Sport Sciences for Health
https://doi.org/10.1007/s11332-023-01113-4

RESEARCH

Electromyographic activity of hip extensor muscles during Nordic hamstring and razor curl exercises on leveled and inclined shanks

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Received: 19 March 2023 / Accepted: 2 August 2023

Abstract

Background Changes in electromyographic (EMG) activity of hip extensor muscles and knee flexion angles at peak biceps femoris long head (BFlh) EMG activity by different shank angles during razor curl (RC) exercises are unknown.

Aims We investigated the changes in EMG activity of hip extensor muscles and knee flexion angle at peak BFlh EMG activity with different shank angles during RC and also compared the Nordic hamstring (NH) and RC exercises in the EMG activity of hip extensor muscles.

Methods Twelve male university students randomly performed two repetitions of NH and RC with the lower leg slope angle set at 0° (NH0, RC0) and 40° (NH40, RC40). The EMG activity of hip extensor muscles was measured at the BFlh and related muscles. EMG activity was calculated based on the peak value of the root mean square, normalized as a percentage of the maximum voluntary isometric contraction.

Results The BFlh EMG activity of NH0 was higher than that of RC0 ($p = 0.002$) and RC40 ($p = 0.008$). The knee flexion angle at peak BFlh EMG activity of NH0 was larger than that of NH40 ($p = 0.003$) and RC40 ($p = 0.002$), and RC0 was larger than that of NH40 ($p = 0.002$) and RC40 ($p = 0.002$).

Conclusion NH40, the BFlh EMG activity equivalent to NH0, might be more effective for preventing recurrence of hamstring injury because the knee flexion angle at peak BFlh EMG activity remains within 30°, combined with a high BFlh EMG activity.

Keywords Athletic rehabilitation · Biceps femoris long head · Gluteus maximus · Injury prevention · Semitendinosus

Abbreviations

EMG	Electromyographic
BFlh	Biceps femoris long head
RC	Razor curl
BPA	Break-point angle
MVIC	Maximum voluntary isometric contraction
GM	Gluteus maximus
ST	Semitendinosus
RMS	Root mean square

Introduction

Hamstring injury often occurs in sports activities that involve high-speed running [1]. A history of hamstring injury is the strongest risk factor for such an injury [2], and it has been reported that 70% of athletes suffer a recurrence of hamstring injury within 100 days of returning to play [3]. Given that the median time to return to play is 19 days (range 5–37 days) [3], it is important to prevent recurrence as well as initial hamstring injury to continue to improve athletic performance.

Most of the hamstring injuries that occur during high-speed running appear at the biceps femoris long head (BFlh) [4, 5]. A history of hamstring injury causes reduced BFlh EMG activity on the injured side compared to the healthy side and/or uninjured subjects [6–8]. Interestingly, it has been reported that this inhibition of BFlh EMG activity occurs within 30° of knee flexion during isokinetic eccentric knee flexion exercise [7, 8]. Therefore, it is possible that applying a facilitating BFlh EMG

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activity to within 30° of knee flexion during knee flexion exercise to reduce inhibition of BFlh EMG activity within 30° of knee flexion might be important to prevent a recurrence of hamstring injury. In fact, it has been reported that imposing an eccentric load to 20° of knee flexion during eccentric knee flexion exercise prevents the recurrence of hamstring injury [9].

Nordic hamstring exercise (NH) is one of the exercises used to strengthen the hamstring muscles. It is necessary to maintain a straight posture from the knees to the head while leaning the upper body forward as far as the hamstring muscles can tolerate. The knee flexion angle at which knee flexor strength is unable to resist the external knee flexion moment accompanying the forward leaning of the trunk is defined as the break-point angle (BPA). It is reported that in standard NH, the BPA is 57.8° in college athletes, resulting in a lower BFlh EMG activity of 46.2% maximum voluntary isometric contraction (MVIC) within 30° of knee flexion [10]. On the other hand, the same study also reported that performing NH in an inclined shank using a sloped platform set at 20° or 40° is as high as 68.5 to 79.4% MVIC of BFlh EMG activity within 30° of knee flexion compared to standard NH [10].

