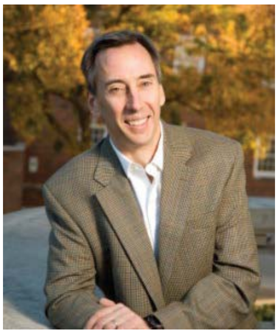

FORCE, MOTION, SPEED: A GROUNDED PERSPECTIVE ON HUMAN RUNNING PERFORMANCE

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Sprint running performance can be investigated relatively simply at the whole-body level by examining the timing of the phases of the stride and the forces applied to the ground in relation to a runners body weight. Research using this approach has been used to address a number of basic questions regarding the limits and determinants of human running speed. The primary differentiating factor for the top speeds of human runners is how forcefully they can strike the ground in relation to body mass. A general relationship between mass-specific force application and maximum running speeds results from from the similar durations of the aerial and swing phases of the stride for different runners. Recent work has elucidated the mechanism by which faster runners are able to apply greater mass-specific ground forces in the very brief foot-ground contact times sprinting requires.

KEY WORDS: two-mass model, spring-mass model, impact-deceleration, contact time, aerial time, swing time

INTRODUCTION: The primary requirement of human locomotion is supporting the body's weight against gravity. This requirement has provided insights into locomotor metabolism (Kram & Taylor, 1990; Roberts et al, 1998; Taylor, 1985), gait mechanics (Blickhan , 1989; Weyand et al., 2001) and the sprinting performance of humans (Kuitunen et al., 2002; Rabita et al., 2015) and other animal runners (Taylor, 1980).

During steady-speed running on a level surface, the stride-averaged vertical force runners apply to the surface equals their body weight. Faster runners can satisfy this force requirement with greater forces that are applied in shorter periods of time. Consequently, the maximal speeds of human and other runners are largely explained by the maximum forces they can apply to the ground in relation to body mass (Weyand et al., 2010).

Here, two questions are considered: 1) why does the general relationship between mass-specific force and top running speed exist? and 2) what is the mechanism by which faster runners are able to apply greater mass-specific ground forces?

QUESTION 1: Why does the general relationship between mass-specific force and top running speed exist?

Elite human sprinters can apply peak forces to the running surface as large as 5.0 times body mass and stance-averaged forces that are as large as 2.5 times body mass. In contrast, capable, but less swift human runners typically apply peak forces of 3.5 times their body weight and stance-averaged forces of up to 2.0 times body weight (Clark & Weyand, 2014).

The strength of the relationship between the mass-specific forces runners apply and how swiftly they can run at top speed results from the similar durations of the non-contact portion of the stride. At tops speed, fast and slow runners alike typically spend 0.12 s in the air between steps and take slightly longer than one-third of a second to reposition the limbs (Weyand et al., 2000).

These observations suggest that maximizing force application may be the only viable mechanical option by which human runners can maximize speed (Clark et al., 2014).

QUESTION 2: What is the mechanism by which faster runners are able to apply greater forces to the ground?

If the speeds of the swiftest human runners are largely determined by the magnitude of the mass-specific forces they can apply to the ground, what confers the ability to apply relatively larger forces? Do the swiftest sprinters have intrinsically stronger limbs and limb muscles? Or, alternatively, do they use the motion of the running stride to maximize the forces applied to the ground?

Recent research indicates that speed athletes exploit a motion-to-force mechanism during the impact portion of the contact period to maximize ground reaction forces applied during the brief contact periods sprinting requires (Calrk & Weyand, 2014; Clark et al., 2017). These athletes attain greater limb velocities before the foot contacts the ground. They also stop the limb more abruptly upon impact. This impact-deceleration mechanism results in a rapid rising edge of the force-time relationship and a peak force that occurs well before the mid-point of the contact period. The resulting asymmetrical pattern of force application deviates substantially from the ground force application predicted by the spring-mass model (Blickhan, 1989) indicating that the model does not include the force-motion elements responsible for sprinting performance.

The variation present in the patterns of ground force application for sprinters and non-sprinters alike can be predicted from body mass and three stride-specific prameters (contact time, aerial time and ankle acceleration) using an anatomically based two-mass model of the human body. These observations indicte that sprinters exploit a motion-based deceleration mechanism to maximize ground force application. To what extent the dynamic mechanism relies on intrinsic limb strength vs. motor control and timing precision remains to be determined.

CONCLUSIONS: The conformation of both the running gait mechanics and ground reaction force patterns of human sprinters to a common pattern: 1) is further evidence that human sprinting performance is constrained by the brief duration of foot-ground force application at very fast running speeds, and 2) implies a convergence that results from the physics of motion and the properties of the tissues that generate and transmit musculoskeletal forces to the ground.

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