

Original Research

The Effect of Variations in Knee and Hip Angles on Electromyographic Activity of the Hamstrings and Related Muscles During the Nordic Hamstring Exercise

Taspol Keerasomboon¹, Toshiaki Soga^{2,3,4}, Norikazu Hirose^{5a}¹ College of Sports Science and Technology, Mahidol University, Thailand, ² Graduate School of Sport Sciences, Waseda University, Japan, ³ Graduate School of Engineering and Science, Shibaura Institute of Technology, Japan, ⁴ Research Fellow of Japan Society for the Promotion of Science, Japan, ⁵ Faculty of Sport Sciences, Waseda University, Japan

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Background

The benefit of performing the Nordic Hamstring Exercise (NHE) on an inclined board has been described, however, isometric hamstring activation in different knee and hip angles has not yet been thoroughly explored.

Purpose

This study investigated the effect of variations in knee and hip angles during the isometric performance of the NHE on electromyographic activity of the hamstring muscles.

Study design

Crossover study

Methods

Thirteen male volunteers performed isometric contractions during the NHE with the knee (30°, 50°, 60°) and the hip (0°, 30°, and 45°) in various angles of flexion on a leg support platform which was inclined at 30°. An electrical goniometer was used to monitor the knee and hip joint angles during 5-s isometric contractions. A multivariate analysis of variance with repeated measures was used to compare normalized electromyographic values of each muscle across different knee and hip angles, followed by pairwise comparisons.

Results

The electromyographic activity of the biceps femoris, semitendinosus, and semimembranosus at a knee angle of 30° and hip angle of 0° were significantly higher than those observed with a knee angle of 50° and hip angle of 0°, or a knee angle of 60° and hip angle of 0° ($p < 0.05$). The electromyographic activity of the semimembranosus at a knee angle of 60° and hip angle of 45° was significantly higher than values obtained with knee and hip angles of 60° and 0°, respectively ($p < 0.05$).

Conclusions

The results indicate that using a knee flexion of 30° and a hip flexion of 0°, while isometrically performing the NHE on a platform inclined at 30°, may optimize electromyographic activity of the hamstrings.

a Corresponding author:
Dr. Norikazu Hirose
Waseda University 2-7-5 Higashifushimi,
Nishitokyo city, Tokyo, 202-0021, Japan
E-mail address: toitsu_hirose@waseda.jp

Level of Evidence

3

INTRODUCTION

The Nordic hamstring exercise (NHE) which emphasizes eccentric contraction has been shown to decrease hamstring injuries by 51% in athletes¹ by increasing strength and inducing positive architectural adaptations in the hamstrings by increasing fascicle length.²⁻⁵ Timmins et al. found that soccer players with shorter biceps femoris long head (BFL) fascicle length and weaker eccentric knee flexors have a higher risk of hamstring strain injuries.⁶ However, several previous studies have pointed out the drawbacks of NHE.⁷⁻⁹ For example, only strong athletes who can resist the downward motion of the trunk to a point at which their knees are nearly fully extended are able to derive the full benefits of this exercise.^{10,11} Thus, the majority of individuals are unable to take full advantage of the NHE. Recently, a number of studies have attempted to remove these drawbacks by having participants perform this exercise in an inclined position.^{9,10,12} In these studies, participants were able to achieve greater knee extension angles during the NHE without falling down (losing control of the trunk).^{9,10,12} Although the general advantage of performing the NHE on an inclined plane has been established, the effects of variations in knee and hip angles on hamstring muscular activation during this exercise have not yet been thoroughly examined.

Differences in knee and hip angles during the NHE affect hamstring muscle length.¹³ Knee extension results in lengthening of hamstring muscles, similar to what is observed during the late swing phase of sprinting, which is when hamstring strains are most likely to occur.^{9,14} Electromyography (EMG) has been used to study muscle activation during various hamstring exercises.^{4,5,7,15,16} During exercise, voluntary activation has been identified by EMG activity which indicates both firing rates and motor unit recruitment.⁵ For this reason, EMG has been used for identifying hamstring activation during various hamstring exercises. The results may provide practical information so that professionals can better prescribe appropriate exercises for injury prevention. A prior study examined the effect of changes in muscle length on the EMG activity of hamstring muscle.¹³ A decrease in EMG activity was observed in the semimembranosus (SM) at hip and knee angles of 0° and 90°, respectively, as well as the semitendinosus (ST) at a hip angle of 90° and knee angle of 0° compared to the other two flexed knee positions (45° and 90°).¹³ The results indicated that changing muscle length affects muscle activation of the hamstrings. In addition, trunk muscles attached to pelvis control length changes of hamstring muscle during NHE. A previous study showed that an isometric contraction of the erector spinae (ES) is necessary for maintaining an optimal standing position.¹⁷ Moreover, rectus abdominis (AD) and hip extensor muscles contribute to spinal stability by contributing to posterior pelvis tilting while back extensor and hip flexor muscles contribute to anterior pelvis tilting, which creates force

