Regular Article

TITLE: Differences in Hip Flexion Angle at the Start of Nordic Hamstring Exercise on Hamstring Electromyographic Activity: A Cross-Sectional Study

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Running title: HFA at Start of NHE effects on Hamstring Electromyographic Activity

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Abstract

In this study, we aimed to investigate the effect of differences in hip flexion angle (HFA) at the start of Nordic hamstring exercise (NHE) on hamstring electromyographic (EMG) activity. Fifteen male volunteers performed three NHE variations implemented at the starting HFA (0° was considered the neutral position): -10° HFA (NHE-10), 10° HFA (NHE10), and 30° HFA (NHE30). The primary outcomes were biceps femoris (BF) and semitendinosus (ST) EMG activities in NHE-10, NHE10, and NHE30. The HFA at the break-point angle (HFA-BPA) was significantly higher in the following order: NHE30, NHE10, and NHE-10 ($P < .05$). BF and ST EMG activities were significantly higher in the NHE-10 group than in the NHE30 group ($P < .05$). Performing NHE with the upper body in an upright position at the start could enhance BF and ST EMG activities.

Keywords: injury prevention, recurrence prevention, iOS app

タイトル：ノルディックハムストリングエクササイズ開始時の股関節屈曲角度の違いがハムストリングの筋放電量に与える影響：横断的研究

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要約

本研究は、ノルディックハムストリングエクササイズ開始時の股関節屈曲角度の違いがハムストリングの筋放電（EMG）活動に及ぼす影響を調査することを目的とした。15 名の男性がノルディックハムストリングエクササイズ（NHE）開始時の股関節屈曲角度（0°を中立位置とみなす）を-10°（NHE-10）、10°（NHE10）、30°（NHE30）に設定した 3 条件の NHE を実施した。主要測定項目は、NHE-10、NHE10、NHE30 における大腿二頭筋（BF）および半腱様筋（ST）の EMG 活動であった。HFA-BPA は、NHE30、NHE10、NHE-10 の順に有意に高かった（$P < .05$）。大腿二頭筋（BF）および半腱様筋（ST）の EMG 活動は、NHE-10 が NHE30 よりも有意に高値を示した（$P < .05$）。本研究により、股関節屈曲角度を-10°で開始することで、NHE 中のハムストリングの EMG 活動を高められる可能性が示唆された。

Introduction

Hamstring injuries occur in several sports activities[1]. The incidence rate of hamstring injuries has reportedly doubled over the past 20 years, with over two-thirds of recurrences occurring after footballers' return to play[2]. Returning to play may require a long recovery period ranging from 15 to 105 days[3]. In particular, recurrent injuries necessitate a longer recovery period to return to play than initial injuries[4]. Therefore, preventing not only the initial hamstring injury but also its recurrence is essential.

Hamstring injuries cause a decrease in the electromyographic (EMG) activities of the biceps femoris (BF) and semitendinosus (ST) during an eccentric knee flexion exercise[5,6]. A previous study reported a difference in BF EMG activity between healthy and injured legs during an eccentric knee flexion exercise performed at slow angular speeds (30˚/s)[5]. Thus, eccentric hamstring training that creates high hamstring EMG activity might help reduce recurrence of hamstring injuries by increasing hamstring EMG activity during an eccentric knee flexion exercise. However, there is no evidence that exercises enhancing EMG activity of BF and ST could be effective in preventing hamstring injury recurrence.

The Nordic hamstring exercise (NHE) involves increased hamstring EMG activity[7] as the upper body leans forward from a kneeling position[8]. The point at which the hamstring muscles can no longer resist the load caused by the forward lean of the upper body and begin to release tension is referred to as the break point, whereas the break-point angle (BPA) is defined as the knee flexion angle when the knee joint extension angular velocity exceeds 30°/s[9,10]. Recently, the Nordic Angle app, an iOS application that can automatically measure not only the BPA but also the hip flexion angle (HFA) at the BPA (HFA-BPA), was developed[9,10]. The HFA is defined as 0° in the neutral position, and the angle increases as the upper body leans forward. However, the effect of differences in HFA at the start of NHE on

HFA-BPA and hamstring EMG activity remains unclear.

