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FUNCTIONAL DIFFERENCES IN THE HAMSTRING MUSCLES DURING SPRINTING

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The purpose of this study was to demonstrate the respective activation of the biceps femoris (BF), semitendinosus (ST), and semimembranosus (SM) muscles during overground sprinting. Lower extremity kinematics and the electromyographic (EMG) activities of the BF, ST, and SM muscles were recorded for 13 male sprinters performing overground sprinting at maximum effort. Mean normalized EMG activity was calculated in the early stance, late stance, middle swing, and late swing phases. The peak activation time during the stance and latter half of the swing phases was also calculated. Significantly different characteristics for EMG activation and different occurrences of peak activation of the BF, ST, and SM were found within the gait cycle, indicating that the activation demand of each hamstring muscle differs during sprinting.

KEY WORDS: hamstrings, sprint, electromyography

INTRODUCTION: The hamstring muscles comprise the biceps femoris (BF) muscle, laterally and the semimembranosus (SM) and semitendinosus (ST) muscles medially. Several investigators have described architectural differences, including variation in muscle weight, pennation angle, muscle volume, physiological cross-sectional area, and muscle fiber length among the hamstring muscles (Friederich & Brand, 1990; Wickiewicz, Roy, Powell, & Edgerton, 1983; Woodley & Mercer, 2005). Studies have also reported that these architectural differences reflect the functions of each muscle (Makihara, Nishino, Fukubayashi, & Kanamori, 2006; Ono, Okuwaki, & Fukubayashi, 2010; Ono, Higashihara, & Fukubayashi, 2011). These reports showed that the electromyographic (EMG) activity of each hamstring muscle varies with knee flexion and hip extension and suggested that activation differences exist among these muscles owing to the morphological and architectural features of the muscles. On the basis of these observations, we hypothesized that activation differences in the hamstring muscles also exist during dynamic movements such as sprinting. Therefore, the aim of this study was to demonstrate the activation of the different hamstring muscles during sprinting and to provide scientific data for estimating the functional characteristics of each hamstring muscle.

METHODS: Thirteen healthy, young male track and field athletes (100 m, 200 m, 400 m, and 400-m hurdles) participated in this study (age, 20.2 ± 0.6 years; height, 173.5 ± 5.0 cm; weight, 64.9 ± 5.8 kg).

The measurement area was set on a straight 100-m section of an athletics track. Three-dimensional kinematic data of 34 reflective markers were recorded at 200 Hz using a 12-camera passive marker system (MAC3D system, Motion Analysis Corporation, Santa Rosa, CA, USA). The surface electromyographic (EMG) activities of the BF, ST, and SM muscles were recorded using a portable EMG system (MQ16, KISSEI COMTEC Co. Ltd., Japan). Bipolar surface Ag/AgCl electrodes were placed over the muscle belly of the selected muscle with an interelectrode distance of 20 mm. A reference electrode was placed on the fibular head. The sampling frequency was 2 kHz. The EMG data were synchronized with the kinematics data.

After a sufficient warm up, each subject performed a maximal-effort sprint from the starting line, set approximately 40 m from the center of the measurement area.

Each trial, consisting of a sprinting gait cycle of the right leg, was analyzed. A stride was defined as the time from ground contact of the right foot to the next ground contact of the same foot. The hip and knee flexion angles in the sprinting gait cycle were calculated (nMotion musculous; NAC Image Technology, Inc., Japan). To adequately describe the relationship between the joint angles and EMG data, sprinting motion was divided into 5 phases according to the right leg movement: early stance phase, beginning with foot strike and ending with maximum knee flexion during ground contact; late stance phase, beginning with maximum knee flexion during ground contact and ending with toe-off; early swing phase, beginning with toe-off and ending with maximum knee flexion; middle swing phase, beginning with maximum knee flexion and ending with maximal hip flexion; and late swing phase, beginning with maximum hip flexion and ending with foot strike (Figure 1a).

A computer software program (Kine Analyzer; KISSEI COMTEC, Co. Ltd, Japan) was used for the EMG analysis. EMG data were band-pass filtered from 20 to 500 Hz. The root mean square of the EMG data was calculated and then normalized to the maximum value during each sprinting gait cycle. Mean normalized EMG activity was calculated for the stance, middle swing, and late swing phases. In addition, we calculated the time at which the EMG activity of the BF, ST, and SM muscles reached its maximum value (peak activation time) during the stance phase and latter half of the swing phase (middle swing and late swing phases).

The EMG activities during each phase were determined using a two-way ANOVA with repeated measures (muscle × phase). The peak activation time of each muscle was compared using a one-way ANOVA. Bonferroni's post hoc analysis was conducted if the ANOVA showed statistically significant main effects or interaction effects. Statistical significance was set at $p < 0.05$.

