Is maximum effort acceleration limited by leg force generation capabilities?

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Introduction:

Acceleration and top speed sprinting capabilities differentiate athletes in a wide variety of sports, including track and field, soccer, football, and basketball, among others. In these sports, the limits of performance continue to be expanded as athletes and coaches continuously refine sprint training and technique, and as equipment becomes more technical and specialized. Despite these advances, the biomechanical limiters remain largely unknown.

Because large forces are required to accelerate the mass center, numerous researchers have investigated the relationship between leg force production capabilities and acceleration and top speed performance. Results from some experiments have suggested that acceleration ability [1] and maximum sprint speed are limited by the force generation capabilities of the lower limb [2,3]. Other researchers have suggested that the force magnitude is less important during sprint acceleration performance than a more horizontal orientation of the total force applied to the ground [4,5].

One reason for the discrepancy in the previous experimental findings may be that relationships between biomechanical factors and maximal effort performance were explored between subjects with different abilities, rather than within each subject. Another experiment altered the mechanical demands of a maximal effort acceleration by adding 17% body mass to the torso and found that athletes produced larger forces during the first step with the added mass [6]. The authors concluded that other factors, such as balancing whole-body angular momentum, may have caused athletes to limit force production without the additional mass.

The goal of this experiment was to examine whether athletes could produce larger leg forces and more power during a maximum effort linear acceleration by increasing the mechanical demands of the performance by adding mass to the torso. The generation of larger forces with the added mass would suggest that maximal effort sprinting performance was not limited by leg force.

Methods:

Eight male athletes (mass: 70.33 ± 8.90 kg, ht: 1.77 ± 0.03 m) performed between three and five maximal effort, 10 m accelerations from a standing position with and without approximately 10% (9.9 ± 2.17 %) body mass (BM) added to the torso. Prior to the data collection, athletes warmed up for at least 15 minutes and completed one maximal effort 10 m acceleration. The 10% BM was chosen to attempt to sufficiently alter the mechanical demands of the acceleration while avoiding large changes in sprint speed and joint kinematics. The order of conditions was randomized and approximately balanced, and all subjects wore Nike Zoom Streak LT 2 racing flats during testing.

Three-dimensional (3D) joint kinematics and kinetics of the athlete’s dominant leg were measured at approximately 8 m into the acceleration. Ground reaction forces (GRF) were measured using two 90 x 60 cm piezoelectric force plates (2500 Hz) embedded in the Mondo track surface, and limb orientations were measured simultaneously using a passive, optical, three-dimensional motion capture system (500 Hz). Spherical 13 mm retro-reflective markers were placed unilaterally to define joint centers of the MTP, ankle, knee and hip, and at least three additional tracking markers were placed on each lower limb segment. Only trials in which an athlete’s dominant foot contacted within the boundary of the force platform were considered.

The external mechanical work performed during stance was estimated using the 3D GRF. Stance occurred when the vertical component of the GRF was larger than 30N. Center of mass (CoM) acceleration was calculated from GRF, and then integrated over time to calculate CoM velocity [7].

Joint kinetics were estimated by first filtering kinematic and kinetic data with a second-order, dual pass Butterworth filter, with a cut-off frequency of 25 Hz. Joint energetics at the ankle were calculated using 6 degree-of-freedom inverse dynamics approach [8], and segmental inertial properties were based on de Leva [9].

Results and Discussion:
There were no differences in the peak resultant GRF (Figure 1A) or peak CoM power (Figure 1B) during maximal effort accelerations with (mass) and without (control) the additional mass attached to the torso. The average speed measured at 8 m into the acceleration was reduced for all subjects by an average of 5.07 ± 1.36 % with the added mass (control: 7.13 ± 0.44 m/s, mass: 6.77 ± 0.41 m/s), and contact time increased by 7.06 ± 3.07 %.

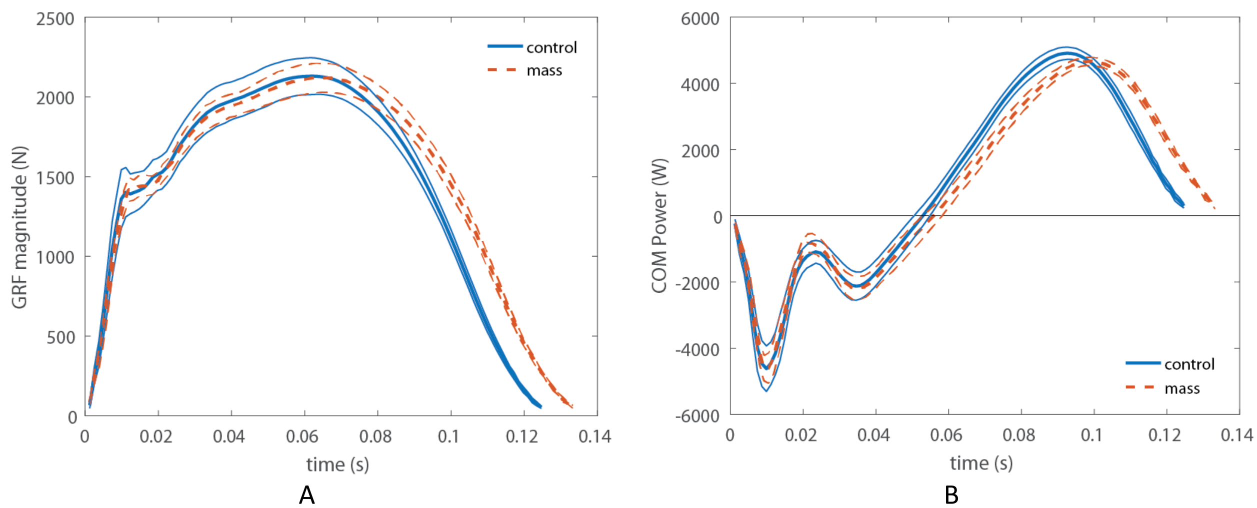

Figure 1: (A) Average peak resultant ground reaction forces and (B) average center of mass power. Thicker lines denote mean values across the population, and thin lines represent the average ± 1 SD within each athlete.

The results of this experiment suggest that athletes produced maximal leg forces and power at 8 m into a maximum effort acceleration without the added mass, and thus acceleration performance was limited by leg force generation capabilities. Additional comparisons of joint kinetics would reveal whether lower limb joints were operating maximally in the control condition, although differences should be interpreted with caution due to the 5% speed reduction with the added mass. Experiments reducing the mechanical demands of sprinting (or increased athlete capabilities) while measuring performance could confirm or refute this study's conclusion that performance was limited by athlete leg force generation capabilities.

References:

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