Different starting hip positions might alter HFA-BPA[11]. Moreover, differences in HFA at the start of NHE might influence hamstring activity[11,12]. In the present study, we aimed to investigate the effects of different initial hip positions on HFA-BPA and their influence on hamstring activity and BPA. We hypothesized that more upright upper body at the start of NHE would result in greater hamstring EMG activity[11].

Methods

Study Design

In this single-visit cross-sectional study, the NHE was implemented at three different starting hip positions: (i) HFA of -10° (NHE-10), (ii) HFA of 10° (NHE10), and (iii) HFA of 30° (NHE30), with 0° being defined as the neutral position.

Participants

The required sample size was estimated using G*Power version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany). The sample size was calculated *a priori* based on the parameters of one-way repeated-measures analysis of variance (ANOVA) (effect size, 0.4; alpha, 0.05; power, 0.8)[13]. The required sample size was determined to be 12.

Fifteen male volunteers (age, 24.8 ± 3.5 years; height, 172.5 ± 5.1 cm; body mass, 66.9 ± 5.7 kg) participated in this study. All participants had prior experience with the NHE. Individuals with a history of hamstring or anterior cruciate ligament injuries were excluded.

All procedures were conducted in accordance with the ethical principles embodied in the Declaration of Helsinki. The experimental protocol was approved by the Ethics Committee of Shibaura Institute of Technology (approval number: 25-030). Informed consent was obtained from all participants after explaining the purpose and procedures of the study.

Procedures

The participants initially performed a static hamstring stretch (standing hamstring stretch on one leg) with a 20-s hold on each leg. Subsequently, the participants performed maximum voluntary isometric knee flexion (MVIC) with the hip joint flexed at 0° and the knee joint flexed at 45° (0° was considered full extension). The participants carried out two warm-up trials of MVIC at 50–80% of maximum effort, followed by two MVIC trials at maximum effort. MVIC was gradually exerted to its maximum over the first 2 s and sustained for the next 2 s. The rest periods between warm-up trials and between MVIC trials were set to 1 and 2 min, respectively.

After the MVIC trials, the participants randomly performed the NHE-10, NHE10, and NHE30. They assumed a kneeling position on a bench approximately 0.5 m high with their elbows bent and hands open in front of them. The HFA at the start of the NHE was defined using a manual goniometer (TTM-KO; SAKAI Medical Inc., Japan), with the reference line delineated by the acromion, greater trochanter, and lateral femoral condyle. The participants were instructed to slowly lean forward while maintaining the assigned HFA. They performed two warm-up trials of the NHE at 50–80% of maximum effort, followed by two NHE trials at maximum effort. The rest periods between warm-up trials and between trials were set to 1 and 2 min, respectively.

Kinematic Data

An iPad camera (iPad 11; Apple Inc., USA) was set to 60 fps and positioned approximately 3 m from the right side of a participant at a height of approximately 0.9 m. The examiner carefully adjusted the angle of the iPad camera so that the participant was centered in the frame. The BPA and HFA-BPA were calculated during NHE variations using the Nordic Angle app (Fig. 1)[9,10]. To calculate BPA and HFA-BPA, filtering and setting of the knee extension angular velocity for BPA were performed (Fig. 1 A). Filtering was applied to data on knee flexion and hip flexion angles using a moving average (Move Average) set to 10.

BPA was defined as the knee flexion angle when the knee extension angular velocity (Break Point Velocity) exceeded 3.5. HFA-BPA was defined as the hip flexion angle at BPA. The knee flexion angle and hip flexion angle were defined as anatomical angles, with a value of 0° indicating an extended hip or knee. The average of two NHE trials was used for statistical analysis.

EMG

The surface EMG amplitude during MVIC was determined using wireless electrodes (TS-MYO; Trunk Solution Inc., Japan). The length and width of the electrodes were 1 and 0.5 cm, respectively; the distance between them was 1 cm. The electrodes were placed on the dominant leg (i.e., the leg used to kick the ball). EMG placement for the BF was performed at the midpoint between the ischial tuberosity and the lateral condyle of the tibia, whereas EMG placement for the ST was performed at the midpoint between the ischial tuberosity and the medial epicondyle of the tibia[14)]. The hair around the target muscle was shaved and cleaned with alcohol-moistened cotton. The sampling rate was 1000 Hz, and bandpass filtering was performed between 20 and 450 Hz. EMG amplitudes were expressed as root mean square (RMS) and calculated with a time width of 100 ms. The maximum RMS value was obtained during two MVICs to normalize each NHE trial. The average of NHE trials was used for statistical analysis.