Another popular hamstring strengthening exercise is razor curl (RC), which involves a push phase, during which the hip and knee joints are simultaneously extended from a flexed posture, and a pull phase, during which the hip and knee joints are simultaneously flexed from an extended posture. RC is characterized not only by high EMG activity of the biceps femoris and medial hamstrings but also by high EMG activity of the gluteus maximus (GM) [11, 12]. During the pull phase of RC, the GM EMG activity can reach a maximum voluntary isometric contraction (%MVIC) of 40 to 100% [11, 12]. The hamstring muscles, except the biceps femoris short head are biarticular and are elongated by flexion of the hip joint and extension of the knee joint. Anterior pelvic tilt (APT) is considered to be involved in hamstring elongation because APT causes upward movement of the ischial tuberosity. Individuals with a large APT in the late swing phase during high-speed running seem to be more susceptible to HSI [13], which could be explained by a decrease in the activity of the GM, resulting in an increase in hamstring elongation stress [14]. In contrast, Mendiguchia et al. reported that a training program that included GM exercise reduced the APT in the late swing phase [15]. Therefore, RC accompanied by high activity of the biceps femoris and GM might further prevent HSI because of the preferable muscle activity patterns during the late swing phase. However, it is unclear whether the high activity of the hip extensor muscles during the push phase of RC as well as the pull phase of RC. In addition, it is also unclear whether the EMG activity of the hip extensor muscles is changed by performing the push phase of RC in an inclined shank using a sloped platform compared to standard RC.

The purpose of this study was to investigate the changes in hip extensor muscles of EMG activity and knee flexion angle at peak BFlh EMG activity with different shank angles during RC. In addition, we compared NH and RC in EMG activity of hip extensor muscles. We hypothesized that the knee flexion angle at peak BFlh EMG activity during RC with inclined shank would be lower compared to RC with leveled shank.

Methods

Study design

This study adopted a crossover design. After a warm-up, the participants performed two repetitions of leg curls and hip extension with maximum voluntary isometric contraction (MVIC). For further analysis, the mean values of the peak EMG activity of the BFlh, semitendinosus (ST), and GM during MVIC were used to convert the peak EMG activity during the four tasks to the percentage of MVIC (%MVIC). Participants randomly performed two repetitions of NH with the lower leg slope angle set at 0° (NH0) and 40° (NH40), and RC with the lower leg slope angle set at 0° (RC0) and 40° (RC40) (Fig. 1). The %MVIC during the tasks was also averaged. The flexion angles of the knee and hip at peak BFlh EMG activity were calculated by synchronizing EMG and motion analysis. We analyzed the differences in the mean values of the %MVIC values of BFlh, ST, and GM among the four tasks (NH0, NH40, RC0, and RC40). We also analyzed the differences in the mean values of the flexion angles of the knee and hip at peak BFlh EMG activity among the four tasks.

Participants

The sample size was calculated a priori using input parameters (effect size = 0.25; alpha = 0.05; power = 0.95; groups = 1; measurements = 4) using one-way repeated-measures ANOVA of the main outcome analysis (G*Power, version 3.1, Heinrich Heine Universität Düsseldorf, Germany). The results confirmed that a sample size of at least nine participants was necessary. Hence, 12 male university students (age 23.3 ± 2.5 years; height 169.9 ± 4.8 cm; weight 66.4 ± 7.3 kg; and resistance training experience 2.7 ± 3.6 years, all reported in mean ± SD) (age 23.3 ± 2.5 years; height 169.9 ± 4.8 cm; weight 66.4 ± 7.3 kg; and resistance training experience 2.7 ± 3.6 years, all reported in mean ± SD) participated in this study. Participants had one or more sports experience, including soccer, baseball, swimming, basketball, rugby, weightlifting,

