FORCE-VELOCITY BEHAVIOUR OF HUMAN MEDIAL GASTROCNEMIUS SHIFTS AT THE WALK TO RUN TRANSITION

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INTRODUCTION

The human medial gastrocnemius (MG) exhibits considerable stretch and recoil in its series elastic element (SEE) during walking and running. This has two main benefits: (1) The SEE can recycle elastic energy to provide power for push-off that would otherwise have to come from active muscle shortening. (2) It allows the muscle fascicles to operate at lower velocities which favours economical force production. This has been established for typical walking speeds and moderate running speeds but the question remains: Is this optimal behaviour maintained across a wider range of speeds?

Simulations of human walking show that positive fascicle work in the MG increases with walking speed [1] and cat gastrocnemius fascicle velocity increases with walking speed [2]. Conversely, running turkeys exhibit nearly isometric MG fascicle behaviour which is almost constant with varied speed [3]. Increasing fascicle velocity with walking speed might impair the muscle's ability to produce force which has been cited as a reason for transitioning to running gait [4]. If, as in turkey's, the fascicles remain at very low velocities in running than fascicle behaviour might be a factor in determining the preferred walk to run transition speed.

Furthermore, were fascicle velocity to increase with walking speed it might require the MG to recruit a larger volume of muscle to produce sufficient force to keep walking. Also, the intrinsic properties of muscle mean that producing force at faster velocities is less efficient. Thus changes in fascicle velocities might be reflected in the metabolic cost of transport and the efficiency of muscular work.

We aimed to test how MG fascicle dynamics varied with locomotor speed and gait. We hypothesised that fascicle velocity would increase with walking speed, impairing force production. Also, fascicle velocity would not change across running speeds.

METHODS

Ten participants (six male, four female) walked at four speeds (0.75, 1.25, 1.75, 2.0 $m \cdot s^{-1}$) and ran at four speeds (2.0, 2.25, 2.75, 3.25 $m \cdot s^{-1}$) on a split-belt treadmill instrumented with bilateral force platforms embedded under the belts (BERTEC, USA). Kinematic data were recorded for the right leg and pelvis using an eight camera motion analysis system (VICON, UK; 120 Hz) and a modified Helen Hayes marker set. Ground reaction forces (980 Hz) and kinematic data were combined in an inverse dynamics analysis of the right leg (symmetry was assumed between legs).

MG fascicle length and pennation angle during walking and running were measured on ultrasound images (50 Hz) taken by a linear transducer (TELEMED, Lithuania) taped over the midbelly of the MG. The length of the whole MG muscle-tendon unit (MTU) was determined from kinematics and SEE length was MTU length minus fascicle length (corrected for pennation angle). Lengths were differentiated to obtain velocities. MG fascicle force was calculated first by dividing the ankle moment by the Achilles tendon moment arm and then multiplying this force by the relative cross sectional area of MG within the triceps surae (this was considered the force in the SEE). This force was then corrected for pennation angle to give fascicle force. Multiplying fascicle and SEE forces with their respective velocities gave fascicle and SEE power which was integrated to estimate fascicle work and SEE energy stored and returned.

Metabolic energy consumption at each speed was determined by indirect calorimetry and cost of transport was calculated. Efficiency of positive work was calculated as average positive mechanical power divided by net metabolic power.

RESULTS & DISCUSSION

The average positive power output of the MG MTU did not change with walking speed but was significantly greater after switching to running gait (Fig 1). This increase in power output was not due to any change in average fascicle power which did not change with speed or gait (Fig 1). It was actually due to increased storage and return of energy in the SEE which was significantly greater during running but did not change with speed within gait (Fig 1).

