THE DYNAMIC LOAD ON HAMSTRING MUSCLES DURING SPRINTING

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The purpose of this study was to analyze the load condition on hamstring muscles during stance and swing phase of sprinting. Three-dimensional videographic and ground reaction force data were collected and the intersegmental dynamics of lower limb was quantified while eight elite male sprint runners performed sprint running with maximum effort. During initial stance phase, the ground reaction torque (EXT) was the main passive torque at knee and hip. During late swing phase, it was motion-dependent torque (MDT) as well. The muscle torques counteracted the large effect of EXT and MDT. This result revealed that the hamstring muscles would suffer from tremendous loads in both initial stance phase and late swing phase. Thus it can be speculated that hamstring muscles were exposed to a higher risk of injury during these two phases in sprinting.

KEY WORDS: load condition, intersegmental dynamics, joint torques, strain injury.

INTRODUCTION: Hamstring muscles strain injury is one of the most commonly seen injuries in sprint (Orchard & Seward, 2002; Schache, Wrigley, Baker, & Pandy, 2009). Since biomechanical analysis of loading condition on hamstring muscles is complex due to its ability to influence movement at multiple joints, researchers disagreed on whether strains occur during initial stance phase or late swing phase during sprinting. As early as 1980s, Mann and colleagues (1981) have speculated that the potentially large load associated with ground contact may cause injury during the stance phase of sprinting. The study results showed that knee flexion moment and hip extension moment both reached the greatest value in the early ground contact phase. However, they could not explain the cause of the knee flexion moment during initial stance phase. Yu et al. (2008) found the late swing phase and late stance phase were the potential phase for hamstring muscles strain injury. The neuromusculoskeletal models were used to study the hamstring function during sprinters' running on a treadmill (Thelen et al., 2005; Thelen, Chumanov, Sherry, & Heiderscheit, 2006), and the results showed that hamstring muscles reached the maximal lengthening and loading during late swing phase. However, Schache et al. (2001) study showed that the kinematics of lower extremity had significant differences between overground and treadmill running.
The purpose of this study was to analyze the loading conditions of the hamstring muscles during the maximal speed phase of sprint running. The intersegmental dynamics were used to discuss the loading on muscles across knee and hip joint.

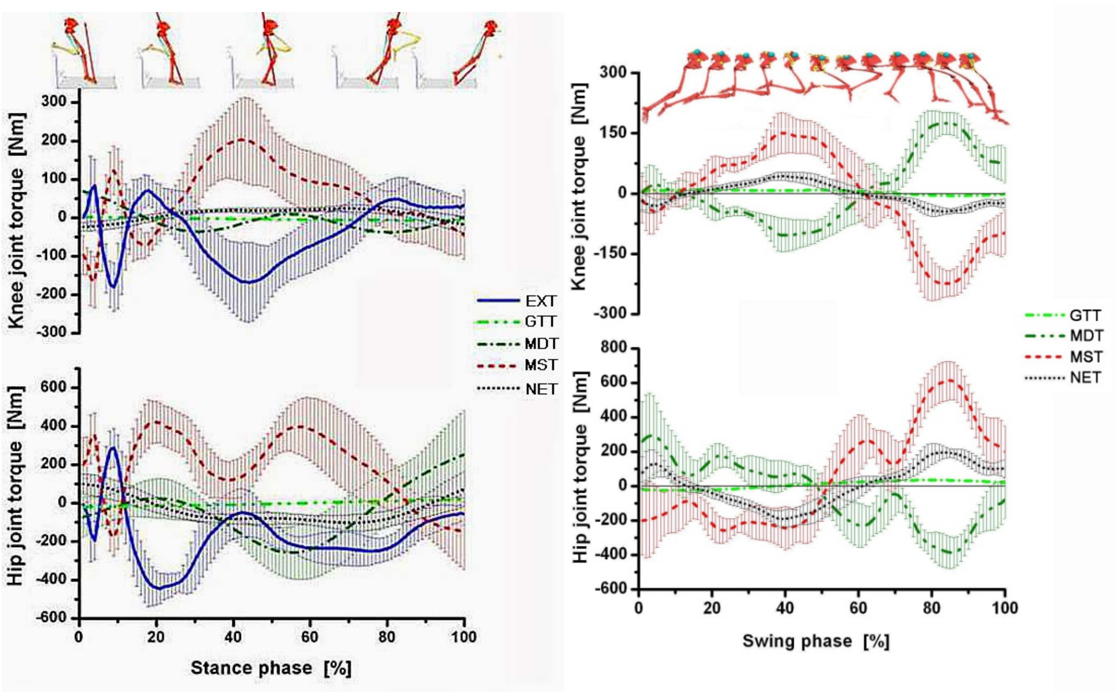
METHODS: Eight male elite sprinters whose best personal performance for 100m ranged from 10'27 to 10'80 performed maximal-effort sprints on a synthetic track and three-dimensional kinematic data were obtained at a sampling rate of 300 Hz by eight Vicon High Resolution Cameras (Vicon Motion Capture). The calibration volume for kinematic data collection was 10.0 m long, 2.5 m high and 2.0 m wide and located 40 m away from the start line. Also, centered within the volume was a recessed Kistler force-plate (60×90 cm) (Kistler 9287B, Kistler Corporation) which was used to measure the ground reaction force (GRF). The force signals were amplified and recorded in Vicon System at a sampling rate of 1200 Hz. Data were processed by Visual 3D software (Visual 3D Version 3.390.23, C-motion Corporation) and torques at the ankle, knee and hip joint were calculated. The study was approved by a local Ethics Committee and subjects signed informed consent forms after all questions were answered satisfactorily.
To calculate the active muscle torque and the dynamic interactions among the thigh, leg and foot, the model of our earlier studies (Liu et al., 2009) was used and intersegment dynamics formulation of Zernicke (1996) was modified. At each of the joints of the linked segments, the

