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A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players

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Purpose: **To compare the effects of a 10-week training program with two different exercises – traditional hamstring curl (HC) and Nordic hamstrings (NH), a partner exercise focusing the eccentric phase – on muscle strength among male soccer players.** ***Methods:*** **Subjects were 21 well-trained players who were randomized to NH training ($n = 11$) or HC training ($n = 10$). The programs were similar, with a gradual increase in the number of repetitions from two sets of six reps to three sets of eight to 12 reps over 4 weeks, and then increasing load during the final 6 weeks of training. Strength was measured as maximal torque on a Cybex dynamometer before and after the training period.** ***Results:*** **In the NH group, there was an 11% increase in eccentric hamstring torque measured at $60^\circ\,s^{-1}$, as well as a 7% increase in isometric hamstring strength at 90°, 60° and 30° of knee flexion. Since there was no effect on concentric quadriceps strength, there was a significant increase in the hamstrings:quadriceps ratio from 0.89 ± 0.12 to 0.98 ± 0.17 (11%) in the NH group. No changes were observed in the HC group.** ***Conclusion:*** **NH training for 10 weeks more effectively develops maximal eccentric hamstring strength in well-trained soccer players than a comparable program based on traditional HC.**

Hamstring injury is a common problem in many sports, especially those involving acceleration and maximal sprints. A review of the literature indicates that hamstring injuries account for 11% of the running injuries (Lysholm & Wiklander, 1987) and 16–23% of the injuries in Australian Rules football (Orchard et al., 1997; Orchard, 2001; Verrall et al., 2001). In soccer, the problem appears to be increasing, with hamstring strains accounting for 7% of the injuries in an early investigation (McMaster & Walter, 1978) and 12–17% in more recent studies (Hawkins et al., 2001; Andersen et al., 2003; Arnason et al., 2003). The likely explanation for this trend is that modern soccer is more physically demanding, involving more matches, with higher intensity and more aggressive play than previously.

Although hamstring strains usually do not lead to post-career disability, they cause significant time loss and may even be career-threatening. Preventing these injuries should therefore be a major objective for athletes and clubs. As a first step, the causes must be established, including information on why a particular athlete may be at risk in a given situation (i.e., risk factors) and how injuries happen (i.e., injury mechanisms) (Bahr et al., 2002). Inadequate hamstring strength, strength imbalance between hamstrings and quadriceps and/or bilateral hamstring strength deficits have been identified by many investigators as causative factors ((Burkett, 1970; Heiser et al., 1984; Yamamoto, 1993; Jönhagen et al., 1994; Orchard et al., 1997; Croisier et al., 2002). Another phenomenon associated with hamstring strains is previous hamstring injury (Bennell et al., 1998; Orchard, 2001; Verrall et al., 2001; Arnason et al., 2003). Poor hamstring flexibility, fatigue and improper warm-up have also been suggested as factors predisposing an athlete to hamstring strains (Liemohn, 1978; Safran et al., 1988; Worrell et al., 1991; Jönhagen et al., 1994; Mair et al., 1996), although the evidence for this is less convincing (Bahr & Holme, 2003).

The present study was built on the assumption that hamstring strains occur as a result of strength deficits in the athlete, particularly lack of eccentric muscle strength (Garrett, 1990; Kaminski et al., 1998). There is some evidence to support the hypothesis that eccentric hamstring strength may be an important protective factor. Studies on hamstring function during running gait have concluded that the hamstrings work eccentrically to decelerate the forward movement of the foot and the leg in the late forward swing phase of the running cycle

(Agre, 1985; Coole & Gieck, 1987). When sprinting, the deceleration phase shortens, requiring a higher eccentric activation of the hamstrings to compensate the forward momentum, and the forces that influence the hamstrings may then cause tearing in the muscle–tendon unit (Garrett, 1990). Analyses of sprinting also reveal that the electromyographic activity of hamstrings is high in the late swing phase, although the peak levels were seen during foot-strike (Mann, 1981; Jönhagen et al., 1996), and that the flexor moment is high during the knee extension phase (Simonsen et al., 1985).