Statistical Analysis

Data are expressed as means ± standard deviations. Data normality was assessed using the Shapiro–Wilk test. The HFA-BPA and BF and ST EMG activities among the starting HFAs were compared using one-way repeated-measures ANOVA. The BPA among the starting HFAs was compared using Friedman's test. Post hoc comparisons were conducted using the Bonferroni test. Partial η^2 values were classified according to the following effect size criteria: trivial, <0.01; small, 0.01–0.06; medium, 0.06–0.14; and large, >0.14. Cohen's *d* was classified according to the following effect size criteria: trivial, <0.2; small, 0.2–0.5; medium, 0.5–0.8; and large, >0.8. Intra-class correlation coefficients (ICCs) (1,1) were calculated to assess the reliability of the two trials. The magnitude of correlation was established according to the following criteria: $r = 1$, perfect correlation; $1 \geq r \geq 0.9$, nearly perfect; $0.9 \geq r \geq 0.7$, very large; $0.7 \geq r \geq 0.5$, large; $0.5 \geq r \geq 0.3$, moderate; $0.3 \geq r \geq 0.1$, small; and $0.1 \leq r$, trivial. All statistical analyses were performed using SPSS version 29 (IBM Corp., Armonk, NY, USA), with statistical significance set at $P < .05$.

Results

EMG

The results for BF EMG activity among the starting HFAs are shown in Fig. 2. One-way repeated-measures ANOVA revealed a significant main effect ($F = 9.0$, $P = .001$, partial $\eta^2 = 0.39$). The BF EMG activity in NHE-10 was significantly higher than that in NHE30 ($P = .006$, $d = 0.71$).

The results for ST EMG activity among the starting HFAs are presented in Fig. 3. One-way repeated-measures ANOVA indicated a significant main effect ($F = 6.8$, $P = .004$, partial $\eta^2 = 0.33$). The ST EMG activity in NHE-10 was significantly higher than that in NHE30 ($P = .002$, $d = 0.94$).

Kinematic Data

The results for the BPA among the starting HFAs are presented in Fig. 4 Friedman's test did not indicate any significant difference ($P = .127$). The results for the HFA-BPA among the starting HFAs are presented in Fig. 5. One-way repeated-measures ANOVA revealed a significant main effect ($F = 105.5$, $P = .000$, partial $\eta^2 = 0.88$). The HFA-BPA in NHE30 was significantly higher than that in NHE-10 ($P = .000$, $d = 3.31$) and NHE10 ($P = .000$, $d = 1.28$). Additionally, the HFA-BPA in NHE10 was significantly higher than that in NHE-10 ($P = .000$, $d = 2.31$).

Reliability of NHE Variations

In NHE-10, the ICCs for the HFA-BPA, BPA, BF EMG activity, and ST EMG activity were 0.67 (large), 0.92 (nearly perfect), 0.90 (nearly perfect), and 0.85 (very large), respectively. In NHE10, the ICCs for the HFA-BPA, BPA, BF EMG activity, and ST EMG activity were 0.55 (large), 0.88 (very large), 0.93 (nearly perfect), and 0.84 (very large), respectively. In NHE30, the ICCs for HFA-BPA, BPA, BF EMG activity, and ST EMG activity were 0.8 (very large), 0.82 (very large), 0.86 (very large), and 0.76 (very large), respectively.

Discussion

The present study sought to investigate the effects of different initial hip positions (NHE-10, NHE10, and NHE30) on HFA-BPA and their influence on hamstring activity and BPA. The main results indicated that the HFA-BPA was significantly higher in the order of NHE30, NHE10, and NHE-10 and that the hamstring EMG activity in NHE-10 was significantly higher than that in NHE30. No significant difference in the BPA was observed among the NHE variations. The results of this study supported our hypothesis. This study is the first to investigate the effect of differences in the HFA-BPA measured using the Nordic Angle app on hamstring EMG activity.

