Iga, J., Fruer, C. S., Deighan, M., Croix, M. D. S., & James, D. V. B. (2012). 'Nordic' Hamstrings Exercise–Engagement Characteristics and Training Responses. *International journal of sports medicine*, *33*(12), 1000-1004.

J. Iga[1, 2], S. Fruer[3], M. De Ste Croix[4], M. Deighan[4] and D. James[4]

[1] Medical and Exercise Science Department, Wolverhampton Wanderers Football Club, UK
[2] Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, UK
[3] Department of Biomolecular and Sports Sciences, Coventry University, UK
[4] Faculty of Sport, Health and Social Care, University of Gloucestershire, UK.

Corresponding author:

Dr. Mark De Ste Croix
Faculty of Sport, Health and Social Care
University of Glocestershire
Oxstalls Campus
Oxstalls Lane
Gloucester
GL2 9HW

Tel: 01242 715159
Fax: 01242715222
Email: mdestecroix@glos.ac.uk

NHE: acute activation and training responses

Abstract

We performed a series of studies to determine the acute neuromuscular activation characteristics of hamstrings during the 'Nordic' hamstrings exercise (NHE) and changes in contractile functioning of this muscle group following NHE training. In *Study 1*, 18 male soccer players (mean ± SD; age, 22.9 ± 3.6 years; stature, 1.81 ± 0.08 m; body mass 78.0 ± 9.7 kg) performed 5 repetitions of the NHE. Paired sample *t*-test revealed no differences ($P > 0.05$) in the amplitude of EMG activity between the dominant (DOM) and non-dominant limb (NDOM). Two-way (2 x 3) fully repeated measures ANOVA designs revealed no significant interaction effect of muscle region (lateral [LAT] / medial [MED]) and knee position on EMG activity. Although the main effect for muscle region on EMG amplitude was not significant, greater muscle activity ($P > 0.05$) was observed during the later phase of the exercise (60 - 31º and 30 - 0º) compared to the initial segment of the movement (90 - 61º). In *Study 2*, a randomly allocated training group (n = 10; age, 23.4 ± 3.3 years; stature, 1.77 ± 0.07 m; body mass, 78.0 ± 8.2 kg) undertook a four week programme of NHE training. A selection of ANOVA models demonstrated interaction effects for time by group on the eccentric peak torque of the hamstrings muscles and the magnitude of work performed in the final third of the isokinetic movements of both limbs across all assessment velocities (60, 120 and 240 º/s). For the training group, the interaction effect of time by limb on the eccentric peak torque and the angle at eccentric peak torque were not significant. Our data indicate that the hamstrings of the DOM and NDOM limbs are similarly engaged during the NHE. Additionally, the LAT and MED hamstrings muscles are activated to a similar extent and that muscle activity remains substantial even at more extended joint angles when performing the NHE. Training significantly improved the eccentric peak torque and the capability to resist lengthening actions at more extended joint positions of the hamstrings of both limbs. However, we observed no change in the eccentric length-tension properties of the hamstring; this observation was surprising and warrants further study.

Keywords: Hamstrings; Eccentric; EMG; Isokinetic Dynamometry, 'Nordic' Hamstrings Exercise

1.0. Introduction

Soccer (football) with 205 national associations affiliated to its international governing body and around 240 million active participants is undoubtedly the most popular sport in the world. In spite of its appeal, research has indicated that the game is associated with a relatively high injury rate, with estimates indicating 10 to 35 injuries per 1000 playing hours (Dvorak and Junge, 2000). Hamstrings strains represent the most prevalent form of injury, accounting for 12 to 16% of reported cases (Hawkins *et al*., 2001; Arnason *et al*., 1996, Arnason *et al*., 2004; Woods *et al*., 2004). Most hamstrings strains involve the long head of the biceps femoris, whereas the semitendinosus and semimembranosus muscles are less frequently injured (Woods *et al*., 2004). Injury most commonly occurs at the muscle tendon junction but the assaults may also occur at other regions between the origins and insertions of the individual hamstrings muscles (Garrett, 1996). A significant proportion of hamstrings injuries are re-occurrences of a previous injury (Hawkins *et al*., 2001; Woods *et al*., 2004); these observations call into question the efficacy of conventional rehabilitation techniques and highlight the importance of prevention in the combat against hamstring injuries (Croisier, 2004).

