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Research article

Influence of Altered Knee Angle and Muscular Contraction Type on Electromyographic Activity of Hamstring Muscles during 45° Hip Extension Exercise

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Abstract
In this study, we investigated differences in electromyographic activity in the biceps femoris long head (BFl), semitendinosus, and semimembranosus muscles during 45° hip extension with different knee angles during eccentric, concentric, and isometric hip 0°, and isometric hip 45° conditions with non-external resistance and 5-kg load. Twenty-two male volunteers performed 45° hip extension with knee flexion angles of 0°, 45° and 90° with non-external resistance and 5-kg load eccentric, concentric, isometric hip 0°, and isometric hip 45° conditions. The electromyographic data obtained during each condition were normalized with the values collected during maximal voluntary isometric contraction of each muscle. A multivariate analysis of variance with repeated measures using syntax was used to compare the normalized electromyography of each muscle across different knee joint angles in each weight condition. Electromyographic activities of the BFl, semitendinosus, and semimembranosus at 45° and 90° knee flexion angles were significantly greater than at 0° in the eccentric, concentric, isometric hip 0°, and in isometric hip 45° conditions with both non-external resistance and 5-kg load ($p<0.05$), except for that of the BFl and semitendinosus in isometric hip 45° with 5-kg load. The electromyographic activity of the BFl was significantly higher than that of the semimembranosus at 90° knee flexion in all conditions ($p < 0.05$), except during eccentric with non-external resistance. There was no significant difference in electromyographic activity in the hamstring muscles among different knee angles and muscular contraction conditions. This study showed that 45° hip extension with 45° and 90° knee flexion might be better in terms of the recruiting hamstring activity compared to 0° knee flexion, regardless of the training intensity. We recommend 45° hip extension exercises with knee flexion angles of 45° and 90° to activate the BFl, in preventing hamstring strain.

Key words: Biceps femoris, knee flexion, external resistance, sports, injuries.

Introduction

It is clear that the recruitment patterns in the hamstring muscles differ according to different strength training exercises. Previous studies have shown that the BFl is more selectively activated to a great degree during 45° hip extension exercises (Bourne et al., 2017a; 2017b). In addition, 45° hip extension exercise training was shown to promote the elongation of BFl fascicles (Bourne et al., 2017a). Soccer players with shorter BFl fascicles (<10.56 cm) had fourfold greater risk of hamstring strain injury than players with longer fascicles (Timmins et al., 2016). Although these findings obviously elucidated the activation of BF during this exercise, there is no research examining the function of the hamstring muscles across different knee joint angles during this exercise. On the other hand, it is well recognized that each of the hamstring muscles namely the semitendinosus (ST), semimembranosus (SM), and BFl muscles have different morphological features, including different physiological and anatomical cross-sectional areas, pennation angles, muscle fiber lengths, and number of joints that the muscle crosses (Friederich and Brand, 1990; Hirose and Tsuruike, 2018). These factors are altered with changes in muscle length, leading to altered electromyography (EMG) activities of the hamstrings at different knee joint angles (Onishi et al., 2002). Although, previous studies have demonstrated the EMG activation pattern of the hamstring muscles across different knee flexion angles during maximum isometric and isokinetic conditions (knee flexion, leg curls, bilateral, and unilateral bridge exercises) (Hirose and Tsuruike, 2018; Onishi et al., 2002), the pattern during 45° hip extension exercise is still unclear. Since this exercise results in more uniform activation of the two-joint hamstrings and more selectively recruits the BFl than other exercises (Bourne et al., 2017b), there has been much interest in investigating the activation pattern of the hamstrings during 45° hip extension exercise.

Hamstring strengthening is an important injury prevention strategy (Bourne et al., 2017a; Guex and Millet, 2013; Malliaropoulos et al., 2012; Opar et al., 2012). Resistance exercise is also widely accepted to promote the strength, size, muscular endurance, or power of a muscle group (Clark, 2008). In addition, a previous study showed that 45° hip extension exercise training promotes hypertrophy more in the BFl than in the Nordic hamstring exercise (Bourne et al., 2017a). Furthermore, 45° hip extension exercise plus additional resistance might help to stimulate more muscle recruitment and muscle strength than the 45° hip extension exercise alone.

