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Abstract

Objectives: To investigate whether five-weeks of concentric (CON) or eccentric (ECC) hamstring strength training have different effects on recovery from sprint running, eccentric strength and architecture of the biceps femoris long head (BF_{LH}). **Design:** Cohort study. **Methods:** Thirty males (age, 22.8 ± 4.1y; height, 180.1 ± 6.4cm; weight, 85.2 ± 14.6kg) were allocated into either a CON or ECC group, both performing nine sessions of resistance training. Prior to and immediately after the five-week intervention, each participant's BF_{LH} fascicle length (FL), pennation angle (PA), muscle thickness (MT), peak isometric KF torque and Nordic eccentric strength were assessed. Post-intervention, participants performed two timed sprint sessions (10x80m) 48 hours apart. Blood samples

and passive KF torques were collected before, immediately after, 24 hours and 48 hours after the first sprint session. **Results:** After five-weeks of strength-training, fascicles lengthened in the ECC ($p<0.001$; $d = 2.0$) and shortened in the CON group ($p<0.001$; $d = 0.92$), while PA decreased for the ECC ($p=0.001$; $d = 0.52$) and increased in the CON group ($p<0.001$; $d = 1.69$). Nordic eccentric strength improved in both ECC ($p<0.001$; $d = 1.49$) and CON ($p<0.001$; $d = 0.95$) groups. No between-group differences were observed in peak isometric strength ($p=0.480$), passive KF torques ($p=0.807$), sprint performance decrements between sprint sessions ($p = 0.317$) and creatine kinase ($p=0.818$). **Conclusion:** Despite inducing significant differences in BF_{LH} muscle architecture, there were no significant between group differences in sprint performance decrements across two sprint sessions.

Keywords: Sports medicine; performance; high-speed running; resistance exercise

Introduction

Eccentric and concentric training programs have unique effects on skeletal muscle. For example, eccentric training decreases and concentric training increases the susceptibility of skeletal muscles to strength loss, shifts in the torque-joint angle relationship and delayed soreness consequent to a bout of eccentric actions [1]. Recently, eccentric training of the hamstrings has been reported to increase fascicle lengths within the long head of the biceps femoris (BF_{LH}), while concentric training decreased them [2].

Eccentric strength training interventions employing the Nordic hamstring exercise (NHE) have been shown to decrease hamstring strain rates in sport [3-5], while low levels of Nordic eccentric strength have been reported to be associated with an increased risk of injury in some [6, 7], but not all prospective studies [8, 9]. While the mechanisms mediating the effectiveness of eccentric strength training are not entirely understood [10] it has been proposed that the addition of in-series sarcomeres may at least partially explain an increased resistance to microtrauma and muscle strain injury [11-13]. Indeed, short BF_{LH} fascicles have been reported to be associated with a higher risk of hamstring strain injury in elite Australian soccer players [6]. Six studies have reported the architectural changes that occur in the hamstrings as a

consequence of the NHE [14], while five of these studies found significant increases in BF_{LH} fascicle lengths, one study suggests fascicle lengthening only occurred when the exercise was performed after soccer training. The one study that reported no changes in BF_{LH} fascicle lengths also found no significant increases in eccentric strength which may suggest the exercise was not performed with adequate intensity.

Large and rapid changes in high-speed running loads over a 1-4 week period are associated with an increased risk of hamstring strain injury [15]. This is consistent with the possibility that hamstring injuries may not always be isolated acute events caused by a single over-long stride, kick or stretch but instead they may occur as a consequence of accumulated microtrauma which eventually becomes macroscopic and presents as a strain injury [15]. However, the architectural and strength adaptations from eccentric hamstring strength training may reduce such trauma.

The effects of eccentric and concentric strength training of the human hamstrings on running performance and recovery from bouts of sprint running are not well known. High-speed running involves high hamstring forces and is proposed to involve powerful eccentric actions during terminal swing which is thought to be a likely time for hamstring strain injury [16, 17]. These powerful eccentric actions in running are also likely to cause hamstring microtrauma, soreness and a loss of strength which may result in a performance decrement when two high-speed running sessions are planned within 24-72 hours of each other. Theoretically, eccentric conditioning should better prepare the hamstrings for repeated bouts of such exercise via sarcomerogenesis, thus decreasing the amount of strain experienced by each sarcomere during muscle lengthening. Accordingly, this study was designed to investigate the effects of eccentric and concentric hamstring conditioning on the change in running performance that occurred between two consecutive running sessions held 48 h apart. We hypothesised that adaptations induced by eccentric training would, in comparison with concentric training, result in a better maintenance of sprint performance between sessions and reduced markers of muscle damage (passive hamstring torques, perceived muscle soreness and venous creatine kinase levels (CK)). For the purpose

of this study, 'recovery' was assessed by monitoring performance in two sprint sessions conducted 48 hours apart.

