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**Research article**

# Biceps Femoris Muscle is Activated by Performing Nordic Hamstring Exercise at a Shallow Knee Flexion Angle

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## Abstract

The semitendinosus (ST) muscle is primarily used during Nordic hamstring exercise (NHE), which is often prescribed for preventing hamstring injury, though the biceps femoris long head (BFlh) muscle that is more susceptible to injuries. Thus, this study aimed to identify the modulation of BFlh muscle activity with different knee flexion angles during NHE using an inclined platform. Fourteen male athletes performed NHE and maintained their position at maximum inclination (NH). Subjects also performed isometric NHE using a platform inclined to 50° (ICL) and 40° (ICH), and the knee flexion angle was controlled to 50° and 30°. The electromyography (EMG) activity of the BFlh, ST, semimembranosus, gluteus maximus, elector spinae, and rectus abdominus muscles was determined during each exercise. The EMG of the ST was higher than that of the BFlh during NHE and the highest of all muscles in all exercises ($p < 0.05$). Moreover, the activity of the BFlh tended to be higher than that of the ST for ICH than for ICL, regardless of the knee joint angle. The activity of the BFlh becomes equivalent to that of the ST during NHE at a knee flexion angle of less than 50°. These results indicate that performing NHE at a shallow knee flexion angle will enhance the activity of the BFlh muscle.

**Key words:** Electromyography, physical conditioning, preventive medicine, muscle strain injury.

## Introduction

Hamstring strain injury (HSI) is one of the most common injuries during various sports events, such as track and field athletics (Yeung et al., 2009), soccer (Ekstrand et al., 2011), and rugby (Brooks et al., 2006). In addition to its high incidence rate, HSI has a high recurrence rate of approximately 30% (Heiser et al., 1984; Orchard and Best, 2002). Thus, preventing initial and recurrent HSI is necessary for improving athletic performance.

HSI commonly occurs during the late swing phase of high-speed running (Schache et al., 2009), and its incidence rate during sprinting can reach 70% in soccer players (Ekstrand et al., 2012) and 93% in sprinters (Askling et al., 2014). In cases of sprint-type HSI, the biceps femoris long head (BFlh) muscle is more vulnerable than both of the other biarticular hamstring muscles, which are the semitendinosus (ST) and semimembranosus (SM) muscles (Brosseau et al., 1997; Ditroilo et al., 2013). HSI mostly occurs in the BFlh muscle during the terminal phase of the leg swing and/or during the initial stance phase. During the late swing phase, the electromyographic (EMG) activity of the BFlh muscle is greater than that during other phases (Higashihara et al., 2015). The EMG activity of the BFlh is also higher than that of the ST during the initial stance phase (Higashihara et al., 2018). In addition to its high muscular work rate, the length of the BFlh muscle peaks during the late swing phase and develops maximal force while undergoing a forceful eccentric contraction to decelerate the shank for the foot strike (Chumanov et al., 2011). These BFlh muscle dynamics during sprinting are thought to represent the possible mechanism of HSI.

The key concept for preventing sprint-type HSI has been the development of eccentric strength contractions in hamstring muscles (Petersen et al., 2011; Opar et al., 2015; Van Der Horst et al., 2015; Timmins et al., 2016). Nordic hamstring exercises (NHE) are usually prescribed as warm-up exercises and for rehabilitation to prevent HSI. A number of studies have provided evidence that NHE prevents HSI by improving eccentric strength (Brooks et al., 2006; Gabbe et al., 2006; Arnason et al., 2008; Petersen et al., 2011) and elongating the fascicle length of the BFlh muscle (Bourne et al., 2017a).

Contrary to these studies, several studies have implied that NHE is insufficient for preventing HSI. A reason for this might be that the ST muscle is more activated than the BFlh muscle during NHE, though the BFlh muscle is more vulnerable to injury (Fernandez-Gonzalo et al., 2016; Bourne et al., 2017b; 2018; Messer et al., 2017). To date, many studies have suggested that the dominant articulation during exercise influences the activation of each hamstring muscle. Hip-dominant exercises, such as 45° hip extension (Bourne et al., 2017b; Bourne et al., 2018) and the Romanian dead lift (Ono et al., 2011), activate the BFlh muscle more than knee-dominant exercises, such as NHE and leg-curl exercises (Ono et al., 2010; Bourne et al., 2018). In contrast, other recent studies have reported that the BFlh muscle is activated even during knee-dominant exercises, such as leg curls (Hirose and Tsuruike, 2018) and NHE, more than the ST muscle (Hegyi et al., 2019). One of the possible factors for these discrepant findings involves knee joint angle and muscular length during exercises. Heygi et al. found that the EMG activity of the BFlh muscle was higher than that of the ST muscle during later phases (94% to 98%) during NHE, meaning that the EMG of BFlh muscle is higher than that of the ST muscle at a shallow knee flexion angle during NHE (Hegyi et al., 2019). Similarly, Hirose and Tsuruike reported that the BFlh muscle works more at a knee flexion angle of 30° during a prone leg curl exercise than the ST muscle, while the ST muscle works more than the BFlh muscle at knee flexion angles of 90° and 120° (Hirose and Tsuruike, 2018). Furthermore, the result of previous study indicates that the greater EMG activity of the ST relative to the BFlh muscles decreases when the length of hamstring muscles is elongated by

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maintaining increased hip flexion during NHE (Šarabon et al., 2019).