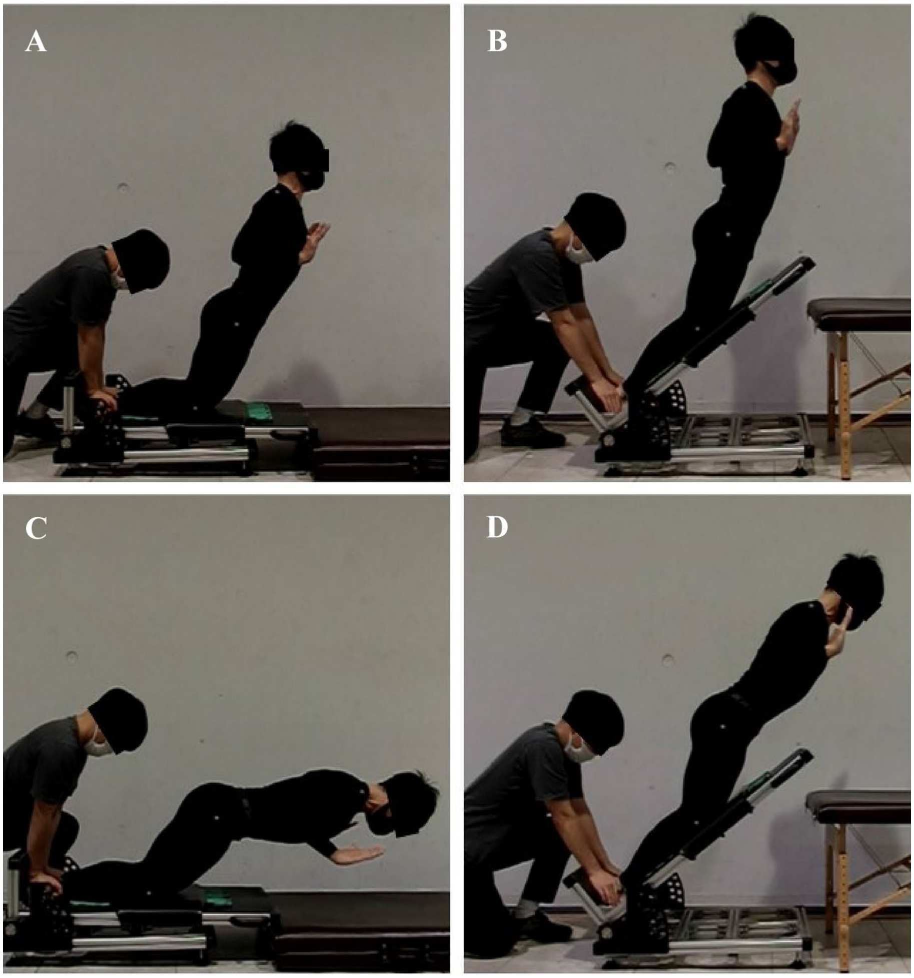

Fig. 1 Demonstration of tasks: **A** NH0, **B** NH40, **C** RC0, and **D** RC40. *NH0* Nordic hamstring exercise at 0° lower leg slope, *NH40* Nordic hamstring exercise at 40° lower leg slope, *RC0* razor curl exercise at 0° lower leg slope, *RC40* razor curl exercise at 40° lower leg slope

lacrosse, and gymnastics. Participants were excluded if they could not perform NH due to a current injury of lower and/or upper extremity. None of the participants had a history of a hamstring injury. The experimental protocol was approved by the institutional review board of Waseda University's ethical committee (approval number: 2021-427), and all procedures in this study were performed in accordance with the Declaration of Helsinki. All participants were informed of the purpose and procedure of this study, and informed consent was obtained from all participants.