However, the benefit of the 45° hip extension exercise plus additional resistance remains unclear in terms of the recruitment and activation pattern of the hamstring muscle. Based on a previous study, hip extension exercise training on BFl fascicle lengths and eccentric knee flexor strength show potential for reducing the risk of injury (Bourne et al., 2017a).

Surface EMG (sEMG) has been used to analyze the mechanisms involved in hamstring exercises (Bourne et al., 2018; 2017b; Ditroilo et al., 2013; Ono et al., 2011; Ono et al., 2010; Zebis et al., 2013). The EMG activity expresses an estimate of the voluntary activation, which

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includes both motor unit recruitment and firing rates for the muscles assessed during exercise (Bourne et al., 2018). For this reason, sEMG is effective for identifying hamstring activation during 45° hip extension. The results may provide practical information so that athletic trainers and clinicians can better prescribe appropriate exercises for injury prevention.

Based on this background, the purpose of this study was to investigate hip extension across different knee flexion angles. In addition, we aimed to examine the isometric hamstring function of the hip at 0° and 45°, and eccentric and concentric contractions. This study also aimed to compare between performing 45° hip extension exercise plus additional resistance with 45° hip extension exercise alone, to identify the preferable exercise for injury prevention. We hypothesized that 45° hip extension at 45° and 90° knee flexion might be more effective for recruiting hamstring activity especially the BFl than 45° hip extension exercise.

Methods

Subjects

Twenty-two recreationally active male volunteers who perform aerobic activity at least twice a week (mean age, 22.1 ± 2.0 years; height, 1.73 ± 0.05 m; and body mass, 65.5 ± 7.6 kg, all measured in mean ± standard deviation [SD]) participated in this study. Subjects with hamstring strain and any other injury were excluded. The study was approved by the Human Research Ethics Committee of the University and was conducted in accordance with their guidelines for human experimentation. All subjects provided written informed consent prior to participation.

Procedures

Before the experiment, subjects were prepared for EMG electrode placement by shaving the hair around the target site and the skin was cleaned with alcohol. The six target muscles (BFl, ST, SM, GM, AD, and ES) were measured using wireless EMG sensors (m-BioLog2 DL-5000, S&ME Co., Ltd., Tokyo, Japan). The EMG electrodes were preamplified (10X) and linked through the EMG mainframe, which further amplified it (100X) to a total gain of 1,000X, and band pass filtered (20-500 Hz) the signals. The electrodes were placed on each target muscle following the landmarks: midpoint between the ischial tuberosity and the lateral epicondyle of the tibia (BFl), midpoint of the line between the ischial tuberosity and the media epicondyle of the tibia (ST), on the line between medial condyle of the tibia and ischial tuberosity (SM), midpoint between the sacral vertebrae and the greater trochanter (GM), two finger-width lateral from the spinous process of the L1 vertebra (ES), and two finger-width lateral from the midline of the umbilicus (AD). Electrodes were placed parallel to the lines between these landmarks as recommended in the SENIAM guidelines (Hermens et al., 2000). To achieve accurate electrode placement on each muscle, the examiner palpated the muscle bellies and tested it for a clean EMG reading during the contraction of each targeted muscle. This study redacted the root mean square (RMS) from the raw EMG data during the middle 2 seconds of the 5-seconds exercise for further analysis. Then, subjects underwent five maximal voluntary isometric contractions (MVICs) during a leg curl with knee flexions of 30° and 90°, respectively, for the hamstring muscles. The GM, ES, and AD were measured using the hip extension with the knee flexed at 90°; with trunk extension and trunk flexion at the supine position, respectively. These exercises were used in previous studies that investigated the EMG activity of the hamstring muscles (Ekstrom et al., 2007; Hirose and Tsuruike, 2018; Onishi et al., 2002). Each MVIC protocol was performed for two bouts of 5 seconds. EMG values were collected during each MVIC protocol. The maximum EMG values during MVIC of each muscle were used to normalize the EMG values during the 45° hip extension exercises.