In contrast, previous studies of knee-dominant exercises averaged the EMG activity obtained from a whole range of motion during exercise (Ono et al., 2010; Bourne et al., 2017b). However, in cases of NHE, many subjects have a break-point angle, which indicates that they are not able to maintain muscular contraction up to a shallow knee flexion angle (0° knee flexion angle). Even trained soccer players can maintain eccentric contractions until reaching a knee flexion angle of approximately 40°(Lee et al., 2018). However, the break-point of male college students was at a knee flexion angle of only approximately 60° (Ditroilo et al., 2013).

These findings led us to hypothesize that the BFlh muscle might become more activated than the ST muscle, even during NHE, by modulating the knee flexion angle. Particularly, we considered that the activity of the BFlh muscle might exceed that of the ST muscle at a shallow knee flexion angle. Thus, the primary purpose of this study was to investigate the activity of the BFlh muscle compared to that of the ST and SM muscles during conventional NHE and knee-angle modulated NHE, and clarify the angle-relationship of muscular activity for each of the hamstring muscles in isometric contractions during NHE. As a secondary aim, we investigated the differences in activity of each hamstring muscle at different exercise intensities by changing the platform inclination.

## Methods

This study was designed as a controlled laboratory study. All data were collected from August 20 to September 17, 2019, in the Faculty of Sport Sciences, Waseda University.

### Participants

The subjects in this study were 14 amateur male athletes who engaged in strength training at least twice per week (age: 21.2 ± 1.5 years; height: 170.0 ± 4.1 cm; weight: 65.6 ± 4.9 kg). Prior to recruitment, the sample size was analyzed (G*Power 3.1.9.4, Heinrich Heine Universität Düsseldorf, Germany). An F test and repeated-measures analysis of variance of three groups (BFlh, ST, and SM muscle groups, in which the gluteus maximus (GM), erector spinae (ES), and rectus abdomens (RA) were analyzed with five exercise variations) was conducted, given an effect size of 0.25, α error probability of 0.05, and a power of 0.95, with a correlation among repeated measures of 0.5 and a nonsphericity correlation ε of 0.1. The total sample size required was 39, with 13 subjects per group. Consequently, we additionally recruited 16 male volunteers from college sports club teams from August 5 to September 4, 2019. The exclusion criteria were as follows: having a history of HSI and anterior cruciate ligament injury at the measured limb, a recent history of lower limb injury within 6 months prior to the experiment, and a current history of lower back and hip pain. This study was approved by the ethics committee of the Waseda University (Approval No. 2019-171). Subjects were fully informed about the study and provided written informed consent.

### Experimental protocol

Subjects were prohibited from performing exhausting physical activity that may affect NHE performance for 24 h prior to the experiment. Before experimental exercise, subjects performed approximately 5 min of warm-up (static and dynamic stretch on hamstrings, hip, and lower back for 2 min, respectively; 10 repetitions of prone knee curl). Then, subjects performed two bouts of 5 s maximum isometric contraction (MVIC) with monitoring by a handheld dynamometer (MT-100W, SAKAI medical Co., Tokyo) in the prone leg curl with knee flexion angles set at 30°, 60°, and 90°, hip extension, back extension, and sit-up to collect the maximum EMG data for calculating normalized EMG activity. Subjects performed two bouts of 5 s isometric NHE followed by isometric NHE using the customized inclined platform (IC), with inclination set at 50° (low intensity; ICL) and 40° (high intensity; ICH) (Figure 1). When performing ICL and ICH, the knee flexion angle was set at 50° (ICL50, ICH50) and 30° (ICL30, ICH30). In such cases, the knee angle shows an anatomical angle, and an angle of 0° of knee flexion indicates an extended knee. Subjects had at least 40 s between each bout and 2 min between exercises for resting. The order of the knee flexion angle and inclination of the platform was randomly assigned to minimize motor learning and fatigue effects.

