ELECTROMYOGRAPHIC COMPARISON OF FLYWHEEL INERTIAL LEG CURL AND NORDIC HAMSTRING EXERCISE AMONG SOCCER PLAYERS.

Running head: Flywheel vs Nordic hamstring exercise

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Abstract

Purpose: The Nordic hamstring exercise has been shown to considerably reduce hamstring injuries among soccer players. However, as the load in the Nordic hamstring exercise is the person`s own bodyweight, it is a very heavy exercise and difficult to individualize. The flywheel inertial leg curl could be an alternative since the eccentric overload is based on the amount of work produced in the concentric movement. Therefore, the primary aim of this study was to compare the activation in the hamstrings at long muscle lengths in the Nordic hamstring exercise and the flywheel inertial leg curl in amateur soccer players. **Methods:** Fifteen male amateur soccer players performed five repetitions in each exercise in a randomized and counterbalanced order. The concentric and eccentric movement were divided into lower and upper phases. Surface EMG (sEMG) was measured distally, proximally and in the middle, at both muscles. **Results:** In the lower phase in the eccentric movement there were no significant differences between the two exercises (p=0.101–0.826). In the lower concentric movement, flywheel inertial leg curl led to higher activation in all parts of both the biceps femoris (31-52%, p<0.001) and the semitendinosus (20-35%, p=0.001–0.023). **Conclusion**: Both exercises activated the hamstrings similarly at long muscle lengths during eccentric contractions (Nordic hamstring, non-significantly higher). However, when performing concentric contractions the flywheel inertial leg curl induced higher activations. Therefore, flywheel inertial leg curl could be a useful alternative to the Nordic hamstring exercise, and particularly suitable for weaker athletes before progressing to Nordic hamstring exercise.

Key words: Resistance training, biceps femoris, semitendinosus, eccentric, hamstring, EMG

Introduction

Acute hamstring injury is one of the most common injuries in soccer[1,2]. The Nordic hamstring exercise (NHE) reduces the risk of acute hamstring injuries in soccer by more than 50% [1]. The explanation of this dramatic effect is likely multifactorial [3], but strengthening the hamstring muscles, especially at long muscle lengths where most strain injuries occur, seems highly important [2]. In the NHE, the stress on the hamstring muscles is increased over the range of motion due to the increasing lever arm, making the exercise especially heavy at long muscle lengths. Further, it has been indicated that different exercises have different regional activating patterns [4], with the NHE having a homogenous regional activating pattern with the semitendinosus being more activated in the proximal region while the biceps femoris is more activated in the distal region [5]. This could be of importance since most hamstring injuries in professional soccer occurs in the long head of the biceps femoris [6].

The NHE uses the bodyweight as the external load. It is therefore difficult to individualize the load to soccer players with different strength levels, especially tall players, and those who are weak in relation to their own bodyweight. This could reduce these players' ability to perform the exercise in a controlled tempo and activate the hamstring muscles at long muscle lengths, where the external torque is greatest [7]. The use of bodyweight as loading causes another problem when shifting from the eccentric to the concentric contractions. The player has to be very strong in the hamstring muscles to be able to perform the ascending movement, hence in most cases the Nordic hamstring is performed as a purely eccentric exercise [8]. A possibility for reducing the external load is to push with the arms in the concentric phase. This should be considered since there have been promising results of combining eccentric overload with a concentric contraction [9].