After performing the MVIC protocol, subjects performed three bouts of 45° hip extension exercises in 4 different knee flexion angles (total 12 bouts). The knee flexion angle was randomly set at 0°, 45° or 90°. A manual goniometer was used to monitor the knee joint angle at the start of each exercise. During the exercise protocol, subjects were instructed to hold their back erect and kneel on the adjustable incline board plan covered with an exercise mat at 45° angle above the ground. Then, subjects adjusted their knee flexion angles and their legs were held by the examiner to stabilize the knee flexion angle. Subjects were instructed to bend their back forward to a 0° hip joint angle and hold it for 5 seconds (neutral isometric phase [(ISO0]). Next, the subjects were instructed to gradually bend their back forward to a 45° hip joint angle for 5 seconds (eccentric phase [ECC]), and then hold the position for 5 seconds (isometric phase during hip extension [ISO45]). Finally, subjects were instructed to gradually elevate their back up to a 0° hip joint angle for 5 seconds (concentric phase [CON]).

During this cross-over study, subjects performed each protocol in non-weight-bearing (NW) and 5 kg weight-bearing (5WT) conditions.

Statistical Analyses

The average value (+SD) of 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 (MANOVA) with repeated measures using syntax was used to compare the nEMG of each muscle across different knee joint angles in each weight condition. In addition, the t-test was used to compare the difference between NW and 5WT conditions for each muscle and degree. When a simple main effect was found, Tukey post hoc test was used to measure any differences. The statistical power was analyzed using SPSS for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). The statistical significance level was set at a P-value < 0.05.

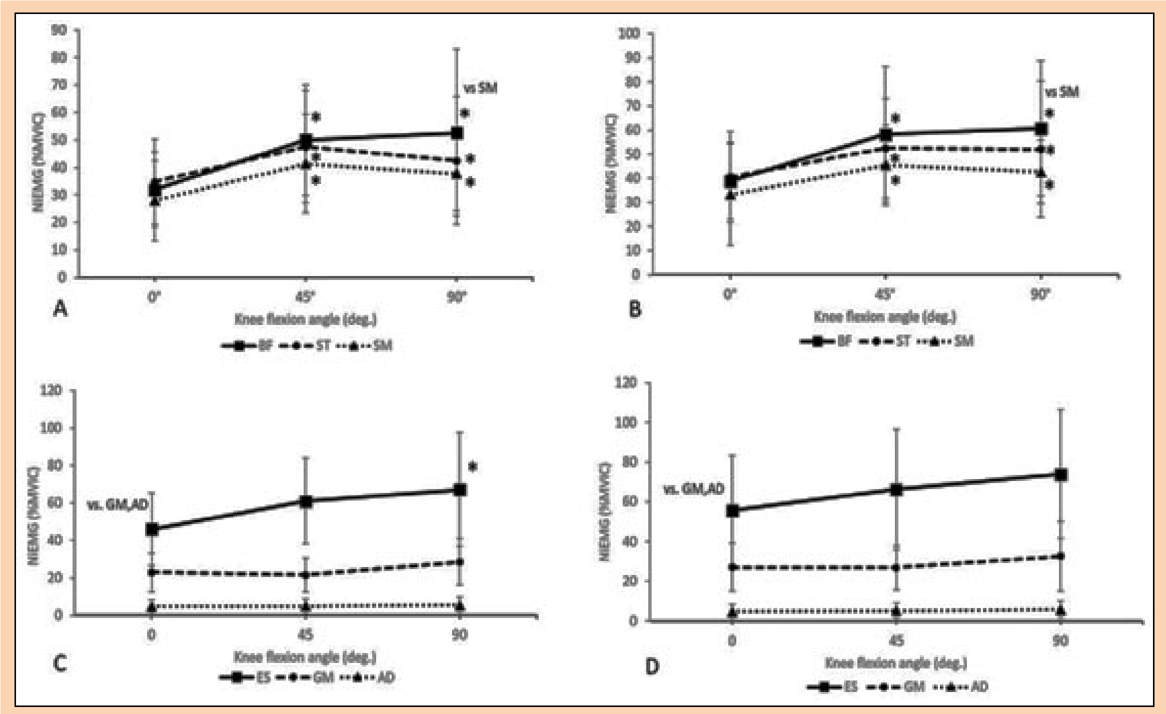

Figure 2. Differences in the NiEMG (%MVIC) between muscle and degree (A) Hamstrings NW; (B) Hamstrings WT; (C) Related muscle NW; and (D) Related muscle WT at each knee flexion angle during 45° hip extension exercise (ISO0). BF=biceps femoris; ST=semitendinosus; SM=Semimembranosus; ES=Erector spinae; GM=Gluteus maximus; AD= Rectus abdominis; MVIC= maximal voluntary isometric contractions; NW=non- external resistance; WT= 5kg load; ISO0= isometric hip 0°. The symbol* indicated statistical significance between 0° and other degrees, and symbol vs. indicated statistical significance between muscles.

