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

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Abstract

Objectives: Although previous research shows that the hamstring length–tension relationship during eccentric contractions plays a role in hamstring injury, training methods to promote beneficial adaptations are still unclear. The purpose of this pilot study was to determine whether an eccentric hamstring specific training programme results in favourable adaptations.

Design: Eccentric training consisting of the Nordic hamstring exercise performed twice a week for four weeks. Pre- and post-training concentric/concentric isokinetic testing of peak torque (PT) and position of peak torque (POS) was performed for both the quadriceps and hamstrings of both legs at 60° s^-1. Vertical jump height was also assessed.

Participants: Nine athletic, male subjects with no previous strength training experience.

Results: There was a significant increase in vertical jump height (pre \( Z = 51.0 \pm 4.8 \text{ cm, post} = 54.4 \pm 6.3 \text{ cm, } p = 0.04 \)), a significant reduction in quadriceps PT (pre \( Z = 204.6 \pm 21.9 \text{ N.m., post} = 181.5 \pm 19.9 \text{ N.m., } p = 0.01 \)), a significant decrease in hamstring POS from full knee extension (pre \( Z = 32.5 \pm 7.4^\circ, \text{ post} = 26.2 \pm 8.6^\circ, \ p = 0.01 \)) and a significant hamstring POS difference between limbs (dominant \( Z = 33.8 \pm 9.5^\circ, \text{ non-dominant} = 24.9 \pm 6.5^\circ, \ p = 0.01 \)).

Conclusion: Nordic hamstring exercise training may produce favourable neuromuscular adaptations for the possible prevention of hamstring injuries while enhancing performance in athletic, untrained males.

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Keywords: Eccentric training; Hamstring injury; Prevention

1. Introduction

One of the most common injuries in nearly all forms of team and individual sports involving the lower body is the hamstring strain (Bennell & Cossey, 1996; Moseley, 1996; Orchard, James, Alcott, Carter, & Farhart, 2002; Orchard, Wood, Seward, & Broad, 1998). Analysis of epidemiological injury studies assessing these sports consistently ranks hamstring strain injuries as one of the most prevalent factors resulting in missed playing time by athletes (Orchard et al., 1998; Seward, Orchard, Hazard, & Collinson, 1993).

The widespread occurrence of this form of injury necessitates the examination of optimal methods of both prevention and rehabilitation. Previous studies have cited numerous potential risk factors associated with hamstring strains, such as muscle weakness and lack of flexibility (Burkett, 1970), insufficient hamstring strength in comparison with the quadriceps (Coombs and Garbutt, 2002; Orchard, Marsden, Lord, & Garlick, 1997), fatigue and inadequate warm-up (Worrell, 1994) and poor lumbar posture and core stability (Hennessy & Watson, 1993).

Although the risk factors for hamstring injury are numerous, epidemiological evidence suggests that the actual occurrence of hamstring muscle strains often takes place during eccentric contraction of the hamstring muscles (Garrett, 1990; Kujala, Orava, & Jarvinen, 1997; Stanton & Purdham, 1989).

More specifically, it has been previously suggested that it is the portion of eccentric hamstring contraction occurring
during the descending limb of the muscle’s length–tension relationship that results in hamstring injuries (Brockett, Morgan, & Proske, 2004). This is postulated to be due to non-uniform lengthening of sarcomeres due to sarcomere length instability, resulting in microscopic damage to the muscles of the hamstring (Gordon, Huxley, & Julian, 1966; Morgan, 1990). If a sport requires multiple eccentric contractions, these microscopic areas of damage may result in a “weak link” of the musculature, from which a major soft tissue tear may arise (Brockett et al., 2004).

This leads to another potential risk factor cited in previous research, the position of knee extension at which peak hamstring torque is produced (Armstrong, Warren, & Warren, 1991; Brockett et al., 2004). In regards to the length–tension relationship, it is suggested that the greater the knee extension angle at which peak torque is produced the lower risk of hamstring injury (Brockett et al., 2004). Therefore, training to increase the knee extension angle at which peak hamstring torque is produced would result in reduced eccentric hamstring loading occurring during this descending limb of the length–tension relation. A previous single session eccentric training study found that just one training session resulted in beneficial adaptations to the length–tension relationship of the hamstrings (Brockett, Morgan, & Proske, 2001). However, whether a multiple session, longitudinal training programme specifically designed to increase eccentric hamstring strength also affects the knee extension angle at which peak hamstring torque is produced is unknown.