couples to affect spinal stability.¹⁸ Thus, coactivation of musculature in force couples is crucial to maintaining a neutral pelvis tilt and lumbar lordosis.¹⁹ Consequently, ES and AD muscles, involved in natural hamstring exercises (NHE), must activate alongside a displacement of the center of gravity. These muscles, acting against the force of gravity through isometric contractions, play a crucial role in maintaining an upright posture.²⁰ Furthermore, the gluteus maximus (Gmax) plays an important role in stabilizing the pelvis which helps to provide the proper conditions for optimal hamstring contraction.^{20,21} If there is a weakness of any of the related muscles acting on a joint, increased muscle activation of another synergist muscle may be induced, which may lead to muscle strain.²⁰ Thus, it is important to examine the activity of Gmax, ES and AD during different knee and hip angles during NHE.

Whether isometric and eccentric exercises have differing effects on hamstring strengthening remains controversial.²² As the hamstrings exhibit a predominantly isometric action during the swing phase, isometric exercises may replicate activities that occur during high-speed running.²² In addition, some athletes position their trunk so far forwards during the NHE that they nearly contact the ground; the short-term maintenance of this position is attributed to isometric contraction.

While prior studies have reported a range of knee and hip angles for the activation of hamstring activity,^{9,10,12,23} the effects of specific variations in knee and hip angles during the NHE have not yet been investigated. Therefore, the purpose of this study was to investigate the effect of variations in knee and hip angles during the isometric performance of the NHE on EMG activity of the hamstring muscles.

METHODS

PARTICIPANTS

The sample size was determined using G*Power 3.1.3 software (Heinrich Heine University Dusseldorf, Dusseldorf, Germany) for a MANOVA repeated measure analysis of variance (ANOVA) with a significance level of 0.05 and a power of 0.9. As a result, it was confirmed that a sample size of 12 was required. Therefore, to account for potential dropouts, thirteen recreationally active male volunteers who performed aerobic activities at least twice a week were recruited to participate in this study. None of the subjects had previously experienced a hamstring strain injury or had a surgical history.

MEASURES

DESIGN AND PROCEDURES

Prior to EMG electrode placement, hair around the target site was shaved and the skin was disinfected with alcohol. The six target muscles (biceps femoris [BFL], ST, SM, gluteus

maximus [GM], rectus abdominis [AD], and erector spinae [ES]) were evaluated with 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 EMG electrodes were pre-amplified (10X) and linked through the EMG mainframe, which provided further amplification (100X) to a total gain of 1,000X; signals were band-pass filtered (20–500 Hz). The EMG electrodes were placed on the dominant limb, targeting each muscle using following landmarks: midpoint between the ischial tuberosity and the lateral epicondyle of the tibia (BFL); midpoint of the line between the ischial tuberosity and the medial epicondyle of the tibia (ST); on the line between the medial condyle of the tibia and ischial tuberosity (SM); mid-point between the sacral vertebrae and the greater trochanter (GM); two finger-widths lateral from the spinous process of the L1 vertebra (ES); and two finger-widths lateral from the midline of the umbilicus (AD). Electrodes were placed parallel to the lines between these landmarks, as recommended by the SENIAM guidelines.²⁴ To achieve accurate electrode placement on each target muscle, the examiner palpated the muscle bellies and tested them to confirm that clear EMG signals could be obtained during muscle contraction. This study reduced the root mean square (RMS) from the raw EMG data during the middle 2 sec of the 5 sec exercise for further analysis.