A characteristic of individuals with a history of hamstring injuries is a decrease in BF EMG activity during an eccentric knee flexion exercise[5)]. Considering that EMG activity during exercise improves with activation training[15], long-term use of NHE protocols that elicit higher BF EMG activity might contribute to hypotheses regarding potential mechanisms related to hamstring injury risk, although the present cross-sectional design does not allow any inference about preventive effects. A previous study investigated differences in the BF EMG activity during the NHE with initial HFAs set at 0°, 25°, 50°, and 75° and demonstrated that greater HFAs at the start of the NHE lead to more significant decreases in BF EMG activity during the NHE[11]. The present study also revealed that NHE30, which had a larger HFA at the start of the NHE, showed a significant decrease in BF EMG activity compared to NHE-10, which had a smaller HFA (Fig. 4). Skeletal muscle fibers can broadly be classified into contractile elements (e.g., actin and myosin) and non-contractile elements (e.g., titin and fascia). In the ascending limb and plateau of the muscle length-tension relationship, the contracting element becomes the primary tension force, while, farther along the descending limb, the non-contracting element becomes the primary tension force[16]. During NHE30, as the hip flexion angle increased (Fig. 2), it might have belonged to the descending limb of the muscle length-tension relationship; furthermore, the generation of tension might have depended more on non-contractile elements than on contractile elements. In fact, more stretched hamstring muscles during an eccentric knee flexion exercise result in greater knee flexion torque; however, the BF EMG activity decreases[17]. However, since the behavior of muscles and tendons during NHE30 has not been confirmed by ultrasound or other methods, this remains mere conjecture. Nevertheless, performing NHE with the upper body in an upright position was effective in enhancing BF EMG activity. Nevertheless, individuals with a history of hamstring injuries characteristically exhibit a decrease in BF EMG activity during an eccentric knee flexion exercise, this occurs mainly when knee flexion is within 35°[5,6,18]. Because BF EMG activity decreases after BPA[10], the use of an angle-adjustable inclined platform may warrant consideration in future research, particularly when examining conditions in which the BPA exceeds 50°, as in the present study[8,13].

Most hamstring injuries occur in the BF[19]. This may be the reason for the decrease in BF EMG activity during an eccentric knee flexion exercise, which is a characteristic of individuals with a history of hamstring injuries[5,18]. ST EMG activity has also been reported to decrease during an eccentric knee flexion exercise in individuals with a history of hamstring injuries[6]. Recent studies have reported on ST injuries[20] and shown that the ST is more likely to be injured than the BF[21]. If muscle injury is accompanied by a decrease in EMG activity in the same muscle, it seems highly significant to measure the ST EMG activity during exercise. Similar to the results for BF EMG activity in this study, the ST EMG activity was significantly lower in NHE30, which had a larger HFA at the start of NHE, than in NHE-10, which had a smaller HFA (Fig. 5), suggesting that tension generation may depend more on noncontractile elements than on contractile elements due to hip flexion[16]. Therefore, performing NHE with the upper body in an upright position, similar to BF EMG activity, was effective in enhancing ST EMG activity. There is no evidence that exercises enhancing EMG activity of BF and ST within 35° of knee flexion [5,6,18)] are effective in preventing hamstring injury recurrence. Therefore, future research is needed to investigate whether such exercises have any relevance to injury recurrence remains entirely speculative and would require longitudinal or interventional research to evaluate.

In the present study, the HFA-BPA increased with an increase in the HFA at the start of the NHE (Fig. 2); however, no effect on the BPA was observed (Fig. 3). The difference in the HFA-BPA depending on the HFA at the start of the NHE was expected to be within an HFA of 30°[11)]. Nevertheless, this is the first attempt to measure the HFA-BPA using the Nordic Angle app. Although the Nordic Angle app has been used to estimate HFA-BPA in previous work, some supporting validation data remain unpublished. Therefore, the present measurements should be interpreted with caution, and further validation using three-dimensional motion analysis will be necessary in future studies. Given these limitations, HFA-BPA should be interpreted as an exploratory or secondary outcome rather than a primary measure.

