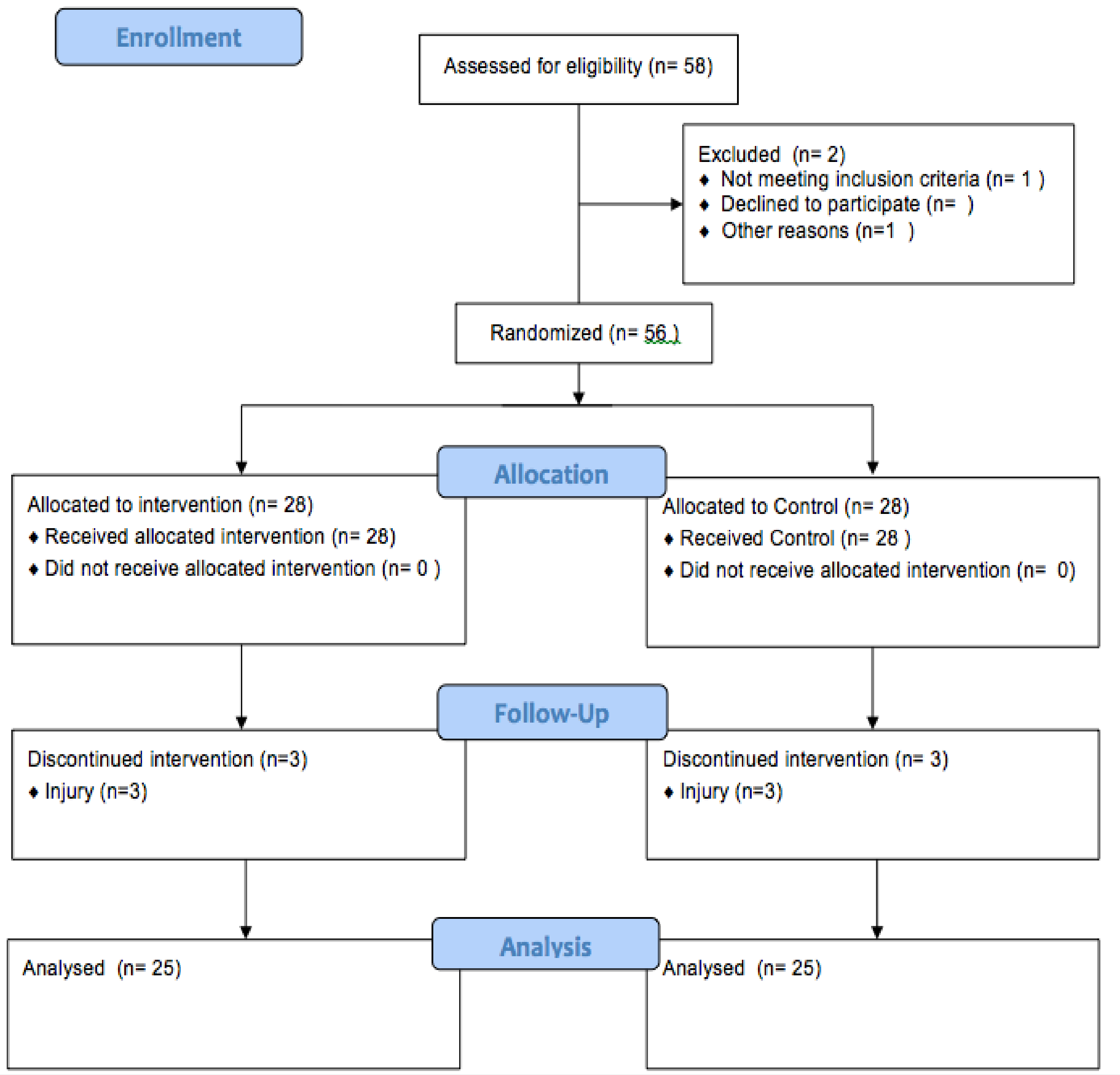
Subjects

There were fifty junior athletes from different rugby academies in Cardiff, competing in regular sport and at least 1-year resistance training, that participated in the study (mean ± SD; age 18.9 ± 0.4 years; height 179.5 ± 5.1 cm; body mass 87.2 ± 14.3). Table 1 shows the participant characteristics of all subjects taking part in the study. They provided written informed consent to participate in this study, following an outline of the study. Participants were free from any injuries to the trunk, hips and lower body. This was assessed through a PAR-Q, which was completed two weeks before the study began. Figure 1 shows the CONSORT flow diagram of number of subjects at each stage of the trial process. This study was approved by the St Mary's University Research Ethics Committee.

Table 1. Participant physical characteristics (mean ± SD)

Group	*n*	Body mass (kg)	Height (cm)	Age (y)
Total	50	87.2 ± 14.3	179.5 ± 5.1	18.9 ± 0.40
Control	25	85.6 ± 13.7	178.6 ± 4.7	18.9 ± 0.5
Intervention	25	88.8 ± 14.9	180.5 ± 5.4	18.9 ± 0.3

Figure 1. CONSORT 2010 Flow diagram of the progress through the phases of the randomised controlled trial (61,82)



An a priori sample size estimates were based on previous research on eccentric hamstring data and power was calculated as 0.80 for the use of two-tailed independent t-test to compare groups with a sample size of 66 (input parameters, effect size= 0.71, alpha = 0.05).

Procedures

Anthropometric measurements were completed with body mass being obtained using an electronic scale (Tanita BC 418, Japan) accurate to within 0.1kg. Body height was measured using a wall mounted Stadiometer (SECA, Germany).

Eccentric hamstring strength was assessed using a NordBord (VALD Performance, Brisbane, Australia**),** as described elsewhere (65,67). The Nordbord is a system specifically used to measure hamstring strength. Participants knelt on a padded board with ankles secured with hooks superior to the lateral malleolus that were fixed to uniaxial load cells (Delphi Force Measurement, Gold Coast, Australia) with wireless data acquisition capabilities (Mantracourt, Devon, UK). The ankle hooks and load cells were attached, which allows force to be measured through the long axis of the load cells. Before performing the test participants were shown a demonstration of how to perform the NHE. Participants leaned forward at the slowest speed possible maintaining hip and trunk in a neutral position with arms across the chest. When the participant couldn't control his descent any longer he was instructed to catch himself with his hands on the floor. A rep was deemed acceptable when there was a distinct peak force output followed by a rapid decline when the participant was unable to resist the force of gravity. Participants performed a low intensity warm up set of three repetitions before completing one set of three maximal repetitions. Force data analysis for the Nordbord has previously been reported (65,67) and this eccentric strength assessment method has been shown to be reliable (ICC 0.83-0.90) (65). Force data was captured for each limb and transferred to a personal computer at 100Hz through a USB cable and forces determined by Scorebord data collection app (VALD Performance, Brisbane, Australia). Eccentric hamstring strength was recorded in absolute force in Newtons (N) for each limb and the data was presented as a mean from both limbs. The highest score of the three reps was recorded. Figure 2 shows the start and end points for the NHE.