Despite extensive study the precise cause of hamstrings injuries remains unclear (for review see Croisier, 2004). Nonetheless, it is documented that hamstrings strains are typically incurred during sprinting and stretching actions (Woods *et al*., 2004), as the hamstrings are subjected to a forced stretch by simultaneous flexion at the hip and extension at the knee (Garrett, 1996). To this end eccentric actions have been implicated in the causation of hamstrings injuries (Brockett *et al*., 2001; Proske and Morgan, 2001). Specifically, Proske and Morgan (2001) have proposed that as a consequence of heterogeneous arrangement of individual sarcomeres, when the hamstrings are actively lengthened (i.e., exposed to an eccentric muscle action), individual sarcomeres within the fascicule may be subjected to non-uniform lengthening resulting in microscopic damage. If a sport required repeated eccentric actions, this microscopic tear may provide a weak point from which a more significant injury may arise.

Resistance training has been advocated as a preventative measure in the avoidance of hamstrings strain injuries in professional games players (Askling *et al*., 2003; Brookes *et al*., 2006; Arnason *et al*., 2008; Croisier *et al*., 2008). The ‘Nordic’ hamstrings exercise (NHE) has been demonstrated to elicit greater activation of the hamstrings compared to a selection of exercises commonly used in resistance training and injury rehabilitation (Ebben *et al*., 2002). Training using the NHE has been shown to result in superior gains in the eccentric strength of the hamstrings compared to a modified curl exercise (Mjølsnes *et al*., 2004) and several research groups have reported a right-wards shift in the angle of peak torque determined during concentric contractions following NHE training (Brockett *et al*., 2001; Clark *et al*., 2005). Ii is possible that by increasing the eccentric peak torque of the hamstrings, the muscle group’s capability to absorb kinetic energy prior to failure may be improved, attenuating the risk of injury (Stanton and Purdam, 1989). Additionally, alterations in the hamstrings length-tension relation may improve the muscles working range, preventing fibres from reaching a position whereby they might be susceptible to initial microscopic injury (Brockett *et al*., 2001; Proske and Morgan, 2001).

A significant reduction in the incidence and severity of hamstrings strain injuries has been reported in elite games players following NHE training (Brookes *et al.,* 2006; Arnason *et al*., 2008), however, little is known about the acute neuromuscular activation characteristics of the hamstrings when performing this exercise or changes in the contractile properties of the knee flexors following training. Brughelli and Cronin (2007) questioned the ability of this exercise to engage the hamstrings at more extended knee angles, suggesting that this limits the ability of this exercise to train the hamstrings at potentially injurious joint angles. The same authors also speculated that due to the bilateral nature of this exercise, the dominant limb may be subjected to a greater magnitude of stress, resulting in enhanced neuromuscular adaptation of the hamstrings in this limb relative to its contralateral over time (Brughelli and Cronin, 2007). These suppositions are yet to be subjected to scientific examination. Therefore the aims of this study were twofold: 1) to assess the acute activation characteristics of the hamstrings in both limbs during various phases of the NHE; and 2) evaluate the effects of NHE training on the contractile properties of the hamstrings.

2.0. Materials and Methods

2.1. Participants

Eighteen male professional football players (mean ± SD; age, 22.9 ± 3.6 years; stature, 1.81 ± 0.08 m; body mass 78.0 ± 9.7 kg) were recruited as participants. All participants had been free of any musculoligamentous injuries about the knees in the six months preceding the studies and they had no experience of systematic eccentric-based resistance training of the hamstrings. The University's Research Ethics committee approved all procedures, and signed informed consent was obtained from each participant prior to commencement of the studies.

2.2. Study designs

Study 1 aimed to investigate the acute activation characteristics of the hamstrings when performing the NHE. From a knelt position with their ankles firmly secured by a partner, the study participants were required to perform five repetitions of the NHE. When performing the exercise, participants were instructed to resist the forward fall of their torso by engaging their hamstrings through the full range of motion, even after they had lost control of the movement. On completion of the exercise, participants were advised to return to their starting position by forcefully extending their elbows (Figure 1). The velocity of the movement was standardised to 30°/s by the use of a metronome set to one beat per second. Surface electromyography (EMG) was used to record the activation of the hamstrings muscles when performing the NHE.

************* Insert Figure 1 *************

To examine the effects of NHE training on the eccentric peak torque and work characteristics of the hamstrings, the participants in *Study 1* were randomly assigned as either the training (*n* = 10; age, 23.4 ± 3.3 years; stature, 1.77 ± 0.07 m; body mass, 78.0 ± 8.2 kg) or a control group (*n* = 8; age, 22.3 ± 3.9 years; stature, 1.85 ± 0.09 m; body mass, 78.0 ± 11.1 kg). There were no significant differences in any of the physical characteristics between the groups prior to the training intervention. The training group completed a four week programme of training (see Table 1) and all the players adhered to the prescribed volumes of training. Training was conducted at the beginning of the training session after a standardised dynamic warm up. The control group continued their normal technical and tactical training. The isokinetic eccentric peak torque of the hamstrings was determined in both groups before and after the four week period.