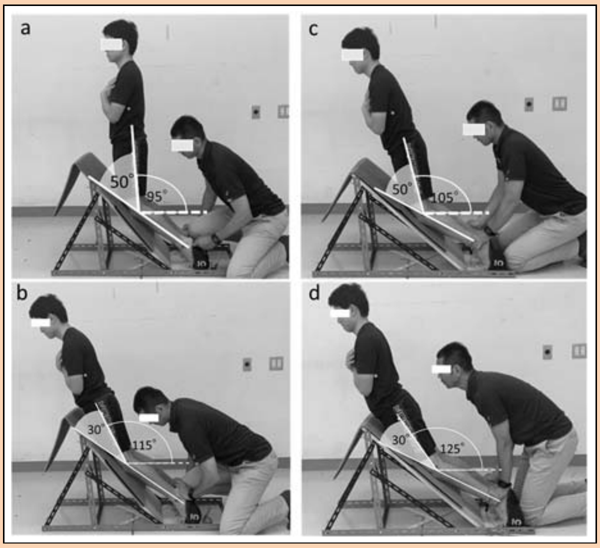


**Figure 1. Performing Nordic Hamstring exercise while using an incline platform. Each figure shows ICL50 (a), ICL30 (b), ICH50 (c), and ICH30 (d).** The knee joint angle and trunk angle compared to the arbitrary horizontal line are shown in each figure. Note: Thin and trunk angles compared to the ground differ among subjects because of the difference in subjects' length of foot and tibia while the difference was very small.

When performing NHE, the subject kneeled with their ankle and hip set at 0°, and both knees were placed on the folded stretch mat at hip-width. The examiner held the subject's ankle while pressing their knees on the subject's plantar surface; then, the subject leaned forward as far as they could while maintaining a position in which their arms crossed across their chest for 5s. The examiner started to record EMG data when subjects started leaning forward, then ended recording when subjects finished keeping their upper body for 5 s.

When performing ICL and ICH, subjects kneeled on the inclined platform to maintain their upper-body at a vertical position to the floor with their toes of both feet placed approximately 10 cm from the end of the inclined platform, both knees at hip-width, hips set at an angle of 0°, and arms crossed across their chest. An examiner stabilized the subject while holding the ankle and pressing the foot stabilizer pad on the subject's plantar surface, and another examiner put the stationary arm of the manual goniometer, which was set at 130° (50° of knee flexion) of 150° (30° of knee flexion) on the fibula (the line between lateral malleolus and fibular head). Then the subject leaned forward from an initial position to a position where the thighs (the line between lateral condyle and greater trochanter) reached at the moving arm; this position was kept for 5 s. The examiner started to record EMG activity when subjects started to lean forward their upper-body, then ended recording when subjects finished keeping their upper-body in that position. We used EMG data during 5 s from the end of recorded EMG data (Figure 2).

In this experimental condition, the angle of the tibia to the floor was influenced by the length of the foot and the tibia. However, the individual difference in foot size (average: 27.0 ± 0.5 cm, range; 26.5 to 28.0 cm, coefficient of variation; 1.9%, 95% CIs; 26.6 to 27.3 cm) and tibial length, measured between the proximal and distal medial malleolus of the tibia (36.2 ± 0.6 cm, 35.2 to 37.4 cm, coefficient of variation; 1.7%, 95% CIs; 35.8 to 36.6 cm), was not remarkable.

During the prone leg curl, NHE, and inclined NHE, the knee flexion angle was monitored using a handheld goniometer. The stationary arm and the moving arm were placed on the skin according to a tape marker placed on a greater trochanter, and the prominence of the femoral lateral condyle, the fibular head, and the lateral malleolus was assessed. Examiners also visually confirmed if the hip joint angle was set at a neutral position in the sagittal and horizontal planes. If the hip angle was not kept at a neutral position, the subject performed an additional trial.

## EMG

EMG activities of the BFlh, ST, and SM muscles, GM, ES, and RA were measured using pre-amplified bipolar surface electromyogram silver electrodes with a bar length of 30 mm, a width of 1 mm, and a distance of 20 mm between active recording sites (Biolog DL-5000, S & ME Co., Tokyo, Japan). EMG electrodes were routed through the EMG mainframe, which amplified (100 ×) and band-pass filtered (20-500 Hz) the signals and digitized them at a 2 kHz sampling rate. Skin impedance was reduced by shaving the hair around the electrode site and wiping the skin with rubbing alcohol before applying electrodes. Electrodes were placed on each target muscle based on the following landmarks: the midpoint of the line between the ischial tuberosity and the medial epicondyle of the tibia (for the ST), the midpoint between the ischial tuberosity and the lateral epicondyle of the tibia (for the BFlh), the midpoint between the sacral vertebrae and the greater trochanter (for the GM), two finger-widths lateral from the spinous process of the L1 vertebra (for the ES), and 2 cm lateral from the midline of the umbilicus (for the RA). Additionally, the accurate placement of the electrodes was validated by the palpation of the muscle bellies by two skilled healthcare specialists (certified athletic trainers) and by ensuring that a clean EMG signal was measured from each muscle. This study redacted the root mean square (RMS) from raw EMG data during the middle 2 s of the 5 s exercise for further analysis. Then, RMS data were normalized as a percentage of the maximum isometric values (NEMG).