If strength is a predictor for hamstring strains, the next question is how to build eccentric hamstring strength most effectively. In general, muscles adapt to training in a very specific manner. However, studies on the specificity of hamstring strengthening are few, and with conflicting results (Ryan et al., 1991; Kaminski et al., 1998). Moreover, to make it easier to include such training in the regular training programs, e.g., for soccer teams, there is a need to develop hamstring strength exercises that are simple and can be performed in the field without special equipment. Thus, we decided to design a randomized training study to compare the effect of a simple eccentric hamstring exercise – Nordic hamstrings (NH) – with the most commonly used concentric strength training exercise – regular hamstring curl (HC).

Methods

Subjects were recruited among students from the Norwegian University of Sport and Physical Education who were competitive soccer players at a level ranging from 2nd to 4th division ($n = 13$) and from the 1st division club Stabæk Fotball ($n = 10$). One subject who volunteered to take part in the study could not be included because of recent hamstring strains (within the previous 3 months). The remaining 22 subjects included in the study did not have any previous hamstring strains that were not fully recovered when the study started. The study was approved by the Regional Committee for Research Ethics, and written consent was obtained.

Before the start of the training period, the subjects underwent a pre-testing protocol of warm-up, hamstring flexibility testing and strength testing. This included three or four initial sessions to familiarize the subjects with the strength testing procedures and isokinetic testing equipment (Cybex 6000, Lumex, Ronkokoma, NY, USA).

First, the subjects pedaled on a cycle ergometer for 5 min at a frequency of $80\,\mathrm{min}^{-1}$ and a constant power of 150 W. Next, the subjects underwent the passive knee extension test for hamstring flexibility described by Fredriksen et al. (1997). Only the right leg was tested.

The tests were performed on an examination table with a firm surface and lumbar support. The subjects were in the supine position with the pelvis and left leg stabilized using belts to avoid accessory movements. The hip of the right leg was fixed at 120° flexion using a belt, and the player supported against further hip flexion by pressing with both hands distally on his anterior thigh. The ankle and foot were relaxed and the hip was in neutral rotation, abduction and adduction. Three reflex points were placed on the right leg: the lateral malleolus, the lateral femoral epicondyle and the major trochanter. The player performed two hold-relax hamstring contractions before the knee was extended passively with an 8-kg load, as measured with a fish scale. The tension meter was placed just proximal to the lateral malleolus at a 90° angle to the calf, as controlled visually. Flexibility was measured as static range of motion (ROM) based on photos taken with a JVC digital camera and then analyzed using the Neat System 4.0 (The Movement Analysis Company, Etters, PA, USA).

After the flexibility tests, the subjects warmed up again for the strength tests by pedaling for another 5 min before doing three series of 20 heel-to-butt kicks and 10 high running steps. Subjects also made three passive stretching exercises for the hamstrings, each stretch lasting for about 15 s. The strength testing protocol consisted of tests for concentric quadriceps strength, eccentric hamstring strength and isometric hamstring strength. Only the right leg was tested. The concentric quadriceps strength was performed at a test velocity of $60^\circ\,\mathrm{s}^{-1}$. Subjects were given four warm-up repetitions, and then performed three maximal contractions. After a 2-min rest, a test for eccentric hamstring strength was performed using the same protocol: four warm-up repetitions and three maximal eccentric muscle actions. Strength was reported as the maximal (peak) torque recorded, and the best performance of the three repetitions was used in the data analysis. Finally, isometric hamstring strength was tested with the knee 90°, 60° and 30° from full extension. Subjects performed a 5-s maximal voluntary contraction at each knee flexion angle with a 30-s rest period between each contraction. The isometric and isokinetic test modes have been shown to be sensitive for changes in maximal force-generating capacity with a very good test–retest reliability in our lab ($CV < 5\%$) (Raastad & Hallen, 2000). The strength tests were performed by an experienced technician who was blinded to group allocation.

