

Research article

Effect of Different Slopes of the Lower Leg during the Nordic Hamstring Exercise on Hamstring Electromyography Activity

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Abstract

The purpose of this study was to examine whether the NHE with an increased lower leg slope angle would enhance hamstring EMG activity in the final phase of the descent. The hamstring EMG activity was measured, the biceps femoris long head (BFlh) and the semitendinosus (ST). Fifteen male volunteers participated in this study. Subjects performed a prone leg curl with maximal voluntary isometric contraction to normalize the hamstring EMG activity. Subsequently, subjects performed the NHE, with the help of a certified strength and conditioning specialist, while the lower leg slope angle were randomly set at 0° (NH), 20° (N20), and 40° (N40). To compare hamstring EMG activity during the NHE variations, the knee flexion angle was set in the range from 0° to 50°, divided into five phases (0–10°, 10–20°, 20–30°, 30–40° and 40–50°), where 0° indicated that the knee was fully extended. To calculate the knee extension angular velocity, the knee flexion angle divided by time, and break point angle (BPA) was the angle at which 10°/s was exceeded. In the statistical analysis, a two-way repeated measures ANOVA was used for the hamstring EMG activity and a one-way repeated measures ANOVA was used for the BPA. The EMG activity of the BFlh and the ST in N20 and N40 was significantly higher than in NH at knee flexion angle of 0–20° ($p < 0.05$). For the BPA, NH ($57.75^\circ \pm 13.28^\circ$), N20 ($36.27^\circ \pm 9.89^\circ$) and N40 ($16.26^\circ \pm 9.58^\circ$) were significantly higher in that order ($p < 0.05$). The results of this study revealed that the NHE with an increased lower leg slope angle shifted the BPA to the lower knee flexion angle and enhanced the hamstring EMG activity in the final phase of the descent.

Key words: Sports injuries, injury recurrence, hamstring muscles, electromyography, rehabilitation exercise, resistance training.

Introduction

Hamstring strain injuries (HSIs) occur in many sports. Eighty-four percent of acute muscle injuries of the lower extremity are HSIs, and 54% of these were grade 2 injuries during the Rio de Janeiro 2016 Summer Olympic Games (Crema et al., 2018). It is known that grade 2 HSIs require approximately 22 days before a return to play (Ekstrand et al., 2012). Moreover, HSIs have a high recurrence rate. Within 25 days of returning to play, more than half of these players will experience a recurrence of HSIs, and about 80% of them will re-injure the same muscle location (Wangenstein et al., 2016). A recent meta-analysis reported that hamstring strain injury (HSI) history appears to be the strongest risk factor for experiencing HSIs (Green et al., 2020). Therefore, in addition to preventing the initial HSIs, it is also important to prevent HSI recurrence.

An HSI is most likely to occur during a sprint (Askling et al., 2014; 2013), especially during the late swing phase (Danielsson et al., 2020). In this phase, the hamstring was considered to be elongated due to shift from the larger knee flexion angle to lower knee flexion angle (Guex and Millet, 2013). In addition, hamstring electromyography (EMG) activity has also been reported as lower in individuals with a history of HSIs (Higashihara et al., 2019). Therefore, resistance training to enhance hamstring EMG activity in the hamstring elongation position may be important in preventing recurrence of HSIs.

The Nordic hamstring exercise (NHE) is recommended for the prevention of HSIs. Previous systematic reviews and meta-analyses have reported that the NHE halves the incidence of HSIs (van Dyk et al., 2019). However, some limitations regarding the prevention of HSIs using the NHE have also been indicated. For instance, even well-trained athletes show a “break point angle (BPA)” when performing the NHE. The BPA is the knee flexion angle at which subjects are no longer able to maintain the required tempo (10°/s) for descent (Lee et al., 2018; 2017). The BPA implies that the hamstring does not go through sufficient eccentric load stimulus in the final phase of the descent. Indeed, it has been suggested that the amount of hamstring EMG activity may reduce after the BPA (Monajati et al., 2017). Individuals with a HSI history may have atrophy of the hamstring and concomitant eccentric strength weakness (Fyfe et al., 2013). Therefore, it is possible that individuals with a HSI history cause BPA to appear early phase of the descent, the hamstring can be unloaded in the final phase of the descent during the standard NHE.

