CHANGES IN MUSCLE MECHANICAL ADVANTAGE OF HUMAN RUNNERS DURING SPRINT ACCELERATION

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INTRODUCTION

Previous studies of muscle mechanical advantage relative to ground reaction force (G_{RF}) mechanical advantage, defined as the ratio: $R/r = \int F_m / \int G_{RF}$ or 'EMA' (Fig. 1), have shown that EMA decreases (i.e. mass-specific muscle force decreases) with increasing size when compared broadly across different sized mammalian runners (mouse to horse; Biewener, 1989), that EMA remains constant across steady speeds within a gait, and that differences in EMA between avian bipeds and mammalian quadrupeds of similar size helps to explain their metabolic cost for generating muscle force to support body weight (Roberts et al., 1998).

In this study we examine how muscle mechanical advantage varies during sprint acceleration in human runners, testing the hypothesis that shifts in limb posture during progressive steps of a sprint are matched to changes in the direction of G_{RF} during limb support to maintain a constant limb mechanical advantage at the hip, knee and ankle joints overall.

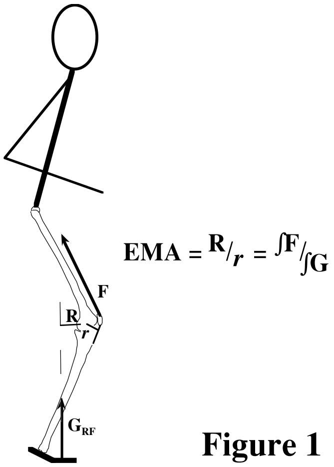

Figure 1

METHODS

Nine runners (5 male/4 female) sprinted from a four-point start (with > 90% of body weight supported over the primary propulsive limb) beginning on a Kistler 9203 force platform and preceding the platform at specific distances to record the fore-aft and vertical ground reaction forces for steps 1, 3, 5, and steady speed (> step 13) of maximal sprints over the force platform. A MacReflex (Qualysis) infrared camera was used to record joint positions of the lower limb and trunk at 60 Hz. Joint coordinate data were smoothed using a four-order digital Butterworth filter (17 Hz 3db cut-off) and referenced to the platform and the location of G_{RF} application in order to calculate the external moments acting at the hip, knee and ankle joints. All signal processing and computations were performed in Matlab. EMA was defined as $\int F_m / \int G_{RF}$ measured over the entire period of ground contact. By focusing on how muscle forces are influenced by limb posture and G_{RF}, EMA ignores inertial and gravitational moments, which are likely important at the hip and knee.

RESULTS AND DISCUSSION

A significant decline in EMA were observed at the hip for step 1 ($p<0.001$) and step 3 ($p<0.005$) compared with step 5 and steady speed (Fig. 2A). No significant change in

EMA however was observed at the knee and ankle joints during different steps of a sprint (Fig. 2B&C). When summed for all three joints, a significant decline ($p < 0.001$) in whole limb EMA (Fig. 2D) was only observed from step 1 to step 3; remaining constant from step 3 to steady speed running.

Consequently, these results partially support our hypothesis that shifts in limb posture during a sprint help to maintain consistent muscle force generating requirements at different limb joints as an individual accelerates during a sprint. However, the decline in limb EMA observed from step 1 to 3 results from the decline in hip extensor EMA. This likely reflects the ‘crouched’ posture that the runners adopted when beginning a sprint, which greatly increases the hip flexor moment during steps 1 and 3.

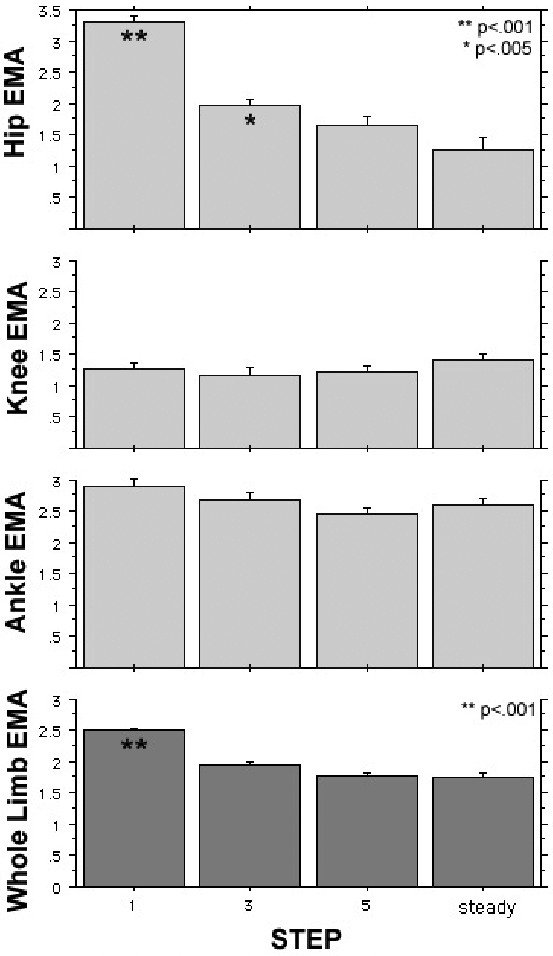

Figure 2. Changes in effective muscle mechanical advantage (EMA = $\int F_m / \int G_{RF}$) of major lower extremity muscle extensor groups as a function of step number during sprinting trials. Whole limb EMA represents the average of the hip, knee and ankle values.

The increase in hip flexor moment reflects the large horizontal component of G_{RF} (net horizontal impulse = 0.60 vertical impulse at step 1 and 0.32 vertical impulse at step 3) and large amount of positive mechanical work (Cavagna et al. 1971) that occurs as a runner accelerates early in a sprint.. The large hip extensor force contributes to increased mechanical power developed at the hip, which is likely transmitted to more distal limb joints in a temporally coordinated manner (Jacobs et al. 1992), in order to facilitate more rapid acceleration of a sprinter.

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