Despite the promising results of the NHE, the inclusion of the exercise into injury preventive training programs has been poor [10]. There are likely several reasons for this, but that the NHE is a high intensity exercise [11], with little room for individual adjustments, and a long recovery period when the exercise is novel, which could interfere with soccer training, seem likely candidates. Therefore, a gentler and more individualized exercise could be preferable for both players and coaches. An alternative is to create an eccentric overload by using inertial resistance via a flywheel device [12]. In this apparatus, the force created in the concentric movement is transferred to a strap. When the strap unwinds, a shaft with the flywheels rotates and thereby stores the energy [13]. When the concentric movement is complete, the strap rewinds, and the athlete must resist the rotation of the flywheel through the eccentric phase. To ensure high loads towards the final parts of the eccentric movement, at long muscle lengths, it would be important to not resist the movement immediately, but emphasize the latter half of the eccentric movement [14]. Previous research have indicated flywheel training to elicit higher neuromuscular activation, especially in the eccentric movement, when compared to traditional resistance exercises [15]. Therefore, inertial exercises for the hamstring, such as the flywheel inertial leg curl (FLC), could be a feasible alternative to the NHE. The FLC could offer a more individualized eccentric overload compared to the NHE since its` magnitude depends on the concentric contraction and has therefore been recommended for weaker athletes [16]. Further, it would be easier to activate the hamstring muscles in the concentric movement in the FLC.

To our knowledge, no study has compared muscle activation in the NHE to an inertial hamstring exercise. Therefore, the primary aim of this study was to compare the muscle activations generated by the NHE and the FLC, in the biceps femoris and the semitendinosus at long muscle lengths in amateur soccer players.

Methods

Experimental approach to the problem

The study used a within-subject cross-over design where measurements were conducted in the same session to assess the neuromuscular activation of the semitendinosus and biceps femoris when performing the NHE and the FLC among amateur soccer players. Five repetitions where performed in each exercise using either the body weight (NHE) or the load yielding maximal power output (FLC). The order of the exercises was randomized and counterbalanced.

Subjects

Comparable to the number of participants in previous research[15,17], 15 active male amateur soccer players (age 22.9 ± 1.8 years, body mass 75.9 ± 7.9 kg, height 179.2 ± 6.8 cm) were recruited for the study. The players had 16.1 ± 1.6 years of experience playing soccer and were at the time of the study playing at level 4-6 in the national series. The participants had to be at least 18 years old and be able to perform the exercises without any pain or pain-related discomfort limiting the effort. The participants had to refrain from resistance- and high intensity training 48 hours before the test. Information about the study was provided orally and in writing and a written consent had to be provided before the individual was enrolled in the study. The study conformed to the Sogn og Fjordane University College and all appropriate consent pursuant to law was obtained before the start of the study.

Procedures

Two familiarization sessions were performed before the experimental test. In the first, the participants were familiarized with the execution of both exercises performing three to five sets of five repetitions. The FLC was performed with increasing resistances to find the load where the participants were able to produce the highest power output. The mean of the five repetitions was used when calculating the power output. The testing started at inertial load 0.025 $kg{\cdot}m^2$ and was increased by 0.010 $kg{\cdot}m^2$ or 0.025 $kg{\cdot}m^2$ for each set until the power output decreased compared to the previous set. The mean power output was measured by an application (exxentric kMeter) from the manufacturer of the flywheel device. In the second familiarization session the protocol from session one was repeated in the NHE, while in the FLC the participants performed all repetitions with the load producing maximal power output, found in session one (ranging from 52 to 143 watts). A minimum of 48 hours separated the sessions.

Before each session, the participants completed the same warm-up consisting of five minutes of cycling at an intensity defined as easy to moderate (10-12 on Borgs` RPE scale; range 6-20), followed by two sets of eight repetitions in a leg curl machine (Technogym, Gambettola, Italy) with moderate intensity (five on the Borg CR10 scale; range 0-10). The different scales were thoroughly explained before the warm-up and a test leader was always present to control a proper warm-up.

The NHE was performed on a gym mat with one person holding the ankles (below the calf muscles) pinned to the floor (see figure 1A). The feet were held in a plantar flexion with the toes pointing backwards. The eccentric part started in an upright position with a straight hip and the arms held in front of the trunk (hand in front of the shoulders, see figure 1A). The participants were instructed to lower them in a slow and controlled tempo, without flexing in the hip. When the trunk touched the mat the participants were instructed to ascend as fast as possible using their hamstrings, whilst maintaining a straight hip. They were allowed to use their arms, but it was emphasized that they should contribute as little as possible. When they were back at the starting position, the concentric part was complete and a new repetition began without rest.

