REDISTRIBTION OF LOWER-LIMB JOINT POWER DURING UPHILL AND DOWNHILL WALKING AND RUNNNING

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INTRODUCTION:

Mechanical output of the lower-limbs during gait is modulated in response to changing environmental demands. For example, at steady speed on level ground, the majority of positive work is performed by the ankle and hip over a range of walking and running speeds (1). On an incline during walking (2) and running (3), joint power contributions are re-distributed, with the hip becoming the predominant source of net work to raise the center of mass against gravity. Our aim was to characterize the distribution of positive and negative mechanical power output across the lower-limb joints in walking and running up and downhill in order to guide design of assistive devices (i.e., exoskeletons and prostheses). We hypothesized that the hip would dominate mechanical energy generation needed to go uphill and the knee would dominate mechanical energy absorption needed to go downhill at steady speed.

METHODS:

3D lower-limb kinematics and kinetics were collected on eight subjects across 5 walking (1.25 m/s; -15%, -10%, 0%, 10%, 15% grade) and running (2.25 m/s; -10%, -5%, 0%, 5%, 10% grade) during 7 minute trials. Using inverse dynamics analysis we computed joint moments and powers for the ankle, knee, and hip in each condition and computed average positive and negative power pie charts including both limbs following (1).

RESULTS AND DISCUSSION:

The distribution of joint power and work output among the ankle, knee, and hip depended on both surface gradient and gait. During walking, positive work shifted from the ankle to hip with increasing grade while the knee was the dominant source of negative work across all grades (Fig. 1a). Net work followed similar trends. On inclines, the majority of net work was performed at the hip, while on

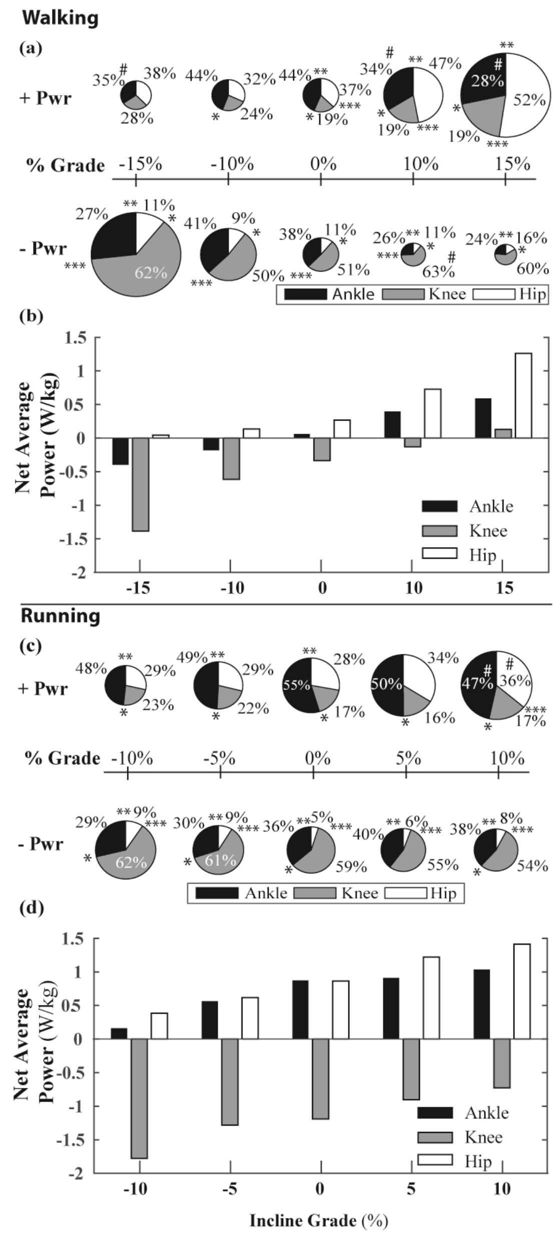

Figure 1: (a) Percent distribution of average positive and negative lower-limb joint power for **(a)** walking (1.25 m/s) and **(c)** running (2.25 m/s) over a range of grades. The area of each pie is normalized to the average positive power at level grade for walking (1.02 W/kg) and running (3.66 W/kg). A significant change (p<0.05) in the individual joint's percent work distribution compared to level walking or running is marked by a hash sign (#). A significant difference (p<0.05) in pairwise comparisons between percent joint work at a given grade is marked by a *(Hip to Knee), ** (Knee to Ankle), and *** (Ankle to Hip). Net average power of each joint across grade conditions for **(b)** walking and **(d)** running.

declines the largest source of net work was the knee (Fig. 1b).

During running, the ankle was the dominant source of <u>positive</u> work and the knee was the dominant source of <u>negative</u> work across all grades (Fig. 1c). The hip did very little negative work during running, and was therefore the dominant source of <u>net</u> work during incline running (Fig. 1d).