Methods

This strength training intervention was conducted between July and September, 2016. Thirty recreationally active males (age, 22.8 ± 4.1 y; height, 180.1 ± 6.4 cm; weight, 85.2 ± 14.6 kg) provided written informed consent and completed a cardiovascular screening questionnaire. All participants were free from soft tissue and orthopaedic injuries to the lower limbs, hips, and trunk with no prior history of hamstring strain or knee ligament injury. The university's research ethics committee approved this study (1600000487).

Participants had their relaxed BF_{LH} architecture, isometric peak hamstring torque and Nordic eccentric strength assessed prior to and after the five-week intervention. Participants were ranked and paired in order of fascicle lengths with one individual from each pair randomly allocated to either the concentric-only (CON) group or eccentric-only (ECC) group. Both groups completed nine strength training sessions over five weeks and were instructed not to participate in any additional hamstring strength training. Seven to nine days after the final strength training session, participants performed a sprint running (Sprint 1) (10 x 80 m) on a flat field, followed 48 hours later by an identical session (Sprint 2). An isokinetic dynamometer (Biodex System 3, Shirley, USA) was used to measure passive hamstring torque during knee extension and perceived muscle soreness was recorded using a 0-10 numeric pain rating scale, 24 and 48 hours after the first sprint training session. Blood samples were drawn using standard venipuncture at four time points (prior to the first sprint session, immediately after then 24 h and 48 h after sprint session 1). Figure 1 provides a schematic diagram for the above methods.

INSERT FIGURE 1 HERE

Fascicle lengths of BF_{LH} were estimated using ultrasound images taken along the longitudinal axis of the muscle belly utilising a 2D, B-mode ultrasound (frequency, 12Mhz; depth, 8 cm; field of view, 14 x 47 mm) (GE Healthcare Vivid-*i*, Wauwatosa, U.S.A). Participants were positioned prone on a plinth with neutral hips and extended knees with images acquired midway between the ischial tuberosity and popliteal fold, parallel to the presumed orientation of BF_{LH} fascicles. The distance of the imaging site from various anatomical landmarks (i.e. ischial tuberosity, fibula head and popliteal fold at the mid-point between hamstring tendons) was recorded to ensure post-testing reproducibility. Minimal pressure was placed on the skin by the probe as this may affect the accuracy of the measures [18]. Probe orientation was manipulated slightly if the superficial and intermediate aponeuroses were not parallel.

Ultrasound images were analysed using MicroDicom software (Version 0.7.8, Bulgaria). For each image, six points were digitised . Following the digitising process, muscle thickness was defined as the distance between the superficial and intermediate aponeuroses of the BF_{LH}. A fascicle of interest was outlined and marked on the image. Fascicle length was determined as the length of the outlined fascicle between aponeuroses and was reported in absolute terms (cm). As the entire fascicles were not visible in the probe's field of view, lengths were estimated using the following:

$$FL = \sin(AA + 90°) \times MT / \sin(180° - (AA + 180° - PA))$$

Where *FL*= fascicle length, *AA*= aponeurosis angle, *MT*= muscle thickness and *PA*= pennation angle .

All images were collected and analysed by the same investigator (RGT) who was blinded to training group allocation. The assessment of BF_{LH} architecture using the aforementioned procedures by this ultrasonographer is highly reliable (intraclass correlations >0.90; minimal detectable changes at 95% confidence interval; MT=0.18 cm, PA=0.96°, FL=0.74 cm) [19].

The assessment of eccentric hamstring force using the NHE has been reported previously [7, 8]. Participants knelt on a padded board, with ankles secured by individual straps attached to uniaxial load cells (MLP-1K, Transducer Techniques, CA, USA). The load cells were calibrated immediately prior

to testing by progressively applying known ~200 N loads up to a total of ~800N (~600 N are the highest our group has previously recorded in tests of the NHE). The distal ends of the straps were placed level with the most prominent point of the lateral malleoli. The ankle braces and load cells were secured to a pivot which allowed the force generated by the hamstrings to be measured through the long axis of the load cells. From the initial kneeling position with their ankles secured, arms at the chest and hips extended, participants lowered their bodies as slowly as possible to a prone position. Only the lowering (eccentric) portion of the exercise was performed with the instruction to use their arms and flex at the hips and knees in order to reassume the starting position with minimal hamstring activity. The warm-up consisted of five submaximal but progressively more intense repetitions of the NHE. To ensure that the load for the Nordic eccentric strength test (NeST) was individualised and represented an overload stimulus for each participant, a pre-test was performed to establish the training load. Specifically, the NeST involved involved performing single repetitions of the NHE as slowly as possible, initially with body mass and thereafter with extra loads held centred over the xiphoid process. The first extra load was 5 kg, increased with 5 kg increments until the sum of the two ankle forces did not increase. A single repetition was performed at each load and the highest sum of the left and right leg forces recorded. Three minutes rest was allowed after warm-up and between maximal repetitions. Participants were encouraged to maintain fully extended hips throughout each repetition. Hamstring torques are the product of force and distance between the femoral lateral epicondyle and middle of the ankle strap.

