

MUSCLE FUNCTION IS BIASED TOWARDS POSITIVE OVER NEGATIVE WORK IN LEVEL HUMAN GAIT

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INTRODUCTION

Level gait at constant average velocity includes the generation and dissipation of equal amounts of mechanical energy (i.e. positive and negative work) through the stride cycle (4). Surprisingly, Elftman (4) and Dutto et al (1) showed net positive joint work in level human running and in level horse trotting. Positive and negative joint work were derived from joint powers and were attributed to shortening (concentric) or lengthening (eccentric) muscle contractions. To our knowledge no subsequent studies of the potential imbalance in joint and therefore muscle work over the stride cycle have been reported.

Theoretically positive mechanical work can be produced in mammals only by converting chemical energy into mechanical energy within muscle sarcomeres (i.e. the power stroke of the cross bridges, 3). In contrast, negative work can be produced by muscles but also other body tissues through compression and tension (5). This suggests that to maintain constant mechanical energy over a stride muscle positive work would have to overcome energy losses from these other tissues. Based on Elftman's and Dutto's empirical data and on these theoretical concepts, we hypothesize that muscles produce a net positive work during level gait despite the maintenance of a constant level of mechanical energy (total mechanical work = 0). The purpose of the study was to determine total negative,

positive and net lower extremity joint work during level human walking and running.

METHODS

Ground forces and 3D kinematics were obtained from 21 adults while walking (1.5 m/s) and 16 other adults while running (3.5 m/s). Inverse dynamics were used to derive 3D joint powers throughout the stride. Positive, negative, and total work at each lower limb joint were derived from these data and assumed to be due to muscle forces (6). We verified that mechanical energy did not change over the stride by comparing the height and velocity of a marker on the L5/S1 joint at the start and end of the stride cycle. T-tests ($p < 0.05$) compared negative and positive work at each joint and total negative and positive work summed across the joints.

RESULTS AND DISCUSSION

The pattern of results was identical in walking and running tests. Total positive joint work was 16% and 8% larger than total negative joint work in these gaits (both $p < 0.05$) producing 9 J and 10 J of net positive work in the two gaits (fig 1). 20 of the 21 subjects in walking and all 16 subjects in running had net positive joint work. Based on the L5/S1 marker kinematics, total body energy changed less than 1% over the stride in walking and running. These results indicated the observed positive bias in joint work was a consistent finding and was not due to a

change in body vertical position or running velocity (i.e. an increase in body mechanical energy).

Hip and ankle joint work were positively biased in both gaits however the hip bias was much larger. Positive vs. negative hip work was 2.6 and 3.3 fold larger in walking and running whereas positive vs. negative ankle work was only 0.2 fold larger in both gaits (fig 1.). Knee joint work was largely negatively biased in both gaits. Negative vs. positive knee work was ~2.5 fold larger in walking and running. These data indicated the hip muscles were primary energy generators and functioned more concentrically than eccentrically, knee muscles were primary energy dissipaters and emphasized eccentric function and ankle muscles had, to a large extent a balance of generating-dissipating or concentric-eccentric functions.

SUMMARY/CONCLUSIONS

Level human gait at a constant average velocity does not balance muscle work through concentric and eccentric contractions but emphasizes the, “over-production,” of energy through shortening contractions to maintain a constant level of total mechanical energy. The net positive muscle work along with the nearly constant vertical position and horizontal velocity over the stride indicated that some of the positive work produced by muscles was not used to maintain upright posture (i.e. potential energy) and gait velocity (i.e. kinetic energy) but was wasted through various energy sinks. These sinks might be spinal discs, joint cartilage, and the shoe and floor however these and other possible energy sinks need further investigation.

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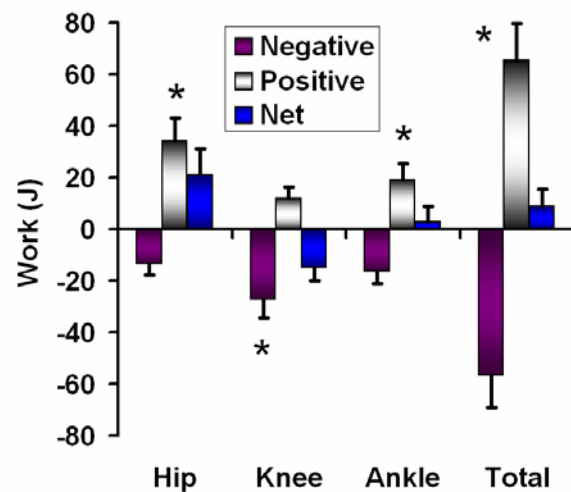
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ACKNOWLEDGEMENTS

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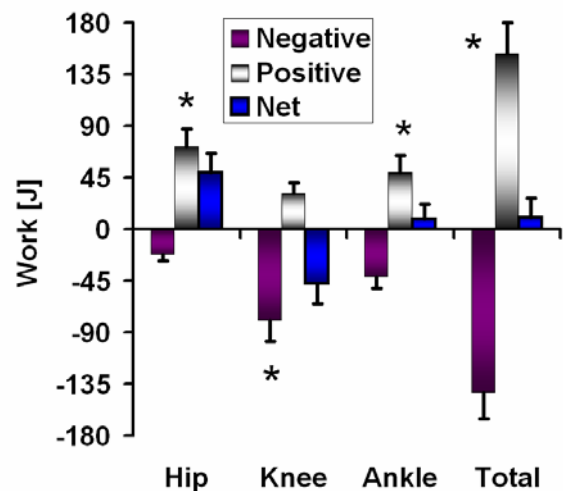


Figure 1, Negative, positive, and net work at each joint and their sums (Total) in A) walking and B) running. * positive or negative work significantly larger than the other (p<0.05).