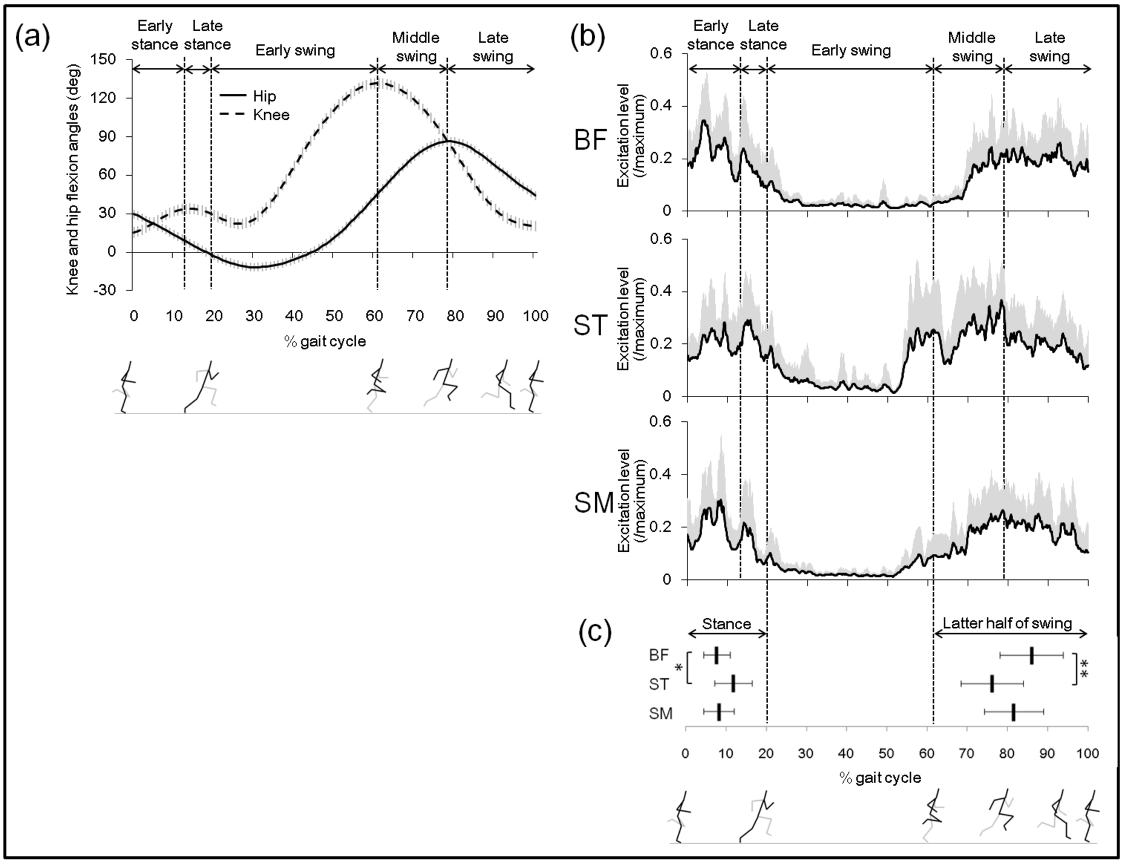

Figure 1. (a) Sprinting phases defined by the mean hip (solid line) and knee flexion (dashed line) angles; (b) mean and standard deviation of the normalized EMG signals; (c) mean and standard deviation of the time (% gait cycle) at which the EMG activity in each muscle reached the maximal value during the stance and latter half of swing phases of the sprinting gait cycle: *p < 0.05; **p < 0.01; biceps femoris (BF); semitendinosus (ST); semimembranosus (SM).

RESULTS: Mean EMG activities during each phase are shown in Figure 2. The two-way ANOVA indicated statistically significant interaction effects (muscle × phase; $p < 0.001$). The activation of the BF muscle during the early stance and late swing phases was significantly greater than during the middle swing phase ($p < 0.01$ and $p < 0.001$, respectively). The activation of the BF and SM muscles during the early stance phase were significantly greater than during the late stance phase ($p < 0.01$ and $p < 0.001$, respectively). The activity of the ST muscle was significantly greater than that of the BF and SM muscles during the late stance and middle swing phases ($p < 0.05$ and $p < 0.01$, respectively).