One method of hamstring training known to increase eccentric strength is the Nordic hamstring exercise (Mjølnes, Arnason, Østhagen, Raastad, & Bahr, 2004). This method of training was shown to increase eccentric hamstring strength more effectively than traditional hamstring curls. However, the effects of this method of training on hamstring position of peak torque and dynamic performance is unknown.

This pilot study attempts to determine whether the Nordic hamstring exercise results in favourable adaptations in relation to the length–tension relationship and hamstring strength levels. Analysis of vertical jump height will also be used to determine whether the training intervention has an impact on lower body power output.

2. Methodology

2.1. Overview

The testing protocol consisted of pre- and post-training intervention isokinetic dynamometer testing of the quadriceps and hamstrings at a velocity of 60° s⁻¹. Peak torque, position of peak torque and vertical jump were assessed to determine lower body strength, effects on the length–tension relationship and dynamic power output. These testing sessions were separated by a supervised 4 week training intervention consisting of the Nordic hamstring exercise.

2.2. Subjects

Nine amateur Australian Rules football players (height = 181.13 ± 6.76 cm, body mass = 79.38 ± 10.33 kg) participated in this experiment. The subjects involved in this study participated in sport but had little strength training experience. Potential subjects who had participated in regular resistance training programmes were excluded. This participation consisted of two Australian Rules football training sessions and one amateur Australian Rules football game per week. All subjects had no prior history of musculoskeletal injuries and in particular hamstring injuries that may have affected the results of the study. Ethical approval was granted by Central Queensland University. All subjects had to complete an Informed Consent form and pass a Pre-Activity Readiness Questionnaire before commencement of the study. Availability of potential subjects for every supervised training and testing session limited the subject numbers to nine.

2.3. Isokinetic dynamometry

Isokinetic measurement of concentric/concentric hamstring/quadriceps torque was measured using a Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, New York, USA) sampling at 300 Hz per second. This system has been previously shown to produce valid and reliable measurements of torque and position (Drouin, Valovich-McLeod, Shultz, Gansneder, & Perrin, 2004). Angular velocity was set at 60° s⁻¹ with five repetitions performed for each leg. These sets were performed with a 2 min rest between sets. This velocity and method of testing were chosen because they closely resemble the testing protocol performed in a previous epidemiological study which reported the importance of position of peak torque as a risk factor in hamstring injuries (Brockett et al., 2004). Testing was preceded by a three minute standardised warm-up on a stationary cycle ergometer at 50 W. The dominant and non-dominant limbs were tested with the order chosen by random assignment. Subjects were seated on the Biodex with their hip joint at approximately 90° flexion, their upper bodies secured with dual crossover straps and their waist secured by a waist strap. The range of motion of the knee was set at 90° of full extension, with the upper leg secured using the thigh strap to limit excess movement of the knee and limb. Full knee extension was standardised between the testing sessions by equalizing knee joint angles with a hand held goniometer. This ensured an accurate assessment of knee joint angle at which peak torque was produced between the testing sessions.

Analysis of isokinetic data was performed using custom written analysis software for Labview (National
Instruments, Austin, TX, USA). The position of peak torque data was measured in degrees from the start of the concentric contraction. Therefore, for the quadriceps the result was in degrees from 90° knee flexion and for the hamstrings the result was in degrees from full knee extension. This means that a lower value in degrees for the hamstrings results in a greater angle of knee extension whereas a lower value in degrees for the quadriceps results in a lower angle of knee extension.