************* Insert Table 1 *************

2.3. Electromyography

Bipolar surface electrodes (DE– 2.3 MA; DelSys Inc., Boston, MA, USA) were placed on the belly of the hamstrings muscles, perpendicular to the muscles fibres in both the DOM and NDOM limbs. Limb dominance was defined as the preferred limb when kicking a football. The MED and LAT hamstrings were represented by the semitendinosus and semimembranosus muscles and the biceps femoris long head and biceps femoris short head respectively. An electrogoniometer (S700; DelSys Inc., Boston, MA, USA) was attached to the participant's right knee, with the knee flexed at approximately 90º. The axis of rotation centred over the lateral femoral condyle. The proximal arm of the electrogoniometer was placed on the lateral aspect of the thigh and aligned with the lateral midline of the femur using the greater trochanter as a reference point. The distal arm was placed on the lateral aspect of the shank and aligned with the lateral midline of the fibula with the lateral malleolus as a reference point. The electrogoniometer allowed the exploration of the interaction between the EMG activity of the hamstrings muscles during three distinct knee positions (90 - 61º, 60 - 31º, 30 - 0º) during the NHE. The start position of the exercise (stationary position kneeling with knees flexed at approximately 90º) was standardised through the construction of 95% confidence limits around the first 250 electrogoniometer data points. The exercise was deemed to have started when two consecutive data points fell below the 95% confidence limit. Termination of the exercise was determined when two consecutive data points had reached their lowest point during the NHE.

The EMG and electrogoniometer data was collected via an 8-channel telemetry system (DelSys Myomonitor III, DelSys Inc., Boston, MA, USA). Raw EMG data was collected at a sampling frequency of 1024 Hz and sent directly to the DelSys Acquisition software package set up on a Toshiba Laptop (L20, Toshiba Corp. Tokyo, Japan), where the raw EMG data was band pass filtered at 20 - 450 Hz and then converted to RMS data. The unit included a common mode rejection ratio of >80 dB and an amplifier gain of 1000. The EMG RMS data for each knee position during the movement was normalised against the maximum EMG RMS amplitude recorded in the same muscle over a 2 ms window during the five repetitions of the NHE, and the EMG activity at each knee position was represented by the mean normalised RMS value across the 5 repetitions.

2.4. Isokinetic Dynamometry

Isokinetic eccentric assessments of the hamstrings were performed on a Biodex isokinetic dynamometer (System-3, Biodex Corp., Shirley, NY, USA). Participants were familiarised with the testing protocols one week prior to formal assessment. Testing commenced with a standardised warm up consisting of cycling on an ergometer (Excalibur Sport, Lode, The Netherlands) at 50 W for 3 minutes. Isokinetic assessments were performed from a prone position with the hip extended.

A strap was applied across the waist to stabilise the trunk, and participants were instructed to hold the handles that were located on either side of the reclined chair. The axis of rotation was visually aligned with the lateral femoral condyle of the knee with the knee flexed at approximately 90º. The resistance pad was placed proximal to the medial malleolus, allowing full dorsi-flexion and plantar-flexion of the ankle joint. Motion ranged from 90º to 0º (0º representing full knee extension) and the isokinetic assessments were conducted in both at 60, 120 and 240º/s; assessments at the low angular velocities proceeded assessments at the higher assessment velocities.

At each test condition two sub-maximal warm-ups were followed by four maximal test efforts. Participants were given 5 s of rest between each maximal effort and 60 s of recovery between the different angular velocities. The limb tested first was randomised order across participants but standardised across trials. To avoid the effects of acceleration and deceleration of the lever arm on torque output, only peak torque data obtained from a period of constant velocity, (within a 5% range of the pre-set angular velocity) were used for analysis (Iga *et al.*, 2006). Torque values were corrected for the effects of gravity according to the procedures outlined by Kellis and Baltzopoulos (1996). Peak torque, the angle at peak torque and the work performed during the final segment of the NHE (0 - 30º) were recorded and used for the analysis.

Prior to the commencement of the training study the between-day reproducibility of the isokinetic test data was examined in 20 participants from a similar age, physique and training background to the study participants (age, 23.0 ± 5.9 years; height, 1.82 ± 0.10 m; body mass, 78.2 ± 9.0 kg). Intraclass correlation coefficient equations (ICC) (1,1) and the methods of Bland and Altman (1986; 1998) were used as indicators of relative and absolute reliability (Atkinson and Nevill, 1998). As the hetroscedastic correlations between the mean and the absolute difference between the test-rest measurement were positive, the 95% limits of agreement (LoA) for the eccentric peak torque data were calculated based up on logarithmically transformed data (Bland and Altman (1998). The ICCs for the peak torque measurements ranged between xxx and xxx and the 95% ratio LoA's were between 1.27 and 1.48. The ICCs for the angle at peak torque were xxx to xxx and the 95% LoA were between 7 and 43º.