Each muscle in the hamstring possesses different muscle morphologies. For example, between the biceps femoris long head (BFlh) and the semitendinosus (ST), the BFlh tends to be larger than the ST in physiological cross-sectional area (Kellis et al., 2012). In contrast, the ST tends to be longer than the BFlh in fascicle length (Kellis et al., 2012). Furthermore, the change in the internal (muscle) moment arm length with the change in the knee flexion angle tends to be different (Navacchia et al., 2017). Perhaps because of such differences in muscle morphology and internal moment arm length, the BFlh is preferentially recruited in lower knee flexion angle, whereas the ST is preferentially recruited in larger knee flexion angle (Kellis et al., 2017). Since most HSIs occur in BFlh (Askling et al., 2014; 2013), resistance training that eccentric load in lower knee flexion angle is considered important for its prevention.

Recently, Sarabon et al. (2019) investigated the effect of different slopes (0–40°) of the lower leg during the NHE on peak hamstring EMG activity. The results showed that peak hamstring EMG activity was reduced when NHE was performed with an increased lower leg slope angle. However, it is not clear at what angle of the knee flexion angle the peak hamstring EMG activity occurred. If the BPA shifts to lower knee flexion angle by increasing the lower leg slope angle, it may enhance hamstring EMG activity in the final phase of the descent. This also has the potential to preferentially recruit BFlh. Therefore, the purpose of this study was to examine whether the NHE with an increased lower leg slope angle would enhance hamstring EMG activity in the final phase of the descent. In addition, this study also examined whether the NHE with an increased lower leg slope angle shifts the BPA to the lower knee flexion angle. It was hypothesized that the hamstring EMG activity in the final phase of the descent could be enhanced by increasing the lower leg slope angle.

Methods

Experimental approach to the problem

This study adopted a crossover design. The NHE variations were performed using a lower leg slope that can be changed in 5° increments in the range of 0–50°. The lower leg slope angle was randomly set at 0° (NH), 20° (N20), and 40° (N40) (Figure 1). To compare hamstring EMG activity during the NHE variations, the knee flexion angle was set in the range from 0° to 50°, divided into five phases (0–10°, 10–20°, 20–30°, 30–40°, and 40–50°), where 0° indicates the fully extended position of the knee. Furthermore, the NHE variations and five phases compared hamstring EMG activity.

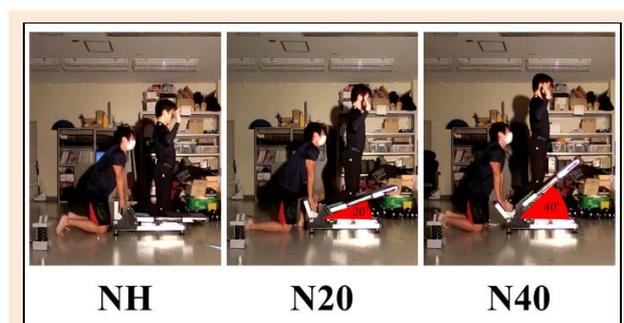


Figure 1. Depiction of NHE variations. Standard NHE was modified by changing the lower leg slope angle (N20: 20°; N40: 40°).

Subjects

The sample size in the present study was determined using G*Power 3.1.3 software (Heinrich Heine University Dusseldorf, Dusseldorf, Germany). It was set as a two-way repeated measure analysis of variance (ANOVA) with a significance level of 0.05 and a power of 0.8. As a result, it was confirmed that a sample size of 12 was sufficient. Hence, 15 male volunteers (age 20.5 ± 1.1 y, height 1.75 ± 0.05 m, weight 69.2 ± 6.5 kg, and resistance training experience 3.1 ± 2.1 y, all measured in mean \pm SD) participated in this study. None of the subjects had previously

experienced an HSI. The NHE was not included in the regular resistance training program, but participants were familiar with this exercise. The study protocol was approved by the institutional review board of Waseda University's ethical committee (approval number: 2020-239), and all procedures in this study were performed in accordance with the Declaration of Helsinki. All subjects were informed of the purpose and procedure of this study, and informed consent was obtained from all subjects.

Procedures

Prior to the experiment, subjects performed 8 repetitions of dynamic hamstring stretching exercise (Inchworm) as a warm-up. Then, surface EMG electrodes were attached to the BFlh and the ST of the dominant leg (defined as the preferred kicking leg). To normalize the EMG activity values for the BFlh and the ST, subjects performed two repetitions of prone leg curl with a maximum voluntary isometric contraction (MVIC) using manual resistance. The knee flexion angle was set at 45° and the subject continued to exert full effort for 3 seconds. After the examiner recorded clean EMG readings of the target muscles during the MVIC, the submaximal NH was used only once as a familiar attempt. The NHE variations were randomly performed two repetitions. Rests between both repetitions and conditions were allowed for at least 3 min. The experiment was conducted under the supervision of an examiner qualified as a National Strength and Conditioning Association Certified Strength and Conditioning Specialist.