The participants then performed maximal voluntary isometric contractions (MVICs) of the hamstrings, in prone, at knee flexion angles of 30°, 45°, and 90° and hip 0°. The GM, ES, and AD were assessed during hip extension with the knee flexed at 90°, and trunk extension and trunk flexion in the supine position, respectively. These MVIC positions have been used in previous studies that investigated the EMG activity of the hamstring muscles.^{23,25,26} Each MVIC protocol was performed for two bouts of 5 seconds. The EMG values were collected during each MVIC protocol. The maximum EMG value for each muscle was used to normalize EMG values recorded during the modified NHE exercises.

Following completion of the MVIC protocol, participants performed two rounds of the modified isometric NHE on a leg support platform inclined at 30°. The isometric NHE comprised different combinations of three different knee and hip flexion angles: knees at 30° with hips at 0°, 30°, and 45°; knees at 50° with hips at 0°, 30°, and 45°; and knees at 60° with hips at 0°, 30°, and 45°. An electrical goniometer was used to monitor knee and hip joint angles during the isometric NHE. Participants were strictly instructed to position their knees and hips at the aforementioned angles on the inclined leg support platform; their legs were subsequently stabilized by strapping them with a band attached to the platform. Participants were then instructed to maintain each of the set positions for 5 seconds.

STATISTICAL ANALYSIS

The average EMG value (\pm standard deviation) for each exercise was calculated. The RMS data were normalized as a percentage of the maximum isometric values (normalized

EMG [nEMG]). A multivariate analysis of variance with repeated measures was used to compare the nEMG of each muscle across different knee and hip joint angles. When a simple main effect was found, the Tukey post-hoc test was used to measure any differences. All statistical analyses were performed using SPSS for Windows (version 25.0; IBM Corp., Armonk, NY, USA). The statistical significance level was set at $p < 0.05$.

RESULTS

Thirteen recreationally active male volunteers participated in this study (mean age, 25.1 ± 2.1 years; height, 1.72 ± 0.05 m; and body mass, 72.7 ± 11.9 kg).

EMG ACTIVITY IN THE HAMSTRING MUSCLES (BFL, ST, SM)

The nEMG values of the hamstring muscle group and other related muscles recorded during the isometric NHE are shown in [Figure 2](#). There was a significant main effect of knee angle for the following muscles: BFL (knee, $F[2,12]=125.43$, $p < 0.05$); ST (knee, $F[2,12]=82.63$, $p < 0.05$), and SM (knee, $F[2,12]=136.02$, $p < 0.05$). However, hip angle did not have a significant main effect for BFL (hip, $F[2,12]=0.95$, $p=0.392$), ST (hip, $F[2,12]=0.27$, $p=0.766$), or SM (hip, $F[2,12]=1.93$, $p=0.153$). The interaction effect between knee and angle was significant for BFL (interaction, $F[4,12]=6.68$, $p < 0.05$), ST (interaction, $F[4,12]=3.81$, $p < 0.05$), and SM (interaction, $F[4,12]=7.12$, $p < 0.05$).

The nEMG values obtained with the hip at 0° and the BFL, ST, and SM at K30H0 were significantly higher than those observed with the knee at K50H0 and K60H0 ($p=0.032$). With the hip at 30°, the nEMG values of BFL and ES at K30H30 were significantly higher than those at K50H30 and K60H30; exceptions included nEMG values of ST and SM at K30H30, which were only significantly higher than the value obtained at K60H30 ($p=0.01$). With the hip at 45°, nEMG values of BF and SM at K30H45 were significantly higher than those at K60H45 ($p=0.046$).

EMG ACTIVITY IN THE RELATED MUSCLES (GM, ES, AD)

The knee angle had a significant main effect for ES (knee, $F[2,12]=44.48$, $p < 0.05$), GM (knee, $F[2,12]=28.47$, $p < 0.05$), and AD (knee, $F[2,12]=20.14$, $p < 0.05$); however, there was no significant main effect of hip angle for ES (hip, $F[2,12]=0.81$, $p=0.447$), GM (hip, $F[2,12]=0.04$, $p=0.960$), or AD (hip, $F[2,12]=1.27$, $p=0.286$). The interaction effect between knee and angle was significant for ES (interaction, $F[4,12]=1.82$, $p < 0.05$). However, there was no significant interaction effect for GM (interaction, $F[4,12]=1.82$, $p=0.134$) or AD (interaction, $F[4,12]=0.53$, $p=0.712$).

The nEMG value of ES at K30H0 was significantly higher than that at K50H0 and K60H0 ($p < 0.001$). With the hip at 30°, the nEMG value of ES at K30H30 was significantly higher than that at K50H30 and K60H30 ($p=0.004$).