2.5. Statistical Analysis

Statistical analysis was performed using SPSS version 14 software package (Chicago, Ill). The level of significance was set at $P \leq 0.05$ for all tests. To examine the difference EMG activity between the DOM and NDOM limbs (LAT and MED pooled), a paired sample *t*-test was applied. As no differences were present, further analysis of the interaction effect of muscle region (LAT/MED) and knee position (90 - 61º, 60 - 31º, 30 - 0º) on the activity of the hamstrings during the NHE was limited to data obtained from the DOM limb and employed a two-way (2 x 3) fully repeated measures analysis of variance (ANOVA) model. Significant interaction effects and main effects were further examined using Bonferroni-corrected post hoc *t*-tests. To examine the effect of NHE training on the DOM and NDOM isokinetic peak torque production and angle of peak torque production at each test velocity, two-way (2 x 2) between (group) within (time) factorial analysis of variance design was applied. A three-way (2 x 2 x 3) between (group) within (time, velocity) repeated measures ANOVA was used to explore differences in work done in the most extended position (0 - 30º of knee flexion) during eccentric hamstring movements. Significant main effects were further examined using Bonferroni-corrected post hoc *t*-tests.

3.0. Results

As reported in Table 2 no difference was observed in the EMG amplitude of the hamstrings between the limbs ($t_{37} = 0.137$; $P = 0.413$). The interaction between muscle region and knee position on the activity of the hamstrings muscles was also not significant ($F_{2, 35} = 1.775$, $P = 0.184$). Although no main effect for muscle region on EMG amplitude was observed ($F_{1, 36} = 1.605$, $P = 0.213$), effect for knee position on muscle activity was significant ($F_{2, 35} = 154.354$, $P <$

0.001). Bonferroni corrected post-hoc *t*-tests indicated that in both muscle regions of the DOM limb the RMS amplitude was significantly higher at the more extended knee positions (see Table 3).

************* Insert Table 2 *************

************* Insert Table 3 *************

Significant interaction effects for time by group were observed for eccentric peak torque of the hamstrings of both limbs across all assessment velocities (60º/s; DOM, $F_{1, 16} = 5.11$, $P = 0.04$; NDOM, $F_{1, 16} = 6.84$, $P = 0.02$; 120º/s; DOM, $F_{1, 16} = 4.46$, $P = 0.05$; 240º/s; DOM, $F_{1, 16} = 8.10$, $P = 0.01$; NDOM, $F_{1, 16} = 5.68$, $P = 0.03$). Whereas the eccentric peak torque of the hamstrings improved by up to 21% in the training group, there was no change in the control group (~4%) (see Table 4). For the training group, no interaction effects for time by limb on the eccentric peak torque of the hamstrings was observed across all the assessment velocities (60º/s, $F_{1, 18} = 0.20$, $P = 0.66$; 120º/s, $F_{1, 18} = 0.026$ $P = 0.88$; 240º/s, $F_{1, 18} = 2.48$, $P = 0.13$). The interaction effects for time by group on the angle of peak torque in all test conditions were not significant. Additionally, the main effects of time and group on the angle of peak torque were also non-significant (see Table 5).

************* Insert Table 4 *************

************* Insert Table 5 *************

There was no significant interaction effect for group by time by velocity on work done during the final segment of the NHE ($F_{1, 18} = 1.19$, $P = 0.34$). However, there was a significant main effect for group x velocity ($F_{1, 18} = 6.46$, $P = 0.01$) and velocity ($F_{1, 18} = 4.77$, $P = 0.02$) with the training groups work done increasing with increasing velocity to a greater extent than the control group. No other main effects were found but the % change in work done pre and post the training intervention was 0% for all velocities in the control group and 16%, 9% and 7% respectively (60º/s, 120º/s, 240 º/s) for the training group (see Table 6)

************* Insert Table 6 *************

4.0. Discussion

The present study was concerned with examining the acute neuromuscular activation characteristics of the hamstrings during the NHE and adaptations in the contractile functioning of hamstrings with NHE training in elite soccer players. The primary observations were that both the DOM and NDOM limbs are engaged to a similar extent during the NHE and the activity of both the LAT and MED hamstrings remain elevated even at more extended joint positions. Additionally, training elicited similar gains in the performance of the hamstrings muscle groups of both limbs and these changes were independent of assessment velocity.