Nordic hamstring exercise

Subjects began in a kneeling position with their elbows fully flexed and their hands opened in front of them. The examiner held the subject's ankles securely to the slope while telling the subject to keep their body straight from the head to the knees. The examiner then instructed the subject to lean forward "as slowly as possible." The examiner ensured that they maintained the correct form.

Electromyography

The dominant leg was selected for EMG electrode placement. Subjects were prepared for EMG electrode placement by shaving the hair around the target site and the skin was cleaned with alcohol. The EMG signals of the BFlh and the ST were measured using wireless EMG electrodes (DL-5000 with m-Biolog2, S&ME Inc., Tokyo, Japan) with a bar length of 10 mm, bar width of 1 mm, and distance of 1 cm between active recording sites. The BFlh EMG electrode was placed at the midpoint between the ischial tuberosity and the lateral condyle of the tibia and the ST EMG electrode at the midpoint between the ischial tuberosity and the medial epicondyle of the tibia (Hermens et al., 2000). To determine proper EMG electrode positioning and eliminate crosstalk, BFlh and ST muscle borders were determined using B-mode 2D ultrasonography (fST9600, LEQUIO Power Technology Co., Ltd., Okinawa, Japan). The EMG electrodes were preamplified (10 \times) and linked through the EMG mainframe, which further amplified them (100 \times) to a total gain of 1,000 \times , and band-pass filtered (10–450 Hz) signals. The sampling rate

of the EMG was 1,000 Hz. To achieve accurate electrode placement on each muscle, the examiner palpated the muscle bellies and tested the electrode for a clean EMG reading during a low-intensity leg curl with manual resistance. This study calculated the average root mean square from the EMG activity data during the middle 1 s of the 3 s MVIC. The hamstring EMG activity during the NHE were normalized by the mean of the two MVICs and described as %MVIC. The BFlh and ST EMG ratio (BFlh/ST ratio) was calculated from raw root mean square data by dividing BFlh activity by ST activity (>1 indicates that the BFlh is preferentially recruited). The mean of the %MVIC and BFlh/ST ratio was used for further analysis.

Kinematics

Kinematics data during the NHE variations were recorded using a high-speed camera (EX-F100, Casio Computer Co., Ltd., Tokyo, Japan). The speed of the camera was set to 120 fps, the height to approximately 0.6 m and the camera position to approximately 3 m away from the right side of the subject. Two-dimensional motion analysis was performed on the obtained data using software (Frame-DIAS V, DKH Inc., Tokyo, Japan). The knee flexion angle was calculated by digitizing using the reflection markers attached to the greater trochanter, lateral epicondyle of the femur and lateral malleolus. The line connecting the greater trochanter with the lateral epicondyle of the femur and the line connecting the lateral epicondyle of the femur with the lateral malleolus created an angle that was defined as the knee flexion angle. In addition, the knee extension angular velocity was calculated by dividing the knee flexion angle by time.

Data analysis

The knee flexion angle was in the range from 0° to 50° for the comparison of hamstring EMG activity during the NHE variations. Furthermore, the knee flexion angle was divided into the five phases (0-10°, 10-20°, 20-30°, 30-40° and 40-50°). The hamstring EMG activity and the five phases of knee flexion angle data were synchronized using a trigger mechanism with a synchronization lamp. Figure 2 shows electromyography and kinematics data during the N20. BPA was defined as the angle at which the knee extension angular velocity exceeded 10°/s (Lee et al., 2018; 2017). The mean of the BPA was used for further analysis.

Statistical analysis

Values are expressed as mean \pm SD. First, the Shapiro-Wilk test was used for normal distribution analysis. Second, the effects of the slope (condition factor: NH, N20, and N40) and five phases (angle factor: 0-10°, 10-20°, 20-30°, 30-40° and 40-50°) were statistically tested using two-way repeated measures ANOVA for the hamstring EMG activity and the BFlh/ST ratio. Finally, the effects of the lower leg slope (condition factor: NH, N20 and N40) were statistically tested using one-way repeated measures ANOVA for the BPA. Significant effects were examined using Bonferroni post hoc tests. SPSS version 26 (IBM SPSS, Armonk, NY, USA) was used to perform the analysis. The statistical significance level was set at $p < 0.05$. Partial η^2 was used as an index of effect size, for which small, medium and large effect sizes were designated as 0.0098, 0.0588 and 0.1379, respectively (Richardson, 2011).