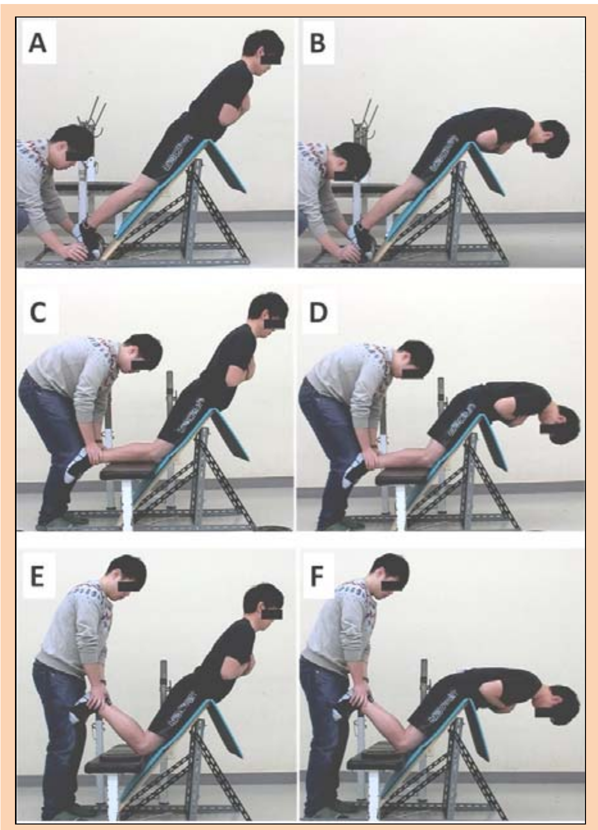

Figure 1. 45° hip extension exercise during Isometric contraction. A) Isometric at knee flexion 0° B) Isometric at knee flexion 0° and hip flexion 45° C) Isometric at knee flexion 45° D) Isometric at knee flexion 45° and hip flexion45° E) Isometric at knee flexion 90° F) Isometric at knee flexion 90° and hip flexion 45°.

Results

Comparison between knee angles for each muscle

The obtained nEMG activity values during exercise in the ISO0, ISO45, ECC and CON contraction conditions are shown in Figures 1, 2, 3, 4 and 5 respectively. There was a significant main effect among knee angles for the BFl, ST, and SM during ISO0, ISO45, ECC and CON ($p < 0.05$). The nEMG activity values for the BFl, ST, and SM at 45° and 90° knee flexion angles were significantly higher compared to the 0° knee flexion angle in both the NW and 5WT conditions during ISO0, ISO45, ECC and CON contractions, ($p < 0.05$), except for BF and ST during ISO45 with 5WT. During ISO45 in the NW condition, the EMG activity of the BFl and ST was higher at a knee flexion angle of 90° compared to at 0° ($p < 0.05$). In related muscles, there was significant main effect among all knee angles for the ES, GM and AD during ISO0, ISO45, ECC and CON except AD during ISO45 ($p < 0.05$). EMG activity of the ES during NW at ISO0 and ECC was significantly higher at 90° knee flexion angle compared to the 0° knee flexion angle ($p < 0.05$).

Comparison between muscles for each knee angle

There was a significant main effect between muscles in both the NW and 5WT conditions during ISO0, ISO45, ECC and CON (all $p < 0.05$). The nEMG activity of the BFl was significantly higher than that of the SM at 90° knee flexion angle in both the NW and 5WT conditions during ISO0, ISO45, ECC and CON, except for ECC in the NW condition ($p < 0.05$). However, there were no significant interactions between muscles and angles. In related muscles (ES, GM and AD), there was a significant main effect between muscles in both the NW and 5WT conditions during ISO0 and CON, respectively ($p < 0.05$). The nEMG activity in the ES was significantly higher than that in the GM and AD at 0° of the knee flexion angle during ISO0 and CON.

Comparison between NW and 5WT for each muscle and angle

We found no main effect between NW and 5WT conditions for all exercises and no interaction between knee angle and load.