The resistance of the relaxed hamstrings to passive stretch, measured as gravity corrected knee flexion torque (Nm), was assessed via isokinetic dynamometry [20]. Prior to testing, neonatal electrocardiograph electrodes (10 mm in diameter, 15 mm interelectrode distance) (Ambu®, Ballerup, Denmark) were placed over the mid-point of the medial and lateral hamstring muscle bellies. Subsequently, participants were seated on the dynamometer with a hip angle of ~85°, and a 5 cm thick foam pad placed between the seat and upper back to increase hip flexion to ~90º. Straps were placed around the tested thigh, waist and chest to minimise compensatory movements. All seating variables were recorded to ensure post-intervention testing replication. The lever angle range of motion was set at 0° and 90° (0° = knee extension) with gravity correction for limb weight conducted at 30°. The warm-up prior to passive

hamstring torque and isometric strength assessment involved two sets of four maximal concentric knee extension and flexion contractions at 240°·s^{-1} and 120°·s^{-1}.

Passive hamstring torque was determined by the maximum torque produced during extension of the knee. Participants were instructed to completely relax their lower limbs while the dynamometer extended their knee at 10°·s^{-1} across three repetitions [21]. Real-time muscle activity traces displayed to both the participant and the researcher provided confirmation of hamstring relaxation. Participants were asked to rate their muscle soreness at knee extension using a numerical pain rating scale between 0 and 10 (0 = no pain; 10 = severe pain).

Isometric hamstring strength was assessed via isometric dynamometry [20]. Isometric contractions were performed with two, 3 s maximal contractions at 10°, 30°, 50°, 70° and 90°. Knee angle order was randomised for each participant and replicated in post-training tests. Rest periods of 30 s were employed between repetitions and 1 min between angles.

On the basis of high sprint running exposure, we chose an 80 m distance with each participant times measured using timing gates (SMARTSPEED LITE, Fusion sport, Brisbane, Australia), which have previously been shown to be reliable [22]. Participants were not familiar with this running intensity or volume. The standardised warm-up consisted of a 3 min jog followed by four, 80 m run-throughs with increasing perceived speed (60%, 70%, 80% and 90%) interspersed with 3 min of dynamic stretches. A recovery period of 3 min was applied between maximum efforts.

Participants were required to complete a training program that consisted of (sessions x sets x repetitions):

- Week 1 (2 x 2 x 6)
- Week 2 (2 x 3 x 6)
- Week 3 (2 x 4 x 6)

- Week 4 (2 x 5 x 6)
- Week 5 (1 x 5 x 6)

A minimum of 48 hours recovery was given between each session. The same laboratory, equipment and training session supervisors were used to ensure procedural consistency.

The NHE training followed the same exercise technique as aforementioned in assessment of eccentric hamstring force. Initially, the exercise was performed with body mass but once participants displayed adequate strength to completely stop the movement at ~10^0 from full knee extension, they were required to hold a weight plate (range = 5 – 10 kg) to their chest. This external load was increased in 5 – 10 kg increments when participants were again able to stop the movement at ~10^o from knee extension.

The concentric unilateral leg curl was performed on a prone leg curl machine (CALGYM, Australia) using a 6-7RM load. Each repetition started at knee extension and finished at ~90^0 of knee flexion (~3 s per rep). At this point, a research assistant held the machine's lever arm allowing the participant to return their shank, without external load, to the starting position of knee extension. The assistant then lowered the lever arm. Training loads were increased whenever participants could perform all repetitions of their planned training session.

Blood samples were collected before the first sprint session, <15 min after, 24 h, and 48 h post-sprint. The blood samples were collected from an antecubital vein into an EDTA tube (BD, Franklin Lakes, NJ). Tubes were then centrifuged at 1000 rpm at 4 ºC for 10 min and stored at -80ºC until the day of analysis. CK activity was measured using a spectrophotometric assay on an automated analyser (Cobas Mira, Roche diagnostics GmbH, Germany).