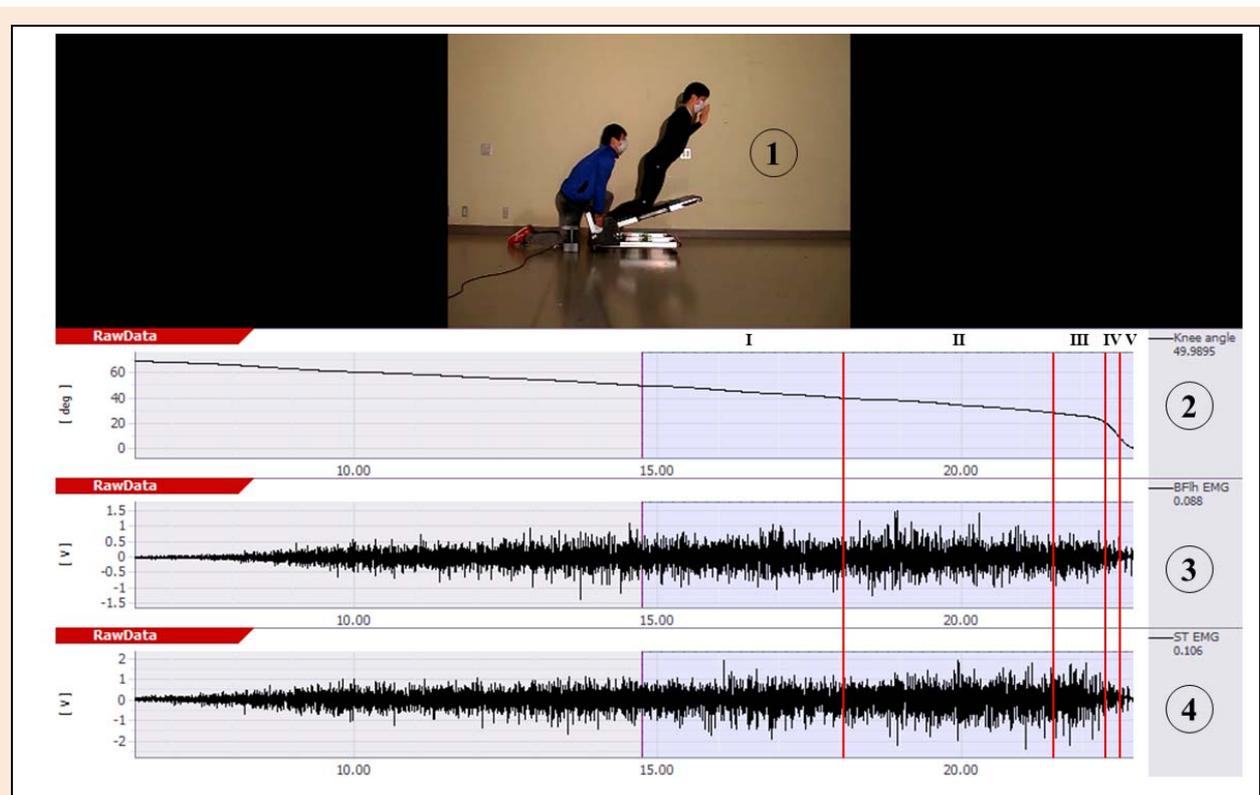


Figure 2. Electromyography and kinematics data during the N20. 1: Knee flexion 50° posture of N20; 2: Knee flexion angle (I: 40-50°; II: 30-40°; III: 20-30°; IV: 10-20°; V: 0-10°); 3: BFlh EMG raw data; 4: ST EMG raw data. The light blue area indicates knee flexion of 0-50°.

Table 1. The hamstring EMG activity and the BF_{lh}/ST ratio in five phases (0–10°, 10–20°, 20–30°, 30–40° and 40–50°) during NHE variations.