torques can be separated into five categories: net joint torques, gravitational torques, motion-dependent torques, contact torques (was called ground reaction torques in this study) and generalized muscle torques, with the first category being the sum of the rest:

net joint torques(NET)= gravitational torques (GTT)
+motion-dependent torques (MDT)
+ground reaction torques (EXT)
+generalized muscle torques (MST)

NET is the sum of all the positive and negative torque components acting at a joint. MST are mainly generated by muscle contractions. Information about this torque is important for revealing changes in the control of interlimb coordination. MDT arising from mechanical interactions occurs between limb segments. GTT results from gravitational force acting at the centre of each joint. EXT are generated at joints by ground reaction force acting on limb segments. In this study, MDT is the sum of all interaction torques produced by segment movements, e.g. angular velocity and angular acceleration of segments.
CON-TREX had been used to measure the maximal isometric contraction torques of knee joint for both flexion and extension before the maximal-effort sprints.

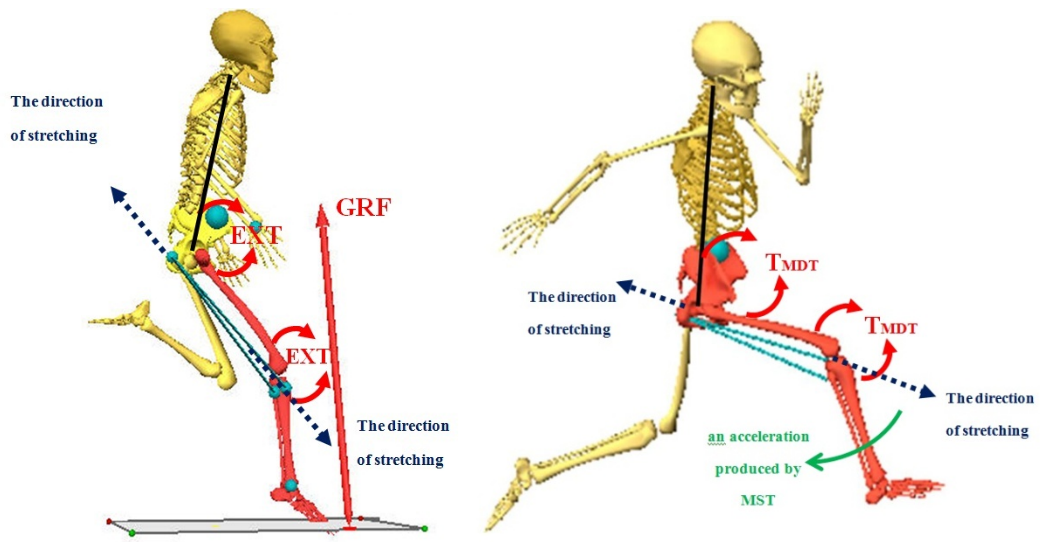
RESULTS: The MST and EXT were the two main torques counterbalancing each other during stance phase because the other torques were much smaller. At knee joint, the MST and EXT torques have a peak values during initial stance phase as well as at hip joint (Figure 1a). Obviously, MST and MDT were much greater than the others during the swing phase. They were counterbalancing and reached the maximum at both knee and hip joint after 80% time of this phase (Figure 1b).