All statistical analyses were performed using SPSS version 22.0.0.1 (IBM Corporation, Chicago, IL). Where appropriate, data were screened for normal distribution using the Shapiro-Wilk test and homoscedasticity using Levene's test. Student's *t*-tests were used to compare age, height and body between groups. NeST forces were converted to torque and expressed as torque per kilogram of bodyweight (Nm/kg). Repeated measures split plot ANOVAs were used to explore group by time effects of the training interventions on BF_{LH} fascicle length, PA and MT, NeST peak torque, passive hamstring torque and perceived muscle soreness, 80 m sprint performance and venous CK. For isometric peak hamstring torque, a three way ANOVA was used with the *time (pre vs post)* and *angle (10, 30, 50, 70 and 90º)* the within-subject variables and *group (CON vs ECC)* the between-subject variable. For the analysis of BF_{LH} architecture and NeST results the within-subject variable was *time (pre and post training intervention)* and the between-subject variable was *group (CON vs ECC)*. The 80 m sprint performance within-subject variable was *time (sprint session one and sprint session two)* and the between-subject variable was *group (CON vs ECC)*. The between limbs (dominant vs non-dominant) BF_{LH} architecture was not significantly different at either time point ($p>0.05$), therefore dominant and non-dominant limbs were averaged to provide a single value for each participant. The 80m sprint performance decrement was reported as the slowest (maximum) time – fastest (minimum) for each sprint session. To explore changes in passive hamstring torque and perceived muscle soreness and CK the within-subject variable was *time* (*before and immediately after first sprint session then at 24 h and 48 h post*) and the between-subject variable was *group (CON vs ECC)*. For all analyses, post hoc independent *t*-tests with Bonferroni corrections were used to determine which comparisons differed significantly. The mean differences were reported with their 95% confidence intervals (CIs). Cohen *d* effect sizes were calculated using the thresholds; trivial < 0.20, small = 0.20-0.49, medium = 0.50-0.79 and large > 0.80 .

Results

No significant differences were observed for age, height or body mass between the groups (CON = age 22.7 ± 3.9 y; stature, 178.3 ± 5.8 cm; mass, 86.2 ± 15.4 kg; ECC = 23.7 ±4.8 y; stature, 181.3 ± 6.9 cm;

mass, 83.8 ± 14.6kg; p > 0.05). Training session compliance rates were 100% and 99.3% for the CON and ECC groups.

Following the training intervention, a significant group by time interaction was found for BF_{LH} fascicle length (p<0.001) (Figure 2) and PA (p<0.001) (Figure 2). No significant group by time interaction was seen for MT (p=0.193). Before training there were no significant between group differences in fascicle length (CON = 10.39cm; ECC = 10.22cm; mean difference = 0.17cm; 95% CI = -0.32 to 0.66; p = 0.484; *d* = 0.25), PA (CON = 14.18º; ECC = 14.16º; mean difference = 0.02º; 95% CI = -0.93 to 0.98; p = 0.964; *d* = 0.01) or MT (CON = 2.55cm; ECC = 2.49cm; mean difference = 0.06cm; 95% CI = -0.14 to 0.25; p = 0.523; *d* = 0.22). Post hoc analyses showed significant BF_{LH} fascicle lengthening in the ECC group (mean difference= 1.40 cm (13%); 95% CI = 1.05 to 1.75; p<0.001; *d* = 2.0) and shortening in the CON group (mean difference = 0.66 cm (6%); 95% CI = -0.92 to -0.40; p<0.001; *d* = 0.92) (Figure 2). After training, the differences between the groups' fascicle lengths were significant (mean difference = 1.90cm; 95% CI = 1.34 to 2.45; p<0.001; *d* = 2.57). There was a significant decrease in PA for the ECC group (mean difference = 0.77º (5%); 95% CI = -0.98 to -0.30; p = 0.001; *d* = 0.52) and increase in the CON group (mean difference = 1.73º (12%); 95% CI = 1.40 to 2.06; p<0.001; *d* = 1.69) (Figure 2). After training, a significant between group difference in PA was found (mean difference = 2.52º; 95% CI = 1.60 to 3.45; p<0.001; *d* = 2.07). A significant increase in MT was shown for both the ECC (mean difference = 0.19cm (7%); 95% CI = 0.12 to 0.29; p<0.001; *d* = 0.73) and CON groups (mean difference = 0.11 cm (4%); 95% CI = 0.39 to 0.19; p=0.005; *d* = 0.43) (Figure 2). However, there was no significant difference between groups after training (mean difference = 0.01cm; 95% CI = -0.20 to 0.23; p=0.868; *d*=0.03).

Insert Figure 2 here

Peak hamstring torques were typically obtained with 5-15kg and 10-20kg of load added to body mass during the pre- and post-training NeST tests, respectively. There was no significant group by time interaction (p=0.065) detected for NeST scores (Pre, CON = 3.88Nm/kg ± 0.47, ECC = 3.69Nm/kg ±

0.53; Post, CON = 4.40Nm/kg ± 0.62, ECC = 4.55 ± 0.55). Furthermore, there was no significant between group differences found in eccentric hamstring strength prior to the intervention (CON = 3.88Nm/kg; ECC = 3.68Nm/kg; mean difference = 0.20Nm/kg; 95% CI = -0.18 to 0.58; p = 0.299; *d* = 0.39). There were strength improvements for both the ECC (mean difference = 0.83Nm/kg (24%); 95% CI = 0.59 to 1.0; p<0.001; *d* =1.49) and CON (mean difference = 0.51Nm/kg (13%); 95% CI = 0.29 to 0.75; p<0.001; *d* = 0.95) groups (Figure 3), however, no significant difference between groups after training (mean difference = 0.15Nm/kg; 95% CI = -2.87 to 0.59; p=0.480; *d*=0.25).