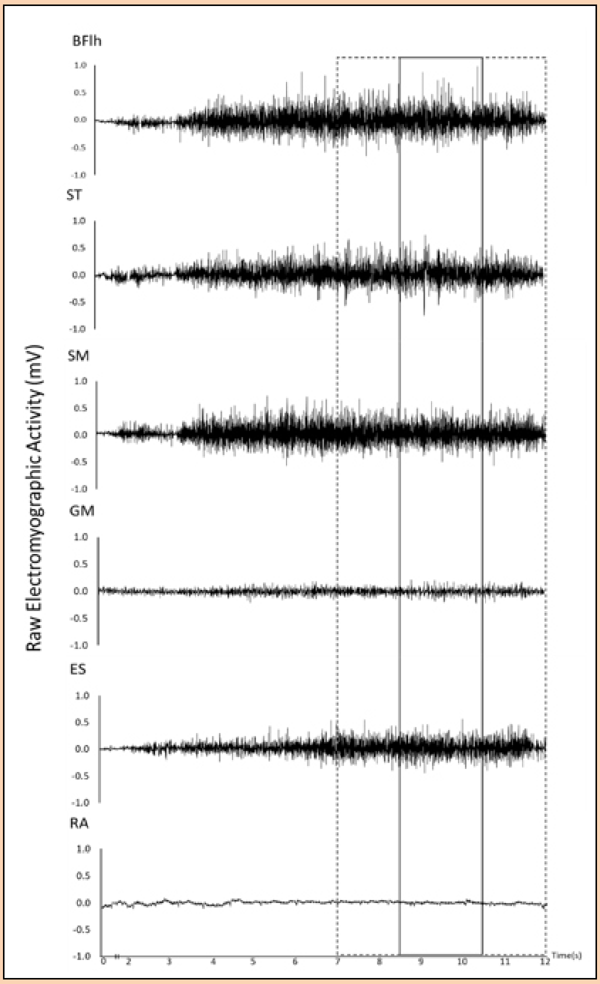


**Figure 2. A representation of typical raw EMG signals during ICL50.** The window of broken line shows the period when subjects performed isometric NHE. The data within the window of the solid line were used for analysis. BFlh: biceps femoris long head, ST: semitendinosus, SM: semimembranosus, GM: gluteus maximus, ES: elector spinae, RA: rectus abdomen, EMG: electromyography, ICL50: Nordic hamstring with 50 degree of incline platform at 50° of knee flexion angle, NHE: Nordic hamstring exercise.

## Statistical analysis

The intra-class correlation coefficients (ICCs) and the coefficient of variation (CV) of the RMS data of each muscle between trials in corresponding exercises were analyzed. The data of ICCs and CV is shown in Table 1. Then, the calculated ICC was evaluated as "almost perfect (ICC > 0.81)," "substantial (ICC = 0.61 to 0.80)," or "moderate (ICC = 0.41 to 0.60)" according to a previous study (Landis and Koch, 1977). Consequently, all RMS data of each muscle were evaluated as “almost perfect,” except for the RA at ICL50 and ICH50, the GM at ICH50, and ES at ICH30.

The average value and standard error for each of the exercises were calculated. A two-way repeated-measures ANOVA design was used to compare the NEMG of each muscle across different exercises (SPSS version 26.0, IBM, New York, NY, USA). Where appropriate, Tukey’s post hoc test was used to assess observed differences. Moreover, η was analyzed, and the mean difference with a 95% confidence interval (CIs) was reported. The statistical significance level was set at 0.05.

**Table1. Intra-class coefficient (ICC) and coefficient of variation (CV) of EMG data between trials.**

| | | BF | ST | SM | GM | ES | RA |
|---|---|---|---|---|---|---|---|
| **NHE** | ICC [2,1] | 0.858 | 0.905 | 0.963 | 0.874 | 0.843 | 0.970 |
| | CV (%) | 11.2 | 11.2 | 8.4 | 19.2 | 13.4 | 14.8 |
| **ICL50** | ICC [2,1] | 0.937 | 0.817 | 0.927 | 0.956 | 0.952 | 0.646 |
| | CV (%) | 14.6 | 14.1 | 13.7 | 9.9 | 13.1 | 12.6 |
| **ICL30** | ICC [2,1] | 0.978 | 0.992 | 0.988 | 0.915 | 0.989 | 0.995 |
| | CV (%) | 11.5 | 5.2 | 8.0 | 10.5 | 8.7 | 12.7 |
| **ICH50** | ICC [2,1] | 0.875 | 0.851 | 0.917 | 0.646 | 0.856 | 0.647 |
| | CV (%) | 14.9 | 12.4 | 13.0 | 15.8 | 15.2 | 11.7 |
| **ICH30** | ICC [2,1] | 0.954 | 0.935 | 0.910 | 0.966 | 0.718 | 0.978 |
| | CV (%) | 13.2 | 10.9 | 14.1 | 15.0 | 15.6 | 14.2 |

## Results

A significant two-way interaction was observed between muscles and exercises (F [8,104] = 3.45, η = 0.45, $p < 0.05$). The NEMG of the ST muscle was higher than that of the BFlh muscle during NHE (mean difference: 19.5%, 95% CIs [6.9%, 32.1%]; $p < 0.05$), whereas there were no differences between the ST and SM muscles, or between the BFlh and SM muscles. In contrast, there were no differences among the BFlh, ST, and SM muscles during any other exercises (Figure 3).