Procedures

Before the experiment, the participants performed 2 min of light aerobic activity (alternate stepping on a 20-cm-high box), followed by ten repetitions of a stiff-leg deadlift without any added weight for hamstring flexibility [16]. Surface EMG electrodes were attached to the BFlh, ST, and GM of the dominant leg (defined as the preferred kicking leg). To normalize the peak EMG activity of the BFlh, ST, and GM during the four tasks, and RC40, participants performed two repetitions of prone leg curls with knee flexion of 45° (BFlh and ST) and hip extension with the knee fixed at 90° (GM) at 3 s MVIC. Next, the four tasks were randomly assigned. Participants performed two valid repetitions per task; two repetitions were performed before the task so they could learn the proper form. The four tasks were performed on custom-made platforms (Riccoh Co., Ltd., Tokyo, Japan). The participants were allowed at least 1 min of rest between each repetition and 2 min of rest between each task.

Nordic hamstring exercise

The participants were instructed to start in a kneeling position with their elbows fully flexed and their hands open in front of them. The examiner held the participant's ankle securely to the leveled platform or to the inclined platform while instructing the participant to keep the area of their body from the knees to the head straight. The examiner also asked the participants to lean forward as slowly as possible.

Razor curl exercise

The RC started with the participant kneeling and with the hip and knee flexed to the point where the greater trochanter was over the center of the lower leg. The participants were instructed to simultaneously extend their knee and hip joints so that their upper body was parallel to the lower leg slope. The examiner asked the participants to extend the knee and hip joints as slowly as possible.

Electromyography

The EMG signal was sampled at 1000 Hz and bandpass-filtered (10–450 Hz) using a wireless telemetry system with surface EMG silver electrodes (DL-5000 with m-Biolog2; S&ME Inc., Tokyo, Japan). The electrode had a bar length of 1 cm, bar width of 0.1 cm, and distance of 1 cm between the recording sites. The skin of the participants was cleaned with cotton dampened with alcohol to reduce noise. The electrode location for the BFlh was at the midpoint between the ischial tuberosity and lateral condyle of the tibia; that for the ST was at the midpoint between the ischial tuberosity and medial epicondyle of the tibia; and that for the GM was at the midpoint between the greater trochanter and sacral vertebrae [17]. The border between the BFlh and ST was carefully identified using B-mode two-dimensional ultrasonography to reduce crosstalk (fST9600; LEQUIO Power Technology Co., Ltd., Okinawa, Japan).

Two-dimensional analysis

Kinematic data during the tasks were recorded using a high-speed camera (EX-F100; Casio Computer., Ltd., Tokyo, Japan). The speed of the camera was set to 120 fps, and the height was approximately 0.8 m; the camera was positioned approximately 3 m from the dominant leg of the participants. A two-dimensional analysis of the obtained data was performed using software (Frame-DIAS V; DKH Inc., Tokyo, Japan). The measuring square was statistically calibrated with a rigid frame of 1.5 × 1.5 m. Reflective markers were attached to four bony landmarks (acromion, greater trochanter, lateral epicondyle of the femur, and lateral malleolus). The knee flexion angle was calculated by digitizing the greater trochanter, lateral epicondyle of the femur, and lateral malleolus. The hip flexion angle was calculated by digitizing the acromion, greater trochanter, and lateral epicondyle of the femur. The knee and hip angles used were anatomical angles; a value of 0° indicated a fully extended hip or knee (Fig. 2).

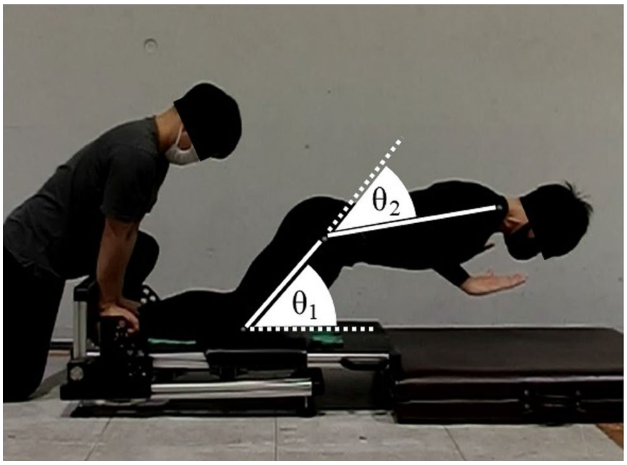

Fig. 2 Kinematics data during RC0: θ1, knee flexion angle; and θ2, hip flexion angle. *RC* razor curl exercise at 0º slope