There are several limitations in this study. First, a possibility of EMG crosstalk might have existed. Although EMG electrodes were attached in accordance with the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles recommendations[14)], crosstalk could have possibly occurred. Future studies will require identifying muscles using ultrasound to reduce any possible crosstalk. Second, the ICC value for HFA-BPA was low. The ICCs for NHE-10, NHE10, and NHE30 were 0.67, 0.55, and 0.8, respectively. The differences between initial hip flexion angle and HFA-BPA for NHE-10, NHE10, and NHE30 were 15.0°, 15.9°, and 7.1°, respectively. This indicates that while NHE-10 and NHE10 feature a forward lean of the upper body from the starting posture to BPA, NHE30 exhibits a smaller change in forward lean of the upper body from the starting posture to BPA. The difference between the initial hip flexion angle and HFA-BPA might have influenced the ICC values. Finally, since the participants did not include female athletes or individuals with a history of hamstring injuries, the results might not be the same under this research protocol.

A characteristic of individuals with a history of hamstring injuries is a decrease in hamstring EMG activity during an eccentric knee flexion exercise. The performing NHE with the upper body in an upright position at the start increased hamstring EMG activity in this study. However, the extent to which such acute EMG responses relate to injury risk or prevention remains unclear and cannot be inferred from this cross-sectional design. These findings also show that performing the NHE with an upright upper-body posture is associated with higher hamstring EMG activity. The potential relevance of these EMG patterns to injury recurrence is entirely speculative and will require future longitudinal or interventional studies to determine.

In the future, it would be desirable to implement the protocol used in this study by attaching EMG electrodes using ultrasound. When implementing NHE protocols, such as those in this study, which involve changing the HFA setting, adding familiarization repetitions will be necessary.

Conclusion

The present study sought to investigate the effects of different initial hip positions (NHE-10, NHE10, and NHE30) on HFA-BPA and their influence on hamstring activity and BPA. The main results indicated that performing NHE with the upper body in an upright position at the start could enhance BF and ST EMG activities.

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Conflict of Interest

The authors declare no conflict of interest.

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Data Availability Statement

The datasets generated and/or analyzed during the current study are not publicly available, but are available from the corresponding author, who was involved in organizing the study.

Author Contributions

All authors contributed to the study design. TS performed the material preparation, data collection, and analysis. TS wrote the first draft of the manuscript, and all authors commented on previous versions of the manuscript. All authors have read and approved the final version of the manuscript.

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Figure Captions

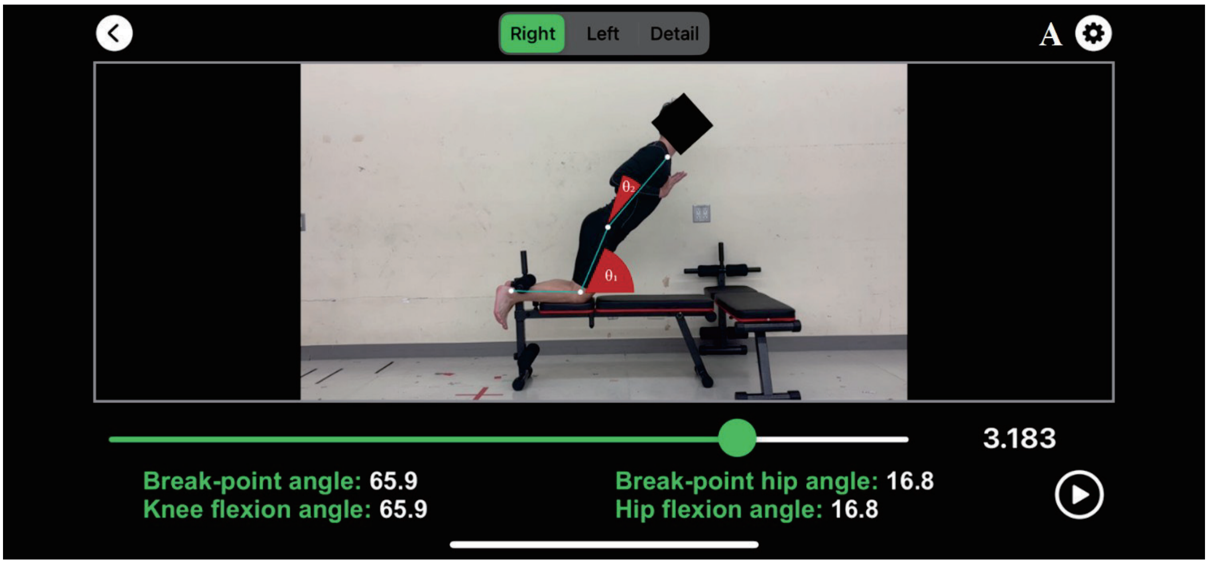

Fig. 1 — The screen on the Nordic Angle app. θ_1, knee flexion angle; θ_2, hip flexion angle. A, Settings button.