Insert Figure 3 here

There was no significant group by time by angle interaction observed for peak isometric hamstring torques (p=0.480). There were no significant differences between groups at any angle before training or after training (see Supplementary table 1). Peak isometric torques did not change at any angle as a consequence of concentric or eccentric strength training (see Supplementary table 1). No significant group by time interactions were observed for the hamstring's peak passive torque (p=0.807) or perceived muscle soreness (p=0.700) (see Supplementary table 2).

No significant between-group differences in fastest times were observed in the first (CON = 11.51s; ECC = 11.32s; mean difference = 0.18s; 95% CI = -0.60 to 0.98; p = 0.630; *d* = 0.07) or second sprint sessions (CON = 11.70s; ECC = 11.43s; mean difference = 0.27s; 95% CI = -0.52 to 1.07; p = 0.483; *d* = 0.27). There were no significant between-group differences in performance decrement in the first (CON = 3.01s; ECC = 2.57s; mean difference = 0.44s; 95% CI = -2.13 to 1.25; p = 0.595; *d* = 0.21) or second sprint session (CON = 1.97s; ECC = 1.93s; mean difference = 0.04s; 95% CI = -0.88 to 0.79; p = 0.910; *d* = 0.04). However, the performance decrement declined significantly between the first (2.92 ± 2.15s) and second (1.98 ± 1.12s) sprint session in the CON group (mean difference = 1.04s; 95% CI = -1.92 to -0.15, p = 0.023; *d* = 0.56) but did not change significantly between first (2.46 ± 1.65s) and second (1.93 ± 0.86s) sprint sessions in the ECC group (mean difference = 0.64s; 95% CI = -1.46 to 1.67; p = 0.114; *d* = 0.48).

While anecdotal, two of 15 participants from the CON group were unable to finish the second sprint session. One sustained a hamstring strain during the first sprint session and the other participant was 'too sore' and fearful of an injury to participate in the second sprint session. All participants from the ECC group were able to complete both sessions.

There was no significant group by time interaction found for CK (p = 0.818). No significant differences in the levels of CK were observed between groups before the first sprint session (CON = 177 $U \cdot L^{-1}$; ECC = 226 $U \cdot L^{-1}$; mean difference = 49 $U \cdot L^{-1}$; 95% CI = -158.31 to 59.08; p = 0.353; *d* = 0.41), immediately after (CON = 239 $U \cdot L^{-1}$; ECC = 327 $U \cdot L^{-1}$; mean difference = 88 $U \cdot L^{-1}$, 95% CI = -217 to 41; p = 0.171; *d* = 0.60), 24 hours after (CON = 951 $U \cdot L^{-1}$; ECC = 972 $U \cdot L^{-1}$; mean difference = 21 $U \cdot L^{-1}$, 95% CI = -538 to 495; p = 0.933; *d*=0.03) or 48 hours after (CON = 607 $U \cdot L^{-1}$; ECC = 609 $U \cdot L^{-1}$; mean difference = 2 $U \cdot L^{-1}$, 95% CI = -320 to 316; p = 0.990; *d* = 0.00) the first sprinting session. CK levels increased significantly after running for both the concentric (immediately after sprinting, mean = +62 $U \cdot L^{-1}$; 95% CI = 11 to 114; p = 0.011; *d* = 0.53; 24h post, mean = +774 $U \cdot L^{-1}$; 95% CI = 242 to 1305; p = 0.002; *d* = 1.80; 48h post, mean = +430 $U \cdot L^{-1}$; 95% CI = 85 to 775; p = 0.009; *d* = 1.53) and eccentric groups (immediately after sprinting, mean difference = 101 $U \cdot L^{-1}$; 95% CI = 55 to 146; p<0.001; *d* = 0.67; 24h post, mean difference = 745 $U \cdot L^{-1}$; 95% CI = 279 to 1211; p = 0.001; *d* = 1.75; 48h post, mean difference = 383 $U \cdot L^{-1}$; 95% CI = 80 to 685; p = 0.008; *d* = 1.44).