Figure 2. Nordic Hamstring test- Start and End point

Assessment of speed and jump was completed on the same day with the jump tests being performed before the speed tests. Prior to the jump testing, a 10 minute standardised general warm up which consisted of light jogging for 2 minutes followed by dynamic stretching for 8 minutes. This was followed by a specific warm up which includes 3 reps of CMJ and SJ before jump testing and 2 repetitions of sub maximal accelerations before speed testing. The participants completed the speed testing on a 60-metre tartan track.

The speed testing was assessed using the Brower Speed trap II timing system (Brower Timing Systems, Utah, USA) that consists of a handheld monitor (CML5MEM) and five infrared beam sets. Each set consists of an infrared sender (IRD-T175) and an infrared emitter (IRE) with antennas mounted on tripods. Data was sent directly from the beam sets to the handheld coach monitor. The timing gates were at 0m, 10m, 20m and 30m. After the warm up, participants completed 2 maximal 30-metre sprints with three minutes rest in between sets. The participants started from a standing start with their foot 30cm behind the first set of beams and the time started once they broke the first beam and stopped when they broke the last beam. Each tripod was placed at the distance measured by a laser (Bosch DLE40 Laser Rangefinder) and were 50cm above the ground as described in previous literature (85).

Assessment of jump height, peak force and peak power was assessed using a Kistler force plate (Type 9287CA, Kistler instruments Ltd, Farnborough, UK) with a sampling frequency of 1000Hz. Set up of the force platform has been explained in previous literature (65). All jumps were completed with hands on hips at all times through the jump. During the CMJ, the participant went down to a self-selected depth and produced a maximal effort upwards landing back on the force plate. During the SJ, the participant descended into a half squat position (90 degree bend at the knees) measured by a goniometer and produced a maximal effort upwards, after a 3 second pause. Any downward movement before jumping would mean a failed rep. This jump protocol has been described in previous literature (5). To analyse CMJ and SJ data, the vertical component of the data was transferred to a custom built excel sheet. Body mass, jump start time and take off were calculated using methods previously described (87) with vertical displacement being calculated using the impulse-momentum method. Jump height was calculated by calculating the difference between maximal vertical displacement and vertical displacement at take off. Absolute peak power was calculated by multiplying vertical GRF and vertical velocity. Jump height (ICC 0.93) and absolute peak power (ICC 0.96) methods have been shown to have a high test-retest reliability (47).

Intervention programme

After the first testing battery, the participants were allocated into an intervention and control group using block randomization to prevent selection bias. The groups completed the same 6-week, 3 times per week program with the intervention group completing the sets of the NHE. Table 2 shows the details of the NHE intervention. Table 3 shows the program all participants followed during the 6-week trial. There was at least 24 hours between each training session.

Table 2. NHE Intervention

Week	Reps/ Sets	Days per week
1	2 x 6	2
2	3 x 6	2
3	3 x 6	2
4	3 x 6	2
5	3 x 6	2
6	3 x 6	2

Table 3. 6 week Resistance training programme for all participants

Session 1	**Sets x reps**	**Load % 1 RM**
1. Hang Clean	4 x 2	85
2. Back Squat	5 x 5	75
3A. Walking Lunge	3 x 10	
3B. SA Row	3 x 10	
4. SL Glute Bridge	3 x 12	

Session 2	**Sets x reps**	**Load % 1 RM**
1. Bench Press	5 x 5	75
2. Bench Pull	5 x 10	65
3A. RFE Split Squat	3 x 8 each leg	
3B. Chins	3 x max reps	

Session 3	**Sets x reps**	**Load % 1 RM**

1. Power Clean	4 x 2	85
2. Back Squat	5 x 5	80
3A. Reverse Lunge	3 x 8 each leg	
3B. Pulldown	3 x 12	
4. RDL	3 x 10	

In the NHE, feet were secured with a partner placing hands on ankles to keep the feet down. Before the exercise, participants were instructed to keep their hands at chest level so that once a repetition was finished they could push themselves up and maintain hip extension throughout the movement. The participant only performed the lowering part of the exercise and when they couldn't control the movement they dropped to the floor and used their arms to push themselves up. When the participants were able to stop the exercise in the final 10-20 degrees range of motion they were required to hold a weight plate (range 2.5-20kg) increasing in 2.5kg increments to ensure the exercise was supramaximal. 3 minutes rest between sets was allowed (16).