2.4. Dynamic lower body performance

Pre and post testing of vertical jump was performed to assess whether a training programme emphasising the hamstring muscle group would affect lower body dynamic power output. Vertical jump was assessed using a Vertec (Swift Performance Equipment, Lismore, NSW, Australia) on the same surface for both pre and post testing. This testing was performed after a three minute, standardised stationary cycle warm-up replicating the one performed prior to the isokinetic testing. Subjects were instructed to wear the same shoes for both testing sessions to reduce the influence of shoe properties on vertical jump performance (Stefanyshyn & Nigg, 2000). Three trials were allowed for the vertical jump, with the mean of the three tests for each session determining the subjects vertical jump height. Subjects were instructed to perform the vertical jump from a stationary position with feet shoulder width apart and no fidgeting for five seconds prior to the countermovement jump. Prior to the jump the subjects were instructed to raise their right hand into the air as high as possible and push the tabs on the vertec so that a baseline level could be attained. When the athlete jumped they were required to lightly tap the highest tab on the vertec so that an accurate measure of vertical jump height could be attained. The vertical jump result was recorded from subtraction of the baseline figure from the highest tab touched while in flight.

2.5. Training intervention

The Nordic hamstring exercise was chosen for this study because of the ease of application and minimal time requirements necessary. This exercise consists of the athlete starting in a kneeling position, with their torso from the knees upwards held rigid and straight. A training partner applied pressure to the athletes’ heels to ensure the feet stay in contact with the ground throughout the movement, isolating the muscles of the hamstrings. The athlete begins the exercise by slowly lowering their body forwards against the force of gravity towards the ground, using the hamstrings to control descent into the prone position. This eccentric contraction of the hamstrings was held for as long as possible by the subjects during lowering of the body to ensure that the hamstrings were contracting at as long a length as possible. Once the athlete could no longer control descent using the eccentric contraction of the hamstrings, they performed a push-up jump followed by concentric contraction of the hamstrings to raise themselves back up to the starting position. The exercise protocol is shown in Figs. 1 and 2, which display the starting position and the upper body ground contact respectively. The four week training protocol was carried out according to the guidelines outlined in Table 1. All training sessions were supervised by the researchers and took place after the subjects Australian rules football-training sessions.

2.6. Statistical analyses

Repeated measures ANOVA was used to compare the peak and the position of peak torque produced by the quadriceps and hamstrings of the dominant and non-dominant limbs prior to, and following eccentric hamstring strength training. Therefore, each ANOVA design included two within factors (test limb; dominant and non-dominant and test occasion; pre and post).
Adapted from Oslo Sports Trauma Research Center (2004)

The main purpose of this design was to determine whether there were any significant differences in the dependant variables as a consequence of test limb or test occasion. In the event of a significant main effect or interaction following ANOVA contrasts, post hoc comparisons of the means were conducted using the least significant difference (LSD) test to delineate differences amongst test limbs or test occasion. Paired samples t-test were used to compare vertical jump performance pre and post training. The level of significance was set at \( p < 0.05 \) for all tests. All analyses were performed using SPSS version 12.

### 3. Results

The pre- and post-training intervention results for the isokinetic testing including peak torque and position of peak torque for the quadriceps and hamstrings of both limbs are presented in Table 2. Statistical analysis revealed a significant main effect of test occasion for quadriceps peak torque with an 11.3% reduction in peak torque from the pre to post tests when the data were pooled across test limbs (see Fig. 3). Statistical analyses also revealed a significant main effect of test limb for the position of hamstring peak torque. In contrast, the subjects in the present study were both lower than the results for the previously mentioned elite athletes, by 4.9 and 38% for the right and left leg respectively. This suggests that the hamstring training protocol the elite athletes in the previous study are participating in has not had a great effect on production of peak torque in comparison to the elite athletes in the previous study for both right (14.9%) and left (5.9%) hamstrings. However, the post-intervention results for the subjects in the present study were both lower than the results for the previously mentioned elite athletes, by 4.9 and 38% for the right and left leg respectively.

### 4. Discussion

The purpose of this pilot study was to assess the effect of a predominantly eccentric hamstring training programme on isokinetic variables associated with hamstring injuries and lower body dynamic power. The pre-intervention results for position of peak hamstring torque for the untrained subjects participating in this experiment were similar to those found in uninjured elite athletes in a previous study (Brockett et al., 2004). The subjects in the present study recorded slightly higher pre-training knee extension angles for production of peak torque in comparison to the elite athletes in the previous study for both right (14.9%) and left (5.9%) hamstrings. In contrast, the subjects in the present study showed a 19.4% change in position of peak hamstring torque. This rapid alteration of the length–tension relationship is similar to the significant shift in position of peak hamstring torque reported in a previous single session eccentric training study (Brockett et al., 2004).