The NEMG of the ST muscle was significantly higher during NHE than during ICL50 (54.4%, [38.1%, 70.6%]), ICL30 (27.1%, [7.5%, 46.7%]), ICH50 (55.9%, [41.1%, 70.8%]), and ICH30 (26.7%, [6.8%, 46.5%]) (all $p < 0.05$). Moreover, the NEMG of the ST was lower during ICL50 than during ICL30 (-27.2%, [-42.4%, -12.0%]) and ICH30 (-27.7%, [-42.7%, -12.6%]) ($p < 0.05$). A similar trend was observed between ICH50 and ICL30 (-28.8%, [-43.7%, -13.9%]) as well as ICH30 (-29.2%, [-44.2%, -14.3%]) (all $p > 0.05$).

The NEMG of the BFlh muscle during ICL50 was lower than that during NHE (-36.2%, [-50.5%, -22.0 %]), ICL30 (-28.4%, [-43.1%, -13.8%]), and ICH30 (-39.4%, [-57.0%, -21.8%]) ($p < 0.05$). Similarly, the NEMG of the BFlh muscle was lower during ICH50 than during NHE (-25.3%, [-36.4%, -14.2%]), and ICH30 (-28.5%, [-46.0%, -11.0%]) (both $p < 0.05$).

Moreover, the NEMG of the SM was lower during ICL50 than during NHE (-40.4%, [-55.5%, -25.2%]), ICL30 (-26.6%, [-38.4%, -14.9%]), and ICH30 (-29.4%, [-42.2%, -16.6%]) ($p < 0.05$). Similarly, the NEMG of the SM was lower during ICH50 than during NHE (-40.2%, [-54.0%, -26.4%]), ICL30 (-26.4%, [-37.5%, -15.4%]) and ICH30 (-29.2%, [-39.5%, -19.0%]) (all $p > 0.05$) (Figure 3).

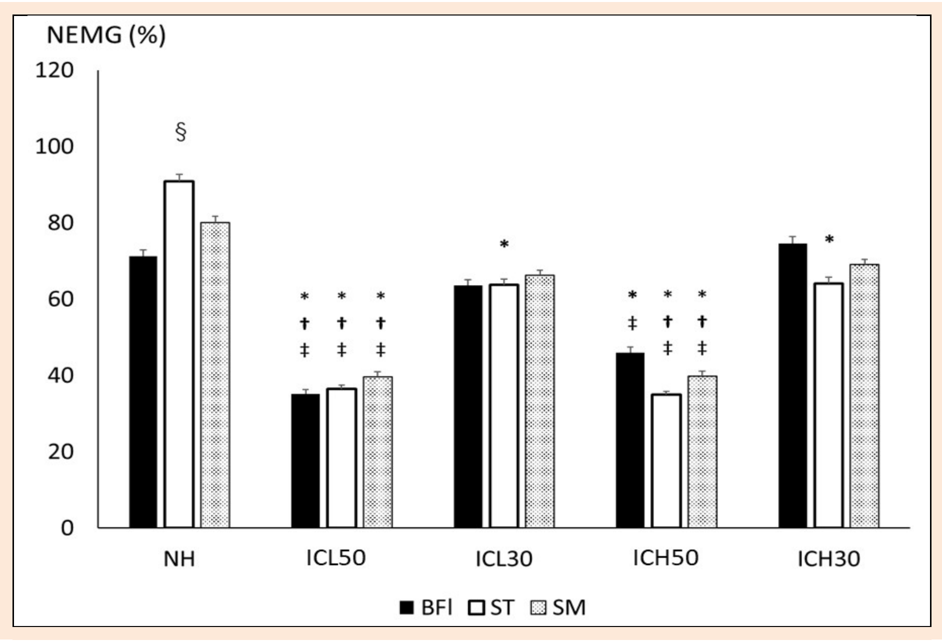


**Figure 3. Comparison of the NEMG (%) of BFlh, ST, and SM muscles among NH, ICL50, ICL30, ICH50, and ICH30.** *, †, and ‡ represent a significant difference ($p < 0.05$) when NH, ICL30, and ICH30 are compared. § represents a significant difference ($p < 0.05$) between ST and BFlh.