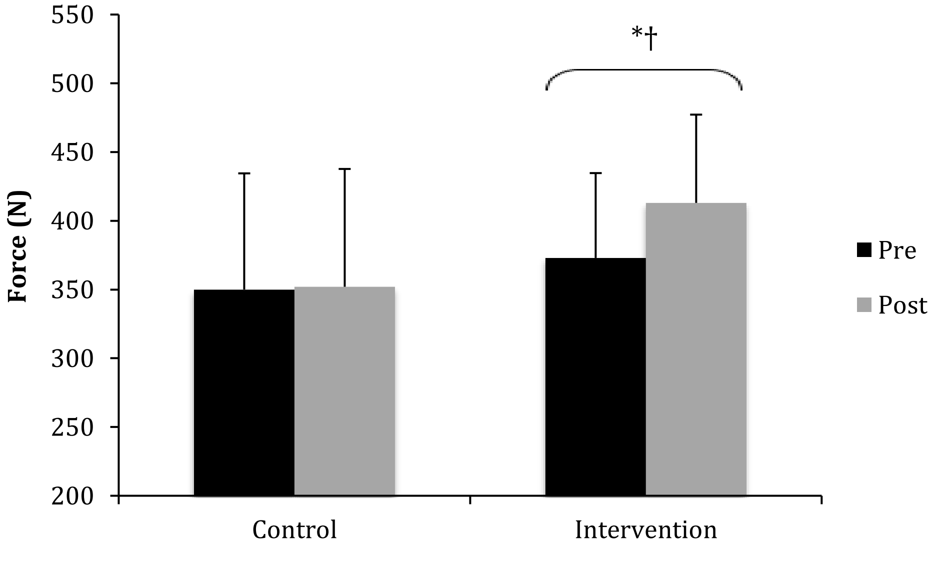
Statistical Analysis

Data are presented as means ±SD. Data was normally distributed as assessed by Shapiro-Wilk test ($p>0.05$). The homogeneity of variance was assessed via the Levene's test. The pre and post measures for 10m sprint showed a violation of the assumption. Due to the normality of data the test was continued despite the violation. A two way repeated measures analysis of variance (ANOVA) was performed to test between (Control, Intervention) and within (pre, post) on all of the dependent variables. Partial eta squared effect sizes were calculated for group x time interaction effects for variables that showed statistical significance. Values of $\eta_p^2 \geq 0.01$, ≥ 0.059 and ≥ 0.138 represented small, medium and large effects, respectively (25). To determine effect sizes between pre and post measures, Cohen *d* method was used and values of 0.2, 0.5 and 0.8 were defined as small, moderate and large, respectively (26). All statistical analyses were performed using SPSS V.22.0.0.1 (IBM Corporation, Chicago, Illinois, USA).

RESULTS

There were no significant differences between the physical characteristics of intervention and control group. The randomization procedure produced groups that were equal in anthropometrics. Figure 3 shows the pre and posttest results for eccentric hamstring strength for both the control and intervention groups. There was a statistically significant improvement between the pre and post measure for the intervention group ($p < 0.0005$, pre = 373N ± 62N vs. post = 413N ± 64N). There was also a statistically significant difference between control group (pre = 350N ± 85N vs. post = 352N ± 86N) and intervention on eccentric hamstring strength improvement ($p < 0.05$). Cohen's d effect size for the pre to post measure for the intervention group was 0.64 representing a moderate value and partial eta squared effect size for between groups was 0.37 representing a large value.

Figure 3. Eccentric hamstring strength pre and post test results for control and intervention groups

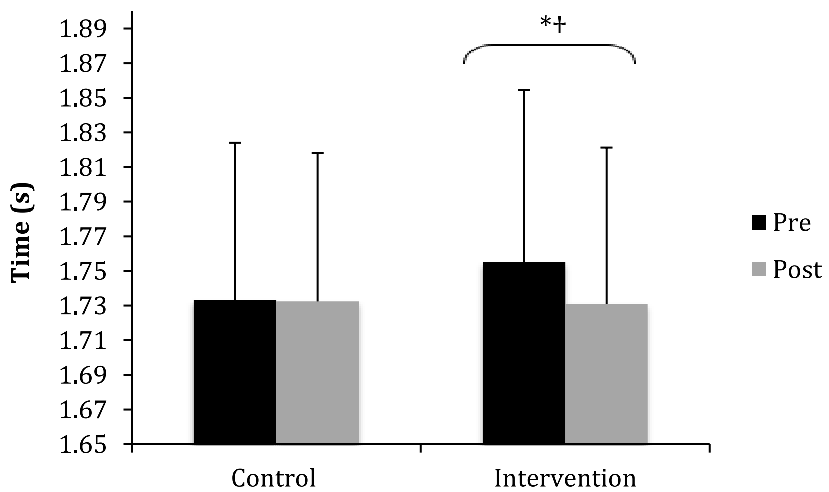


* Indicates significant change from pre-test (p<0.05) † indicates significant difference from control group (p<0.05).

Figure 4 shows the pre to post results for 10m sprint time for the control and intervention groups. Results show statistically significant improvement in 10m sprint time for the intervention group ($p < 0.05$; pre 1.72 ± 0.49 vs. post intervention 1.71 ± 0.51) and no improvement in the control group.

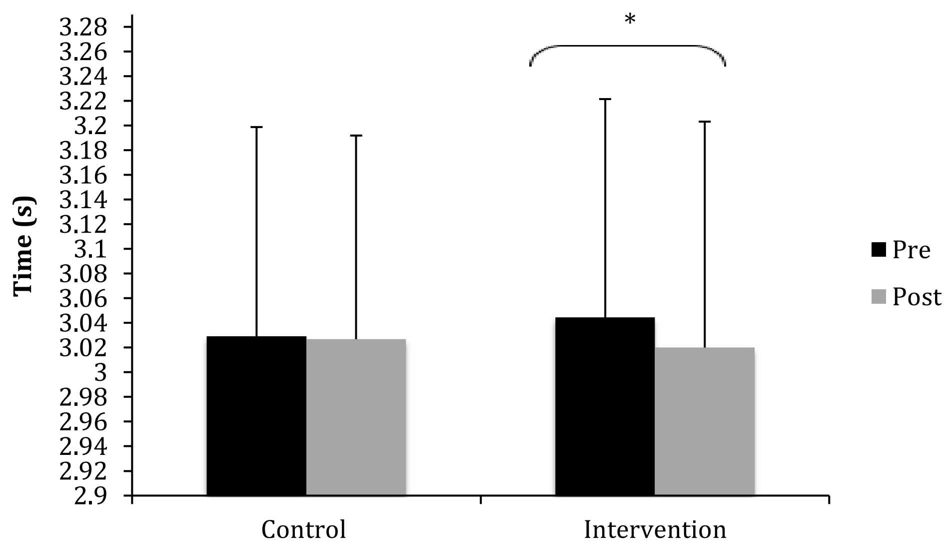
Partial eta squared effect sizes for between the groups shows a moderate value (η_p^2 =0.83). However there is a negligible effect size for pre to post measurement for the intervention group (*d*=-0.02). Figure 5 shows the pre to post results for 20m sprint time for the control and intervention groups. There was a statistically significant improvement in the intervention group from pre to post measure for 20m time (p < 0.05; pre 3.02 ± 0.12 vs. post intervention 3.00 ± 0.12) and no improvement for the control group. However effect sizes for pre to post measure showed a negligible effect size (*d*=-0.17). There was no statistical significance between the two groups for 20m time however partial eta squared effect sizes for between groups showed a moderate value (η_p^2 =0.76). Figure 6 shows the pre to post results for 30m sprint time for the control and intervention groups. A statistically significant improvement in 30m sprint time for the intervention group was observed (p < 0.05; pre 4.24 ± 0.17 vs. post intervention 4.20 ± 0.17) with no improvement in the control group. However the effect size for pre to post measure for the intervention group showed a small value (*d*=-0.24). There was a statistical significant difference between the intervention and control group for 30m sprint time results with the partial eta squared effect size between the groups representing a moderate value (η_p^2 =0.103).