FIGURE 1 AROUND HERE

The FLC was performed standing and unilaterally in a flywheel apparatus (kBox4 active, Exxentric, Bromma, Sweden) with only the dominant leg being tested. The participants were positioned on a step higher than the apparatus to allow for full extension in the knee with the hip straight above the flywheel (see figure 1B). They held onto a rack to keep their trunk and hip in the same position during the exercise. The device/strap was adjusted to the desired position (90 degree in the knee joint) using a goniometer. The participants were instructed to contract with maximal effort ("as hard and fast as possible") throughout the complete concentric phase. After unwinding the strap from the shaft, stopping at a 90 degree angle in the knee joint, the strap rewound due to the inertial forces, initiating the eccentric phase. In this phase, the participants were instructed to resist the forces gently in the first third of the movement before resisting the movement maximally until the knee was extended [14]. Five repetitions with maximal effort were completed in both exercises. The participants were given a minimum of three minutes rest between each exercise[18].

Electromyography

Before the experimental testing the skin on the dominant leg was prepared (shaved, abraded and washed with alcohol) in accordance to the guidelines of SENIAM [19]. Gel-coated self adhesive electrodes (11 mm contact diameter and a 2 cm center-to-center distance, Dri-Stick Silver circular surface EMG Electrodes AE-131, NeuroDyne Medical, USA) were placed in the presumed direction of the underlying muscle fibers on three different parts (distal, middle and proximal) of the semitendinosus and biceps femoris[20]. For the middle part of the semitendinosus the electrode was placed at 50% on the line between the ischial tuberosity and the medial epycondyle of the tibia. The middle part of the biceps femoris was placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia (www.seniam.org). The electrodes on the distal and proximal part of both muscles were placed the same line as the middle electrode, however, the exact position was individually adjusted based on the palpation of each individuals' hamstring[21]. In general, the proximal electrodes were placed as high as possible without overlapping the glutei muscles and the distal parts as low as possible without overlapping the tendons. The electrodes in each region were always placed parallel to each other.

The raw EMG signal sampled at 1000 Hz, was amplified and filtered (8-600 Hz; fourth-order Butterworth filter) using a preamplifier located close to the sampling point. The preamplifier had a common mode rejection ratio of 106 dB. The EMG signals were root mean square (RMS) converted using a hardware circuit network (frequency response 450 kHz, averaging constant 12 ms, total error ± 0.5%). Commercial software (MuscleLab 6000 system, Ergotest Technology AS, Langesund, Norway) was used to analyze the stored EMG data. The mean EMG amplitude obtained during repetition 1, 3 and 5 was used to calculate RMS EMG of the upper and lower phases of the eccentric and concentric movement in addition to the whole eccentric and concentric movement. The mean EMG amplitude of each phase was used to calculate the RMS values. Finally, to normalize EMG activity, the participants performed two maximal voluntary contractions (MVCs). The participants were placed on a mat lying in the prone position, before instructed to perform an isometric knee flexion while the leg (knee angle of approximately 45 degrees) and hip were manually held still. In both attempts (separated by 1-2 minutes), the participants were instructed to obtain maximal force and hold it for five seconds. The attempt with the highest EMG amplitude was used to normalize the EMG signal for each muscle. Commercial software (MuscleLab V10.4, Ergotest Technology AS, Langesund, Norway) was used to analyze the stored EMG data.

To identify the beginning and the end of the eccentric and concentric movement, as well as the different phases and the lifting time, a linear encoder (Ergotest Technology AS, Langesund Norway, sampling frequency of 200 Hz) was attached to the trunk (NHE) or ankle (FLC). The classification of the different phases (upper and lower) was made from the displacement of the trunk (NHE) or ankle (leg curl), where the separation was done at 50% of the displacement. The linear encoder was synchronized with the EMG recording system (MuscleLab 6000, Ergotest Technology AS, Langesund, Norway).