Discussion

As far as we are aware, this study is the first to investigate the effects of eccentric and concentric hamstring conditioning on the change in running performance during or between sprint sessions in inexperienced sprint athletes. Contrary to our hypothesis and despite significant between- group differences in BF_{LH} fascicle lengths and PA before sprint session 1, there were no between-group differences for sprint performance decrements or markers of muscle damage. Concentrically trained rat vastus intermedius muscles lose more force and have their force-length relationships shifted further

towards longer muscle lengths than eccentrically trained muscles after a single bout of maximal electrically stimulated eccentric contractions [1]. There is also evidence in humans that muscle soreness and weakness induced by eccentric contractions are elevated after periods of concentric training [23] and there is significant evidence that eccentric training has the opposite effects [12, 13, 24]. Furthermore, a recent randomized control trial showed small-to-medium improvements in 10 m sprint time in male soccer players who took part in a 10-week NHE protocol [25]. These previous findings led to the hypothesis that eccentrically trained hamstrings would recover significantly better than concentrically trained muscles and that this would influence the recovery of sprint performance when two sprint sessions were performed 48 hours apart.

There are a number of possible explanations for the lack of differences between the eccentrically and concentrically trained participants in this study. Firstly, the extent of muscle soreness and the changes to indices of muscle damage (CK) were modest, although similar to that found after one study of downhill running [26]. Previous studies employing maximal eccentric contractions of single muscle groups such as the elbow flexors [27] have reported blood CK levels in the region of 10000 $U \cdot L^{-1}$ and the enzyme elevations seen in the current study were only about 7% of this. This suggests only moderate muscle damage as a consequence of sprinting and whether or how much of this CK originated from the hamstrings is unknown. Van Hooren, Bosch [28] have recently argued that human hamstring fascicles perform isometric rather than eccentric actions during the late swing phase of gait. This suggestion runs contrary to the results of modelling studies which suggest that the hamstrings actively lengthen in late swing [29, 30], however, the low CK and soreness levels reported after sprinting do suggest limited exposure to eccentric actions to which the concentrically trained participants were unaccustomed. The relatively low sprint training status of the sampled participants may have also contributed to the high variability in performance, thereby masking any effects of hamstring conditioning. Furthermore, the degree of hip flexion during the passive hamstring torque assessment was less than that in a previous report [21] which may be the reason no between-group differences were found for peak passive torque or perceived muscle soreness. Despite no apparent differences in recovery between groups, clinicians may consider some association between concentric-only training and elevated hamstring injury risk given

2/15 participants from the CON group were unable to complete the second sprint session due to hamstring injury or soreness. Future studies may benefit from recruiting more highly trained participants or including regular sprint sessions within the training program.

This study provides further evidence that BF_{LH} fascicle lengths and PA respond differently to eccentric and concentric training [2]. Fascicle lengthening, presumably consequent to the addition of in-series sarcomeres, is expected to reduce the strain experienced per sarcomere at any given muscle length and thereby reduce the risk of muscle strain injury [11-13, 24]. The torque-joint angle relationship and the joint angle at which muscles generate peak torques are proposed to shift in response to changes in muscle fascicle lengths [12], although the current results do not support this as no such shifts occurred, despite a ~2 cm fascicle length difference between groups after training.

We acknowledge that there are some other limitations to the current study. Muscle architectural change was only assessed in the BF_{LH} and these adaptations may differ between hamstrings. There is also a degree of estimation required with the measurement of fascicle length using 2D ultrasound because the entire length of the BF_{LH} fascicles is not visible in ultrasound images. While the estimation equation used in this study has been validated against cadaveric samples [18], we recognise the room for error and suggest future studies employ extended field-of-view ultrasonography to reduce this. Despite our recreationally active participants displaying similar, or higher, levels of Nordic eccentric strength compared with elite Australian Rules footballers [7] and professional soccer players [6], it remains to be seen if the sprint recovery results are applicable to other 'well-trained' populations. Finally, the current participants were only averaging a velocity of ~25 km/h across their best 80m performance in both sessions which may have limited the forces and the amount of work required of the hamstrings during sprint running.

Conclusion

This is the first study to show that concentric and eccentric hamstring training do not have different effects on decrements in sprint performance when two sprint training sessions are held 48 h apart.

Practical Implications

- Concentric and eccentric hamstring training does not have different effects on decrements in sprint performance when two sprint training sessions are held 48 h apart.
- Isometric knee flexor torque-joint angle relationships are unaffected by changes in muscle architecture.
- BF_{LH} fascicle lengths and pennation angles respond differently to eccentric-only and concentric-only strength training.

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No funding was received for this research. Anthony Shield is listed as a co-inventor on a patent filed for a device that tests hamstring strength (PCT/AU2012/001041,2012) and is a minor shareholder in a company responsible for commercialising the device. The results of the present study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation and do not constitute endorsement by the Journal.