Discussion

In this study, we examined the recruitment patterns of each hamstring muscles during a 45° hip extension across different knee flexion angles during ISO0, ISO45, ECC and CON in the NW and 5WT conditions. We found that the EMG activity of the BFl was higher at increasing knee flexion angles (45° and 90°). The results indicated that the BFl worked harder at a deep knee flexion angle than the other two hamstring muscles and this finding differs from those of previous report (Onishi et al., 2002). The peak activity of the BFl was found between 15° and 30° of knee flexion whilst the ST and SM worked harder between 90° and 105°. However, the previous study examined the hamstring activity during knee flexion in the prone position with a constant hip flexion angle of 0° (Onishi et al., 2002). This is in contrast to our study, in which various hip and knee angles were used to contract the hamstring muscle. This kinematic difference between the two exercises can affect the recruitment pattern of the hamstring. In our study, the hamstring contracted not only for the hip extension but also for knee flexion. In related muscles, we observed that only the ES at ISO0 and ECC were more recruited to keep the trunk from falling forward into flexion. For the prevention of falling down, ES, which is the back extensor, has to work to maintain the back position against the gravity force.

In this study, we showed that the nEMG activity of the BFl was significantly higher than that of the SM at 90° of the knee flexion in both the NW and 5WT conditions during ISO0, ISO45, ECC and CON ($p < 0.05$), except during ECC in the NW condition. In related muscles, nEMG activity of the ES was significantly higher than that of the GM and AD at 0° of the knee flexion during ISO0, ECC and CON except for ECC in the 5WT condition. This result implied that the EMG activity of the BFl was similar to that of the ST during 45° hip extension. Our findings differ from that of a previous study on hamstring recruitment by Bourne et al. (2017a; 2017b), in which a higher EMG activity level in the BFl compared to the ST was found (Bourne et al., 2017a; 2017b). These differences may be related to the degree of the hip movement during exercise. In this previous investigation, participants were instructed to flex their hip until they reached a point 90° from the starting position and to return to the starting position by extending their hip.