After the pre-tests, the 22 subjects were randomized by drawing lots into one of two training groups, the HC group ($n = 11$) or the NH group ($n = 11$). One of the subjects in the HC group quit the team because of an ankle injury not related to the study halfway through the training period, and dropped out of the study before the post-tests. Another subject in the HC group could not take part in the flexibility post-test for practical reasons.

After the pre-testing had been completed, the subjects started out on one of the 10-week training protocols presented in Tables 1 and 2. The HC exercise was performed in a traditional HC machine (Isotonic Line M010 – Leg curl, 1996–1997, Gambettola, Italia). The subjects were instructed to lie flat on the bench, stomach down, keeping their hip in a fixed position and their ankles hooked under a padded bar attached to a weight rack by a cable pulley. They were asked to rest their forehead on the bench, grab the handgrips, and bring their heels up towards their bottom as fast and forcefully as possible to maximize the effort during the concentric phase. They were instructed to return the load using as little effort as possible to minimize loading in the eccentric phase. Their 10 repetitions maximum (10 RM) was tested in the first training session, and the initial training load was based on this test as shown in Table 1.

The NH exercise is a partner exercise where the subject attempts to resist a forward-falling motion using his hamstrings to maximize loading in the eccentric phase (Fig. 1). The subjects were asked to keep their hips fixed in a slightly flexed position throughout the whole range of motion, and to brake the forward fall for as long as possible using their hamstrings, and to try keeping tension in their hamstrings even after they have to "let go". They were asked to use their arms and hands

Table 1. Training protocol for the hamstring curl group

Week	Sessions per week	Sets and repetitions	Load (% of 1 RM)
1	1	10 RM test	
2	2	2 × 6	60%
3	3	3 × 6–8	60–80%
4	3	3 × 8–12	Progressive loading. Increase load by 2.5 kg when subject is capable of doing 3 × 12 reps
5–10	3	3 × 8–12	

RM = repetitions maximum.

Table 2. Training protocol for Nordic hamstring group

Week	Sessions per week	Sets and repetitions	Load
1	1	2 × 5	Load is increased as subject can withstand the forward fall longer. When managing to withstand the whole ROM for 12 reps, increase load by adding speed to the starting phase of the motion. The partner can also increase loading further by pushing at the back of shoulders
2	2	2 × 6	
3	3	3 × 6–8	
4	3	3 × 8–10	
5–10	3	3 sets, 12–10–8 reps	

ROM: range of motion.

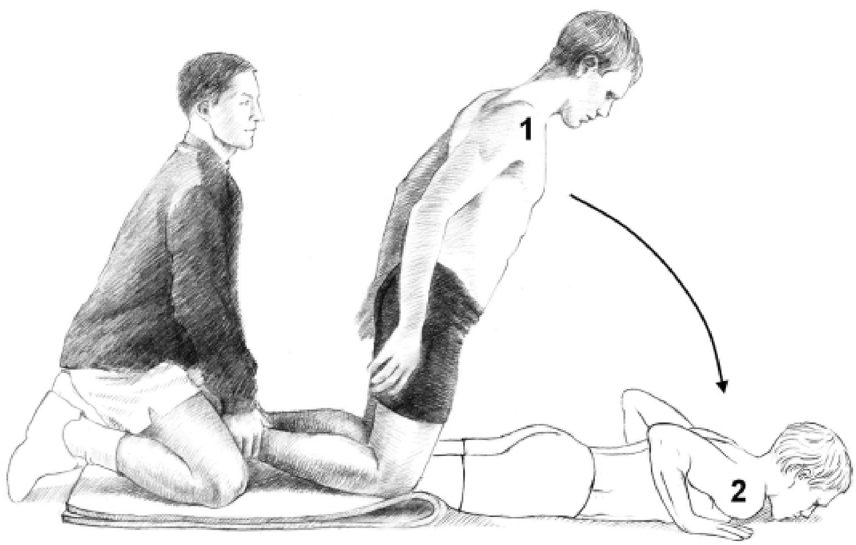

Fig. 1. The Nordic hamstrings exercise. Subjects were instructed to let themselves fall forward, and then resist the fall against the ground as long as possible using their hamstrings. Reproduced from Bahr and Mæhlum (2002) with permission from the publisher (©Lill-Ann Prøis & Gazette Bok).

to buffer the fall, let the chest touch the surface, and immediately get back to the starting position by forcefully pushing with their hands to minimize loading in the concentric phase.