Statistical analyses

The normality of the data was checked and confirmed with the Shapiro-Wilk test. Thus, paired t-tests were used to compare the neuromuscular activation and the lifting time between the different exercises. Statistical analyses were performed with SPSS version 17.0 (SPSS, Inc., Chicago, IL, USA).

Statistical significance was accepted at $p \leq 0.05$. All results are presented as mean ± 95% confidence interval (95%CI) and Cohen`s *d* effect size (ES) calculated by: mean FLC – mean NHE divided by the pooled standard deviations of the two exercises. An ES of 0.2 was considered small, 0.5 medium and 0.8 large [22].

Results

In the lower eccentric phase, both exercises showed similar activation in all parts of the two muscles (p = 0.101 – 0.826, figure 2A). In the lower concentric movement the FLC lead to higher activation in all parts of both the biceps femoris (31 - 52%, $p < 0.001$, ES = 0.98 – 1.31, figure 2B) and the semitendinosus (20 - 35%, p = < 0.001 – 0.023, ES = 0.53 – 1.01).

FIGURE 2 AROUND HERE

In the upper phase of the eccentric movement the three parts of the biceps femoris were more activated when performing FLC compared to the NHE (10 – 21%, $p = 0.005 – 0.049$, ES = 0.38 – 0.67, table 1), but no significant differences were observed in the semitendinosus ($p = 0.177 – 0.284$). In the upper concentric phase the FLC lead to higher activation in all parts of both muscles when compared to the NHE (52 – 79%, $p < 0.001$, ES = 1.29 – 3.77).

TABLE 1 AROUND HERE

When analyzing the whole eccentric movement, the proximal part of semitendinosus demonstrated higher activation during the NHE compared to the FLC (23%, $p = 0.016$, ES = 0.89). There were no significant differences for any of the other parts of the muscles in the eccentric movement ($p = 0.237 – 0.807$). In the whole concentric movement, FLC lead to higher activation for all parts of both semitendinosus (52 – 68%, $p < 0.001$, ES = 1.51 – 1.99) and biceps femoris (64 – 78%, $p < 0.001$, ES = 2.22 – 2.79) when compared to NHE.

The mean time used in both the eccentric and concentric part of the movement was higher ($p < 0.001$) in the NHE (eccentric: 3.9 ± 0.7 sec. and concentric: 2.4 ± 0.5 sec.) compared to the FLC (eccentric: 1.7 ± 0.2 sec. and concentric: 1.6 ± 0.2 sec.). The same differences were apparent in the different phases with the exception of the lower eccentric phases where the times were not statistical different ($p = 0.165$).

Discussion

The NHE and FLC induced similarly high activations in the semitendinosus and the biceps femoris during the eccentric phase at long muscle length, while the FLC led to greater activation in the concentric movement.

It should be noted that although there were no statistical differences between the exercises in the lower phase of the eccentric movement, the EMG-activation was non-significantly higher in all parts of the two muscles for the NHE (effect sizes ranging from 0.08 to 0.61). Although the number of participants (i.e. 15) is similar to comparable studies [15,17], it is possible that the lack of statistical differences could be due to limited statistical power. Nevertheless, both exercises induced quite high levels of neuromuscular activations at long muscle lengths during the eccentric contraction. Since high levels of muscle activation is important for developing muscle strength and muscle strength at long muscle lengths seems to be important for preventing acute hamstring injuries, these results imply that the FLC could be a useful alternative to the NHE as an injury preventing hamstring exercise. This implication is strengthened by Askling et al. [23] who reported an injury preventing effect of inertial flywheel training on the occurrence of hamstring injury among professional soccer players

Although most of the focus has been on eccentric strength, previous research have shown that imbalances in concentric and eccentric hamstring strength may increase the chance of hamstring injury [24]. Exercises that activate the muscles optimally in both actions, could therefore be preferable. To this end, the FLC could have some advantages. During the NHE, all subjects in the present study had to use their arms to push off in the beginning of the concentric movement, which indicates that they were not strong enough to activate the hamstring muscles optimally in the concentric movement. Therefore, it could be argued that the NHE is better for stronger athletes. This argument is supported by a previous study showing the glute-ham raise, a similar exercise to the NHE, to be superior for concentric hamstring activation compared to the leg curl when performed by resistance-trained subjects[17].