Resistance training of the hamstrings has been advocated as a preventative measure in the avoidance of hamstrings strain injuries (e.g., Askling *et al*., 2003). The NHE has been demonstrated to evoke greater activation of the hamstrings compared to a selection of exercises commonly used in resistance training and injury rehabilitation (Ebben *et al*., 2002), and to results in superior gains in the eccentric peak torque of the hamstrings compared to training utilizing a modified hamstrings curl exercise (Mjølsnes *et al*., 2004). Despite these observations no research had considered the characteristics by which the hamstrings are innovated when performing the NHE or sought to examine changes in the contractile functioning of the hamstrings during eccentric actions with NHE training in professional football players. Brughelli and Cronin (2007) argued that due to the bilateral nature of the exercise, the hamstrings of the DOM limb may be subjected to a greater magnitude of overload which may result in greater neuromuscular adaptation in this limb over time. Our observations challenge both these notions. We recorded comparable amplitudes of EMG activity between the DOM and NDOM limbs suggesting that both limbs are engaged to a similar extent during this exercise. Moreover, in our training study, the intervention group demonstrated equivalent improvements in the eccentric peak torque of hamstrings of both limbs and the angle at peak torque remained identical pre and post training in both the DOM and NDOM limbs.

The ability of the NHE to engage the hamstrings at more extended joint positions and thus it's capability to induce modifications in muscle performance at potentially injurious knee angles had also been questioned (Brughelli and Cronin, 2007). Our EMG data indicated that the activity of the LAT and MED hamstrings remained elevated during the terminal segment of the NHE and that that the magnitude of EMG activity was consistent between both regions of the hamstrings muscle group. The significantly higher EMG activity of the hamstrings in the later segments of the NHE compared to the initial part of the exercise may be explained by a greater recruitment of the available motor units to generate sufficient torque to control the fall of the torso compensate for the reduced mechanical advantage of the hamstrings at the extended knee positions. Several epidemiological reports have indicated that the biceps femoris (represented by the lateral surface electrode), may be at greater risk of strain injury compared to the semitendinosus and semimembranosus muscles (Hawkins *et al*., 2001; Woods *et al*., 2004). Although the precise cause of these divergent statistics remains unclear, it is thought that architectural and functional differences between the individual hamstrings muscles might contribute to differences in injury rates (Woods *et al*., 2004; Thelen *et al*., 2005). The similarity in the activation characteristics of both the LAT and MED hamstrings may be interpreted that the NHE is effective in activating and thus strengthening the biceps femoris muscle, potentially reducing its risk to injury. It is important to recognise that we used surface EMG to examine the activation characteristics of the LAT and

MED hamstrings. We acknowledge that this assessment technique does not permit the precise determination of the recruitment patterns of the individual hamstrings muscles. Further study may consider the use of indwelling electrodes so as elucidate fully the characteristics of the hamstrings muscles during the NHE. The results of our training study demonstrated that the magnitude of work performed in the final third of the isokinetic assessments was augmented following NHE training. The significant increases in the peak torque of the hamstrings of both limbs, allied with the enhancement in the work performed at extended knee positions indicate the NHE training may increase the magnitude of tensile force that the hamstrings can withstand, particularly at potentially injurious zones.

It is important to note that the eccentric peak torque of the hamstrings was significantly improved after only four weeks of training. The rapid gains in peak torque may be related to the training history of our study participants and to the fact that all the study participants completed the full volume of the prescribed training. Our participants had no previous experience of eccentric-based resistance training of the hamstrings. A recent report has indicated that the hamstrings are not routinely stimulated by conventional football training (Iga *et al*., 2008). Therefore, despite their professional status, the participant's hamstrings may have been relatively deconditioned, resulting in greater potential for eccentric strength gains with resistance training. The excellent compliance to the training programme may be explained by the relative ease by which the NHE training may be incorporated into the normal training routines without the need to schedule additional resistance training sessions (see Smalls et al., 2010). A further interesting observation was that the gains in eccentric peak torque with NHE training occurred independent of the training velocity. These findings are consistent with other reports in the literature (Duncan *et al*., 1989; Ryan *et al*., 1991; Paddon-Jones *et al*., 2001; Shepstone *et al*., 2005) and suggest that although the NHE is performed at low velocity, training results in adaptations that are transferable to high velocity movements. As hamstrings strain injuries are typically incurred during high velocity actions, these observations have clear implications for injury prevention and rehabilitation; the adaptation to eccentric-based resistance training may confer protection against stretch forces during high velocity lengthening actions. With regards to the mechanisms that may have mediated these observations, it has been demonstrated that eccentric-based resistance training provokes modification in the series elastic components of the musculotendinious unit (). It is possible that these changes in contractile and non-contractile components of the muscle tendon unit may mediate the training velocity independent gains in peak torque post training; however, further study is needed to confirm this postulate.