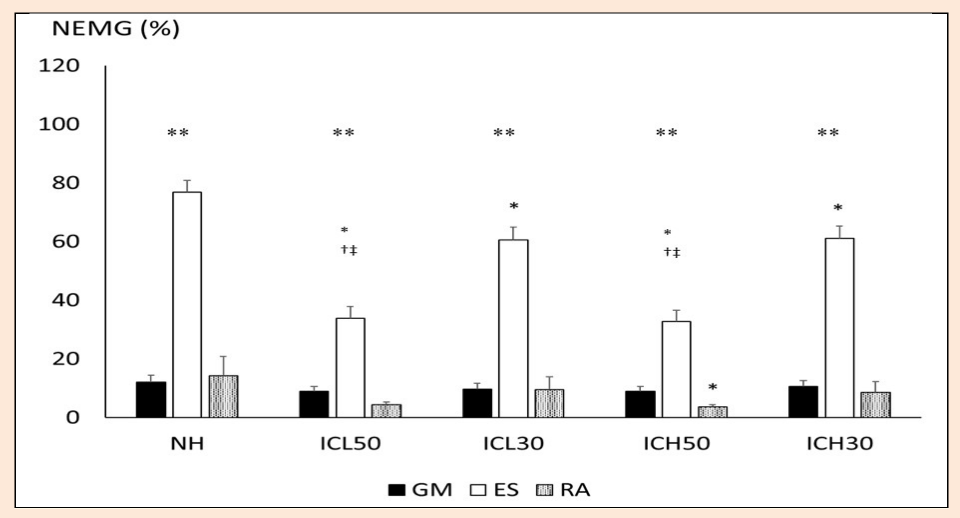


**Figure 4. Comparison of the NEMG (%) of GM, ES, and RA muscle among NH, ICL50, ICL30, ICH50, and ICH30.** *, †, and ‡ represent a significant difference ($p < 0.05$) when NH, ICL30, and ICH30 are compared. ** represents a significant difference ($p < 0.05$) between ES compared to GM and RA.

### EMG activity of GM, ES, and RA

A significant two-way interaction was observed between muscle and exercise ($F$ [8,104] = 13.55, $\eta = 0.07$, $p < 0.05$). For the ES muscle, the NEMG was higher during NHE than during ICL50 (42.9%, [30.5%, 55.4%]), ICL30 (16.2%, [5.1%, 27.3%]), ICH50 (44.1%, [32.6%, 55.6%]), and ICH30 (15.8%, [4.3%, 27.3%]) (all $p < 0.05$). Moreover, the NEMG of the ES was lower during ICL50 than during ICL30 (-26.8%, [-36.8%, -16.7%]) and ICH30 (-27.2%, [-37.1%, -17.3%]) (both $p < 0.05$). Moreover, ES was lower during ICH50 than during ICL30 (-27.9%, [-37.8%, -18.0%]) and ICH30 (-28.3%, [-38.3%, -18.4%]) ($p < 0.05$). The NEMG of the RA was higher during NHE than during ICH50 (10.6%, [-3.6%, 24.7%]) ($p < 0.05$). There was no difference in the NEMG of the GM across exercises (Figure 4).

Moreover, the NEMG of the ES was higher than that of the GM (64.8%, 24.9%, 50.9%, 23.8%, and 50.4%, respect tively) and RA (62.5%, 29.6%, 51.1%, 29.0%, and 52.4%, respectively) during NHE, ICL50, ICL30, ICH50, and ICH30 (all $p < 0.05$; Figure 4).

### BFlh/ST and SM/ST NEMG ratios

As shown in Figure 5, the BFlh/ST ratio and SM/ST ratio had a correlation with knee joint angle during NHE ($r$ = -0.48 and -0.43, respectively; $p < 0.05$).

## Discussion

This study investigated the effect of different knee flexion angles during NHE with the inclined platform on BFlh muscle activity. The main finding of this study was that the NEMG of the BFlh and SM muscles became equivalent to that of the ST muscle at a shallow knee flexion angle during NHE with an inclined platform, whereas the ST muscle worked more during conventional NHE than the BFlh muscle. Furthermore, there were no inter-load differences in the EMG activity of all muscles during isometric NHE at an equivalent knee joint angle by modulating the inclination of platform. To the best of our knowledge, no previous study has demonstrated that the NEMG of the BFlh and ST muscles can be modulated by changing the knee flexion angle; however, the activity may not be modulated by work load during NHE.