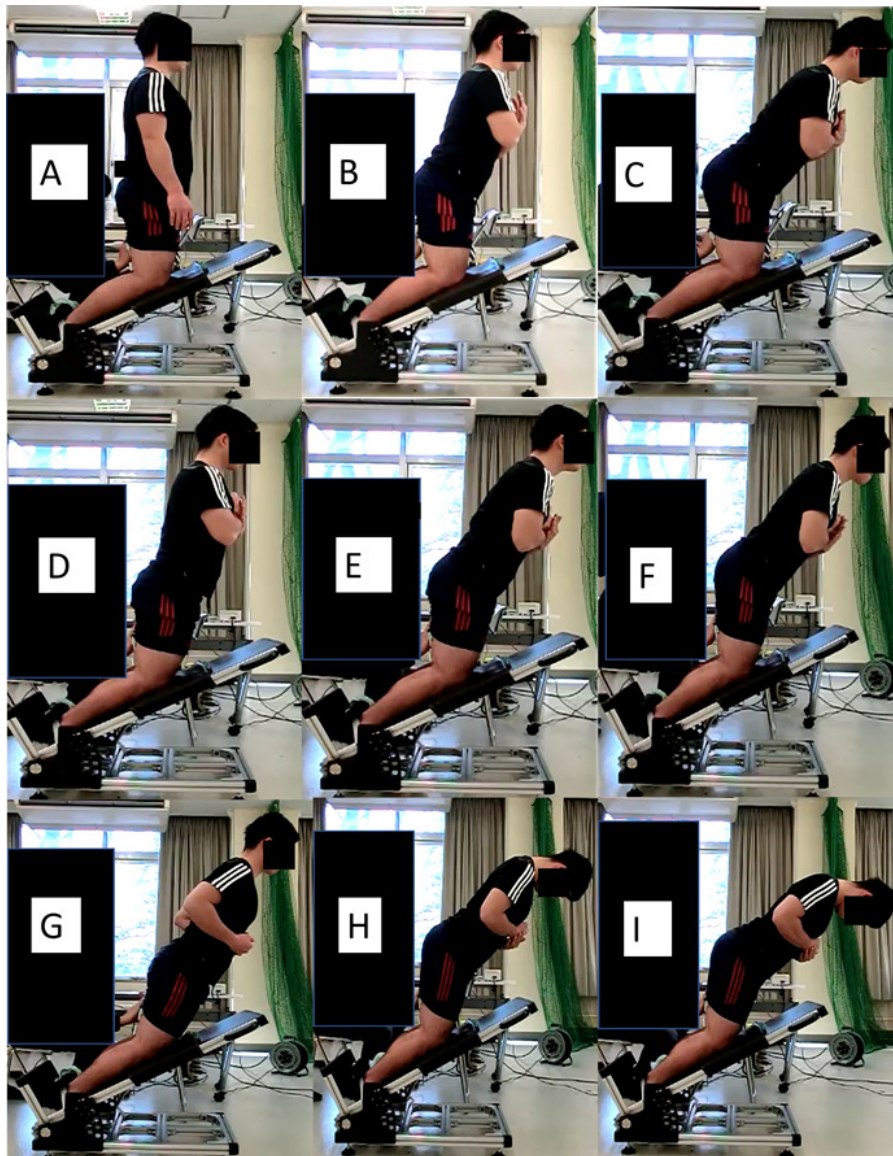


Figure 1. Nordic hamstring exercise on a leg support platform inclined at 30° during isometric contractions: A) K60H0 B), K60H30, C) K60H45, D) K50H0, E) K50H30, F) K50H45, G) K30H0, H) K30H30, I) K30H45.

