Joint Moment Contributions to Segmental Power During Walking

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Introduction

Joint power is a variable commonly included in clinical analyses of gait to determine the role of muscle groups in producing and controlling movement. However, joint power represents the net effect of a joint moment on the mechanical energy of the whole body, not any one particular body segment. Other power techniques (Robertson et al) can account for the effect of muscles on energy of the segments to which they are attached. Passive transfer of energy to adjacent, but not remote segments, also is included in the technique, but the muscle group responsible for the energy transfer cannot be directly identified. The purpose of the present study was to characterize the role of lower extremity muscle groups in controlling movement of the entire kinetic chain using an approach that can follow the energy flow associated with any given joint moment from the foot through to the trunk.

Methodology

While 5 healthy adult subjects walked at a self-selected speed, ground reaction forces and the movement of the lower extremities and trunk were sampled with a six camera, two force platform, Vicon motion capture system. Joint and segmental kinematics and kinetics were calculated from the sampled data. Using a method previously described by Kepple et al, each computed joint moment was individually entered into a biomechanical model of the subject created in ADAMS software. Model output included the reaction forces at all joints resulting from each joint moment. Segmental velocities, joint moments, and the output joint reaction forces were used to calculate segmental power using the equations described by Robertson et al. This procedure was performed to compute the power of the foot, shank, thigh, and head-arms-trunk (HAT) segments which was associated with each of the net muscular moments at the ankle, knee, and hip or gravity. Work done by the muscle groups on each segment was calculated from the area under the segmental power curve during selected phases of gait.

Results

As compared to the segmental power analysis, joint power was unable to account for energy transfers due to gravity and underestimated the amount of work done by the joint moments on the segments. During loading response, gravity was responsible for the transfer of 15 J of energy out of the HAT and into the lower extremity segments (Fig 1A). Meanwhile, the knee and hip extensors worked together to resist the effects of gravity on the shank and thigh.

During the negative A1 ankle power burst in mid stance, joint power revealed the net work to be -6.8 J, but the ankle plantar flexor moment during this time was responsible for transferring 16.6 J of energy into the HAT, approximately 2.4 times more energy than the net effect of the ankle joint power (Fig 1B). This pattern of energy transfer into the HAT continued during the positive A2 ankle power burst. During later stance, the knee flexors and then extensors opposed the effect of the ankle plantar flexors on the energy of the shank and thigh, allowing the energy generated by the plantar flexors to be transferred to the HAT.

During the positive H3 hip power burst in late stance, joint power revealed the net work to be 5.9 J. However, the hip flexor moment during this interval was responsible for a loss of 27.4 J of energy from the HAT, approximately 4.6 times more energy than the net effect of the hip joint power (Fig 1C). This energy needed to be delivered to the shank and thigh segments in preparation for swing phase, but the high amount of energy removed from the HAT segment by the hip moment required the large energy contribution from the ankle plantar flexors to maintain the energy level of the HAT. Thus, the segmental power analysis provided insight into synergistic and antagonistic muscle function across multiple joints.

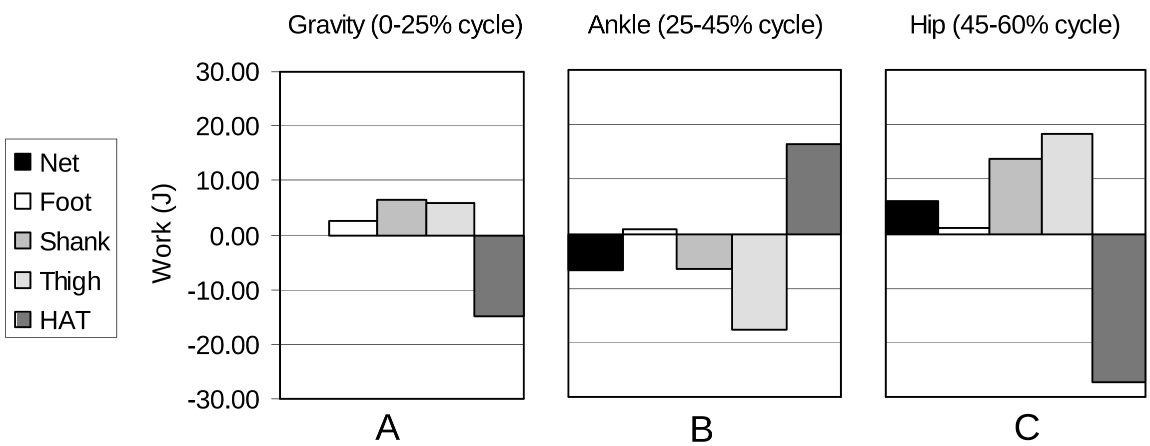

Figure 1. Work done by the joint moments on the foot, shank, thigh, and HAT segments compared to the net effect associated with: A, gravity (0-25% of the gait cycle); B, the negative ankle joint power burst (A1, 25-45% of the gait cycle); and C, the positive hip joint power burst (H3, 45-60% of the gait cycle) from one of the study subjects.

Discussion

In the interpretation of net joint power, positive power represents energy generation by concentric muscle activity and negative power represents energy absorption by eccentric muscle activity. Although joint power does represent the net effect of a muscle group on the mechanical energy of the entire body, it does not adequately reveal the role of the muscle group in changing the energy level of each segment within the body. The local effects of energy transfer can be several times greater than the magnitude of the net joint power and even opposite in sign. The data presented demonstrate that by transferring energy across joints, eccentric muscle activity actually can increase segmental energy and concentric contractions can decrease segmental energy. The results of the more comprehensive segmental power analysis revealed new information about how lower extremity muscle groups control not only the segments they span, but also anatomically remote segments, at a level of detail not allowed by existing techniques.

References

Robertson DGE et al. *Journal of Biomechanics*, 13:845-854, 1980.
Kepple TM et al. *Gait and Posture*, 6:1-8, 1997.