Data analysis

The peak EMG activity was calculated based on the peak value of the root mean square (RMS). The RMS value was calculated during a window of 100 ms. The mean values of the peak EMG activity of the BFlh, ST, and GM during MVIC were calculated. The mean value of the peak EMG activity of two valid repetitions during each task was used for further analyses.

The kinematic data obtained by motion analysis were smoothed using a Butterworth low-pass filter with a cutoff frequency of 6 Hz. The flexion angles of the knee and hip at peak BFlh EMG activity were calculated by synchronizing EMG and motion analysis (TRIAS; DKH Inc., Tokyo, Japan).

Statistical analysis

The values are expressed as mean ± standard deviation. The Shapiro–Wilk test was used for normality. As a result, normality was confirmed for BFlh EMG activity and hip flexion angle at peak BFlh EMG activity, while normality was not confirmed for ST EMG activity, GM EMG activity, and knee flexion angle at peak BFlh EMG activity. A one-way repeated-measures ANOVA (task-factors: NH0, NH40, RC0, and RC40) was performed to compare the BFlh EMG activity, hip flexion angle at peak BFlh EMG activity among the four tasks. The Friedman test (task-factors: NH0, NH40, RC0, and RC40) was used to compare the ST EMG activity, GM EMG activity, and knee flexion angle at peak BFlh EMG activity among the four tasks. Significant effects were examined using the Bonferroni post hoc test. The partial η^2 was classified based on the following effect size criteria: trivial < 0.02; small 0.02–0.129; medium 0.13–0.259; and large > 0.26 [18]. Cohen's d was classified based on the following effect size criteria: trivial < 0.2; small 0.2–0.49; medium 0.5–0.79; and large > 0.8 [18]. The statistical analysis was performed using SPSS version 27 (IBM SPSS, Armonk, NY, USA). The significance level was set at $p < 0.05$.

Results

Electromyographic activity of hip extensor muscles

The top of Fig. 3 shows the electromyographic activity of BFlh during the tasks. The main effect of task factors was significant ($F = 11.2$; partial $\eta^2 = 0.51$; $p < 0.001$). The BFlh EMG activity of NH0 was higher than that of RC0 ($d = 1.45$; $p = 0.002$) and RC40 ($d = 1.12$; $p = 0.008$).

The middle of Fig. 3 shows the electromyographic activity of ST during the tasks. The ST EMG activity of NH0 was higher than that of NH40 ($d = 0.94$; $p = 0.028$), RC0 ($d = 1.45$; $p = 0.006$), and RC40 ($d = 1.12$; $p = 0.004$).

The bottom of Fig. 3 shows the electromyographic activity of GM during the tasks. The GM EMG activity of NH0 was higher than that of NH40 ($d = 0.73$; $p = 0.003$). The GM EMG activity of NH40 was higher than that of RC0 ($d = 0.45$; $p = 0.028$) and RC40 ($d = 0.39$; $p = 0.041$).