Figure 4. 10m pre and post test results for control and intervention groups



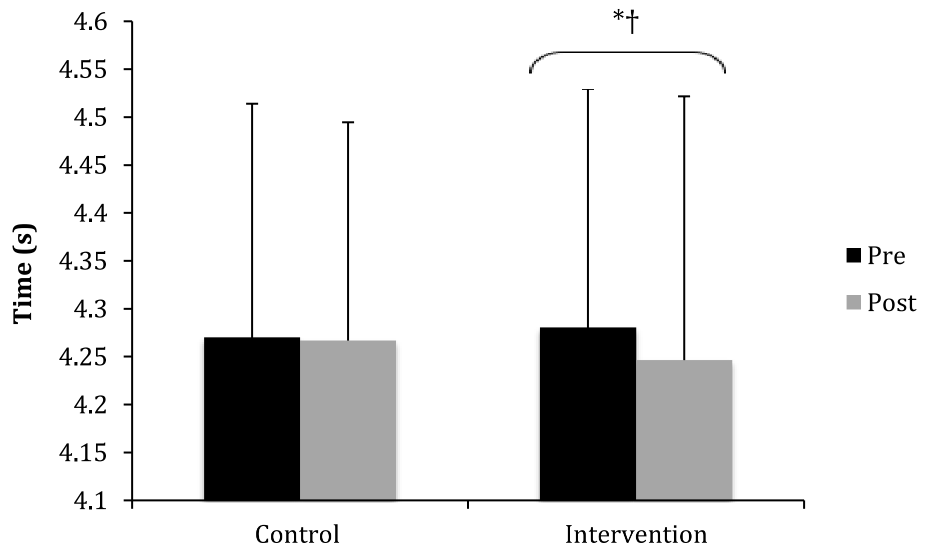
* Indicates significant change from pre-test (p<0.05) † indicates significant difference from control group (p<0.05).

Figure 5. 20m pre and post test results for control and intervention groups



* Indicates significant change from pre-test (p<0.05)

Figure 6. 30m pre and post test results for control and intervention groups



* Indicates significant change from pre-test (p<0.05) † indicates significant difference from control group (p<0.05).

Analysis of CMJ peak power, CMJ jump height and CMJ peak force showed no significant differences between groups as well as no significant changes from pre to post measure. Figure 7 shows the CMJ peak power results for both groups. Figure 8 shows the results for CMJ jump height for both groups. Figure 9 shows the CMJ peak force results for both groups.

Figure 7. CMJ Peak Power pre and post test results for control and intervention groups

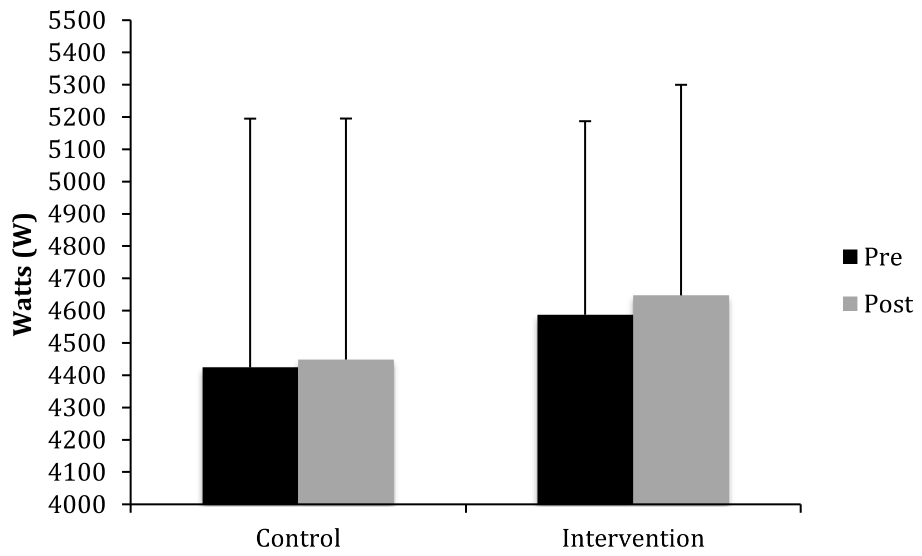


Figure 8. CMJ Jump Height pre and post test results for control and intervention groups