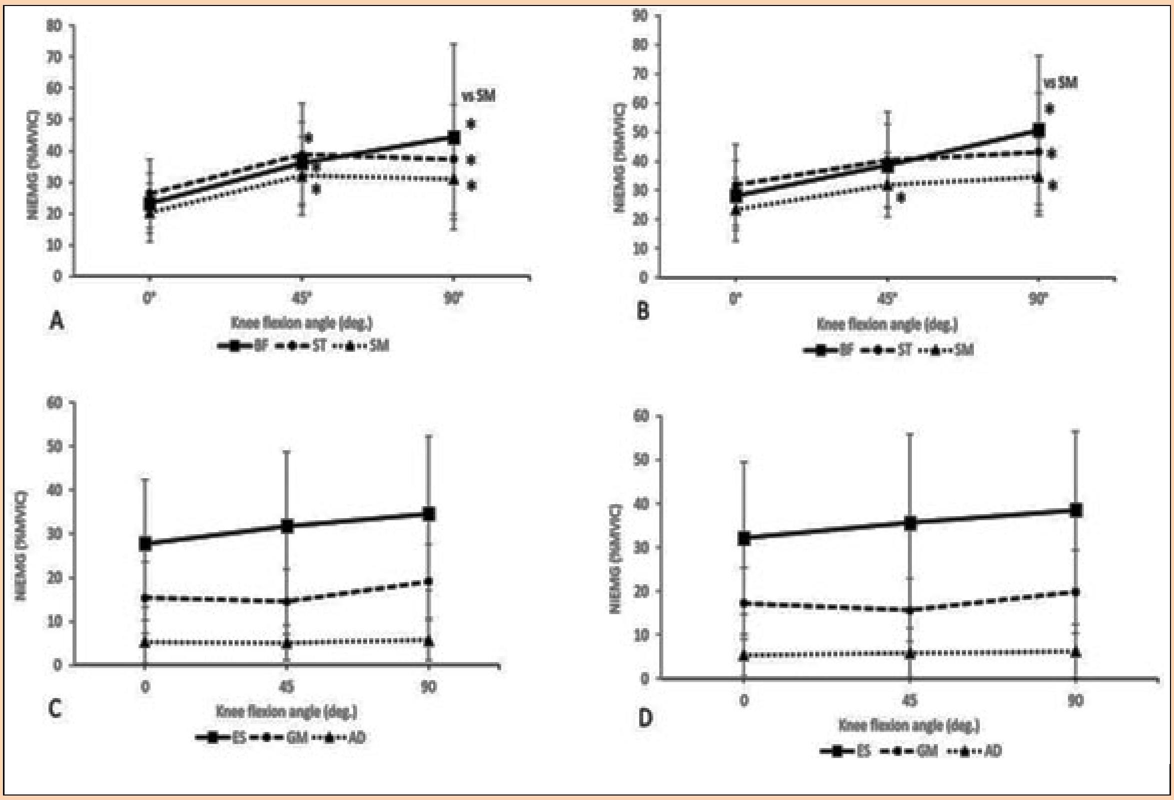

Figure 3. Differences in the NiEMG (%MVIC) between muscle and degree (A) Hamstrings NW; (B) Hamstrings WT; (C) Related muscle NW; and (D) Related muscle WT at each knee flexion angle during 45° hip extension exercise (ISO45). BF=biceps femoris; ST=semitendinosus; SM=Semimembranosus; ES=Erector spinae; GM=Gluteus maximus; AD= Rectus abdominis; MVIC= maximal voluntary isometric contractions; NW=non- external resistance; WT= 5kg load; ISO45= isometric hip 45°. The symbol* indicated statistical significance between 0° and other degrees, and symbol vs. indicated statistical significance between muscles.

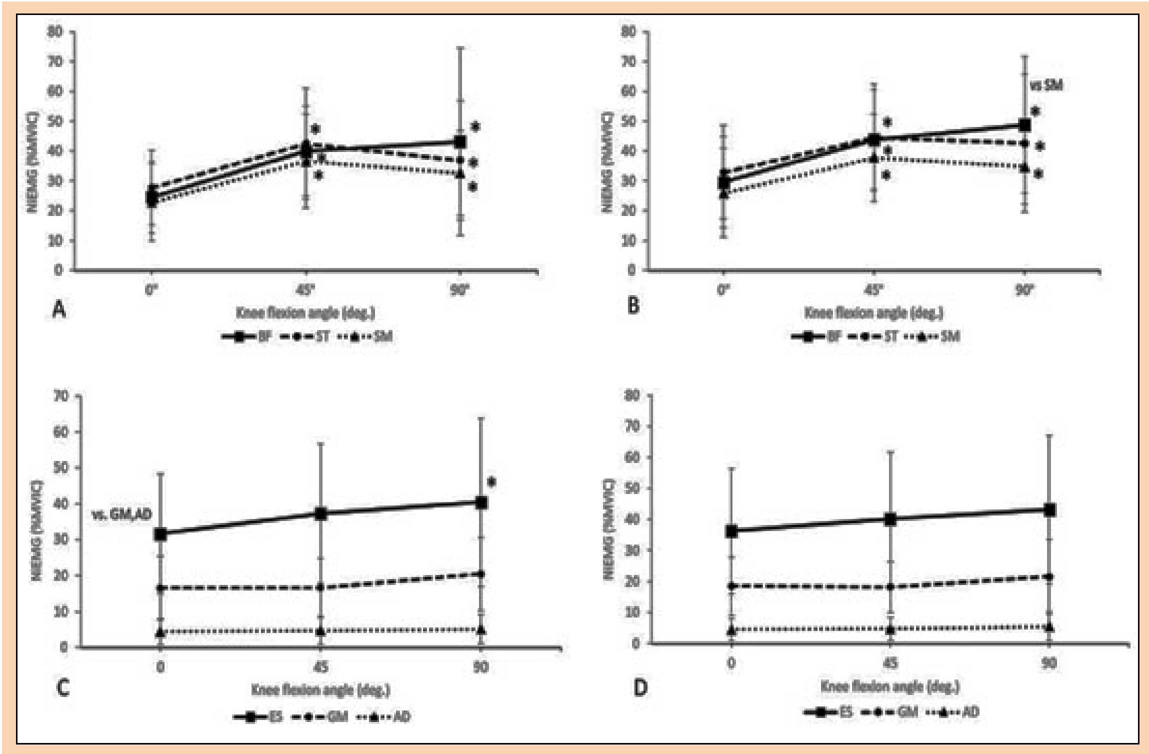

Figure 4. Differences in the NiEMG (%MVIC) between muscle and degree (A) Hamstrings NW; (B) Hamstrings WT; (C) Related muscle NW; and (D) Related muscle WT at each knee flexion angle during 45° hip extension exercise (ECC). BF=biceps femoris; ST=semitendinosus; SM=Semimembranosus; ES=Erector spinae; GM=Gluteus maximus; AD= Rectus abdominis; MVIC= maximal voluntary isometric contractions; NW=non-external resistance; WT= 5kg load; ECC=eccentric. The symbol* indicated statistical significance between 0° and other degrees, and symbol vs. indicated statistical significance between muscles.