### Table 1

<table>
<thead>
<tr>
<th>Week</th>
<th>Sessions per week</th>
<th>Sets–Reps</th>
<th>Technical notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2/5</td>
<td>The subject is encouraged to resist falling as long as possible</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2/6</td>
<td>Subject tries to reduce lowering speed</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3/6</td>
<td>Subjects can resist falling even longer, and for an increased number of repetitions</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>3/8</td>
<td>Load on the subject increases by allowing more speed in the start phase, as well as another gradual increase in repetitions</td>
</tr>
</tbody>
</table>

Adapted from Oslo Sports Trauma Research Center (2004)

### Table 2

<table>
<thead>
<tr>
<th>Isokinetic performance measure</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dominant</td>
<td>Non-dominant</td>
</tr>
<tr>
<td>Quadriceps PT (N.m.)</td>
<td>204.34</td>
<td>204.93</td>
</tr>
<tr>
<td></td>
<td>±20.1</td>
<td>±23.8</td>
</tr>
<tr>
<td>Pos PT (°)</td>
<td>69.32</td>
<td>62.82</td>
</tr>
<tr>
<td></td>
<td>±4.0</td>
<td>±6.3</td>
</tr>
<tr>
<td>Hamstrings PT (N.m.)</td>
<td>98.61</td>
<td>99.00</td>
</tr>
<tr>
<td></td>
<td>±13.3</td>
<td>±28.4</td>
</tr>
<tr>
<td>Pos PT (°)</td>
<td>36.76</td>
<td>28.21</td>
</tr>
<tr>
<td></td>
<td>±10.8</td>
<td>±4.0</td>
</tr>
</tbody>
</table>

L, effect for Limb (dominant and non-dominant); T, effect for test (pre- and post-intervention); LxT, interaction between limb and test; PT, peak torque; Pos PT, position of peak torque. *Indicates significant difference \( p < 0.05 \).
2001). The findings of this study showed that the position of peak hamstring torque shifted to a more extended knee position after the training intervention, which may allow for reduced eccentric muscle damage of the hamstrings occurring during eccentric contractions. This may be due to a reduced length of the descending limb of the length tension relationship, possibly resulting in diminished non-uniform lengthening of the sarcomeres of the hamstring muscles. A reduced descending limb of the length-tension relationship has been previously suggested to lower the risk of hamstring injury (Brockett et al., 2004). These results suggest that a training protocol designed to produce a more favourable hamstring length–tension relationship in terms of hamstring injury prevention can be beneficial after only a minimal amount of training sessions.

It is also worth noting that the position of peak hamstring torque in both the present and the previously mentioned study (Brockett et al., 2004) varied between the dominant and non-dominant limb. However, in the uninjured elite athletes (Brockett et al., 2004) there was only a 7% difference between limbs, whereas in the present study there was a 30.3% pre- and 42.4% post-intervention difference in the position of peak hamstring torque. This between limb imbalance suggests that there may be a need for unilateral eccentric hamstring training in untrained athletes to reduce the difference between the legs before bilateral eccentric specific training commences.

The results of the present study suggest that the training intervention created a greater magnitude of difference between test limbs. It appears that the limb with the initially higher knee extension angle benefits most from this method of training, which is logical due to the nature of the training protocol. As the athlete lowers themselves towards the ground using eccentric contraction of the hamstrings, the limb with the higher knee extension angle of peak hamstring torque may be required to take over control of the movement towards the end of the repetition. This places a greater magnitude of stress on the limb with the greater knee extension angle of peak torque, because it may be required to dominate control of the descending torso. This greater degree of overload on the already dominant hamstring may result in enhanced neuromuscular adaptation in this limb to the training protocol, further increasing the magnitude of imbalance between the limbs. This potential drawback to bilateral eccentric hamstring training warrants further examination.
Despite the beneficial adaptations in terms of the length-tension relationship, there was no increase in hamstring concentric peak torque as a result of the training intervention. This replicates the findings of Mjølnes et al. (2004) who found a limited effect of this method of training on concentric hamstring strength.