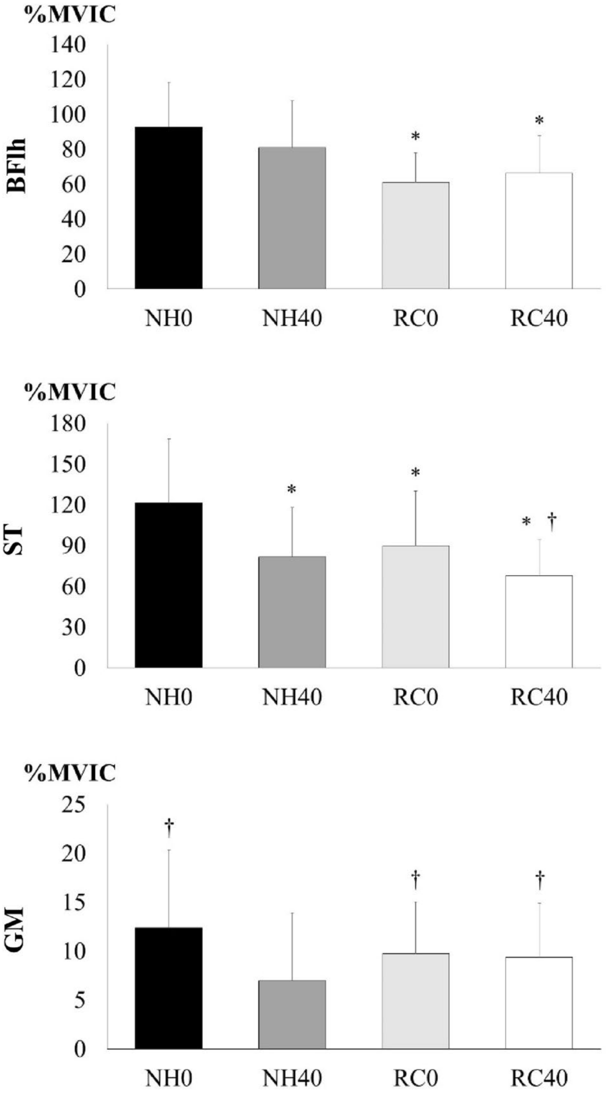

Fig. 3 Comparison of the %MVIC of the BFlh and ST among NH0, NH40, RC0, and RC40. *Significant difference ($p < 0.05$) compared with NH0. †Significant difference ($p < 0.05$) compared with N40. ‡Significant difference ($p < 0.05$) compared with RC0. *NH0* Nordic hamstring exercise at 0° lower leg slope, *NH40* Nordic hamstring exercise at 40° lower leg slope, *RC0* razor curl exercise at 0° lower leg slope, *RC40* razor curl exercise at 40° lower leg slope, *MVIC* maximum voluntary isometric contraction

Flexion angles of knee and hip at peak BFlh EMG activity

Table 1 shows the flexion angles of knee and hip at peak BFlh EMG activity during the tasks. The knee flexion angle at peak BFlh EMG activity of NH0 was larger than that of NH40 ($d = 2.77$; $p = 0.003$) and RC40 ($d = 2.69$; $p = 0.002$). The knee flexion angle at peak BFlh EMG activity of RC0 was larger than that of NH40 ($d = 3.28$; $p = 0.002$) and RC40 ($d = 3.18$; $p = 0.002$).

The main effect of task factors in the hip flexion angle at peak BFlh EMG activity was significant ($F = 80.3$; partial $\eta^2 = 0.88$; $p < 0.001$). The hip flexion angle at peak BFlh EMG activity of RC0 was larger than that of NH0 ($d = 3.22$; $p < 0.001$), NH40 ($d = 3.85$; $p < 0.001$), and RC40 ($d = 2.23$; $p < 0.001$). The hip flexion angle at peak BFlh EMG activity of RC40 was larger than that of NH0 ($d = 1.33$; $p = 0.009$) and NH40 ($d = 2.19$; $p < 0.001$). The hip flexion angle at peak BFlh EMG activity of NH0 was larger than that of NH40 ($d = 0.89$; $p < 0.001$).

