COULD MUSCLE REFLEXES DOMINATE HUMAN MOTOR OUTPUT IN WALKING?

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INTRODUCTION

Human locomotion is controlled by an extensive network of neurons. In the current view, this locomotion network is dominated by the central pattern generator (CPG) that generates a rhythmic movement of extensor and flexor muscles, propelling the legs through stance and swing [1]. Although muscle reflexes are part of this network, they are mainly related to timing and modulating the CPG output.

Here we show that muscle reflexes could play a far more dominant role in the control of human locomotion. We present a human model with a motor control solely based on muscle reflexes. These reflexes are designed to encode basic principles of legged dynamics and control. Comparing the model behavior with experimental evidence, we find that this model surprisingly well matches human walking mechanics and muscle activities, suggesting that human motor output could largely be shaped by muscle reflexes that link principles of legged dynamics and control into the neural networks responsible for locomotion.

MODEL

We built a human model consisting of a trunk and two three-segment legs, each actuated by seven Hill-type muscles representing soleus (SOL), tibialis anterior (TA), gastrocnemius (GAS), vastii (VAS), hamstrings (HAM), glutei (GLU) and hip flexors (HFL) (Fig. 1). We combined these muscles with positive force (F+) and length feedback schemes (L+/-), to effectively encode basic principles of legged dynamics and control, including the reliance on compliant leg behavior in stance [2], the stabilization of segmented legs based on static joint torque equilibria [3], the exploitation of ballistic swing-leg mechanics [4], and the enhancement of gait stability using leg retraction [5].

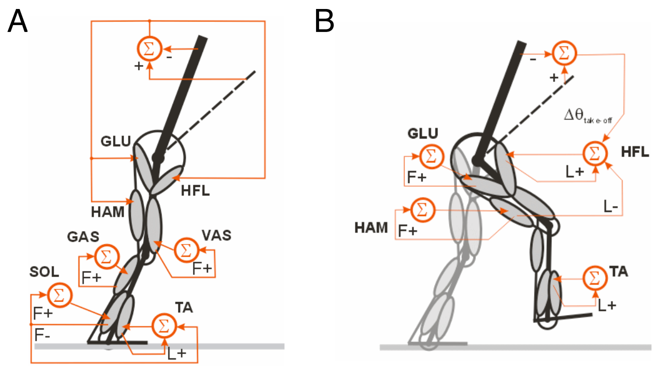

Figure 1: Human model with (A) stance and (B) swing leg reflexes. In (A), only one leg is shown for clarity.

RESULTS AND DISCUSSION

We explore the model behavior by simulating its dynamics. For instance, with an initial speed of $2.4 ms^{-1}$, the model nearly runs, but converges in a few steps into steady-state walking at about $1.3 ms^{-1}$ (Fig. 2). In steady-state walking,

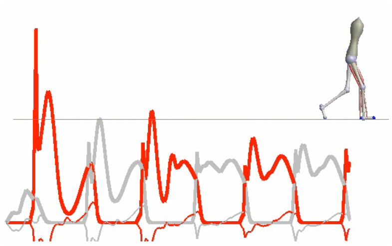

Figure 2: Converging from nearly running into steady state walking. Red and gray traces indicate the model's ground reaction forces for its right and left leg.

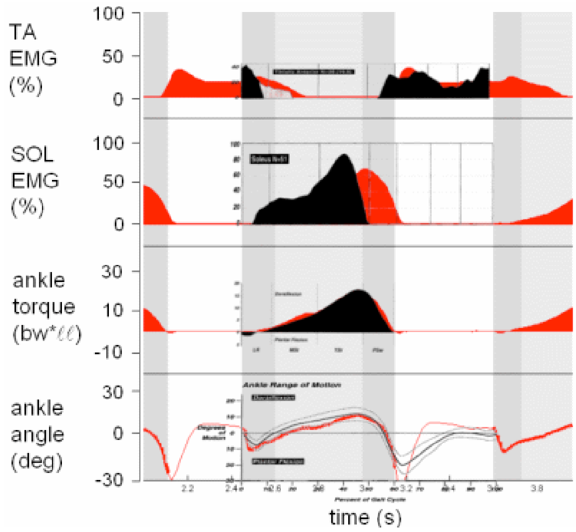

Figure 3: Ankle angle & torque, and SOL & TA activities of human model (red) and adapted from [6] (black).

the model shows qualitative agreement with angle, torque and muscle activation patterns known from human walking data (shown for ankle in Fig. 3).

Our results suggest that in principle no CPG is required to generate human walking mechanics and muscle activities. Quite contrary, muscle reflexes that encode principles of legged dynamics and control could play a far greater role in human motor control than anticipated before, and may even take precedence over central inputs in the control of normal human locomotion.

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