The peak activation time of each hamstring muscles during the stance phase and latter half of the swing phase are shown in Figure 1c. In the stance phase, the peak activation time occurred in the following order: BF (7.7% ± 3.3% gait cycle), SM (8.2% ± 3.9% gait cycle), and ST (11.8% ± 4.7% gait cycle). We observed a statistically significant difference in the peak activation time between the BF and ST ($p < 0.05$) and also found a tendency for difference between the SM and ST muscles ($p = 0.081$). During the latter half of the swing phase, peak activation time for each muscle was observed in the following order: ST (76.2% ± 7.8% gait cycle), SM (81.6% ± 7.4% gait cycle), and BF (86.0% ± 7.9% gait cycle). We observed a statistically significant difference in the peak activation time between the BF and ST ($p < 0.01$) and also found a tendency for difference between the SM and ST muscles ($p = 0.077$).

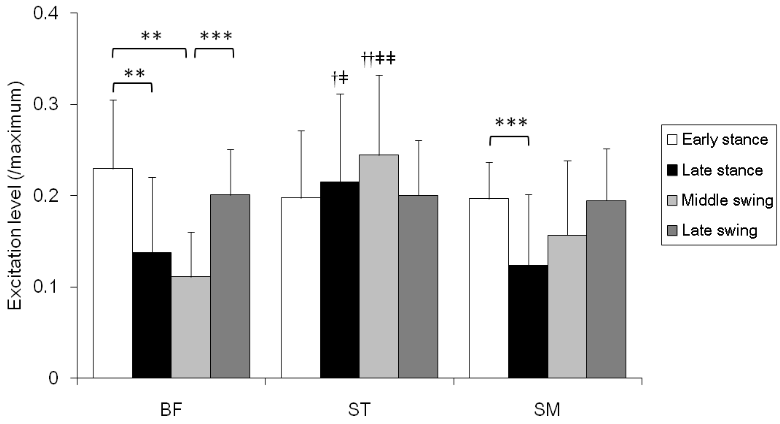

Figure 2. Mean and standard deviation of the normalized EMG values of each phase during sprinting: **$p < 0.01$; ***$p < 0.001$; †$p < 0.05$; ††$p < 0.01$ vs. BF; ‡$p < 0.05$; ‡‡$p < 0.01$ vs. SM.

DISCUSSION: The ST muscle has long fibers with many sarcomeres in series, illustrating its potential to contract quickly over long distances (Heron & Richmond, 1993). A previous study has reported that this muscle is selectively recruited during eccentric knee flexion exercise because of its morphological property of effectively dealing with strain (Ono, Okuwaki, & Fukubayashi, 2010). On the other hand, the BF and SM are pennate muscles, which have large physiological cross-sectional areas and are more suitable for torque production than fusiform muscles (Koulouris & Connell, 2005; Lieber & Friden, 2000; Woodley & Mercer, 2005).A previous study reported that because of their morphological properties, the BF and SM muscles are selectively recruited during hip extension exercise to provide the high muscle torque necessary for this exercise (Ono, Higashihara, & Fukubayashi, 2011).

During the stance phase of sprinting, the hamstring muscles activate against for hip flexion and knee extension during foot contact and thus play an important role in the generation of the forward propulsive force. The results of present study show that the activation of the BF and SM muscles were significantly greater during the early stance phase than during the late stance phase, whereas the activity of the ST muscle was significantly greater than that of the other 2 muscles during the late stance (Figure 2). In addition, peak activation during the stance phase occurred significantly earlier for the BF and SM muscles than that for the ST muscle (Figure 1c). The results indicate that the BF and SM muscles are selectively recruited primarily as strong hip extensors during the early stance phase, and that the ST muscle is selectively recruited for eccentric knee flexion during the late stance phase.

The EMG activation of the ST muscle was higher than the other 2 muscles during the middle swing phase (Figure 2). Moreover, we found that the peak activation of the ST muscle occurred significantly earlier than that of the BF and SM muscles during the latter half of the swing phase (Figure 1c). During the middle swing phase, the biarticular hamstring muscles are stretched, due to hip flexion along with simultaneous knee extension. The results indicate that during this phase, the ST muscle is selectively recruited for simultaneously controlling knee extension and hip flexion because of its morphological property of effectively dealing with strain. In contrast to the EMG activation of the ST muscle, the peak activation of the BF and SM muscles occurred significantly later than that of the ST muscle during the latter half of the swing phase (Figure 1c). During the late swing phase, the hamstrings act concentrically to extend the hip before foot contact. Therefore, these 2 muscles may also play an important role in the generation of hip extension force at the terminal swing phase.

CONCLUSION: In this study, we examined the EMG activation characteristics of the BF, ST, and SM muscles during sprinting. The respective hamstring muscles exhibited very different characteristics for EMG activation and different occurrences of peak activation within the sprinting gait cycle. The activation demand of the BF and SM muscles is high before and after foot contact because their function as hip extensors, while the ST muscle shows high activation primarily during the control of knee extension during the late stance and middle swing phases. The mechanism underlying these activation characteristics may involve the architectural differences in the hamstring muscles, which may reflect each muscle's function during sprinting.

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