Another interesting finding of this study was the significant 11.3% reduction in peak torque produced by the quadriceps after the training intervention. This may be due to a number of factors, such as changes in the viscoelastic properties of the muscular unit in response to the training stimulus and/or increased antagonistic activation of the hamstrings during the concentric quadriceps phase of the testing protocol (Solomonow, Baratta, & D’Ambrosia, 1989). A change in the stiffness properties of the hamstrings and/or increased antagonistic activation may adversely affect the force output of the quadriceps by applying internal opposition to the quadriceps contraction in addition to the external opposition supplied by the isokinetic dynamometer (Solomonow et al., 1989).

Although a dramatic reduction in quadriceps peak torque and only minor changes in hamstring peak torque were observed in the open kinetic chain testing, a significant 6.6% increase in vertical jump height was reported. This revealed that the Nordic hamstring exercise not only appears to have a beneficial effect on the length tension relationship of the hamstrings, but results in enhanced explosive power performance in untrained athletes. Although there was a reduction in open-kinetic chain quadriceps peak torque in the post-training results, this may not carry over into closed kinetic chain jumping movements. Furthermore, the minor changes in hamstring peak torque may not be the reason for the improvement in vertical jump. The change in hamstring position of peak torque towards a more extended knee angle is likely to have contributed to the increase in vertical jump height. This may be due to increased joint stability of the knee during the final takeoff phase of the jumping movement, allowing for more efficient transfer of force through the joint (Baratta, Solomonow, Zhou, Letson, Chuinard, & D’Ambrosia, 1988).

Previous studies have shown that the hamstrings play a key role in preserving joint stiffness and stability during the deceleration phase which occurs towards the terminal stage of the knee extension movement (Baratta et al., 1988; Hagood, Solomonow, Baratta, Zhou, & D’Ambrosia, 1990). Therefore it would be expected that to optimise force transfer through the knee joint during dynamic movements it would be necessary to maintain or increase hamstring coactivation during the terminal phase of the movement. However, Baratta et al. (1988) found that in untrained athletes who participated in sports requiring repetitive jumping movements, this activation of the antagonist hamstring muscles during the final phase of the knee extension was markedly reduced. This suggests that their level of activation during the final phase of knee extension to potentially decrease opposition to the quadriceps, resulting in increased force output of the quadriceps at the expense of the joint stability supplied by the hamstrings. Not only would this reduction in joint stability reduce the efficiency of the movement, but it may increase the risk of knee joint injury (Baratta et al., 1988). In contrast, the athletes involved in the Baratta et al. (1988) study who were undertaking hamstring specific weight training produced similar activation patterns of the hamstrings to control subjects who were sedentary. These weight trained athletes recorded similar or increased activation of the hamstrings in comparison with the sedentary subjects, suggesting that performing hamstring specific weight training maintained or increased their knee joint stability. While the previous study did not look at dynamic performance characteristics of the subjects, the results of the present study suggests that hamstring specific training can result in beneficial adaptations to hamstring activation in terms of joint stability during the final phase of knee extension as well as increase dynamic performance.

4.1. Limitations

Despite the limited number of subjects participating in this study, a number of significant findings were observed. However, further studies incorporating greater subject numbers, the inclusion of a control group and multiple trials for assessment of reliability would help to determine the role of lower body eccentric training on performance and injury risk factors. The results of this study suggest that eccentric hamstring training may result in adaptations that reduce the risk of hamstring strain injury, however further studies are required before these benefits can be deemed conclusive.

5. Practical applications and clinical relevance

The findings of this study suggest that the Nordic hamstring exercise results in favourable adaptations to the length–tension relationship in the hamstring muscle group. Although the Nordic hamstring exercise was found to be beneficial in terms of the hamstrings position of peak torque, it had little effect on overall peak torque values. Possibly a combination of Nordic hamstring exercise training and traditional hamstring weight lifting movements may provide beneficial strength and length-tension adaptations to prevent soft tissue hamstring injuries. Overall the results of this study suggest that the Nordic Hamstring exercise, because of its ease of implementation, may be an effective method of both enhancing performance and reducing injury in sub-elite athletes performing in sports requiring jumping movements.
References


Oslo Sports Trauma Research Center (2004). www.ostrc.no


