SEGMENT-INTERACTION AND ITS RELEVANCE TO THE CONTROL OF MOVEMENT
DURING SPRINT RUNNING

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INTRODUCTION
Human movements of lower extremities are created by a complex combination of muscle force and other forces, i.e. external forces, motion dependent forces, and gravity forces. These forces arise from within the body and from the body interact with the environment. Coordinated and skilled movements involved optimization of the interactions between muscle forces and other forces (Bernstein, 1967).

Study the relationship of inter-segmental torques and their effects at lower extremity joints can help us to understand movement control during sprinting. Furthermore, it can also help us to gain insights into the muscle function of lower extremity during stance and swing phases. Putnam (1991) and Zernicke (1996) suggested that the main function of MUS were to counteract MDT during sprinting. But Mann and his colleagues (1981), as well as Hunter et al. (2004), suggested that MUS were mainly to counterbalance the effects of EXT in stance phase during sprinting. One common limitation of these studies is their participants were not running at their maximum speed. For example, the top speed in Hunter et al. (2004) study was only 8.60±0.24 m/s. Such work was just focusing on stance phase of sprinting. Interssegment dynamic study at full speed can give us a clear picture of the relationship between muscle torques and other passive torques and also provide us better understanding of lower extremity movement control during sprinting.

The purpose of this study was to investigate function of MUS, and its relations to other torque components, i.e. EXF & MDT. The contribution of MUS to the net joint torque (NET) will be a window for us to understand the overall contribution of MUS to join torque. MUS’s relationship with other components and contribution to NET can help us to study the lower extremity movement control mechanisms during sprinting stance and swing phases.

METHODS
Seven male elite sprinters participated in the study (age: 21.1±1.9 yrs, mass: 74.7±4.1 kg, height: 181.5±3.9 cm). Their best personal performance for 100 m ranged from 10’27 to 10’80.

The athletes performed maximal-effort sprints on a synthetic track. Three-dimensional kinematics data were collected at a sampling rate of 300Hz from eight Vicon High Resolution Cameras (Vicon Motion Capture, Vicon, England). The calibration volume for kinematic data collection was 10.0 × 2.5 × 2.0 m and centered at 40 m from the sprint start line. A recessed Kistler force-plate (60 × 90 cm) (Kistler 9287B, Kistler Corporation, Switzerland) located at 40 m from the sprint starting line was used to measure the ground reaction force (GRF). The force signals were amplified and recorded by the Vicon System at a sampling rate of 1200 Hz.

The inter-segment dynamics formulation of Zernicke et al. (1996) was modified and used to calculate the active muscle torque and the dynamic interactions among the thigh, leg and foot. The torques of each joint can be separated into five categories: net joint torques (NET), gravitational torques (GTT), motion-dependent torques, contact torques (MDT), ground reaction torques (EXF) and muscle torques (MUS), with the first category being the sum of the rest:

\[ NET = GTT + MDT + EXF + MUS \]

NET are the sum of all the torque components acting at a joint. MUS are mainly generated by muscle contractions. Information about this torques is important for revealing changes in the control of inter-limb coordination. GTT are resulted from gravitational force acting at the centre of mass of each segment. EXF are generated at joints by ground reaction force acting on the foot. MDT are arising from mechanical interactions occurs between limb segments. MDT are the sum of all interaction torques produced by segment movements, e.g. angular velocity and angular acceleration of segments.

RESULTS AND DISCUSSION
The mean running speed, stride length, stance phase and swing phase duration for the 7 subjects were 9.7±0.3 m/s, 1.9±0.3 m, 0.11±0.01 s and 0.16±0.03 s, respectively.

During stance phase, hip joint MUS and EXF were the greater torques, and the MDT experienced greater changes after first 40% of the stance phase. Compared with MUS, EXF and MDT, the GTT was smaller and closer to zero. The NET was negative during most of stance phase except initial (0-20%) and late stance phase (80-100%) (Figure 1). Those results indicated that the MUS of hip joint no longer provide an impelling force for human movement in last quintile, at this time MUS with EXF were mainly to counterbalance MDT to flex hip joint and the effects of MDT to lower extremity movement became more obviously.

During stance phase, knee joint EXF and MUS were greater compared with MDT, GTT and NET. The curve of EXF and MUS show multiple peaks and reached maximum value at about 45% of stance phase. The MDT was negative except initial stance phase (0-20%). The NET was positive during most of stance phase except initial (0-20%) and late stance phase (80-100%). MUS served a flexor in the first quintile was significantly less than when it served as extensor in the rest stance phase except in the last 20% where it was close
to zero. The changing pattern of MUS was similar to that of the NET during stance (Figure 2).

During swing phase, hip joint MUS and MDT were the greater torques and reached peak value in the last quintile. Compared with MUS, MDT, the GTT was smaller and closer to zero. The NET was changed from positive value to negative value at about 20% swing phase and then changed to positive value at about 60% swing phase. Hip joint MUS was in the same direction as the NET during most of the swing phase other than the first 20% where a strong MUS flexion torque was accompanied by a weak extensor NET torque (Figure 3).

During swing phase, knee joint MDT and MUS were greater compared with GTT and NET. There were two peaks at about 40% and 80% swing phase of MDT and MUS curves. MUS was changed from negative value to positive value at about 10% swing phase, and then changed from positive value to negative value at about 60% swing phase. NET showed changes with similar timing, the changing of MDT were opposite to MUS and NET. The values of GTT were relatively smaller and close to zero (Figure 4).

Our observations showed that the joint torques had similar tendencies as earlier reports, however, the timing and magnitude were different. The switching time of hip and knee flexion torque to extension torque were different between walking, running and sprinting during swing phase, the hip and knee joint maximal torque of sprinting were about ten times to walking and five times to running. The differentiations may caused by movement speed in our study were higher than walking and running in their studies.

CONCLUSIONS
In conclusion, inter-segment analysis helped us further understand the role of muscle during sprinting. MUS functioned mainly to counteract the external torques created by the ground reaction force at hip and knee joint during stance phase. Such functional role changed during swing phase to mainly counteract movement related torques partially due to the absence of ground reaction forces. Specifically, our data support the notion that the MUS of hip joint no longer provided an impelling force for human movement in last quintile stance phase, and hamstring injuries likely occurs during the end of swing phase.

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