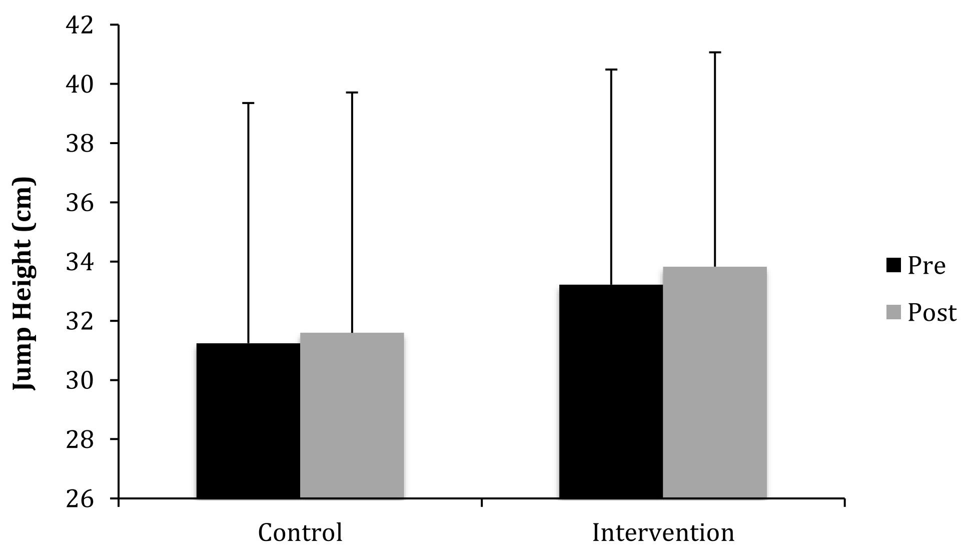
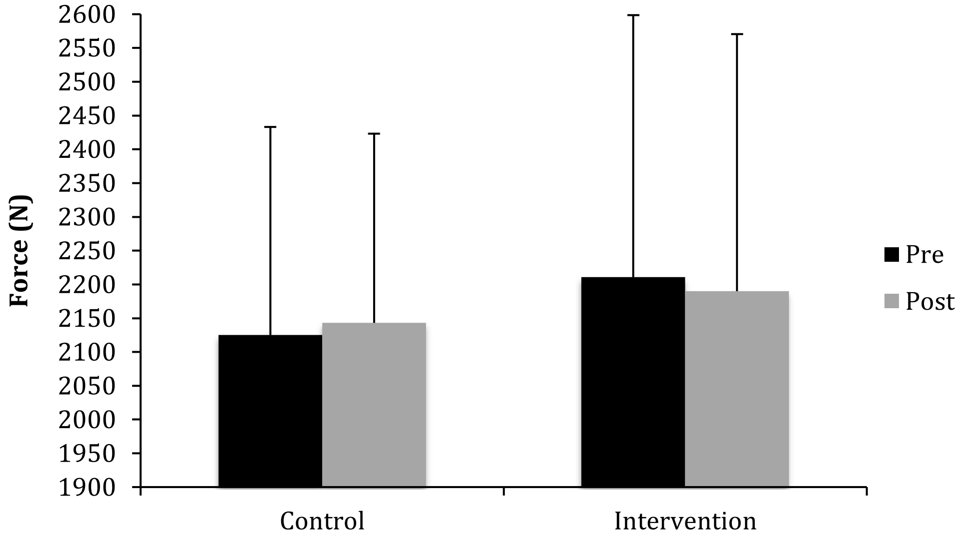


Figure 9. CMJ Peak Force pre and post test results for control and intervention groups



Analysis of SJ peak power, SJ jump height and SJ peak force showed no significant differences between groups as well as no significant changes from pre to post measure. Figure 10 shows the SJ peak power results for both groups. Figure 11 shows the results for SJ jump height for both groups. Figure 12 shows the SJ peak force results for both groups.

Figure 10. SJ Peak Power pre and post test results for control and intervention groups

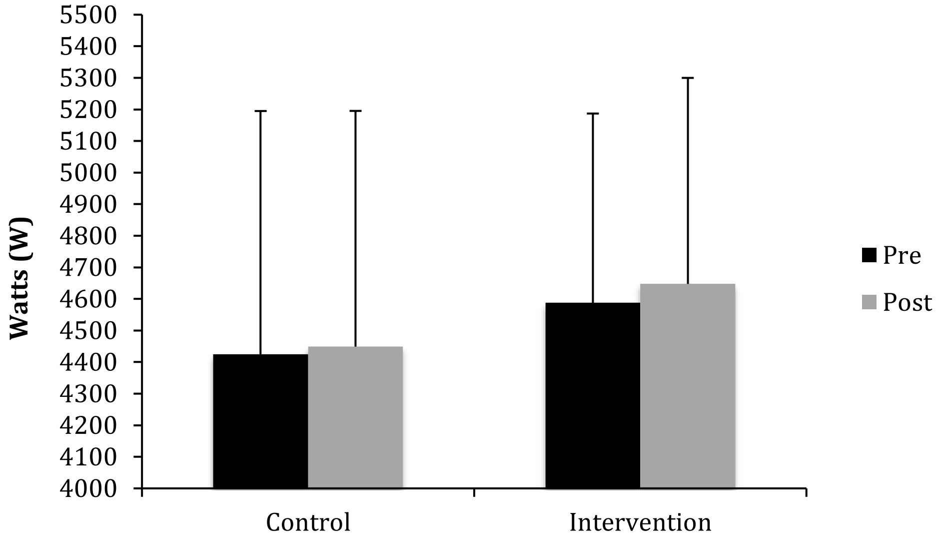


Figure 11. SJ Jump Height pre and post test results for control and intervention groups

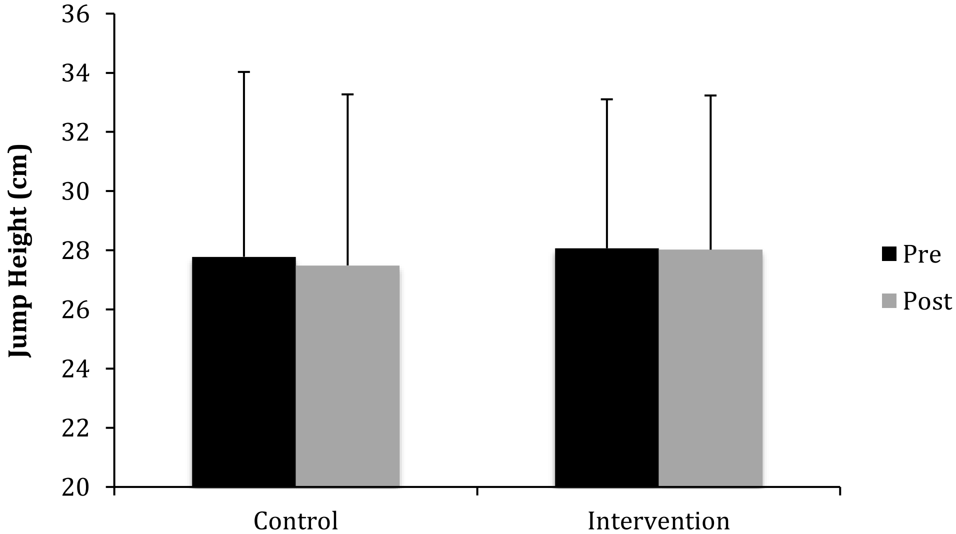
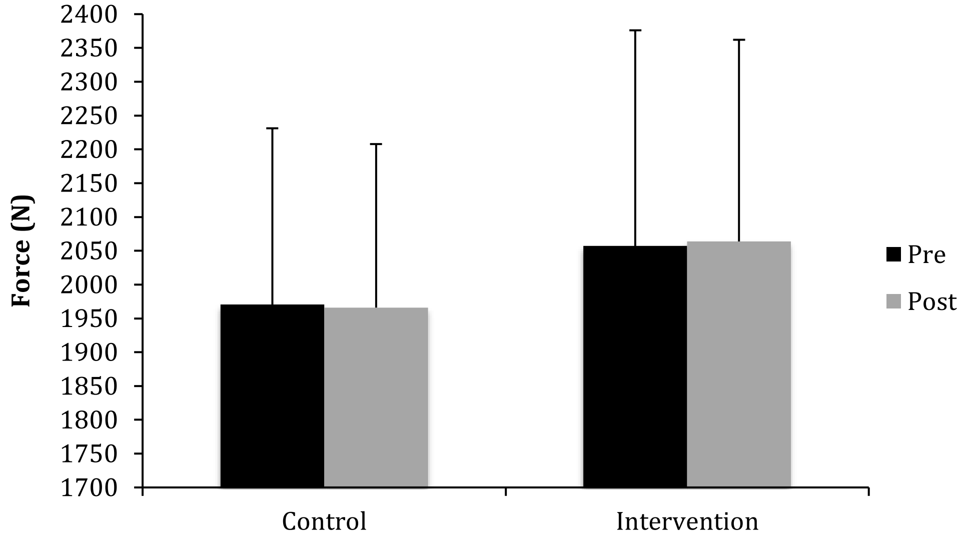