A 10-cm visual analog scale was used to register the highest level of muscle soreness sensed by each subject after each of the initial 10 training sessions, i.e., the initial 4 weeks of strength training. The registration was done before the start of the second to the 11th training session for all subjects. A visual analog scale is a valid and reliable instrument to measure both chronic and acute pain (Fitzgerald et al., 1991; Bijur et al., 2001).

Statistics. Differences in strength and flexibility between groups were assessed using a repeated measures analysis of variance, testing for interaction between group (NH vs. HC) and time (pre-test vs. post-test). If a significant interaction was observed, paired *t*-tests were used to analyze within-group differences. An α level of 0.05 was considered significant. Results are presented as means ± SE unless otherwise noted.

Results

The NH group completed 24.5 ± 1.4 hamstring strength training sessions throughout the 10-week training period (96% participation rate), while the HC group completed 22.4 ± 2.7 training sessions (89% participation, non-significant (n.s.)). There was no difference in the total amount of other training, soccer training, strength training or endurance training between groups. Compared with the result from the initial 10 RM test (32 ± 2 kg, SD), the

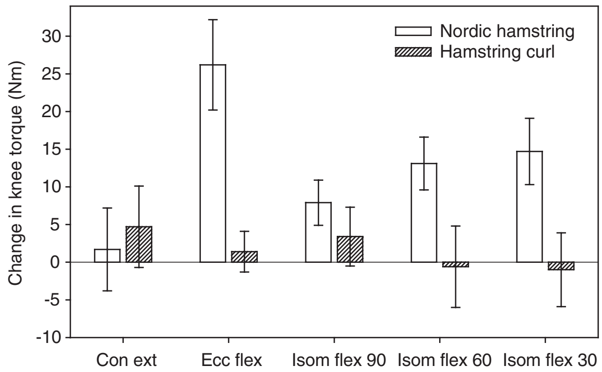

Fig. 2. Mean difference (± SE) in maximal torque from pre- to post-test for the Nordic hamstring ($n = 11$) and hamstring curl ($n = 10$) groups measured in three different strength protocols: concentric quadriceps extension torque (Con ext), eccentric hamstring flexion torque (Ecc flex) and isometric hamstring torque at 90°, 60° and 30° of knee flexion (Isom flex 90, Isom flex 60 and Isom flex 30).

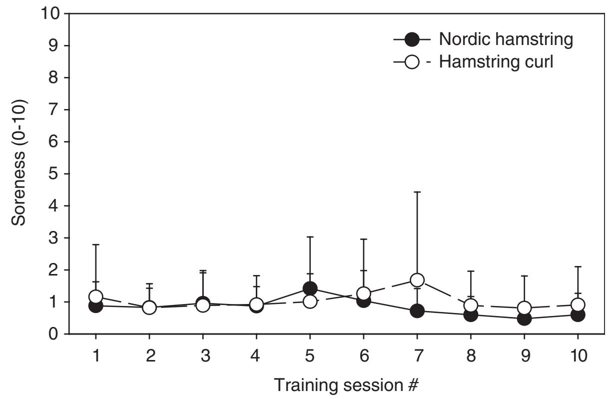

Fig. 3. Mean soreness (± SD) measured using a visual analog scale after the initial 10 strength training sessions, i.e., the initial 4 weeks of training.

training load increased to 45 ± 8 kg during the final week of training ($P < 0.0001$) in the HC group.