Although eccentric peak torque was significantly improved with NHE training, we recorded no change in the angle of peak torque, indicating that the length tension properties of the hamstrings were unaltered following NHE training. Our observations are in contrast to the findings reported by several other research groups (Brockett *et al*., 2002; Clark *et al*., 2005; Kilgallon *et al*, 2007); these authors have reported a sustained shift in the length-tension properties of the hamstrings following resistance training biased towards providing an eccentric overload. However, it should be acknowledged that these finding were noted during isometric (Kilgallon *et al*, 2007) and concentric muscle actions (Brockett *et al.*, 2001; Clark *et al*., 2005). Examination of changes in the length-tension relations of the hamstrings during isokinetic eccentric actions may provide greater insight into the risk of strain injuries. This is because hamstrings strain injuries typically occur during eccentric muscle action as the hamstrings are activated to counter simultaneous flexion at the hip and extension at the knee during sprinting and/or kicking actions (Woods *et al*., 2004). During such actions, Proske and Morgan (2001) have proposed that as a result of non-uniform arrangement of individual sarcomeres, some sarcomeres may be subjected to a load resulting in a microscopic tear from which a more significant injury may arise with repeated eccentric actions. Our findings raise the possibility that the adaptation in the length-tension relation of the hamstrings following eccentric-biased resistance training may not be apparent during eccentric actions. However, it is also possible that the positioning of our participants during the isokinetic eccentric assessments and high variability of this measurement may have contributed to these observations. We chose to perform the isokinetic eccentric assessments with the participants stationed in a prone position so as to provide closer approximation of the length tension-relation of the hamstrings muscles during locomotion (Stanton and Purdon, 1989). Changes in hip angle have been shown to affect the peak torque of the hamstrings during both concentric and eccentric modes of exercise, possibly by placing the muscle in a shortened position, hampering the coupling of the contractile apparatus (Worrell et al., 1989; Worrell et al., 1990). Additionally, the possibility that the non-significant finding were a Type II error (false negative) attributable to high measurement error and a relatively small sample size cannot be discounted. Further study is needed to examine the effects of eccentric-based resistance training on the length-tension relations of the hamstrings.

In conclusion, our data provide evidence supporting the efficacy of the NHE to engage and training the hamstrings of the DOM and NDOM limb throughout their full range of motion. Training may be incorporated into the normal training routines of games players without the need to schedule additional resistance training sessions.

5.0. References

Arnason A, Gudmundsson A, Dahl HA, Johannsson E. Soccer injuries in Iceland. *Scand J Med Sci Sports* 1996: 6: 40-45

Arnason A, Anderson TE, Holme I, Engebretsen L, Bahr R. Prevention of hamstring strains in elite soccer: an intervention study. *Scand J Med Sci Sports* 2008: 18: 40-48

Askling C, Karlson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after strength training with eccentric overload. *Scand J Med Sci Sports* 2003: 13: 244-250

Atkinson G, Nevill A. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 1998: 26: 217-238

Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1:307–310, 1986.

Bland JM, Altman DG. Measuring agreement in method comparison studies. *Stat Methods Med Res* 1999: 8: 135-160

Brooks HM, Fuller CW, Kemp SPT, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *Am J Sports Med* 2006: 34: 1297-1306

Brockett CL, Morgan LM, Proske U. Human hamstring muscles adapt to eccentric exercise by changing optimum length. *Med Sci Sports Exerc* 2001: 33: 783-790

Brockett CL, Morgan LM, Proske U. Predicting hamstring strain in elite athletes. *Med Sci Sports Exerc* 2004: 36: 379-387

Brughelli M, Cronin J. Altering the length-tension relationship with eccentric exercise: Implications for performance injury. *Sports Med* 2007: 37: 807-826

Clark R, Bryant A, Culgan J, Hartley B. The effects of eccentric hamstring strength training on dynamic jumping performance and isokinetic strength parameters: a pilot study on the implications for the prevention of hamstring injuries. *Phys Ther Sport* 2005: 6: 67-73

Croisier J, Forthomme B, Namurois M, Vanderthommen M, Crielaard J. Hamstring muscle strain recurrence and strength performance disorders. *Am J Sports Med* 2002: 30: 199-203

Croisier J. Factors associated with recurrent hamstring injuries. *Sports Med* 2004: 34: 681-695

Croisier JL, Ganteaume S, Binet J, Genty M, Ferret JM. Strength imbalances and prevention of hamstring injury in professional soccer players. *Am J Sports Med* 2008: 36: 1469

Duncan PW, Chandler JM, Cavanaugh DK, Johnson KR, Buehler AG. Mode and Speed Specificity of Eccentric and Concentric Exercise Training. *J Orthop Sports Phys Ther* 1989: 11: 70-75

Dvorak J, Astrid J. Football injuries and physical symptoms: A review of the literature. *Am J Sports Medicine* 2000: 28: 3-9.