Table 1 Flexion angles of knee and hip at peak biceps femoris long head electromyography activity among NH0, NH40, RC0, and RC40

Measurement category	Tasks	Mean ± SD
Knee flexion angle at peak BFlh EMG activity (°)	NH0	55.8 ± 16.4
	NH40	18.9 ± 9.2*‡
	RC0	55.7 ± 12.9
	RC40	20.0 ± 9.2*‡
Hip flexion angle at peak BFlh EMG activity (°)	NH0	5.2 ± 9.0
	NH40	− 2.5 ± 8.6*
	RC0	48.5 ± 16.7*†
	RC40	17.9 ± 10.0*†‡

NH0 Nordic hamstring exercise at 0° lower leg slope, *NH40* Nordic hamstring exercise at 40° lower leg slope, *RC0* razor curl exercise at 0° lower leg slope, *RC40* razor curl exercise at 40° lower leg slope, *BFlh* biceps femoris long head, *EMG* electromyographic

*Significant difference ($p < 0.05$) compared with NH0

†Significant difference ($p < 0.05$) compared with N40

‡Significant difference ($p < 0.05$) compared with RC0

Discussion

This study investigated the effect of different shank angles during NH and RC on BFlh EMG activity and knee at peak BFlh EMG activity. The main finding of this study was that the amount of BFlh EMG activity did not change with different shank angles, whereas NH0 had higher amounts of BFlh EMG activity than RC0 and RC40. Furthermore, only NH40 and RC40 achieved a knee flexion angle at peak BFlh EMG activity within 30°.

The difference in BFlh EMG activity results between NH0 and RC0 may support the findings of a previous study. Pincheira et al. examined the differences in the amount of BFlh EMG activity between NH with neutral hips and NH performed from hip flexion to extension (similar to a razor curl) [19]. They reported that BFlh EMG activity of NH with neutral hips was higher than NH performed from hip flexion to extension. Although there was no difference in knee flexion angle at peak BFlh EMG activity between RC0 and NH0 in this study (Table 1), RC0 was greater than NH0 in hip flexion angle at peak BFlh EMG activity (Table 1), which might have contributed to the lower BFlh EMG activity in RC0 compared to NH0. This is because the hamstring muscles are elongated in hip flexion, and thus the passive elements (e.g., tendons, extracellular matrix, titin) might contribute a greater proportion of the force generation due to passive insufficiency [20]. Supporting this hypothesis are the findings of previous study that reported an inverse relationship between BFlh EMG activity and hamstring length during eccentric knee flexion contractions [21]. On the other hand, the lack of difference in BFlh EMG activity between N40 and RC40 may be attributed to the smaller difference in hip flexion angle at peak BFlh EMG activity between NH40 and RC40 compared to the larger difference in hip flexion angle at peak BFlh EMG activity between NH0 and RC0 (Table 1) [22]. Since it has been reported that a history of hamstring injury causes a difference in BFlh EMG activity between the healthy and injured side during isokinetic eccentric knee flexion exercise [7, 8], improving BFlh EMG activity on the injured side might be effective in preventing recurrence of hamstring injury. Therefore, NH0 and/or NH40 might be a preventive exercise for recurrence of hamstring injury that improves BFlh EMG activity on the injured side. However, although the changes in BFlh EMG activity with NH0 training interventions have been investigated [23], changes in BFlh EMG activity with N40, RC or R40 training intervention have not yet been studied; thus, further research is expected.

The results of this study showed that the knee flexion angle at peak BFlh EMG activity is smaller at inclined shank than at leveled shank for both NH and RC. The results of this study support the finding of Soga et al., who examined the influence of different shank angles on knee flexion angle at peak BFlh EMG activity during unilateral NH [24]. They reported that the knee flexion angle at peak BFlh EMG activity became smaller as the shank angle inclined. Because a history of hamstring injury has been reported to inhibit BFlh EMG activity within 30° of knee flexion on the injured side [7, 8], improving BFlh EMG activity within 30° of knee flexion on the injured side might be effective for preventing recurrence of hamstring injury. Therefore, NH40 might be more effective than NH0 for preventing recurrence of hamstring injury because the knee flexion angle at peak BFlh EMG activity remains within 30°, combined with a high BFlh EMG activity. Reportedly, BFlh EMG activity of N40 is significantly smaller compared to NH in the case that individuals are able to descend actively to at least half of the range of motion in the NH [22]. For such individuals who have a strong hamstring strength in the inclined shank condition, performing NH unilaterally [24] or with an additional external load to the NH [25] is recommended to attempt to increase the BFlh EMG activity within 30° of knee flexion.