DISCUSSION

In this study, differences in the EMG activation of the hamstring muscles (BFI, ST, and SM) and related muscles (ES, GM, and AD) were investigated, using variations in knee and hip angles during the isometric NHE, which was performed on a support platform inclined at 30°. The results indicated that the EMG activities of the hamstrings and ES were greater at knee and hip flexions of 30° and 0°, respectively, compared to other positions. This is the first study to examine isometric contraction at various knee and hip angles, while performing the NHE on a support platform inclined at 30°. The current results are consistent with those that showed that an increase in the angle of the lower leg (from 0° to 20° and 40°) resulted in a higher hamstring EMG activity in the final descent phase of the NHE.¹⁰ This might be explained by the fact that when the knee is extended further, the spine angle relative to the horizontal increases. As a result, the force of gravity shifts away from the cen-

ter of rotation of the trunk, leading to an increase in the gravity force over the lever arm.^{11,12} Isometric contraction of the hamstrings and ES are required for joint stabilization, which counteracts the gravitational force and prevents flexion of trunk.²⁰ In addition, the current results showed no difference in EMG activity between BFI and ST, which is consistent with the findings of Hirose et al. who found that BF and ST muscle activities were equivalent when a shallow knee flexion angle was used during the NHE on an inclined platform.¹²

While a decrease in hamstring EMG activity was observed when the hip angle was increased while keeping the knee angle constant at 30°, this did not reach a statistically significant difference. This may be attributed to a decrease in the hip angle when the hip is flexed, which shifts the center of gravity closer to the knee. In addition, EMG activity at a hip angle of 30° was higher than that at 45° when the knee angle was set at 50° or 60°. This is supported by the results of Mohamed et al. which reported decreases in the