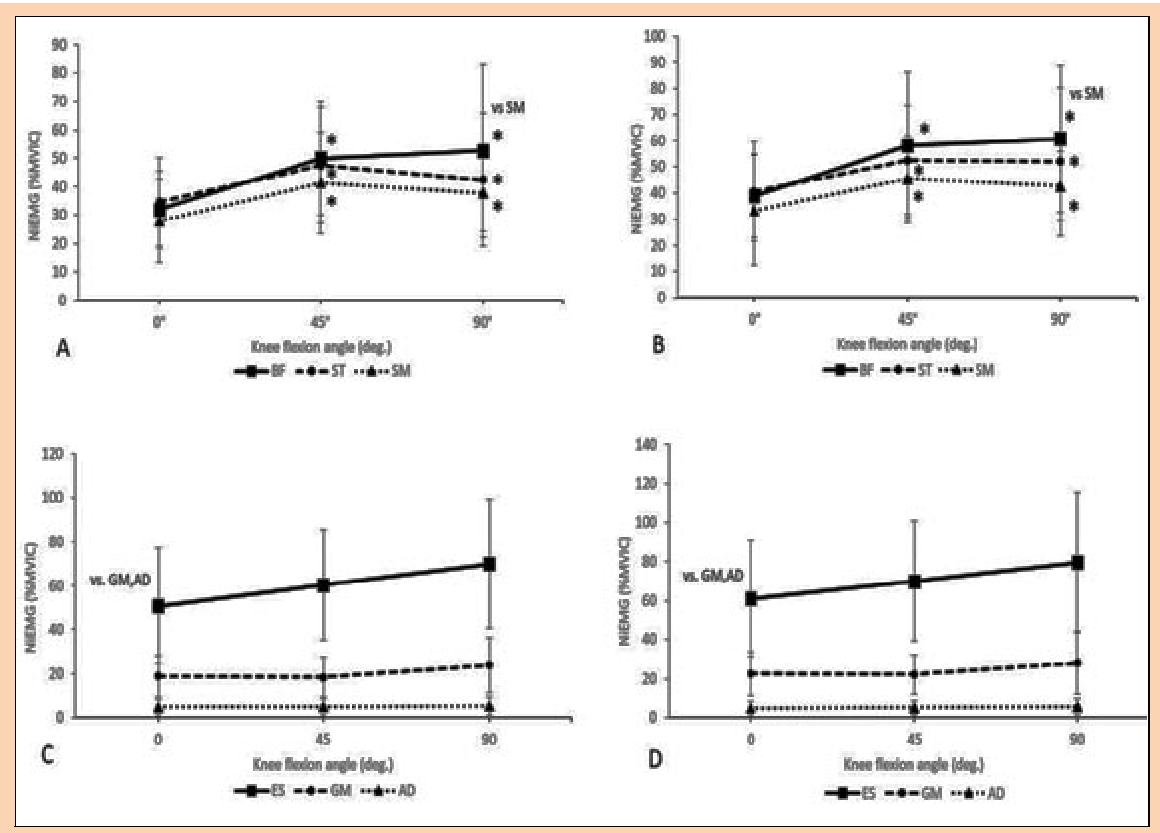

Figure 5. Differences in the NiEMG (%MVIC) between muscle and degree (A) Hamstrings NW; (B) Hamstrings WT; (C) Related muscle NW; and (D) Related muscle WT at each knee flexion angle during 45° hip extension exercise (CON). BF=biceps femoris; ST=semitendinosus; SM=Semimembranosus; ES=Erector spinae; GM=Gluteus maximus; AD= Rectus abdominis; MVIC= maximal voluntary isometric contractions; NW=non-external resistance; WT= 5kg load; CON=concentric. The symbol* indicated statistical significance between 0° and other degrees, and symbol vs. indicated statistical significance between muscles.