	NH	N20	N40	Intra-condition difference	
BF _{lh} (%MVIC)	0-10°	34.5 (21.0) †‡§	44.4 (21.0) †‡§	70.7 (33.7) †	N-20; N-40; 20-40
	10-20°	45.5 (24.2) *‡§	71.8 (28.6) *‡	88.0 (27.7) *§	N-20; N-40
	20-30°	58.5 (32.1) *†§	89.4 (36.0) *†	79.5 (21.4) §	N-20
	30-40°	79.6 (49.8) *†‡	90.1 (27.3) *	52.9 (20.3) †‡	20-40
	40-50°	96.3 (52.9) *†‡	82.2 (20.1) *	25.9 (13.6) *†‡§	N-40; 20-40
ST (%MVIC)	0-10°	21.6 (14.3) †‡§	33.9 (17.0) †‡§	47.9 (26.9) †	N-20; N-40
	10-20°	28.5 (17.1) *‡§	58.7 (31.1) *‡§	68.3 (29.3) *§	N-20; N-40
	20-30°	38.0 (20.7) *†§	77.2 (41.7) *†	69.3 (29.0) §	N-20; N-40
	30-40°	57.9 (31.2) *†‡	82.2 (33.5) *†	49.8 (25.5) †‡	N-20; 20-40
	40-50°	79.1 (41.7) *†‡	75.8 (25.4) *	27.2 (16.1) †‡§	N-40; 20-40
BF _{lh} /ST ratio	0-10°	1.6 (0.9)	1.3 (0.7)	1.3 (0.5) †‡§	
	10-20°	1.4 (0.5)	1.2 (0.6)	1.1 (0.3) §	N-40
	20-30°	1.3 (0.4)	1.0 (0.3)	1.0 (0.3)	N-40
	30-40°	1.2 (0.4)	0.9 (0.2)	0.9 (0.4)	N-20
	40-50°	1.0 (0.3)	0.9 (0.2)	0.8 (0.4)	

The symbols (*0-10°, †10-20°, ‡20-30°, §30-40° and ||40-50°) and abbreviations (N, NH; 20, N20; 40, N40) indicate significant difference ($p < 0.05$).

Results

Hamstring EMG activity and BF_{lh}/ST ratio

Table 1 shows the hamstring EMG activity and the BF_{lh}/ST ratio in five phases during the NHE variations. For the changes in the amount of BF_{lh} EMG activity, the main effects of condition factors were not significant (condition: $F(1,18) = 3.04$, partial $\eta^2 = 0.18$, $p = 0.09$), the main effects of angle factors were significant (angle: $F(1,26) = 22.01$, partial $\eta^2 = 0.61$, $p < 0.001$) and the interaction effect was significant (interaction: $F(1,25) = 24.20$, partial $\eta^2 = 0.63$, $p < 0.001$). For the changes in the amount of ST EMG activity, the main effects of condition and angle factors were significant (condition: $F(2,28) = 9.32$, partial $\eta^2 = 0.40$, $p < 0.01$, angle: $F(1,24) = 36.74$, partial $\eta^2 = 0.72$, $p < 0.001$) and the interaction effect was significant (interaction: $F(2,31) = 22.36$, partial $\eta^2 = 0.62$, $p < 0.001$). For the changes in the BF_{lh}/ST ratio, the main effects of condition and angle factors were significant (condition: $F(2,28) = 8.99$, partial $\eta^2 = 0.39$, $p < 0.01$, angle: $F(1,18) = 9.43$, partial $\eta^2 = 0.40$, $p < 0.001$) but the interaction effect was not significant ($F(3,42) = 0.28$, partial $\eta^2 = 0.02$, $p = 0.84$).

Break point angle

Figure 3 shows the BPA during the NHE variations. The main effects of condition factors were significant ($F(2,28) = 159.61$, partial $\eta^2 = 0.92$, $p < 0.001$). The Bonferroni post hoc test results showed that NH was significantly higher than both N20 and N40 ($p < 0.05$) and that N20 was significantly higher than N40 in BPA ($p < 0.05$).

Discussion

In this study, we examined whether the NHE with an increased lower leg slope angle would enhance hamstring EMG activity in the final phase of the descend. In addition, we also examined whether the NHE with an increased lower leg slope angle shifts the BPA to the lower knee flexion angle. The results of this study revealed that increasing the lower leg slope angle shifted the BPA to the lower knee flexion angle and enhanced the hamstring EMG activity in

the final phase of the descent.