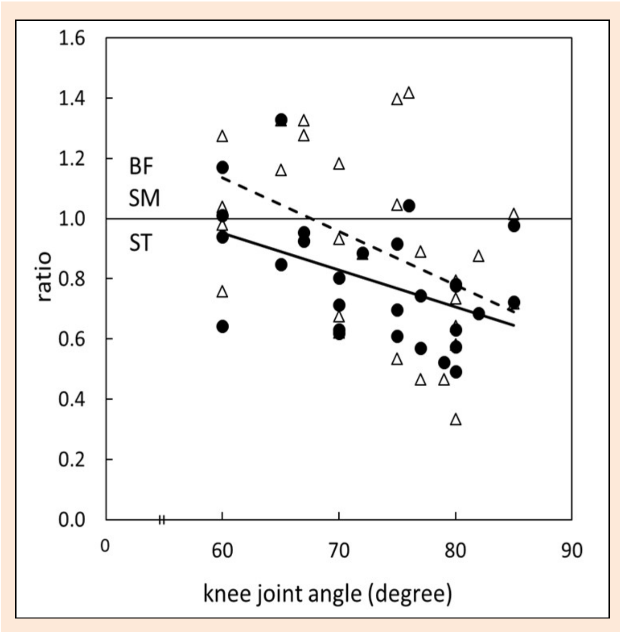


**Figure 5. A scatter plot of BFlh/ST and SM/ST corresponding to the knee joint angle. ● and △ show BFlh/ST and SM/ST, respectively.** The broken line and solid line show the linear regression of a knee angle with BF/ST ($y = -0.0208x + 3.5587$, $r = -0.47$) and SM/ST ($y = -0.0241x + 3.7886$, $r = -0.45$) ($p < 0.05$), respectively. The ratio over 1.0 means that the NEMG of BF or SM is higher than that of ST (solid horizontal line).

The finding that the NEMG of the ST was higher during conventional NHE than during BFlh was in line with that in previous studies (Ono et al., 2010; Bourne et al., 2018). However, even during conventional NHE, the BFlh muscle work is equivalent to that of the ST muscle at a shallow knee flexion angle with an inclined platform.

Moreover, even when using an inclined platform, the NEMG of the BFlh at a knee flexion angle of 30° (ICL30; 63.5 ± 5.6%, ICH; 74.5 ± 7.0%) reached the same level as that during NHE (71.3 ± 5.9%) and other preferred exercises for HSI prevention, such as stiff-legged dead lift with 10–12 RM weight (38–55%) (Bourne et al., 2017b; Iversen et al., 2017). While several studies referred to the limitation of the NHE in terms of the lack of activation of the BFlh muscle, which is the most susceptible muscle to HSI (Bourne et al., 2017b, 2018), the finding of the present study suggests the usefulness of NHE for HSI prevention (Brooks et al., 2006; Gabbe et al., 2006; Arnason et al., 2008; Tsaklis et al., 2015) when the knee angle is set to a shallow flexion angle.

This study could not provide a clear underlying mechanism related to this result. As speculated in a previous study (Hegyi et al., 2019), one possible mechanism may be that the BFlh muscle works more for hip extension than the ST or SM muscle to keep the upper body straight during NHE at a shallow knee flexion angle. The GM and hamstring muscles might generate internal hip extension torque to keep the pelvis and upper trunk straight during NHE (Narouei et al., 2018). Additionally, the ES muscle also works to keep the upper body straight during NHE (Narouei et al., 2018). However, the activity of the GM was small regardless of the exercise condition, and no inter-exercise difference was observed. In contrast, an altered center of mass (COM) in the upper body can cause differences in ES muscle activity between different knee joint angles during NH, ICL, and ICH. Theoretically, the COM of the upper body is away from the knee joint (which acts as the fulcrum during NHE) when the angle between the floor (horizontal line) and thigh-trunk line increases. The angle between the floor (horizontal line) and thigh-trunk line of ICL30 (115°) and ICH30 (125°) will be greater than that of NHE (approximately 100-120°). However, there was no significant inter-task difference in GM. Moreover, the activity of ES was significantly lower during ICL and ICH than during NHE regardless of the knee joint angle. The mechanism is still unclear, and this trend has led us to speculate that the required effort for hamstring muscles to keep the thigh to trunk straight will be greater during ICL30 and ICH50 than during NHE. As previously reported, the relative activity of BFlh to ST muscles is higher in hip extension than knee flexion (Bourne et al., 2018; ); thus, the activity of the BFlh muscle was equivalent to that of the ST muscle in ICL30 and ICH30, while the EMG activity of the ST muscle was higher than that of the BFlh muscle. In contrast, the above mechanism may not be responsible for differences in the EMG of the BFlh muscle relative to the ST muscle among NHE, ICL50, and ICH50 because the angle between floor (horizontal line) and thigh-trunk line is almost the same in all inclinations (NH; 100-120°, ICL50; 95°, ICH50; 105°). Although we could not provide the exact reason of this trend, one possible lying mechanism may be the change of the length in hamstring muscles. For instance, the finding of previous studies indicates that the peak EMG of the ST muscle was obviously greater than that of BFlh muscle in NHE, while the difference between the two muscles was less significant or the BFlh muscle activity was greater than the ST muscle activity when the hamstring muscles were lengthened using NHE with a flexed hip (Šarabon et al., 2019; Marušič and Šarabon, 2020) and a glider (Marušič and Šarabon, 2020). Additionally, other previous studies speculated the lying mechanism of the differences in EMG activity between the BFlh and ST muscles across different knee angle from morphological features (Makihara et al., 2006; Higashihara et al., 2019) and the moment arm (Hirose and Tsuruike, 2018). Further research for investigating the mechanism of our findings from various factors is warranted.