Figure 12. SJ Peak Force pre and post test results for control and intervention groups



DISCUSSION

The effect of the NHE intervention on eccentric hamstring strength was the most statistically significant finding with a 10% improvement. The sprint results showed a small but significant improvement in the intervention group with the most improvement being in the 30m test and there were no significant changes in any jump tests. The following discussion will discuss the reasons for the observed results with reference to previous literature.

Mjolsnes et al. (60) found a significant 11% difference in strength after a 10-week NHE intervention, significantly higher than the concentric group. However, one of the few studies to show no improvement in eccentric hamstring strength or torque employed a high volume of repetitions (83). Coincidentally, players did not perform the exercise maximally due to muscle soreness, which has been shown in injury prevention studies (9,36,72). A study showing a decrease in eccentric hamstring strength employed a very low volume over the 21 weeks (33). The authors concede that the volume was not enough to stimulate any adaptation. Similarly, a study that employed a lower volume than the present study found a 10% increase across a seasonal long NHE intervention in junior elite athletes (43). This has implications for volume of repetitions NHE intervention and the way the exercise is performed. The present study shows a large junior elite group with full compliance and improvement in eccentric hamstring strength indicating a volume of repetitions that stimulates an adaptation and is attainable in an elite environment. Several studies utilising NHE showing large improvement (79,80) and no effect (84) on eccentric hamstring strength, however, the participants involved were recreational athletes. Additionally, the high volume of repetitions would not be applicable in an elite environment due to soreness observed, lack of compliance and additional training. Eccentric activity is often associated with high levels of muscle damage and consequently muscle soreness (37). Therefore, soreness and fatigue could have serious implications for short term performance. Additionally, recent research on low volume vs. high volume repetitions found no additional benefit from a higher volume NHE on biceps femoris fascicle length compared to low volume of repetitions (74).

A key advantage of the NHE is the shift in optimum length and the production of force at longer muscle lengths (18). Studies investigating --term inventions into angle of peak torque show improvement ranging from 6 degrees to 21 degrees (18,24,49). However, the study that shows the greatest improvement has the smallest volume, indicating that the high volume of repetitions is unnecessary to stimulate further adaptation. Participants in these studies are all untrained, however, the trend indicates that short-term interventions show initial adaptations to be improvement in angle of peak torque which could be associated with an improvement in eccentric strength. However, a study that did not notice a change in angle of peak torque or fascicle length also did not notice a change in eccentric hamstring strength (84). This being said a strong correlation was observed between biceps femoris PCSA and eccentric hamstring strength (84). Therefore, reasons for the observed improved eccentric hamstring strength can be through a shift in optimum angle of torque generation and increase in cross sectional area. The stretch in conjunction with a large overload stimulus, as experienced in the NHE, has been shown to be highly effective for muscle growth (42). Considering the training background of the participants in the present study, this may be a more feasible reason for the strength adaptation observed. Subjectively, across the 6-week intervention, the majority of participant's ability to control their descent was improved and they were able to descend further, indicating improved strength at longer muscle lengths. However, inter-subject variability was high in response the strength stimulus**.** Individual responses to a stimulus are common the present study showed variance of -7% to 39% improvement in eccentric hamstring strength. The effort put into the NHE to maintain the supramaximal nature is the key determinant of the benefits associated with the exercise. A recent meta-analysis assessing the effect of compliance level on the effectiveness of eccentric hamstring interventions for injury prevention showed that compliance level has a highly significant effect on whether the intervention would reduce injury levels or chances of injury (37).

The present study's results showed a small but significant improvement in 10m, 20m and 30m with the 10m and 30m being significantly different to the control group. However, effect sizes for between and within subjects were minimal with greater improvement found in the 30m results in comparison to the 10m and 20m.

A study consisting of the same time frame found similar results as the present study, but with greater effect sizes. This could be due to the participants having little or no experience with high intensity strength training. The lack of control group reduces the power of the study's results slightly, however, the study shows significant improvement (88). This improvement may be explained by an improved muscle excitability (94) and voluntary contraction (1) stemming from the eccentric activity. The high intensity resistance trained participants won't produce the same improvement in neural drive compared to the less trained participants (31,32). However, the motor unit recruitment from the NHE intervention will still have a contribution to increases in strength observed in the population in the present study. The aforementioned study by Seblien et al. also analysed the effect of NHE intervention on speed performance and found a negative result where the participants achieved slower times (83). Therefore, the high volume and subsequent hesitation by participants to perform the exercise maximally due to muscle soreness means that the exercise benefits become negligible and effort during NHE remains the determinant factor for improvement of speed.

Studies utilising eccentric emphasised activity have found positive results on sprint performance.