We found that the amount of ST EMG activity changed with different shank angles in the NH condition, whereas the amount of ST EMG activity did not change with different shank angles in the RC condition (Fig. 1). The results of this study firmly support the finding of a previous study by Sarabon et al., who examined the effect of different shank angles during NH on the amount of ST EMG activity [22]. They reported that ST EMG activity of NH with leveled shank was higher than NH with inclined shank. The decrease in ST EMG activity might be due to the characteristics of ST, which is more likely to generate passive force. The percentage of fast-twitch muscle fibers of ST has been reported to be as high as approximately 70% [26]; furthermore, fast-twitch muscle fibers have been reported to produce more passive force generation compared to slow-twitch muscle fibers [27]. This could be the mechanism underlying the reduced ST EMG activity during NH with inclined shank.

The results of this study indicate that the GM EMG activity of NH with leveled shank is higher than that of NH with inclined shank. The results of this study firmly support the finding of Sarabon et al., who examined the effect of different shank angles during NH on the amount of GM EMG activity [22]. They reported that GM EMG activity of NH with leveled shank was higher than NH with inclined shank.

It has been reported that GM EMG activity during hip extension decreases with knee extension [28], possibly due to a greater proportion of force generation due to passive insufficiency of hamstring muscles [20]. Since hip extension moment is also demonstrated in NH [22], this might be the mechanism by which GM EMG activity was reduced in NH with inclined shank.

Limitations

There were several limitations to this study. First, only one of the participants in this study had experienced razor curls previously. The GM EMG activity during razor curls in the previous study was as high as 40–100% MVIC [11, 12], while this study showed a lower value within 15% MVIC. The GM EMG activity could have been higher if all participants had previous experience of razor curls. Second, if the participants in this study had stronger hamstring strength (If all participants were capable of at least half of the NH range of motion), the hamstring muscle activity patterns during NH with the inclined shank may be different [22]. Further research is needed on the effects of BPA differences during NH with the leveled shanks on hamstring activity patterns during NH with the inclined shanks. Finally, in a previous study, isokinetic eccentric training prevented recurrent hamstring strain [9]. Since neither NH nor RC are isokinetic contractions, it would be necessary to verify whether both NH and RC are effective in preventing recurrence of hamstring injury.

Conclusion

This study investigated the effect of different shank angles during NH and RC on BFlh EMG activity and knee flexion at peak BFlh EMG activity. The main finding of this study was that the amount of BFlh EMG activity did not change with different shank angles, whereas NH0 was higher in the amount of BFlh EMG activity than RC0 and RC40. Furthermore, only NH40 and RC40 achieved a knee flexion angle at peak BFlh EMG activity within 30°. Therefore, NH40, the BFlh EMG activity equivalent to NH0, might be more effective for preventing recurrence of hamstring injury because the knee flexion angle at peak BFlh EMG activity remains within 30°, combined with a high BFlh EMG activity.

Acknowledgements The authors would like to acknowledge the facilities and assistance of the Graduate School of Sport Sciences, Waseda University. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who was an organizer of the study.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by TS, NH, HS. The first draft of the manuscript was written by TS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This work was supported by JST SPRING, Grant Number JPMJSP2128.

Data availability All data generated or analysed during this study are included in this published article.

Code availability Not applicable.

Material availability Not applicable.

Declarations

Conflict of interest The authors have no competing interests to declare.

Ethics approval The experimental protocol was approved by the institutional review board of Waseda University's ethical committee (approval number: 2021-427), and all procedures in this study were performed in accordance with the Declaration of Helsinki.

Informed consent All participants were informed of the purpose and procedure of this study, and informed consent was obtained from all participants.

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