A COMPARISON OF HAMSTRING MUSCULOTENDON DYNAMICS DURING HIGH-SPEED RUNNING BEFORE AND AFTER A FATIGUE EXERCISE

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The purpose of this study was to compare the musculotendon dynamics of individual hamstring muscles between before and after a soccer-specific fatigue exercise during the late swing phase of high-speed running. Eight male soccer players performed three sprintings before and after the fatigue exercise. Whole-body kinematic data and ground reaction forces of the support leg were recorded using a three-dimensional motion analysis system and force platform. A three-dimensional musculoskeletal model with 43 Hill-type musculotendon models was used to estimate the musculotendon dynamics. The results of this study showed that there were no significant differences in the peak values of musculotendon force, power, length, and elongation velocity in the hamstring muscles before and after the fatigue exercise.

KEYWORDS: strain injury, fatigue, musculoskeletal model, hill-type model.

INTRODUCTION: Hamstring strain injuries are common injuries in sports involving sprinting such as track and field, soccer, and rugby (Brooks et al., 2006; Woods et al., 2004). Most hamstring strain injuries occur during high-speed running in soccer and rugby (Brooks et al., 2006; Woods et al., 2004). The long head of biceps femoris (BFlh) is the most frequently injured muscle among the biarticular hamstring group. The hamstring group consists of biarticular muscles that include the BFlh, semitendinosus (ST), semimembranosus (SM), and mono-articular muscle, namely, the short head of biceps femoris (BFsh). Woods et al. (2004) reported that the occurrence of hamstring strain injuries increased at the end of each half of a soccer match, which implies that the fatigue condition is one of the risk factors for hamstring strain injuries (Mendiguchia et al., 2013).
The biarticular hamstring muscles generate peak muscle force with peak musculotendon strain during the late swing phase of running at various speeds (Chumanov et al., 2007; Higashihara et al., 2010; Yu et al., 2008). The late swing phase was defined as a sprinting gait cycle from the knee maximum flexion to the foot contact. A previous study indicated that the active states and muscle forces of the hamstrings increase as sprinting speed increases (Chumanov et al., 2007; Higashihara et al., 2010). Therefore, the hamstring muscles are more susceptible to strain injuries during the late swing phase of high-speed running. In addition, Small et al. (2009) reported the differences in the kinematics of pelvis, hip joint, and knee joint before and after a 90-minutes soccer-specific fatigue task ($SAFT^{90}$). According to these results, hip flexion and knee extension changed after the $SAFT^{90}$. However, the hamstring musculotendon dynamics such as generated force, power, length and elongation velocity are not clarified. These musculotendon dynamics would help elucidate why the risk of hamstring injuries is higher under fatigue conditions.
The purpose of this study was to compare the hamstring musculotendon dynamics during the late swing phase of high-speed running before and after a soccer-specific fatigue exercise protocol. We hypothesized that the hamstring musculotendon length and elongation velocity changed after the fatigue exercise because the kinematics of pelvis, hip joint, and knee joint are change. We also hypothesized the change of musculotendon kinematics affects the musculotendon kinetics after the fatigue task.

METHODS: Eight male soccer players (mean age, 22.2±0.4 years; mean weight, 64.6±3.9 kg; mean height, 170.3±5.9 cm) participated in this study. All participants performed three sprinting trials at their maximal effort before and after a 40-minutes soccer-specific fatigue task. The soccer-specific fatigue exercise was a multidirectional and continuous 40-minutes exercise task. The fatigue exercise had three differential courses based on data from soccer matches. We randomly gave the participant verbal instructions on the sprint speed and course for 40 minutes. The fatigue exercise in this study was based on the running distance, the number of changes in direction, and the proportion of sprint speed in soccer matches reported by previous studies (Bloomfield et al., 2007; Small et al., 2009).

Kinematic data from 47 reflective markers attached on the body were recorded using a three-dimensional motion analysis system (VICON-MX, Vicon Motion Systems Ltd., Oxford, UK) with 14 cameras sampling at 250 Hz. Ground reaction force (GRF) data of the support leg were recorded using force platforms (9287B, Kistler Inst.) sampling at 1500 Hz. Low-pass filtering of the kinematic data was performed using a fourth-order Butterworth digital filter with optimal cut-frequencies of 5-16 Hz determined by residual analysis (Wells and Winter, 1980).