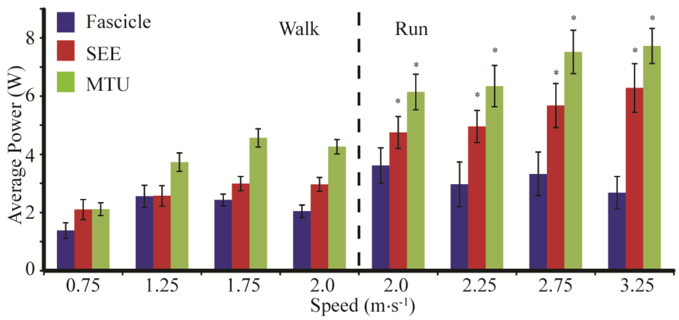

Fig 1. Average positive power output of the fascicle, SEE and MTU of MG vs. speed

An increase in storage and return of energy in the tendon implies greater forces being applied to it and this was the case as peak fascicle force (F_{MGmax}) increased for all running conditions compared with walking at 2.0 m·s^{-1} (Fig 2). This increase in force coincided with a significant decrease in fascicle velocity at the time of peak force (V_{MGmax}) (Fig 2). F_{MGmax} declined significantly with increasing walking speed and V_{MGmax} increased significantly as walking speed increased from 1.25 to 2.0 m·s^{-1} (Fig 2).

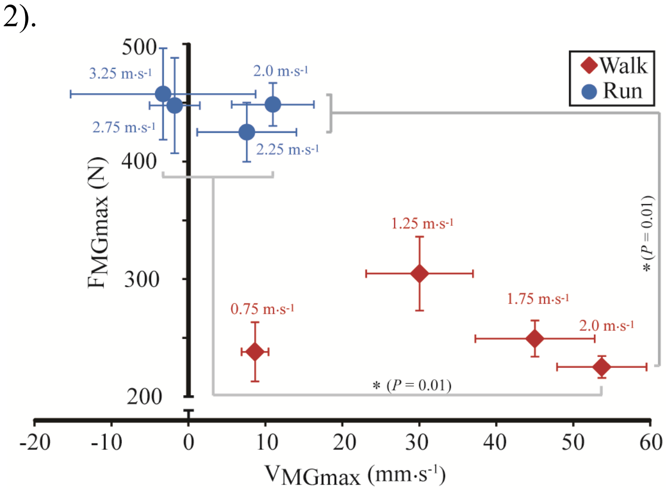

Fig 2. Peak MG fascicle force vs. Fascicle velocity at the time of peak MG force

The trends in V_{MGmax} were mirrored in the efficiency of positive work with higher efficiencies occurring at walking speeds where V_{MGmax} was less (except for at 0.75 m·s^{-1}). Efficiency of positive work increased and V_{MGmax} decreased after switching to running. However linking the two is difficult as there was no data for other muscles.

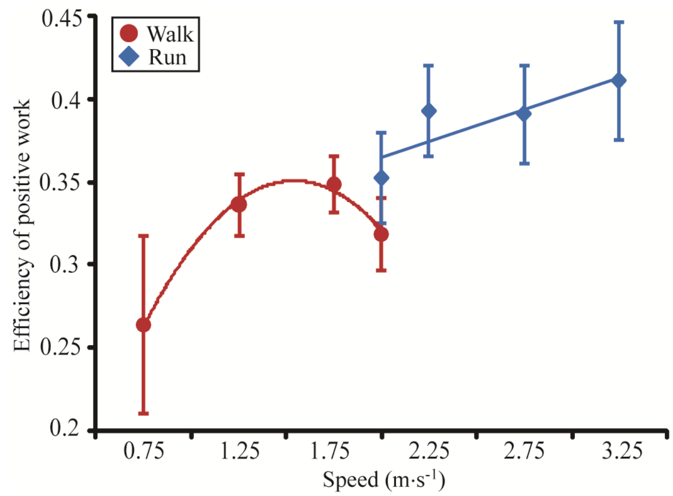

Fig 3. The efficiency of positive work vs. walking and running speed

CONCLUSION

Transitioning from walking to running shifts MG fascicles to a more favourable part of the force-velocity relationship. If other muscles behave similarly this might help to explain trends in efficiency and cost of transport.

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