Significant group by time effects were observed for maximal eccentric hamstring torque (MANOVA; $F_{1,19} = 13.3$, $P = 0.002$), and isometric hamstring torque at 30° ($F_{1,19} = 5.7$, $P = 0.028$) and 60° of knee flexion ($F_{1,19} = 4.7$, $P = 0.043$) (Fig. 2). No interaction was observed for isometric hamstring torque at 90° of knee flexion ($F_{1,19} = 0.86$, $P = 0.36$) or maximal concentric quadriceps torque ($F_{1,19} = 0.15$, $P = 0.71$) (Fig. 2). There were no changes in any of the hamstring strength tests for the HC group, while the NH group showed significant improvements in all the hamstring strength tests. Maximal eccentric hamstring torque increased by 11%, from 240 ± 12 N m at pre-test to 267 ± 13 N m at post-test (*t*-test, $P = 0.001$). Maximal isometric hamstring strength measured at 90° increased by 7%, from 108 ± 5 N m at pre-test to 116 ± 7 N m at post-test ($P = 0.027$). Likewise, an increase of 7% was also observed at 60° (pre: 186 ± 6 N m vs. post: 199 ± 8 N m, $P = 0.004$) and 30° of knee flexion (pre: 219 ± 7 N m vs. post: 234 ± 9 N m, $P = 0.007$). Maximal concentric quadriceps strength did not change from pre- to post-test.

Following the improvements in eccentric hamstring strength, there was a significant group by time interaction for the ratio between eccentric hamstring torque and concentric quadriceps torque (H:Q ratio) (MANOVA; $F_{1,19} = 9.3$, $P = 0.007$). The H:Q ratio increased from 0.89 ± 0.04 at pre-test to 0.98 ± 0.05 at post-test (*t*-test, $P = 0.005$), while there was no change in the HC group (pre: 0.88 ± 0.03 N m vs. post: 0.87 ± 0.04 N m, $P = 0.70$).

There was no group by time interaction in the results from the passive knee extension test used to measure hamstring flexibility (MANOVA; $F_{1,19} = 0.23$, $P = 0.64$).

We observed no time or group by time effect (MANOVA; $F_{1,10} = 0.55$, $P = 0.81$) on the soreness reported by the subjects (Fig. 3). The average soreness reported during the 10-session registration period was 1.0 ± 0.6 (SD) in the HC group and 0.8 ± 0.3 in the NH group ($P = 0.72$). Two subjects in each of the groups reported a soreness score above 3.0 during the registration period.

Discussion

The main finding of this study was that a program of the eccentric strength exercise NH was more effective than the concentric strength exercise HC in developing eccentric hamstring strength measured at $60° s^{-1}$ among well-trained male soccer players. No change was observed in maximal concentric quadriceps torque in any of the groups. Consequently, there was a significant increase in H:Q ratio in the NH group, but not in the HC group. Significant gains were also seen for maximal isometric torque in the NH group at the three knee angles tested, while no change was observed in the HC group.

These results support earlier investigations that have found both eccentric and concentric strength training to be mode specific (Tomberlin et al., 1991; Higbie et al., 1996; Hortobagyi et al., 1996; Seger et al., 1998). Mode specificity has also been shown for the hamstring muscles by Kaminski et al. (1998). They found that in a group of untrained college students, eccentric strength training was more effective than concentric strength training on peak isokinetic eccentric hamstring torque after 6 weeks of training (two sessions per week) in a leg curl machine. Therefore, the present findings are not surprising. The two interesting features of the present study were that (1) a significant eccentric strength gain and increase in H:Q ratio could be obtained in a well-trained group of soccer players using a simple partner exercise that can be performed on the pitch, and (2) no increase in the same factors was seen using a progressive program of HC exercise, a program at least as intensive as that regularly used by athletes to prevent injury and increase performance.

The increase in eccentric hamstring strength is interesting from an injury perspective, as muscle strains are thought to occur during eccentric muscle action (Garrett, 1990; Kaminski et al., 1998). In the running gait cycle, the hamstrings act eccentrically to decelerate forward movement of the leg (Agre, 1985; Coole & Gieck, 1987). A number of studies have shown that low hamstring strength is a risk factor for sustaining hamstring strain (Burkett, 1970; Liemohn, 1978; Yamamoto, 1993; Jönhagen et al., 1994; Orchard et al., 1997). The players in our study who used the NH exercise improved their ability to develop eccentric hamstring torque, and such an improvement can potentially prevent hamstring strains. Conversely, it is possible that the regular HC exercise does not protect against hamstring strains, although the players appeared to have become stronger judged by the steady increase in training load. However, these hypotheses need to be tested in a clinical trial on well-trained athletes using hamstring injury as the end point.