References

1. Lynn R, Talbot J, Morgan D. Differences in rat skeletal muscles after incline and decline running. *J Appl Physiol.* 1998; 85(1):98.
2. Timmins R, Ruddy J, Presland J, et al. Architectural changes of the biceps femoris long head after concentric or eccentric training. *Medicine and Science in Sports and Exercise.* 2016; 48(3):499-508.
3. Arnason A, Andersen TE, Holme I, Engebretsen L, Bahr R. Prevention of Hamstring Strains in Elite Soccer: An Intervention Study. *Scand J Med Sci Sports.* 2008; 18(1):40-48.
4. Petersen J, Thorborg K, Nielsen MB, Budtz-Jørgensen E, Hölmich P. Preventive Effect of Eccentric Training on Acute Hamstring Injuries in Men's Soccer A Cluster-Randomized Controlled Trial. *The American Journal of Sports Medicine.* 2011; 39(11):2296-2303.
5. van der Horst N, Smits DW, Petersen J, Goedhart EA, Backx FJ. The Preventive Effect of the Nordic Hamstring Exercise on Hamstring Injuries in Amateur Soccer Players a Randomized Controlled Trial. . *The American Journal of Sports* 2015; 43(6):1316-1323.
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. *British Journal of Sports Medicine.* 2015:bjsports-2015-095362.
7. Opar D, Williams M, Timmins R, Hickey J, Duhig S, Shield A. Eccentric hamstring strength and hamstring injury risk in Australian footballers. *Medicine and Science in Sports and Exercise.* 2015; 47(4):857-865.
8. Bourne MN, Opar DA, Williams MD, Shield AJ. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: a prospective study. *The American Journal of Sports Medicine.* 2015; 43(11):2663-2670.
9. van Dyk N, Bahr R, Burnett AF, et al. A comprehensive strength testing protocol offers no clinical value in predicting risk of hamstring injury: a prospective cohort study of 413 professional football players. *British Journal of Sports Medicine.* 2017; 51(23):1695-1702.
10. McHugh MP. Recent advances in the understanding of the repeated bout effect: the protective effect against muscle damage from a single bout of eccentric exercise. *Scandinavian Journal of Medicine & Science in Sports.* 2003; 13(2):88-97.
11. Lynn R, Morgan D. Decline running produces more sarcomeres in rat vastus intermedius muscle fibers than does incline running. *J Appl Physiol.* 1994; 77(3):1439-1444.
12. Brockett CL, Morgan DL, Proske U. Predicting Hamstring Strain Injury in Elite Athletes. *Medicine & Science in Sports & Exercise.* 2004; 36(3):379-387.
13. Morgan DL. New Insights into the Behavior of Muscle during Active Lengthening. *Biophysical Journal.* 1990; 57(2):209-221.
14. Bourne MN, Timmins RG, Opar DA, et al. An Evidence-Based Framework for Strengthening Exercises to Prevent Hamstring Injury. *Sports Medicine.* 2018; 48(2):251-267.
15. Duhig S, Shield AJ, Opar D, Gabbett TJ, Ferguson C, Williams M. Effect of high-speed running on hamstring strain injury risk. *British Journal of Sports Medicine.* 2016:bjsports-2015-095679.

16. Heiderscheit BC, Hoerth DM, Chumanov ES, Swanson SC, Thelen BJ, Thelen DG. Identifying the time of occurrence of a hamstring strain injury during treadmill running: a case study. *Clinical Biomechanics.* 2005; 20(10):1072-1078.
17. Schache AG, Wrigley TV, Baker R, Pandy MG. Biomechanical response to hamstring muscle strain injury. *Gait & posture.* 2009; 29(2):332-338.
18. Klimstra M, Dowling J, Durkin JL, MacDonald M. The effect of ultrasound probe orientation on muscle architecture measurement. *Journal of Electromyography and Kinesiology.* 2007; 17(4):504-514.
19. Timmins RG, Shield AJ, Williams MD, Lorenzen C, Opar DA. Biceps Femoris Long Head Architecture: A Reliability and Retrospective Injury Study. *Medicine and Science in Sports and Exercise.* 2015; 47(5):905-913.
20. Knapik J, Wright J, Mawdsley R, Braun J. Isokinetic, isometric and isotonic strength relationships. *Archives of Physical Medicine and Rehabilitation.* 1983; 64(2):77-80.
21. Magnusson SP, Simonsen EB, Aagaard P, Boesen J, Johannsen F, Kjaer M. Determinants of musculoskeletal flexibility: viscoelastic properties, cross-sectional area, EMG and stretch tolerance. *Scand J Med Sci Sports.* 1997; 7(4):195-202.
22. Oliver JL, Meyers RW. Reliability and generality of measures of acceleration, planned agility, and reactive agility. *International Journal of Sports Physiology and Performance.* 2009; 4(3):345-354.
23. Gleeson N, Eston R, Marginson V, McHugh M. Effects of prior concentric training on eccentric exercise induced muscle damage. *British Journal of Sports Medicine.* 2003; 37(2):119-125.
24. Whitehead N, Allen T, Morgan D, Proske U. Damage to human muscle from eccentric exercise after training with concentric exercise. *The Journal of Physiology.* 1998; 512(2):615-620.
25. Ishøi L, Hölmich P, Aagaard P, Thorborg K, Bandholm T, Serner A. Effects of the Nordic Hamstring exercise on sprint capacity in male football players: a randomized controlled trial. *Journal of Sports Sciences.* 2018; 36(14):1663-1672.
26. Byrnes WC, Clarkson PM, White JS, Hsieh SS, Frykman PN, Maughan RJ. Delayed onset muscle soreness following repeated bouts of downhill running. *J Appl Physiol.* 1985; 59(3):710-715.
27. Nosaka K, Clarkson P. Variability in serum creatine kinase response after eccentric exercise of the elbow flexors. *International Journal of Sports Medicine.* 1996; 17(02):120-127.
28. Van Hooren B, Bosch F. Is there really an eccentric action of the hamstrings during the swing phase of high-speed running? part I: A critical review of the literature. *Journal of Sports Sciences.* 2017; 35(23):2313-2321.
29. Chumanov ES, Heiderscheit BC, Thelen DG. Hamstring Musculotendon Dynamics During Stance and Swing Phases of High-Speed Running. *Medicine & Science in Sports & Exercise.* 2011; 43(3):525-532.
30. Thelen DG, Chumanov ES, Best TM, Swanson SC, Heiderscheit BC. Simulation of biceps femoris musculotendon mechanics during the swing phase of sprinting. *Medicine & Science in Sports & Exercise.* 2005; 37(11):1931-1938.