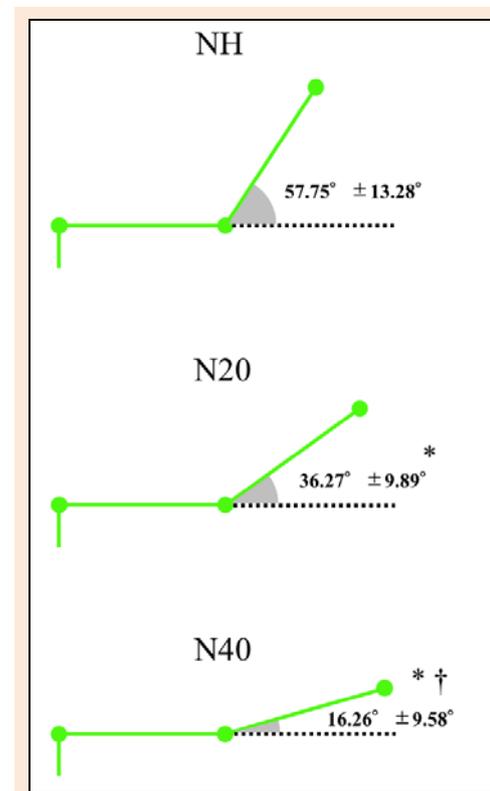


Figure 3. Break point angle during the NHE variations. * Significant difference from NH ($p < 0.05$). † Significant difference from N20 ($p < 0.05$).

The phase of the sprint in which the hamstring is most stretched is the late swing phase (Kennally-Dabrowski et al., 2019). It is the load on the elongated hamstring at this phase that causes the HSIs (Danielsson et al., 2020). Once the HSI occurs, the amount of hamstring EMG activity in the lower knee flexion angle is reduced. This reduction occurs both in the eccentric isokinetic knee flexion testing and in the late swing phase of the sprint (Sole et al., 2011; Higashihara et al., 2019). Therefore, resistance training that increases hamstring EMG activity

in the lower knee flexion angle may be necessary to prevent the recurrence of HSIs. There is previous study to support this hypothesis. Tyler et al. (2017) conducted eccentric isokinetic knee flexion training with hamstring in the elongated position as rehabilitation after the HSIs for those with a history of HSI. Those who participated in the training did not experience a recurrence of the HSIs, whereas 50% of those who did not participate in the training experienced a recurrence within 12 months. Although in the standard NHE it is not possible to apply elongation stress due to the early presence of the BPA (Guex and Millet, 2013), the results of the present study show that the NHE with an increased lower leg slope angle shifted the BPA into the lower knee flexion angle with a concomitant enhances in hamstring EMG activity in the final phase of the descent. Therefore, the NHE with an increased lower leg slope angle may reduce the recurrence rate of HSI more than the standard NHE. In addition, while a bilateral NHE may not apply eccentric load to the leg with HSI (Bourne et al., 2016), a unilateral NHE may further reduce the risk of HSI recurrence. In fact, unilateral eccentric isokinetic knee flexion training has been reported to prevent recurrence (Tyler et al., 2017).

The results of this study showed that only N40 enhanced the BFlh/ST ratio with lowering the knee flexion angle but not for NH or N20 (Table 1). These results suggest that the recruitment of the BFlh may depend not only on muscle morphology and internal moment arm length but also on the magnitude of the eccentric load. Since the majority of HSIs occur in the BFlh (Askling et al., 2014; 2013), this is further evidence that the NHE with an increased lower leg slope angle may be important for HSI prevention.

This study has several limitations. First, all participants were male. Therefore, it is unclear to what extent the use of lower leg slope would change the BPA and the hamstring EMG activity in NHE if the participants were female. Second, we could not adjust for other activities (e.g., sports activities) because fatigue may alter the hamstring EMG activity in NHE.

Conclusion

In this study, we examined whether the NHE with an increased lower leg slope angle would enhance hamstring EMG activity in the final phase of the descend. In addition, we also examined whether the NHE with an increased lower leg slope angle shifts the BPA to the lower knee flexion angle. The results of this study revealed that increasing the lower leg slope angle shifted the BPA to the lower knee flexion angle and enhanced the hamstring EMG activity in the final phase of the descent. The NHE with an increased lower leg slope angle may be an important rehabilitation exercise to prevent recurrence of HSIs.

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Key points

- The NHE with an increased lower leg slope angle enhances the hamstring EMG activity in the final phase of the descent.
- The NHE with an increased lower leg slope angle shifts the BPA to the lower knee flexion angle.
- The NHE with an increased lower leg slope angle may be an important rehabilitation exercise to prevent recurrence of HSI.

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