(a) (b)

Figure 1: Averaged time-normalized graphs for joint torques at knee and hip joint (a)during stance phase. (b)during swing phase. (+: extension; -: flexion)

DISCUSSION: During stance phase, the results of intersegmental dynamics analysis revealed that the MST acted to counterbalance the effect of the torque produced by the ground reaction force (EXT) at the knee and the hip joint (Figure 1a). The findings of the present study indicated that the GRF passed through in front of the knee and the hip joint, producing a large extension torque at the knee and a flexion torque at the hip during initial stance phase. The two EXT at knee and hip stretched the hamstring muscles in opposite directions (Figure 2a). To counteract the effect of GRF, the knee flexor (hamstring muscles) and the hip extensor (hamstring muscles) were required to create a flexion torque at the knee and an extension torque at the hip. So, this may explain why a flexion torques at the knee joint was presented during initial stance phase (Mann, 1981). During initial stance phase, the maximal MST at the knee and hip joint were -203.40±93.60 Nm and 455.24±198.72 Nm, respectively. Based on the MRI and videofluoroscopy (Bonnefoy et al., 2007; Scheys, Spaepen, Suetens, & Jonkers, 2008) study results which have shown that the force arm of hamstring muscles at knee joint ranges from 0.02 ~ 0.04 m through ranges of the joint angles, we could reasonably estimate the force of the hamstring muscles which was applied across the knee joint during initial stance phase. The force which were produced by hamstring at knee joint ranged from 5777 ~ 11554 N, and it's at least eight times body weight. The maximal isometric contraction torques of knee flexor were 164.82±29.58 Nm, so the force ranged from 4120 ~ 8241 N. Without considering the loading on hamstring muscles at hip joint, the muscle force was still bigger than the muscle force which originated from hamstring maximal isometric contraction.



(a) (b)

Figure 2: Diagram of sprinting(a) during the initial stance phase (b)during the late swing phase.

In addition, since the muscle joint torque is a resultant torque produced by agonist and antagonist muscles, the torque produced by the bi-articular muscle hamstring not only counteracted the torque of the ground reaction force at the knee and hip joint, but also encountered the torques produced by the knee extensors (quadriceps femoris) and the hip flexors. That means the actual torque values produced by the knee flexors and hip extensors might be far bigger than the present results of joint muscle torques. If the strength of hamstring muscles was not sufficient, it would be likely to be exposed to a risk of strain injury.

During late swing phase, the thigh started to swing backward, but the leg still swung forward because of the MDT. In order to purposely make the leg swing backward before ground contact, the hamstring muscles intensely contracted and created a clockwise acceleration where there is a rapid change from eccentric to concentric function (Figure 2b). The peak values of MST at knee and hip joint were -249.32±38.81 Nm and 650.81±101.06 Nm. Using the force arm of hamstring muscles based on MRI studies (Bonnefoy et al., 2007; Scheys et al., 2008), we could easily estimate that the force produced by knee flexors ranged from 6225 ~12450 N, and it was about 10 times body weight.

Compared with the loading conditions of knee flexors and hip extensors during initial stance phase, it was also necessary to consider the effect of antagonistic muscles because the MST was the net joint muscle torques. So the actual torque values produced by the hamstring muscles at the knee and the hip might be far bigger than the estimated results.

In summary, the calculation results of MST revealed that the hamstring muscles would suffer from tremendous loads in both initial stance phase and late swing phase.

CONCLUSION: During initial stance phase and late swing phase, the torques (EXT, MDT) produced by GRF and segments interaction stretched the hamstring muscles in the opposite directions at both the knee and hip joint. To counterbalance the external torques in stance phase and the MDT in swing phase, hamstring muscles endure great load. By understanding the loading condition on hamstring muscles, especially the load production mechanism, researchers would develop prevention and rehabilitation programs for hamstring injury.

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