Figure Captions

Figure 1 – Methods timeline.

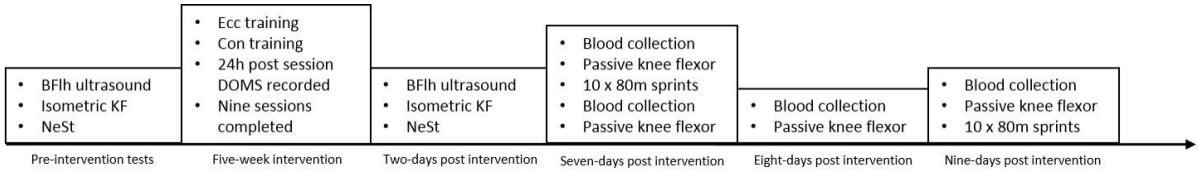

Figure 2 – (top) Pre and post intervention individual and mean changes in bicep femoris long head fascicle lengths; (middle) PA.; (bottom) and muscle thickness. CON = green squares; ECC = red circles. The dashed red line represents the ECC group average and the green line shows the CON group average. Shaded areas represent 95% CI.

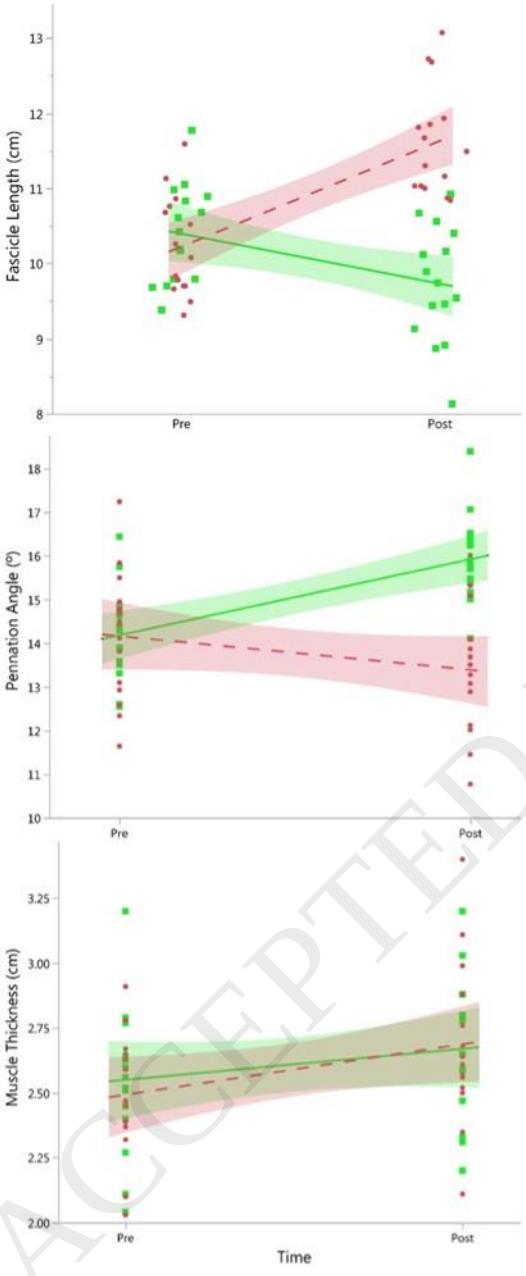

Figure 3 – Pre and post intervention individual and mean changes in Nordic eccentric strength. CON = green squares; ECC = red circles. Dashed red line represents the ECC group average and the green line shows the CON group average. Shaded areas represent 95% CI.