In contrast, the fact that the EMG activity of ES was greater during NHE than during ICL and ICH implies that subjects performed the over-extension of the trunk to shorten the distance between the COM and the knee joint to decrease the load applied to the hamstring muscles. As shown in Figure 2, the high NEMG of the hamstring muscles during NHE implies that high muscle activity was required to keep the knee-to-trunk region straight. However, subjects were required to keep their hip joint straight, leading to an extension of their lumbar region; this was the only strategy to decrease the high load applied to their hamstring muscle. The findings of this may reflect that performing NHE with an inclined platform enables athletes to maximize their hamstring activity with less compensational activity of GM and ES. This finding might contribute to maximizing compliance with NHE to increase its effectivity in preventing HSI (Lacome et al., 2020).

This study found no inter-load difference in NEMG activities between ICL and ICH in all hamstring muscles during NHE with an inclination platform when the knee flexion angle was set at an equivalent angle. However, the type of task was different. Hirose and Tsuruike (2018) reported that the increment of applied external loads (manual resistance from 20% to 40% MVIC) increases EMG activity in BFlh, SM, and ST muscles during prone leg curl. Accordingly, the increment of a slope angle from 50° to 40° may not be sufficient to modulate hamstring activity. Furthermore, even the lying mechanism is still unclear, and the above report also suggested that there was no significant difference in the relative EMG activity of the BFlh, SM, and ST muscles; this suggestion supports the finding of this study, which indicates that performing NHE with an inclination platform even at low inclination angle with a shallow knee flexion angle (i.e., ICL30) may activate the BFlh and ST muscle; this is an alternative to conventional NHE.

This study has several limitations. The reliability of this study may limit our finding in some extent. In case of BFlh during NHE, the CV of this study must be acceptable (11.2%) although the value is lower than that of previous study (4.4%) (Marušič and Šarabon, 2020). However, the means of their NEMG values appeared to reach the ceiling effect, ranged between 113.9 and 124.4% NEMG, leading to less CV value while the mean values of our study was 71.9% NEMG in BFlh during NHE (Figure3), leading to larger standard deviations across the subjects in the present study. We did not monitor the knee flexion angle by means of electrogoniometers. Although manual goniometers yield highly reliable data (Brosseau et al., 1997; Piriyaprasarth and Morris, 2007), further research will be needed with digital measurements. Moreover, the knee angle and load with further changes in platform angle during eccentric

NHE should be investigated in the future, and intervention research is warranted to clarify the effectiveness of this approach for preventing BFlh muscle injury. In addition, as shown in Figure 4, individual differences in the BFlh/ST ratio exist. For instance, even at a 50° knee flexion angle, the ST muscle worked more than the BFlh muscle in two of four trials. Thus, additional research with a focus on individual characteristics is required. Finally, even the influence of the biceps femoris short head (BFsh) muscle activity will be less apparent because EMG activity of the aforementioned muscle decreases and the activity of BFlh muscle increases at a shallow knee flexion angle compared to that at a deep knee flexion angle (Onishi et al., 2002). Further investigations on how the activity of the BFsh muscle influences our result are needed. Moreover, the difference in the knee flexion angle between during NHE (80° to 60°) and during ICL/ICH50 was small; we need further studies using more valid procedures such as a wire electrode to verify this matter.

Although the study had several limitations, the findings of this study might have some implications for practical settings. For instance, even trained athletes are not able to perform conventional NHE at a shallow knee flexion angle under 50°. In this regard, using the inclined platform can help athletes to perform NHE at a shallow knee flexion angle. Helping perform NHE at a shallow knee flexion angle may indicate that this protocol assists athletes to perform eccentric exercise in lengthened positions; this has positive effects on preventing HIS (Askling et al., 2013, 2014). Moreover, the finding of this study might assist in providing a progressive program for preventing BFlh muscle injury. As a recent study suggested the importance of a progressive prevention program for HSI (Presland et al., 2018), the findings of this study may help healthcare specialists develop a progressive program for activating the BFlh muscle by modulating the angle of the platform from a greater angle, such as ICL.

## Conclusion

This study clarified that the BFlh and ST muscles are equally activated during NHE at shallow knee flexion angles with the inclination platform, whereas the ST muscle worked more during conventional NHE than the BFlh muscle. Moreover, there was no load-dependent difference in the EMG activity of hamstrings and that of trunk muscles during NHE with an incline platform by modulating the inclination angle from 50° to 40°. From these findings, we conclude that performing NHE at a shallow knee flexion angle while using an inclined platform might help prevent HIS by activating the BFlh muscle as much as ST muscles.

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## Key points

- Performing Nordic Hamstring exercise at a shallow knee flexion angle will enhance the biceps femoris muscle rather than the semitendinosus muscle
- There is no significant inter-load difference in the EMG activity of hamstring muscles across different inclination platform angles when the knee joint angle is the same
- Using an incline platform enables athletes with an insufficient strength of hamstring muscles to perform Nordic Hamstring exercises at a shallow knee angle.

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