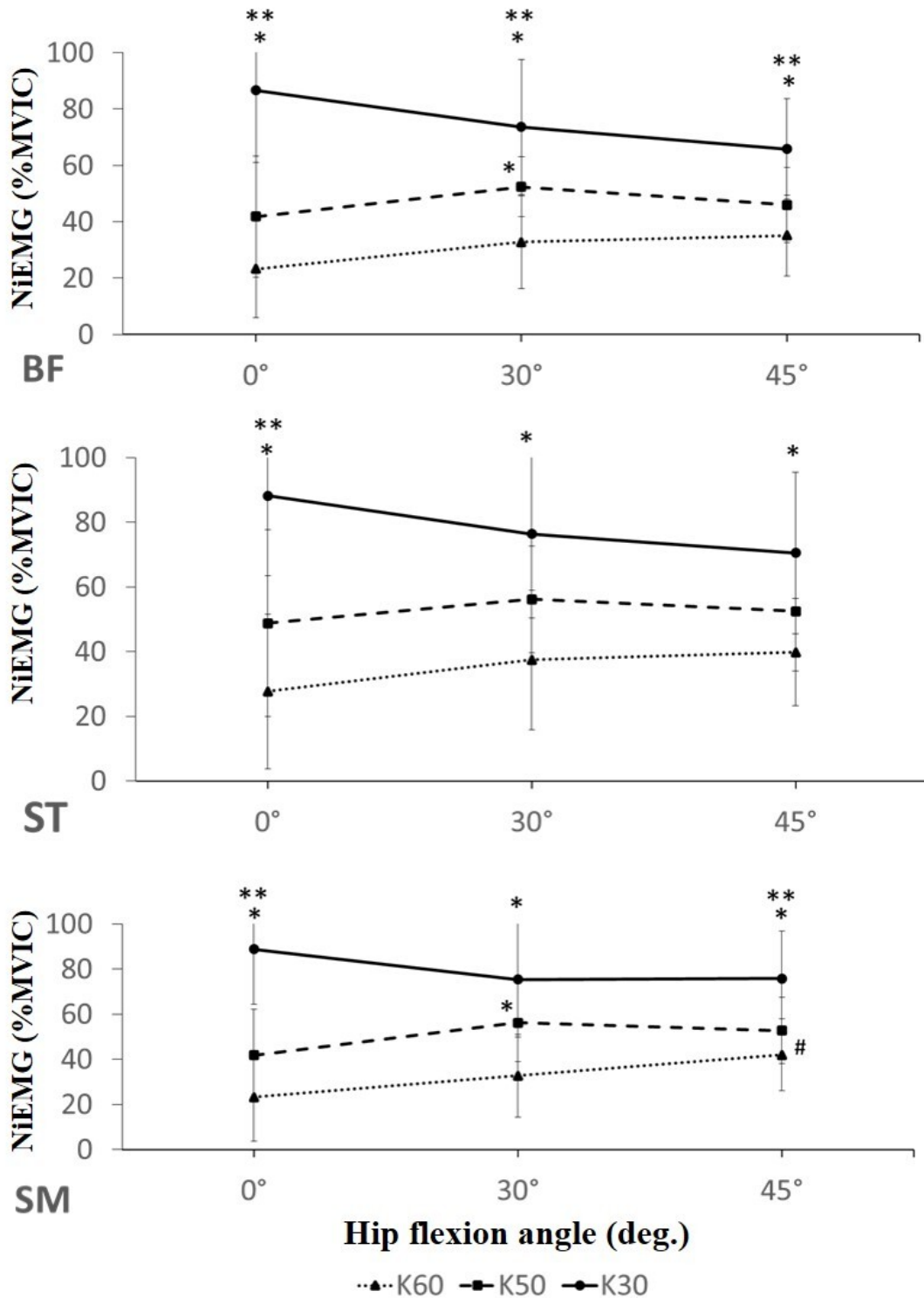


Figure 2. Differences in nEMG (%MVIC) activity (Y axis) during knee flexion (30°, 50°, 60°) and hip flexion on the X axis (0°, 30°, 45°) in the BF, ST, SM, muscles during isometric NHE on a leg support platform inclined at 30°. The symbol * indicates a statistically significant difference between 60° and other angles. The symbol ** indicates a statistically significant difference between 50° and other angles. The symbol # indicates a statistically significant difference between a hip angle of 0° and other angles

BF=biceps femoris; ST=semitendinosus; SM=semimembranosus; ES=erector spinae; GM=gluteus maximus; AD= rectus abdominis; MVIC= maximal voluntary isometric contractions; NHE=Nordic hamstring exercise; nEMG=normalized electromyographic activity. K30= knee flexed to 30°, K50= knee flexed to 50°, K60= knee flexed to 60°.