Unlike the FLC, the NHE stresses the hamstring both as a knee flexor and as a hip extensor, stabilizing the hip throughout the movement. The role as a hip stabilizer could explain the increased activation in the proximal part of the semitendinosus during the NHE in the eccentric movement. The semitendinosus is morphologically divided into two compartments by a tendinous inscription which anchors the fascicles in the different compartments [25]. Therefore, it could be that the fibers in the upper compartment are more activated during hip movement compared to the knee movement.

The increased activation in the upper phase of the eccentric movement during the FLC could be explained by the function of the muscle. The biceps femoris is inserted at the head of the fibula and therefore being active in the external rotation of the tibia [17]. It has been shown that the tibia moves posteriorly as the knee is flexed [26] and performing an external rotation of the foot during the knee flexion have led to higher activation of the lateral hamstring [27]. Furthermore, the FLC was performed unilaterally making it possible to externally rotate the leg during the movement. However, in the NHE exercise, both ankles were pinned to the floor counteracting such a rotation and hence reducing the neuromuscular stress on the biceps femoris.

There are some limitations with the present study. Only male amateur soccer players were recruited to the study. The results can therefore not necessarily be generalized to elite level players. Moreover, EMG gives only an estimate of the neuromuscular activation of the muscles and there will always be a possibility of crosstalk from neighboring muscles when using surface EMG [28]. There are also some additional methodological challenges when assessing EMG during dynamic contractions such electrode shifting and changes in conductivity in the tissue[29]. However, to mitigate this all data were collected in the same session without having to replace any of the electrodes[29].

Practical applications

Strengthening the hamstring muscles at long muscle lengths appear to be important to avoid injuries in soccer players [2]. The results of the present study suggest that the NHE and the FLC exercises induces relatively similar and high activities at longer muscle lengths in the eccentric movement. However, if the practitioners also want to highlight the lower phase of the concentric movement, the FLC is better. Furthermore, as the NHE uses body weight as loading, it could be less suitable for weaker players, and in the beginning of a program, due to the need for a long recovery period, which could impede soccer training. Conversely, the load in the FLC can be individualized since the principle behind the flywheel equipment is that the energy produced in the concentric movement will eventually be used in the eccentric movement [30]. Therefore, if proper progression is followed, the FLC can be a “gentler” exercise that is suitable for weaker athletes or in the beginning of a training program, or during rehabilitation after injury. Also, performing unilateral exercises have the advantage of stressing each limb more optimally, thus reducing potential differences in strength between the dominant and non-dominant side. However, the time under tension was longer for the NHE which could be of importance for muscular adaptations over time.

In addition, performing the concentric movement of the NHE would require very strong hamstring muscles, and would therefore be reserved for stronger individuals [11], while weaker players use their arms to push past this phase, which could lead to strength imbalances. However, an alternative could be to use elastic bands to assist during the movement, reducing some of the bodyweight, but this would also reduce the load in the eccentric part of the movement.

Conclusion

In conclusion, the NHE and the FLC showed similar activation of the hamstring muscles in the lower phase of the eccentric movement, while the FLC induced higher activation in the concentric phase. Nevertheless, the injury-reducing potential of the FLC should be investigated in intervention studies.

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Figure Legends

Figure 1: The Nordic hamstring exercise (A) and the flywheel inertial leg curl (B).

Figure 2: Normalized electromyographic (EMG) activation of the semitendinosus and the biceps femoris during the Nordic hamstring exercise and the flywheel inertial leg curl in the lower eccentric phase (A) and the lower concentric phase (B). Values are means and 95%CI. * $p < 0.05$, ** $p < 0.01$, a = moderate effect size, b = large effect size. MVC = maximal voluntary contraction