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ScienceDirect
Journal of Sport and Health Science 6 (2017) 133–136
www.jshs.org.cn

Opinion

The late swing and early stance of sprinting are most hazardous for hamstring injuries

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Received 31 August 2016; revised 8 November 2016; accepted 21 November 2016
Available online 26 January 2017

Hamstring strain injury is one of most prevalent noncontact injuries in sports that involve high-speed running, such as sprinting, soccer, and rugby.[1] In order to optimize prevention strategies and injury rehabilitation, studies have been conducted to understand hamstring function during sprinting.[2–4] However, differences have long existed in the literature as to the cause of hamstring strain injuries. One of the most controversial topics is the debate over which phase of high-speed running is most associated with hamstring injuries.[5]

Studies of running biomechanics indicate that the hamstrings are active for the entire gait cycle, with peaks in activation during the early stance and the late swing phases.[6,7] Mann and Sprague[3] reported that the highest torques of hip extension and knee flexion occur secondary to a peak value of the ground reaction forces (GRFs) during the initial stance phase. Based on this information, they concluded that the early stance was highly associated with hamstring strains. In contrast, many subsequent researchers held the view that the late swing phase of sprinting is the most hazardous.[4,6–9] These studies found that the hamstrings contract forcefully while reaching maximum length during the late swing phase. They ignored Mann's argument of high torques as an indicator of hamstring injury risk and preferred the hypothesis that hamstring strains occur during eccentric contractions.[10]

However, most previous observers used treadmill sprinting rather than overground sprinting in their studies.[6,8,9] Although the treadmill is a convenient tool for assessment of running biomechanics, it has been shown that the biomechanics of treadmill running differ significantly from those of overground running, and thus may lead to erroneous conclusions about overground running.[11,12] Additionally, much of the previous research was aimed at investigating the kinematics of the hamstring during running alone.[7–9] Limited attempts have been made to measure the GRFs during overground sprinting and use these data to estimate the hamstring kinetics during stance.[3,4] To fill this gap, we investigated the loading conditions of the hamstring muscles during maximum-effort overground running.[2] Our results suggest that the hamstrings are most susceptible to injury during the swing and stance transitions of sprinting.

We used a lower extremity intersegmental dynamics analysis for each body segment.[2,13] The intersegmental dynamics analysis we used allows for torques at each joint to be separated into 5 categories: gravitational torque (GTT), motion-dependent torque (MDT), external contact torque (EXT), generalized muscle torque (MST), and net joint torque (NET), which is the vector sum of the 4 previous components. Detailed interactions between the active muscle torques and the passive torque components could be quantified, giving us insight into how the hamstrings' function switches during the running cycle.

Using this approach, we reached 3 main conclusions. First, the MST primarily countered the MDT during the swing phase for the knee and hip joints (Fig. 1A). In late swing, the leg was swinging forward due to its inertia, which cause a large hip-flexion MDT and a knee-extension MDT at the same time. Therefore, the hamstrings were active and started to extend the hip and flex the knee joints to counteract these passive effects for the subsequent ground contact (Fig. 1B). Further analysis of the components of the MDT showed that MDT at both joints was caused mainly by torques due to the leg angular acceleration. These passive torques applied stress to the hamstring muscles in the opposite direction of contraction at both joints. To counter this negative effect, the hamstrings encountered enormous loads, approximately 10 times the subjects' average body weight, to control the rapid leg rotation, which created conditions for hamstring injuries. Previous studies reported that the hamstrings stretch to their maximum length and the muscle force reaches its maximal value in this phase.[6–8] Our results confirmed these findings and showed how they happened. The key contributor to these high torques was the MDT created

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Peer review under responsibility of Shanghai University of Sport.
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http://dx.doi.org/10.1016/j.jshs.2017.01.011