Two 10-week studies on yo-yo half squat and eccentric hamstring curl fly wheel found similar mean improvements to the current study for 20m (27) and 30m sprint times, respectively (10). This shows that the mechanism of activity is important when looking to improve hamstring strength and athletic performance. This benefit is even more pronounced when comparing studies using eccentric and concentric exercises showing highly significant differences in strength (30,38) and fascicle length (12,49,73) Considering the NHE is highly eccentric and supramaximal (17), the benefits for improved speed are clear. As previously mentioned, the improvement of optimum length, torque at longer muscle length and improved fascicle length from the NHE, has shown to improve generation of horizontal force in sprinting. The improvement of eccentric hamstring strength observed in the present study can lead to an increased ability for production of eccentric peak torque capability (62). The improved eccentric strength of the hamstrings allows for an improved efficiency of the lower limb during the early and late swing phase. The enhanced ability of the hamstrings to reduce the kinetic energy while lengthening during the late swing phase increases stride frequency (53,97). Subsequently, this contributes to early stance ground reaction force due to a reduced deceleration time during impact. Specifically, the NHE has previously been shown to preferentially stimulate the semitendinosus and biceps femoris muscles (33,57,63). Considering that the biceps femoris is highly active in terminal swing and semitendinosus during mid swing (39,81), there is a possible mechanism for improved speed qualities, through an improved capability of these specific hamstring muscles.

Krommes et al. (51) studied the NHE intervention over a 4-month period with 1-2 sessions per week. Consistent with the present study there was a significant improvement in 10m performance. The study also found improvement in 5m performance but no improvement in 30m performance. The authors concluded that hamstring intervention improved explosive characteristics i.e. acceleration as opposed to maximal speed. The present study found more improvement in the maximal speed component of the tested variables in the form of the 30m test. The studies on acceleration mechanics have shown significant relationships between ground reaction force and EMG activity of hamstrings and eccentric knee flexor peak torque (40,62,97). Equally, during upright maximal speed running, many studies have shown the significant contribution the hamstrings have in the production of force during all phases of the swing leg (53,81). The kinematics of acceleration and maximal speed running are significantly different (62,97), however, the hamstring has been shown to have significant contribution efficiency of both components. The greater effect sizes in the 20m and 30m results provide evidence to suggest the improvement in eccentric hamstring strength provides a greater improvement of maximal speed running. This could be explained by the large increases in hamstring force production and absorption observed when running speed increases from 80% to maximal (23). Indicating an increase in eccentric strength improves force absorption and production inducing a more efficient stretch reflex prior and during ground contact. At 10m, the participant is still in acceleration mechanics and therefore peak hamstring activity is not achieved because the participant is not at maximal speed. At 30m the participant is at maximal speed and bicep femoris long head and semitendinosus is at peak activation during different phases of the swing leg (39). Therefore, due to an improvement of eccentric hamstring strength, the peak torque capability is enhanced and therefore 30m time has a greater improvement than the 10m acceleration marker. Even though a high contribution of the hamstring is evident in acceleration, the gluteus maximus and vastus lateralis have been shown to have higher EMG activity and therefore may have a greater contribution to acceleration speed (62). Furthermore, even though greater effect sizes were seen in the 20m and 30m sprint times, the effect sizes are still small and greater results have been seen in longer studies (10,27,51). Therefore, to see greater improvement in running speed, this intervention may need to be administered over a longer period.

Associations have been found between faster sprinters possessing longer fascicle lengths and smaller pennation angles than slower sprinters (2,3,52). High power output has been attributed to longer muscle fibers because they contract at faster velocities than shorter fibers (98). The increase in fascicle length associated with the NHE produces a higher number of sarcomeres in series (48) and therefore faster contraction velocities leading to greater running speeds. Research into fast eccentrics has provided very positive results with regards to muscle size (34), SSC (54), strength (34) and rate of force development (28). Therefore, it can be hypothesized that faster contraction velocities may transfer to sprint performance better than slow eccentrics. Even though the present study found small significant improvements, heavy load faster eccentrics may be needed to improve sprint performance further. In the study by Mjolsnes et al. (60) once the athletes were adept at controlling full range of motion, they were pushed by another participant to further test an athlete's control of their descent. Considering the very promising research into faster eccentrics, this could provide a stimulus to further improve sprint performance using the NHE intervention.

The results in the present study found no significant change in CMJ or SJ measures. The initial hypothesis was based off the large contribution of the hamstring to hip extension and the important role in the eccentric phase of the CMJ. Similarly, a recent study investigating the same 6-week NHE intervention found similar non-significant results to CMJ jump height (84). A 10-week study by Anastasi et al. (7) showed a significant improvement in vertical jump height in conjunction with improvement in isokinetic hamstring strength. Authors concluded that the improvement of peak torque at longer muscle lengths produced a more efficient transfer of force to the distal muscles and therefore take off velocity (7). Similar results and conclusions were found in a 5-week study on untrained subjects, which showed a significant improvement in vertical jump height in conjunction with an improvement in eccentric hamstring strength (90). Authors attributed the improved jump height to the improved knee stability that came from the enhanced hamstring eccentric strength. The improved knee stability allows for more efficient transfer of force from the eccentric phase to concentric (90). The role of hamstrings in improving CMJ measures can be explained by its contribution to an improved SSC (13,77), knee stabilisation (71) and hip extension (8,15,22,91). The two studies finding the most significant improvements in CMJ performance have lasted longer periods than the current study and previous shorter studies. As discussed previously in the context of sprinting, the length of the NHE intervention may be a key variable in the enhancement of dynamic jump performance. The only short-term study to show small but significant improvement in vertical jump height was a 4-week high volume NHE intervention (24). However, the study had a small sample size, no control group and untrained participants. The present study shows a considerable improvement in eccentric hamstring strength and consequently a potential improvement in elastic energy and knee stability. Therefore, further research into using this NHE intervention over a longer period may provide favourable results among an elite junior population. In an accentuated eccentric hamstring programme substantial improvements were found in CMJ performance. However, one of the exercises used was the half squat using the Yo-Yo technology. The specificity principle may have a biased towards a highly significant improvement due to the similarity in exercises (27). The specificity principle is particularly important when improving CMJ performance and many studies have shown a highly significant improvement in jump performance when variations of jump training are included (11,41). Research into eccentric leg press training showed a highly significant increase in CMJ height, power and contact time through an improved SSC (70). Both these studies use participants with previous strength training indicating a more specific eccentric jump protocol may be more beneficial for this population. The improved motor unit firing frequency and voluntary contraction of Type 2 muscle fibres from eccentric training can improve eccentric force control, consequently, improving the SSC (38). However, as the present study shows a specific improvement in eccentric hamstring strength does not corroborate these adaptations. Even though the hamstring muscle group has been proposed as one of the important biarticular muscles during CMJ tasks, the quadriceps muscle group and gastrocnemius are of higher importance. This is due to their role in knee extension and ankle plantar flexion, respectively, as shown by EMG (21) and biomechanical analysis (95).