The lack of eccentric strength improvement in the HC group can also be explained by mode specificity. Studies have shown concentric strength training to be effective in developing maximal concentric strength, but less effective on eccentric strength than eccentric training, although a modest effect has been seen in some studies (Tomberlin et al., 1991; Higbie et al., 1996; Hortobagyi et al., 1996; Kaminski et al., 1998; Seger et al., 1998). In the present study, we would have liked to test concentric hamstring strength and maximal sprinting performance. However, since many of our subjects were professional athletes, we had to limit the time and effort required for testing, and priority was given to the tests we thought would be the most relevant from an injury prevention perspective. Therefore, we do not know if the HC exercise was effective in developing concentric hamstring strength.

It is reasonable to assume that not only mode specificity but also other factors need to be considered if injury prevention or rehabilitation is the objective. These include angular velocity and joint angle, which may need to mimic the characteristics of the typical injury situation for the exercise to be effective. Since the hamstring, with the exception of the short head of the biceps, is a two-joint muscle group that can act as a hip extensor or knee flexor, the joint motion pattern may be relevant as well. The knee angular velocity in a sprint gait cycle is claimed to be as high as 600–700° s^{-1} (Sale, 1990), and the injury is thought to occur during maximal eccentric muscle action to decelerate the forward movement of the foot and the leg in the late forward swing phase until the leg is stopped about 30° from full knee extension (Agre, 1985; Walter et al., 1985; Coole & Gieck, 1987; Garrett, 1990). This assumption is also based on analyses of sprinting, revealing that the electromyographic activity of the hamstrings is high in the late swing phase (Mann, 1981; Jönhagen et al., 1996). At the same time, the hip is being extended at a moderate velocity, which increases the eccentric load on the hamstrings. Thus, from an injury prevention or rehabilitation point of view it appears that the ideal exercise would be eccentric to decelerate a very high angular knee velocity with maximum force production around 30° of knee flexion. We know of no exercise that fulfills all these criteria, but the NH exercise appears to have a number of advantages when compared with regular leg curls. By the end of the 10-week training period, many of the subjects were able to stop the downward motion completely before touching the ground (i.e., at about 30° of knee flexion), even after being pushed by his partner(s) at a considerable speed. When a player can reach this stage, the characteristics of the NH exercise appear to resemble the typical injury situation: eccentric muscle action, high forces, near-full-knee extension. Nevertheless, since the subjects were tested at 60° s^{-1} only, we do not know whether NH exercise has a velocity-specific effect on hamstring strength. Previous studies are equivocal, one reporting a velocity-specific effect (Seger et al., 1998) and others not (Duncan et al., 1989; Ryan et al., 1991).

Conclusion

A 10-week training regimen with the eccentric strength exercise NH was more effective than a comparable training regimen with regular HC exercise in developing maximal eccentric hamstring strength, the H:Q strength ratio and isometric hamstring strength. Thus, NH exercise may in turn reduce the risk of sustaining a hamstring strain.

Perspectives

Based on the present results, the NH exercise appears to be effective in improving eccentric strength, which may be advantageous to prevent or rehabilitate hamstring strains. From a practical point of view, the advantage of the NH exercise is that it can be done anywhere; the only requirement is that the knees need to be cushioned. This means that in contrast to leg curls, an entire team can train at the same time, taking turns between training and supporting their partner. However, it should be noted that as strength increases, two or even three players might be required to provide adequate support. The present protocol with a slow increase in repetitions and load was designed to minimize muscle soreness, and it appeared to be well tolerated by the players. No injuries were seen.

Key words: hamstring torque, hamstring injury, hamstrings:quadriceps ratio, range of motion.

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