A three-dimensional musculoskeletal model with 43 Hill-type musculotendon actuators of the right leg was used to estimate the musculotendon dynamics during the late swing phase of sprinting. The hip joint was modelled as a ball-and-socket joint with 3 degrees of freedom (hip flexion-extension, abduction-adduction, and external-internal rotation). The knee and ankle joints were modelled as a hinge joint with 1 degree of freedom (knee flexion-extension, ankle plantar flexion-dorsiflexion). The muscle fiber included a passive element in parallel with a contractile element. The contractile element of the muscle model was controlled by muscle activation. In this musculoskeletal model, excitation-to-activation dynamics were not considered. Both tendon force-length and muscle fiber force-length-velocity relationships were determined according to Thelen (2003) (Figure1). The strain of the tendon and muscle fiber at the maximum muscle force was set at 0.04 and 1.7, respectively. The musculotendon parameters such as origin and insertion points, tendon slack length, pennation angle at optimal muscle fiber length, optimal muscle fiber length, and maximum isometric force were determined by reference to Gait2392model of OpenSim4.0 and Ward et al. (2009). Furthermore, origin and insertion points, tendon slack length, and optimal fiber length were scaled to each participant's anthropometry.

We used a static optimization method to solve the redundant problem regarding the distribution of the total joint torque between muscles. The objective function was set at the sum of the square of muscle activation. The net joint torque calculated by an inverse dynamics approach was matched to the sum of muscle moment exerted on the joint. The static optimization was carried out to determine the activation of each muscle with minimization of the objective function. We performed the static optimization and kinetic calculation using MATLAB software version 2018a (MathWorks Inc., USA).

The statistics analysis was conducted using the paired t-test to compare the peak value of musculotendon length, elongation velocity, force, and power of each biarticular hamstring muscle before and after the fatigue exercise. The statistical significance was defined as $p<0.05$

RESULTS: The mean sprinting velocity was no significant difference between before and after the fatigue task ($p>0.05$; before, 7.62±0.52 m/s; after, 7.51±0.52 m/s). Figure 2 shows the musculotendon force, power, length, and elongation velocity of biarticular hamstring muscles during the late swing phase of sprinting before and after the fatigue exercise. Peak values of these variables were no significant differences between before and after the fatigue exercise.

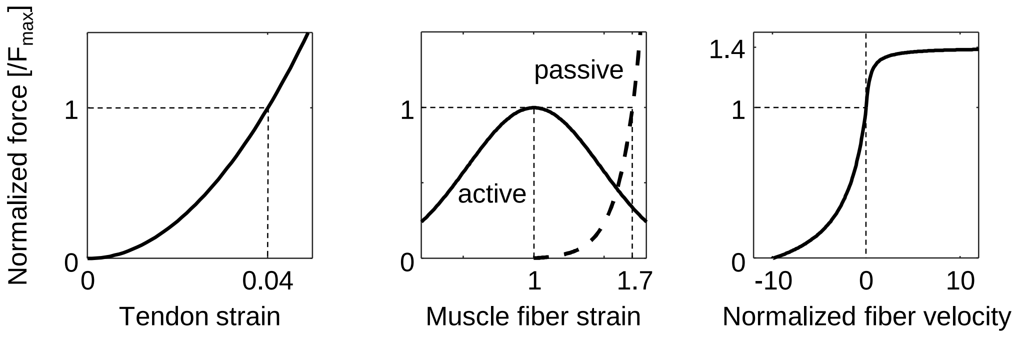

Figure 1: Force-length-velocity relationships of the Hill-type musculotendon model.