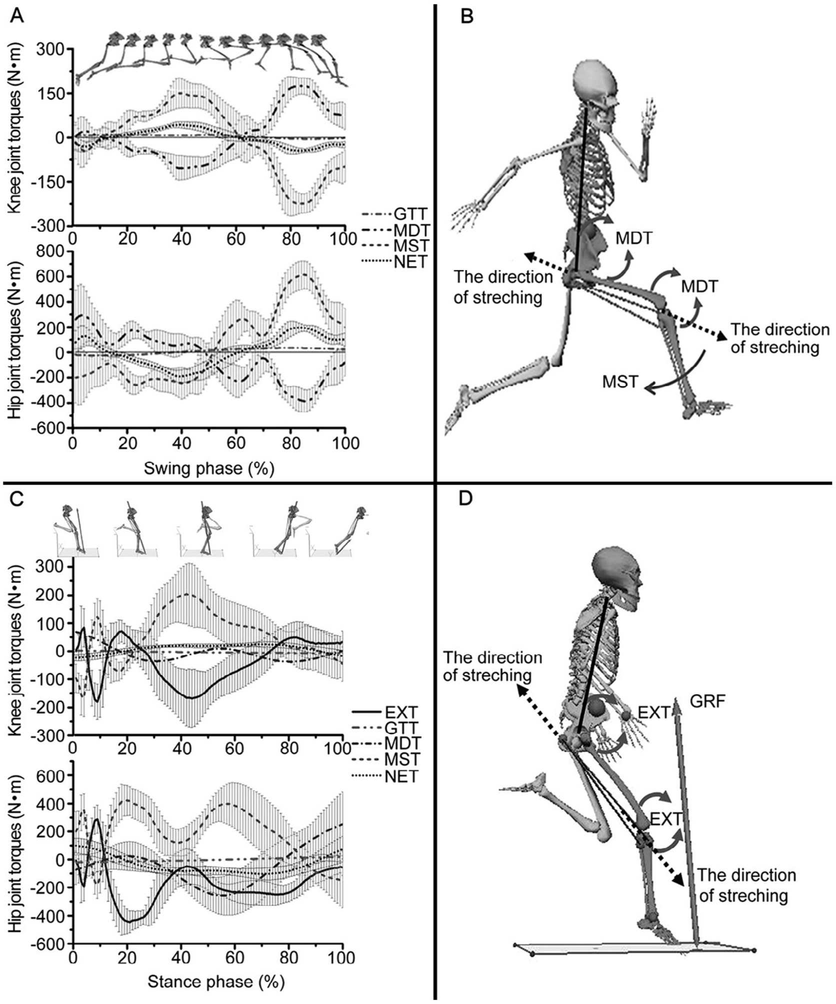

Fig. 1. Averaged time-normalized graphs for joint torques at knee and hip joints during the swing (A) and stance (C) phases of sprinting. The top panels show positions of the lower extremity during the swing (A) and stance (C) phases. Data represent the group mean (lines) with 1SD (shading). (B) Diagram of sprinting during the late swing phase: the inertial loads (MDT) produced by segment motion at the knee and hip joints. (D) Diagram of sprinting during the initial stance phase: the GRF passes anteriorly to the knee and hip joints. EXT = external contact torque; GRF = ground reaction force; GTT = gravitational torque; MDT = motion-dependent torque; MST = muscle torque; NET = net torque. (Positive value indicates extension; negative value indicates flexion.) Adapted with permission.[2]

mainly due to the leg angular acceleration.[2] Although there is debate as to whether eccentric muscle strain or muscle stress is the causative factor in muscle strain injuries,[1,10] it is known that an eccentric contraction occurs when the external force is greater than the muscle contraction force, that is, the eccentric muscle action is induced by an external force. During late swing, the leg angular acceleration led to a tremendous MDT, which caused the hamstring muscles to work eccentrically. This suggests that hamstring strains are associated with high loading caused by the inertial torque MDT.

Second, the dominant passive torque switched to EXT in the transition from late swing to initial stance (Fig. 1C). We noticed that the GRFs passed anteriorly to the knee and hip joints during the initial stance phase, which generates a large extension torque at the knee and a flexion torque at the hip at the same time (Fig. 1D). As with the knee flexors and hip extensors in the late swing phase, the hamstring muscles serve both roles required to counteract the effect of the GRFs. It is likely that the hamstrings, which encounter at least 8 times the subjects' body weight in the initial stance phase, are susceptible to strain injury in this phase. This conclusion supports Mann's finding.[3] Additionally, we discovered that the external GRF passing anteriorly to the knee and hip generate the peak loads on the hamstrings.[2] As the early stance is a continuation of the late swing, the hamstrings were contracting concentrically after being fully extended. The muscles were suffering from enormous loads caused by 2 different factors (the inertia and the GRFs) throughout this eccentric–concentric transition.

Chumanov et al.[6] indicated an increased loading for the hamstring muscles during the initial stance phase. However, they did not regard this phase as injurious because negative work (i.e., energy absorbed) during eccentric contraction has been shown to correlate best with muscle injuries in animal models. This is a widely held belief, despite experimental evidence of muscle strains being produced during concentric (shortening) contractions.[14] However, we currently cannot know