Ebben WP, Leigh DH, Long N, Clewien R, Davies JA. Electromyographic analysis of hamstring resistance training exercises. International Symposium of the Society of Biomechanics in Sports 2006: S1-S4

Garrett WE. Muscle strain injuries. *Am J Sports Med* 1996: 24: S2-S8

Iga J, George K, Lees A, Reilly T. Cross-sectional investigation of indices of isokinetic leg strength in youth soccer players and untrained individuals. *Scand J Med Sci Sports* 2009: 19: 714-720

Kilgallon M, Donnelly, Shafat A, Progressive resistance training temporarily alters hamstrings torque-angle relationship. *Scand J Med Sci Sports* 2007: 17: 18-24

Lynn SK, Costigan PA. Changes in the medial–lateral hamstring activation ratio with foot rotation during lower limb exercise. *J Electromyogr Kinesiol* 2009: 19: 197-205

Mjølsnes R, Arnason A, Osthagen T, Raastad T, Bahr R. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scand J Med Sci Sports* 2004: 14: 311-317

Morgan DL. New insight into the behaviour of muscle during active lengthening. *Biophys J* 1990: 57: 209-221

Proske U, Morgan DL. Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *J Physiol* 2001: 537: 333-345

Ryan LM, Magidow PW, Duncan PW. Velocity-Specific and Mode-Specific Effects of Eccentric Isokinetic Training of the Hamstrings. *J Orthop Sports Phys Ther* 1991: 13: 33-39

Shepstone TN, Tang JE, Dallaire S, Schuenke MD, Staron RS, Phillips SM. Short-term high- vs. low-velocity isokinetic lengthening training results in greater hypertrophy of the elbow flexors in young men. *J Appl Physiol* 2005 98:1768-1776

Small K, McNaughton L, Greig M, Lovell R. Effect of timing of eccentric hamstring strengthening exercises during soccer training: implications for muscle fatigability. *J Strength Cond Res* 2010: 23: 1077-1083

Spoor CW, Vanleeuwen JL. Knee muscle moment arms from MRI and from tendon travel. *J Biomech* 1992: 25: 201-206

Thelen D, Chumanov D, Hoerth M, Best TM, Swanson SC, Li L, Young M, Heiderscheit BC. Hamstring muscle kinematics during treadmill sprinting. *Med Sci Sports Exerc* 2005: 37: 108-14

Westing SH, Seger JY. Eccentric and concentric torque velocity characteristics, torque output comparisons and gravity effect torque corrections for the quadriceps and hamstrings muscles in females. *Int J Sports Med* 1989: 10:175-180

Worrell T, Perrin DH, Denegar CR. The influence of hip position on quadriceps and hamstring peak torque and reciprocal muscle group ratio values. *J Orthop Sports Phys Ther* 1989: 11: 104-7

Worrell TW, Denegar CR, Armstrong SL, Perrin DH. Effect of body position on hamstrings muscle group average torque. *J Orthop Sports Phys Ther* 1990: 11: 449-52

Woodley SJ, Mercer SR. Hamstrings muscles: architecture and innervantion. *Cells Tissues organs* 2005: 179: 125-141

Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hodson A. The football association medical research programme: an audit of injuries in professional football: Analysis of hamstring injuries. *Br J Sports Med* 2004: 38: 36-41