In contrast, our participants were instructed to flex and extend the hip until they reached a point 45° from the starting position and this difference led to the different muscle lengths during hamstring contraction. However, Bourne et al. (2017) also examined the muscle activation by using functional magnetic resonance imaging (fMRI), which is effective in showing the reliance on different hamstring muscles during each exercise. They reported that 45° hip extension heavily recruit both BFl and ST. These findings are consistent with the EMG component of our study, which showed similar BFl and ST activation. Mohamed et al. (2002) examined the effect of muscle length on the EMG activity of the knee flexor muscles. They reported decreased activity of the ST muscle in the most lengthened position (hip flexion 90° and knee flexion 0°). They indicated that when the knee is fully extended, the ST tendon lays very close to the axis of the knee joint, providing a poor lever arm for the knee flexion. Moreover, the muscle is elongated at both joints (Mohamed et al., 2002). This might be the reason why a decline in EMG activity of the ST was observed in the previous study. However, in our study, the ST was not fully lengthened. It is possible that the ST works harder during hip movement. Although several authors have explained that the SM and BFl work harder during hip extension and the ST works harder during knee flexion (Bourne et al., 2017a; Bourne et al., 2017b), it might be that muscle length also affects hamstring activity.

Several factors, such as differences in morphological features and the number of joint recruitments, may be responsible for the difference in the EMG activity of the hamstring at different knee joint angles. The BFl muscles are composed of unipennate fibers which have large cross-sectional areas, making them more suitable for torque production than the ST, which has a fusiform shape (Mohamed et al., 2002). In addition, when the knee is flexed, hip extension exercises generate external knee torque during hip movement to prevent falling down. This means that the BF contributes not only to the hip extension, but also to knee flexion to produce the internal knee flexion torque for resisting external knee extension torque. This movement requires high muscle torque and the BFl might be more recruited in response to this movement according to its architecture. Several authors have supported that the BF is selectively recruited in order to deal with the hip and knee joint movement during hip extension exercises (Bourne et al., 2017b; Onishi et al., 2002; Ono et al., 2011). In terms of the weight factors (NW and 5WT) across different knee flexion angles, we found no significant difference between the NW and 5WT conditions in all exercises. Although, we found increasing hamstring activity in the 5WT condition, there was a similar recruitment pattern in the NW and 5WT conditions. This means that a 5 kg weight might not affect the recruitment pattern of the hamstring.

This study had several limitations, the first of which was the uncontrollable intensity during 45° hip extension. In the 5WT condition, all participants were instructed to hold a 5 kg weight; however, the effect of this weight-bearing may differ between participants because of each individual's strength. Further studies are required to determine the intensity of weight-bearing effect on each participant during exercise. We need to conduct further research to clarify the mechanisms of different joint angles and compare different hamstring exercises to identify the most effective exercise for preventing hamstring strains.

Conclusion

Previous study argued that the motor unit recruitment can not be inferred from changes in sEMG amplitude. However, some studies which indicated that a high level of nEMG is an important indicator of improved strength and that the establishment of voluntary activation exercises prevent hamstring strains, may have implications for rehabilitation (Bourne et al., 2017a; Bourne et al., 2017b). The interpretation of EMG is still controversial and a contentious issue. According to our results, we believe that the 45° hip extension with 45° and 90° knee flexion angles stimulated the hamstring muscles to work harder than the 45° hip extension. According to the epidemiological characteristics of hamstring strain injuries, the BFl is the most susceptible to injury, while the ST and SM muscles are less often injured. Although a previous study clearly demonstrated that 45° hip extension helps to recruit and strengthen the BFl, we found that hamstring muscles activities during 45° hip extension with higher knee flexion angles are more effective in activating the BFl muscle. Thus, we recommend that 45° hip extension with 45° and 90° knee flexion angles might be able to stimulate the hamstring muscles to work harder than the 0° knee flexion. In addition, nEMG activity of the BFl was significantly higher than that of SM activity at 90° knee flexion. Weight-bearing (5 kg) had no effect on EMG activity in any of the exercises.

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Key points

- Alteration of the knee angles during 45° hip extension affect the EMG activity of the hamstring muscles.
- 45° hip extension with 45° and 90° knee flexion angles activates the hamstring muscles to work harder than might be the optimal exercise for the recruitment of the hamstring activity.
- Holding a 5 kg weight during 45° hip extension might not affect the recruitment of the hamstring activity.

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