Whilst the study provides unique insights into the practicality of the NHE and improvement in strength and speed measures, there are some limitations to note. The subjects continued participating in their respective sports during the course of the intervention. It is acknowledged that these sessions may have had an influence on sprint and jump performance. It would not have been feasible to remove these sessions from the 6-week study due to their junior elite status. However, this does increase the ecological validity of the study. Secondly, the number of participants was below the a priori sample size calculation, which required 66 participants for 0.8 statistical power. However this study does have more subjects than many other studies on NHE (51,60,84) and therefore the conclusions are still highly relevant. The reason for the number of subjects not being achieved is due to only a certain number of players from the rugby academies being available due to the time of the season.

PRACTICAL APPLICATIONS

The findings of the study show that a simple NHE intervention can improve eccentric hamstring strength and sprint performance in junior elite athletes. This study highlights that the benefits of the NHE for jumping are negligible over a 6-week period, however CMJ performance benefits may be seen with a longer intervention. Further research into using this NHE intervention protocol over a longer period will provide evidence into whether this would be an additional benefit for sprint and jump performance. Furthermore the findings present a volume of NHE prescription that stimulates an adaptation and full compliance in junior elite athletes. Consequently, the low volume of NHE does not affect other training units and match performance, which is a key factor to acknowledge for the practitioner when programming for the junior elite population. It is recommended that strength and conditioning coaches ensure the exercise is completed maximally due to the benefits associated with the supramaximal intensity of the exercise. Furthermore, research into comparisons between different eccentric hamstring exercises will provide further knowledge into which intervention can improve athletic qualities. It may be hypothesised that fast eccentric NHE provide a great SSC response and therefore improve speed and jump qualities further.

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Appendices

Appendix A: Signed Ethics Application

St Mary's University Twickenham London

23 January 2017 Unique Ref: SMEC_2016-17_038

Daniel Akenhead (SHAS): ''Effect of a 6 week eccentric hamstring training intervention on athletic performance measures: a randomised controlled trial'.

Dear Dan
University Ethics Sub-Committee
Thank you for submitting your ethics application for the above research.
I can confirm that your application has been considered by the Ethics Sub-Committee and that ethical approval is granted.
Yours sincerely

Prof Conor Gissane
Chair of the Ethics Sub-Committee

Appendix B- Participant Information Sheet

St Mary's
University College
Twickenham
London

145368@live.stmarys.ac.uk 01/02/17

Dear Sir

This is a letter of invitation to enquire if you would like to take part in a postgraduate research project investigating whether a 6 week training intervention of eccentric hamstring exercise 3 times per week will improve hamstring strength and speed and jump height.

Before you decide if you would like to take part it is important for you to understand why the project is being done and what it will involve. Please take time to carefully read the Participant Information Sheet on the following pages and discuss it with others if you wish. Ask me if there is anything that is not clear, or if you would like more information.

If you would like to take part please complete and return the Informed Consent Declaration form as well as the PAR-Q form. Please do not hesitate to contact me if you have any questions.

Yours faithfully,

Daniel Akenhead

St Mary's University College Twickenham London

145368@live.stmarys.ac.uk 01/02/17

Study Title

Effect of a 6-week Nordic hamstring intervention on athletic performance measures in rugby academy players: a randomised controlled trial

Invitation

You are invited to take part in a research study. Please take time to read the following details about the study before you decide whether you would like to be involved. Please do not hesitate to ask any questions. If you decide to take part you will be asked to sign a consent form and fill out a PAR-Q. You are able to withdraw from the study at any time without giving reason. You will be given a copy of the consent form along with a copy of this information sheet.

Purpose of the study

The purpose of the study is to assess whether a simple training exercise intervention can improve hamstring strength and speed and jump height.

Why you have been chosen

You have been chosen because you fit the criteria of being a male aged between 18-20 with a history of strength training.

Remuneration

The study is completely voluntary and no remuneration will be given for participation

Data Protection

Your consent form and Par-Q information will be kept completely confidential with only the lead researcher and supervisor having access to the information. The forms will be kept in a locked cabinet. Any electronic data will be secured on a password protected computer on St Mary's University servers with only the lead researcher and supervisor having access to results.

The Study

The study will involve a battery of tests that will assess your strength speed and jump height. This will then be followed by a 6 week strength training programme followed by a subsequent test. Your everyday life will be unaffected and the only factors that will be changed will be your training programme, which will take place at the same time as your normal training times. Specifically, the training intervention will be 2-3 times per week.

The Speed tests involved are 10m , 20m, 30m, 40m, the jump tests involved are countermovement jump and Squat jump and hamstring strength testing will be assessed via a Nordic hamstring test on a NORDBoard

How will the study benefit you?

We cannot promise the study will help you but it provide information to us on how we can better prescribe exercises. However, the study will give you information on your speed, jump scores and hamstring strength and show whether you improved in the 6 week programme.

Are there any risks?

The risk for injury is very low due to your strength training background and previous experience of some of the tests involved. To keep any risk as low as possible, an appropriate warm up will be administered and supervised by the lead researcher and all training sessions will be supervised by the lead researcher.

Appendix C- Consent form

St Mary's University Twickenham London

Name of Participant: ______________________________________

Title of the project: Effect of a 6 week eccentric hamstring training intervention on athletic performance measures: a randomised controlled trial

Main investigator and contact details: Daniel Akenhead- 145368@live.stmarys.ac.uk

Members of the research team:

1. I agree to take part in the above research. I have read the Participant Information Sheet which is attached to this form. I understand what my role will be in this research, and all my questions have been answered to my satisfaction.
2. I understand that I am free to withdraw from the research at any time, for any reason and without prejudice.
3. I have been informed that the confidentiality of the information I provide will be safeguarded.
4. I am free to ask any questions at any time before and during the study.
5. I have been provided with a copy of this form and the Participant Information Sheet.

Data Protection: I agree to the University processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant (print)……………………………………………………………………………..

Signed………………..…………………   Date…………………………..........

If you wish to withdraw from the research, please complete the form below and return to the main investigator named above.

Title of Project: ____

I WISH TO WITHDRAW FROM THIS STUDY

Name: ____

Signed: _________________________________ Date: ____________________