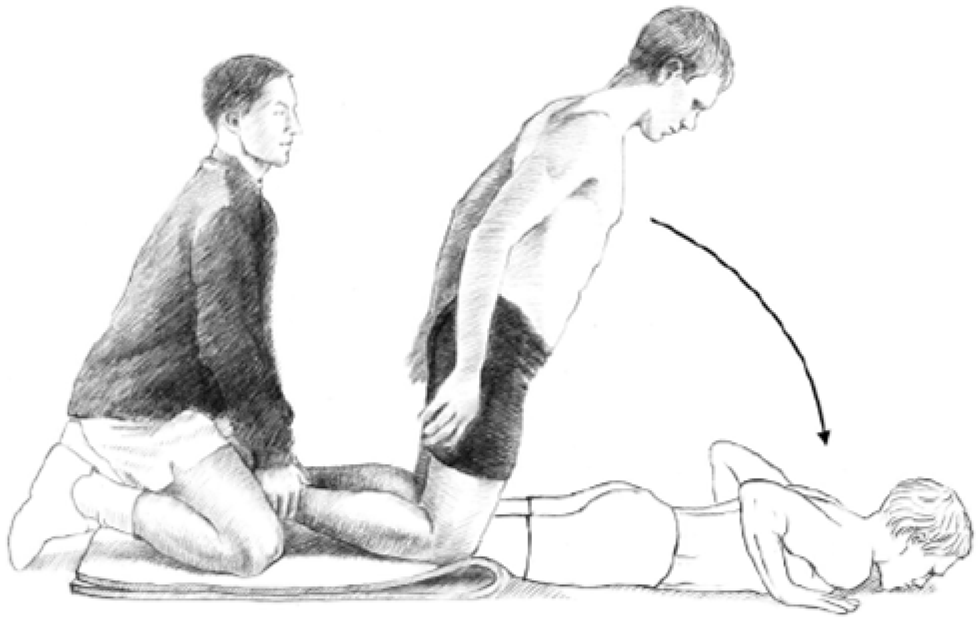

Figure 1. Illustrated is the NHE. The trainee resists the forward fall of their truck by activating their hamstrings for as long as possible (reproduced with permission from Bahr and Mæhlum, 2002).

Table 1. NHE training protocol (Adapted from Mjølsnes *et al*., 2004)

Week	Session per week	Sets and reps
1	1	2 × 5
2	2	2 × 6
3	3	3 × 6
4	3	3 × 8

Table 2. Mean (± SD) EMG activity (%) of the hamstrings in the DOM and NDOM limbs during the NHE

Phase of movement	DOM	NDOM
0 – 30º	3.7 ± 1.5	4.3 ± 1.9
31 – 60º	11.2 ± 3.3	10.8 ± 3.4
61 – 90º	8.3 ± 2.4	9.7 ± 3.1

* Indicates significant different between 0 – 30º and 31 – 60º; # Indicates significant different between 0 – 30º and 61 – 90º.

Table 3. Mean (± SD) EMG activity (%) of the MED and LAT hamstrings in both the DOM and NDOM limbs during the NHE.

Phase of movement	DOM		NDOM	
	LAT	MED	LAT	MED
0 – 30º	3.4 ± 2.0	4.1 ± 1.5	3.4 ± 1.6	5.2 ± 2.6
31 – 60º	10.1 ± 3.7*	12.3 ± 3.8*	8.9 ± 3.7*	12.6 ± 4.4*
61 – 90º	8.3 ± 2.6#	8.4 ± 2.8#	8.4 ± 3.3#	10.9 ± 3.5#

* Indicates significant different between 0 – 30º and 31 – 60º; # Indicates significant different between 0 – 30º and 61 – 90º.

Table 4. Mean (± SD) eccentric peak torque (Nm) of the hamstrings muscles pre and post the training intervention.

Velocity	Training				Controls			
	Pre		Post		Pre		Post	
	DOM	NDOM	DOM	NDOM	DOM	NDOM	DOM	NDOM
60 °/s	115 ± 42	99 ± 30	132 ± 43#	119 ± 37#	120 ± 38	107 ± 37	121 ± 33	109 ± 29
120 °/s	121 ± 45	105 ± 32	134 ± 42*	119 ± 33#	122 ± 40	105 ± 37	121 ± 35	110 ± 28
240 °/s	121 ± 43	102 ± 34	130 ± 42*	122 ± 32#	114 ± 46	103 ± 34	110 ± 41	107 ± 27

* Indicates the significant interaction effects for time by group. # Indicates the significant main effects for time.

Table 5. Mean (± SD) angle of eccentric peak torque (º) of the hamstrings muscles pre and post the training intervention.

Velocity	Training				Controls			
	Pre		Post		Pre		Post	
	DOM	NDOM	DOM	NDOM	DOM	NDOM	DOM	NDOM
60 º/s	34 ± 19	34 ± 16	31 ± 18	26 ± 12	30 ± 19	27 ± 16	25 ± 11	25 ± 14
120 º/s	31 ± 21	30 ± 17	22 ± 14	23 ± 14	27 ± 17	26 ± 13	23 ± 16	27 ± 15
240 º/s	28 ± 4	29 ± 5	25 ± 3	28 ± 5	28 ± 5	29 ± 9	29 ± 4	29 ± 4

Table 6. Mean (± SD) eccentric hamstring work done (J) (0 - 30º) pre and post the training intervention

Velocity	Training		Control	
	Pre	Post	Pre	Post
60 º/s †	45 ± 12	52 ± 10*	52 ± 19	53 ± 14
120 º/s †	53 ± 13	58 ± 11*	52 ± 20	51 ± 14
240 º/s †	54 ± 12	58 ± 12*	53 ± 22	53 ± 18

* Significant main effect for group x velocity; † Significant main effect for velocity