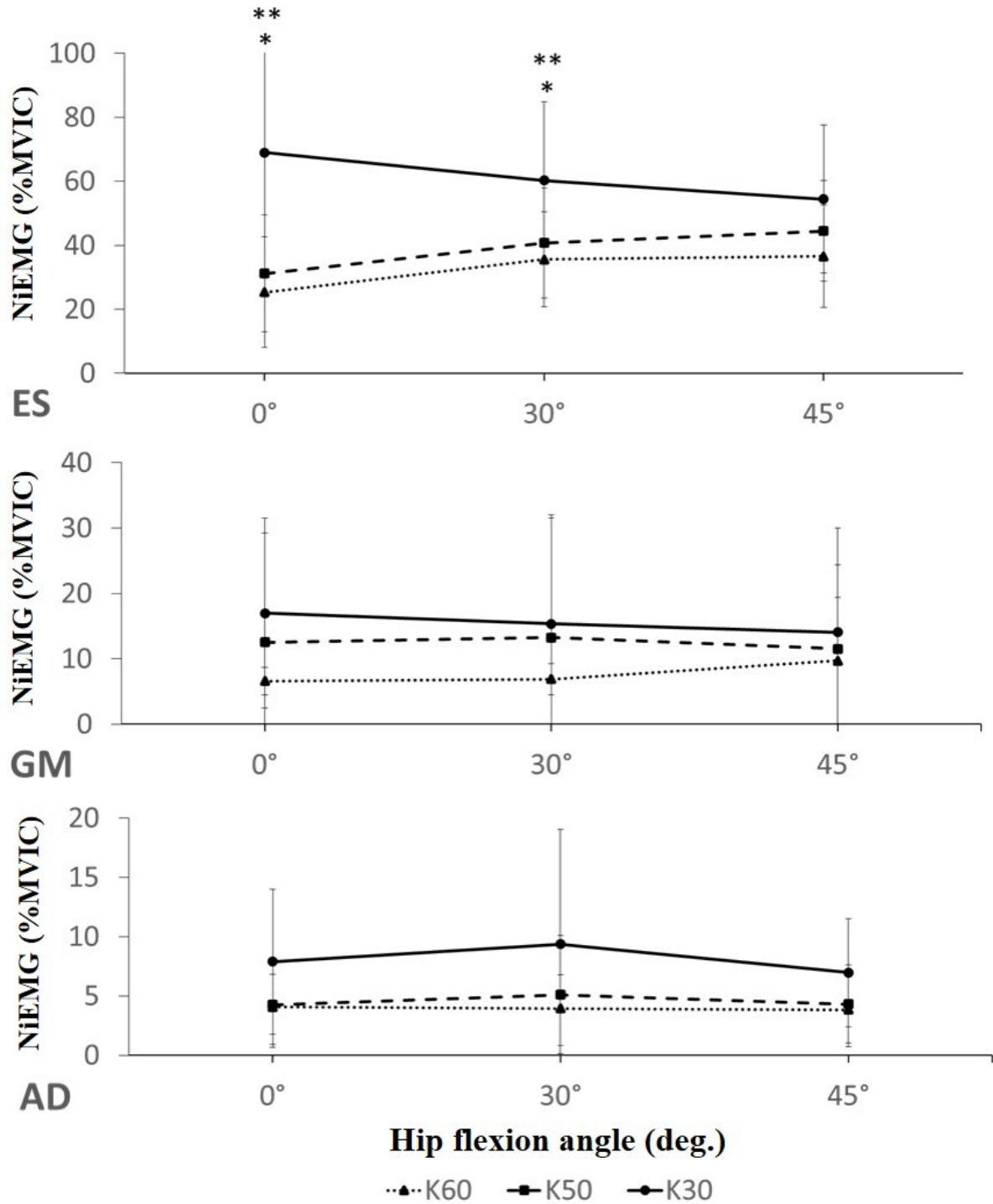


Figure 3. Differences in nEMG (%MVIC) activity during knee flexion (30°, 50°, 60°) and hip flexion (0°, 30°, 45°) in the ES, GM, and AD muscles during isometric NHE on a leg support platform inclined at 30° The symbol * indicates a statistically significant difference between 60° and other angles. The symbol ** indicates a statistically significant difference between 50° and other angles. The symbol # indicates a statistically significant difference between a hip angle of 0° and other angles

BF=biceps femoris; ST=semitendinosus; SM=semimembranosus; ES=erector spinae; GM=gluteus maximus; AD= rectus abdominis; MVIC= maximal voluntary isometric contractions; NHE=Nordic hamstring exercise; nEMG=normalized electromyographic activity; K30= knee flexed to 30°, K50= knee flexed to 50°, K60= knee flexed to 60°.

activities of ST when subjects were in a sitting position (hip at 90°), with their knees at 0°; a decline in the EMG activity of SM was also observed when this muscle was at the most shortened position.¹³ These findings can be explained by the interaction between muscle length and the anatomical location of its tendon.¹³ When the knee is fully extended, the ST tendon lies very close to the axis of the knee joint, providing a poor lever arm for knee flexion. This suggests its ineffectiveness as a knee flexor; in addition, the muscle is elongated at both of the two joints it crosses. The interaction of these two factors may have caused the observed decline in EMG activity. Another possible explanation is that the decrease in EMG activity was due to the movement of the recording electrodes may move away from the center of the muscle belly closer to its tendon.²⁷ Prior studies have shown that intramuscular electrodes may move upon muscle contraction.²⁸

In terms of the related muscles, the ES muscle activity was substantial when performing variations of NHE with the knee angle at 30°. This is consistent with the results of a previous study, which showed that despite the knee extension angle, ES activation was higher than GM and AD.²⁰ This was attributed to a decrease in the hip extension torque which relative to Gmax activity, the ES makes a larger contribution towards counteracting of gravitational forces and the maintenance of an erect trunk position and hip extension torque. While isometric abdominal contractions help to maintain the erect position of the spine during the NHE, the posterior hip and trunk muscles are activated upon a shift in the center of gravity; thus, both are responsible for the maintenance of an erect posture during the NHE.

This study had several limitations. First, the NHE was examined on a board that was only inclined at 30°; boards inclined at other angles may have yielded different outcomes. Secondly, surface electrodes may have moved during contraction and between angles with respect to the

tendons and the innervation zones, which is a typical limitation of surface EMG. Potential cross-talk may also have existed between the hamstring muscles. This study only recruited and studied males, so results cannot be expected to be the same for females. Finally, the sample size, although having met power calculations is relatively small. Further studies are required to determine the effect of variations in the angle of the support board, and for female athletes.

CONCLUSION

Among the different tested combinations of knee and hip angles, the result of this study indicate that a knee extension of 30° and hip angle of 0° during isometric NHE on a platform inclined at 30° were associated with the highest nEMG activity values in the hamstring and ES muscles. Thus, the authors' suggest using a knee flexion angle of 30° and hip flexion angle of 0° to optimize the training stimulus for the hamstring during the isometric NHE.

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CONFLICTS OF INTEREST

The authors report no conflicts of interest regarding the material discussed in the manuscript.

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