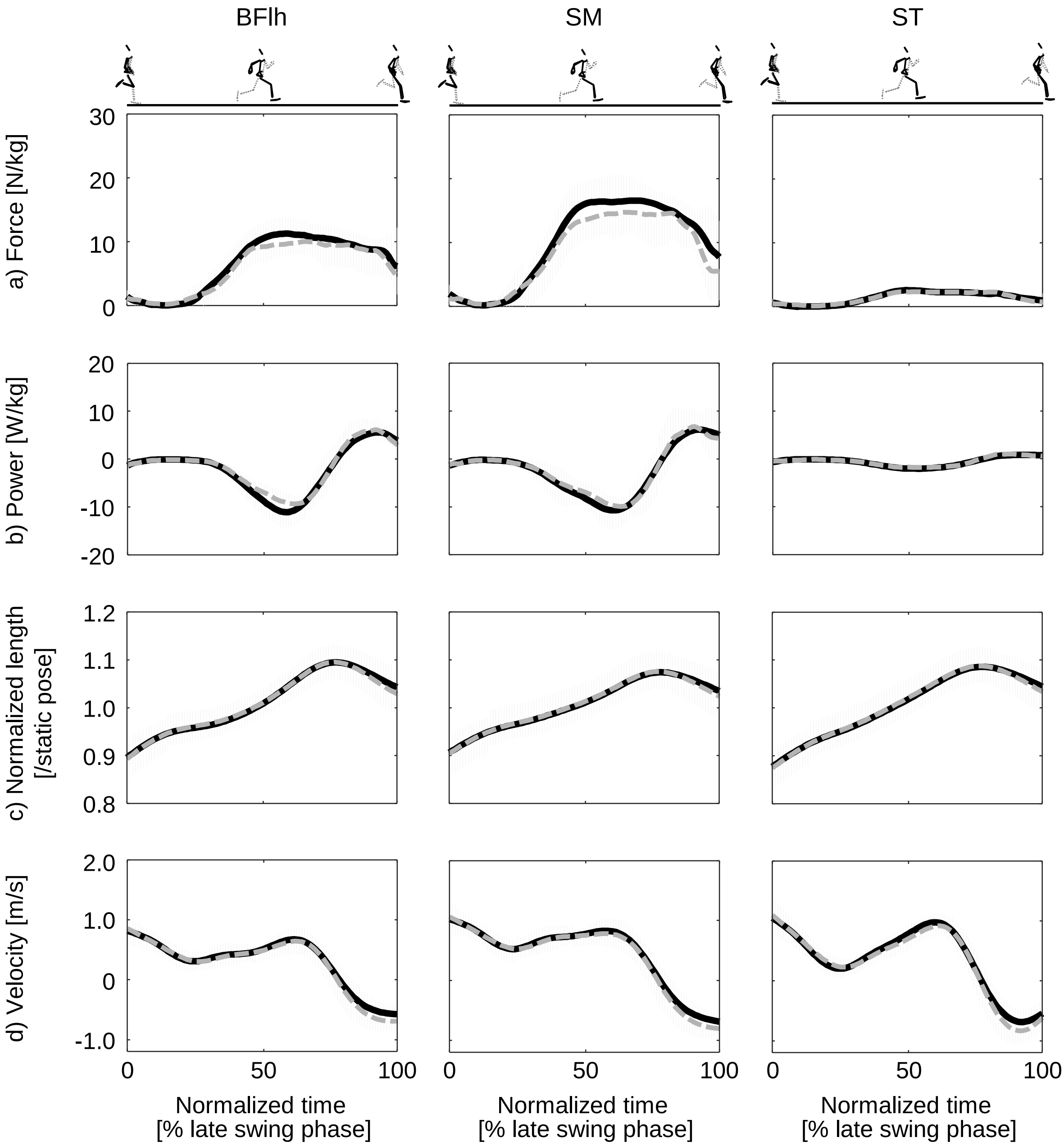

Figure 2: Mean and standard deviation of musculotendon force (a), power (b), normalized length (c), and elongation velocity (d) in the biarticular hamstrings before (solid line) and after (dashed line) the fatigue exercise.

DISCUSSION: The results of the present study showed that there were no significant differences in hamstring musculotendon dynamics between before and after the 40-minutes fatigue exercise. Small et al. (2009) reported that the kinematics of pelvis, hip joint, and knee joint changed after a 90-minutes soccer-specific fatigue task. In addition, the occurrence of hamstring strain injuries also increased after each half of a soccer match (Woods et al., 2004). From these results, we hypothesized that the hamstring musculotendon dynamics change after the 40-minutes fatigue task. In this study, our hypothesis was not supported.

Timmins et al. (2014) reported that the BFlh myoelectrical activity during the eccentric contraction reduced after repeat sprinting trials, which implies the neuromuscular function changes under the fatigue condition. Opar et al. (2013) also compared the hamstring myoelectrical activity during eccentric and concentric contractions between injured and uninjured limb in the athletes who have a history of hamstring strain injuries. The results indicated that the BFlh myoelectrical activity during the eccentric contraction reduced in the injured limb. The changes in neuromuscular function might have the potential risk for hamstring strain injuries. In addition, some previous studies suggested that the differences in loading response after eccentric exercise among the biarticular hamstring muscles (Schuermans et al., 2014). It is considered that the muscle asymmetry activation patterns among the hamstring muscles caused by fatigue conditions might be one of the risk factors for hamstring strain injuries during high-speed running. Therefore, further studies are needed to clarify the differences in the neuromuscular function among the hamstring muscles by measuring the myoelectrical activity before and after a fatigue task. We should also compare the musculotendon dynamics and myoelectrical activity in hamstring muscles between fatigue and non-fatigue conditions using a 90-minutes fatigue exercise such as $SAFT^{90}$ in future work.

CONCLUSION: The purpose of this study was to compare the hamstring musculotendon dynamics during the late swing phase of high-speed running before and after a soccer-specific fatigue exercise. The results of this study showed that there were no significant differences in the peak values of musculotendon force, power, length, and elongation velocity before and after the fatigue exercise.

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