Time series plots show the redistribution of joint moment and power over the stride cycle for walking (Fig. 2) and running (Fig. 3). Again, the general trend was a shift in positive power to the hip with increasing incline, while the knee was the primary site of negative work (i.e. absorption). Changes in ankle positive power were predominately seen at push-off (~60% stride), with changes in the knee negative power and hip positive power coming in initial stance.

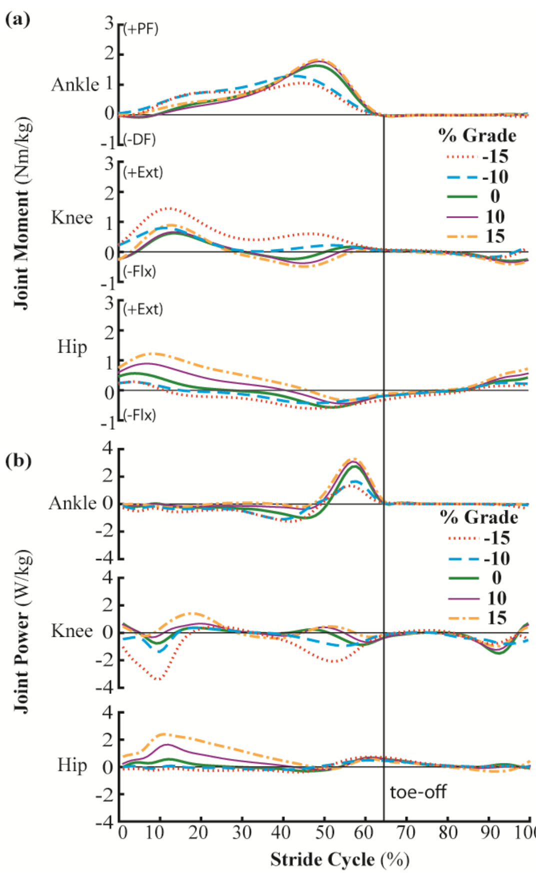

Figure 2: Normalized time series plots of the joint moments (a) and powers (b) during walking across grades. Data shown are a group mean over one complete stride defined with 0% and 100% = heel-strike of same limb.

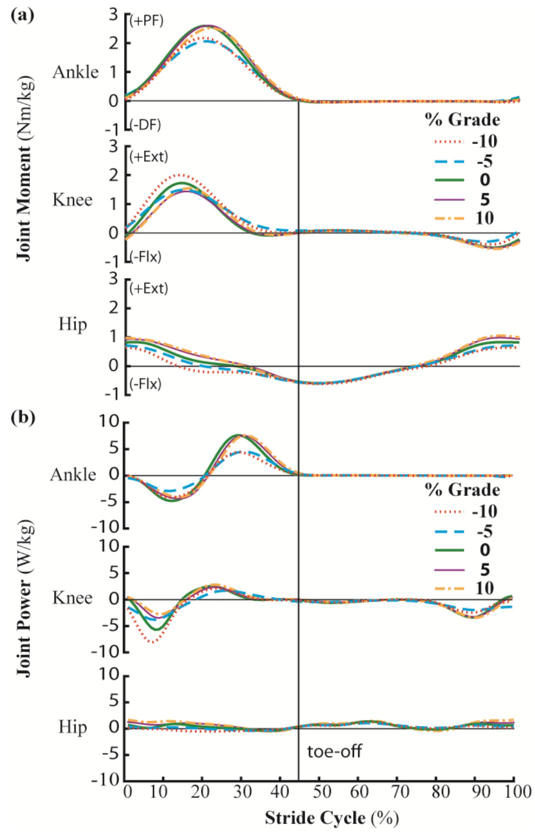

Figure 3: Normalized time series plots of the joint moments (a) and powers (b) during running across grades. Data shown are a group mean over one complete stride defined with 0% and 100% = heel-strike of same limb.

These results support our hypothesis and the previous work of others (1,2,3) that for uphill locomotion, the hip is an important source of net mechanical energy generation. In addition, we have demonstrated that the knee is the predominant source of absorption during both walking and running downhill-highlighting a strong opportunity for energy harvesting during downhill gait. Interestingly, during uphill running, the ankle joint remains an important contributor to overall positive work, making it an ideal site for assistance with simple exoskeletal devices. Future work will be directed at assessing the mechanical and metabolic effects of assistive devices in similar conditions of increased mechanical demand.

REFERENCES

1. Farris DJ, *J R Soc Interface*. 2012 Jan 7;**9**(66):110-8.
2. Franz JR, *Gait Posture*. 2014 Jan;**39**(1):135-40.
3. Roberts TJ, *J Exp Biol*. 2005 May;**208**(Pt 10):1963-70