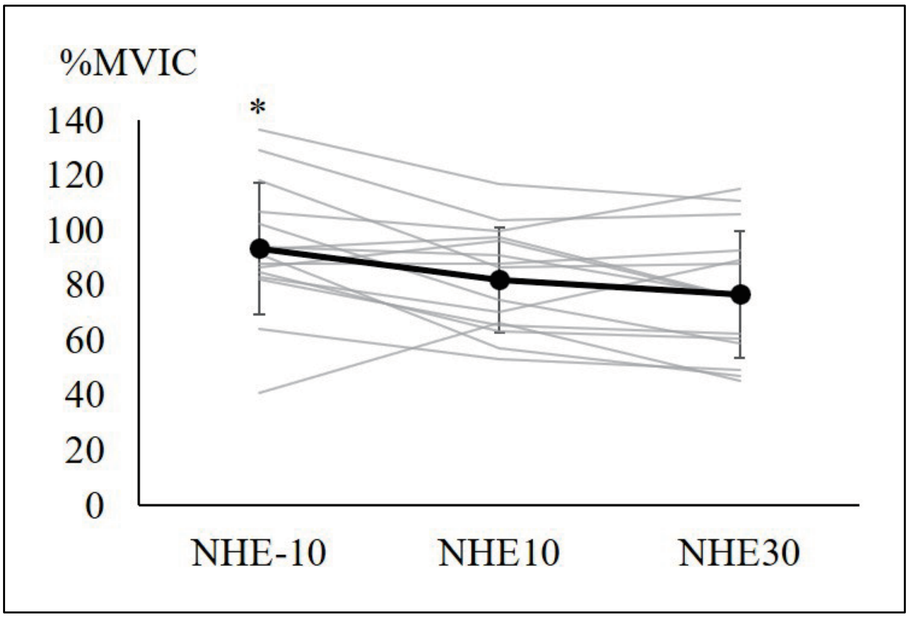

Fig. 2 — BF EMG activity among the starting HFAs. * indicates a significant difference from NHE30 ($P < .05$).

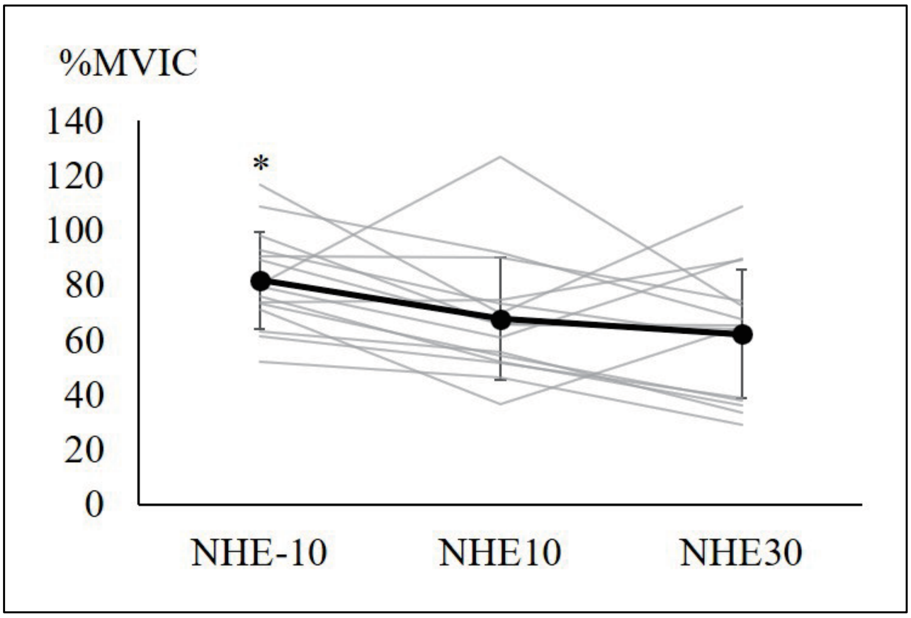

Fig. 3 — ST EMG activity among the starting HFAs. * indicates a significant difference from NHE30 ($P < .05$).

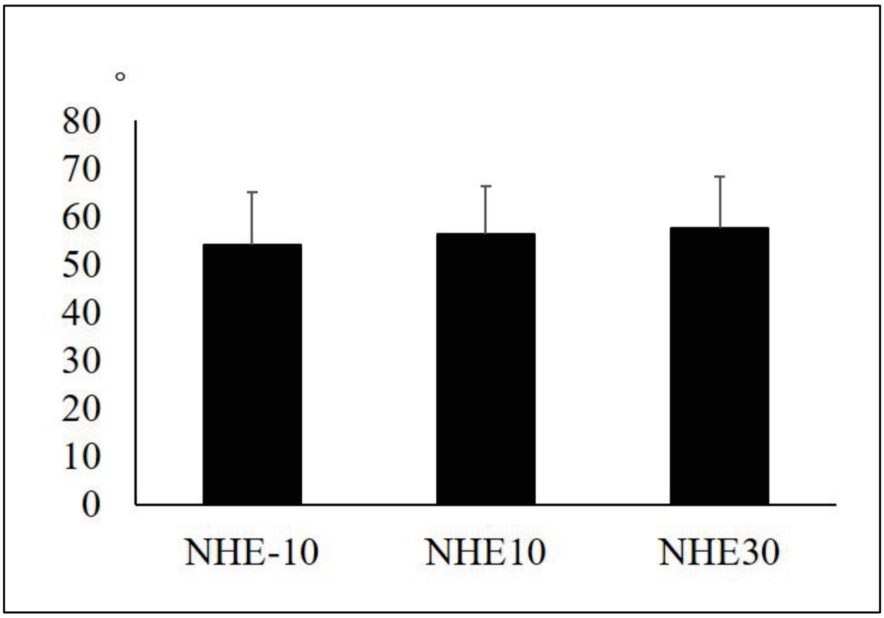

Fig. 4 — BPA among the starting HFAs.

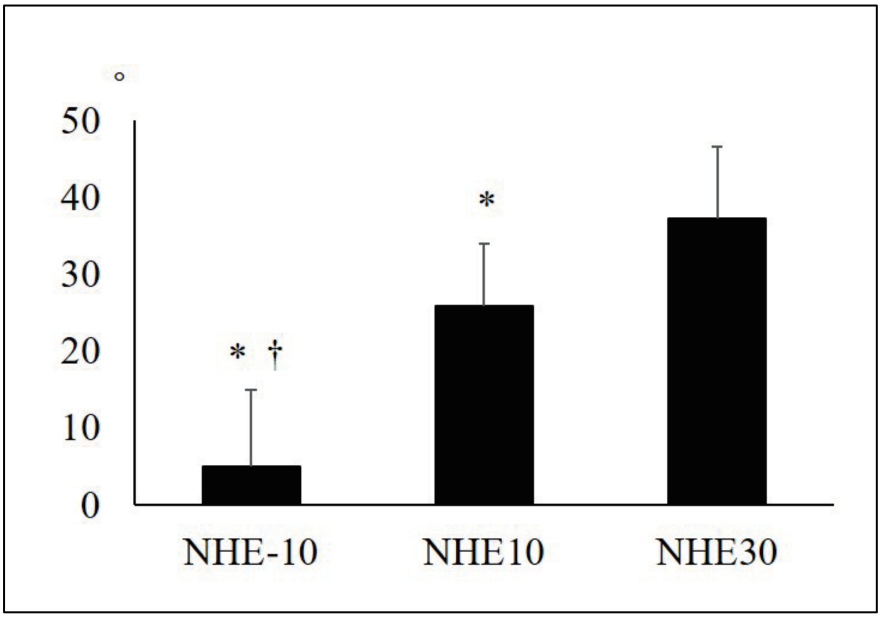

Fig. 5 — HFA-BPA among the starting HFAs. * indicates a significant difference from NHE30 ($P < .05$). † indicates a significant difference from NHE10 ($P < .05$).