COMPARISON OF METHODS FOR CALCULATING INTERNAL WORK OF AMBULATORY MOVEMENTS IN ELITE RUNNERS

Sheila B.A. Purkiss and D.G.E. Robertson, University of Ottawa, Ottawa, Canada

INTRODUCTION

Traditionally, when a researcher wanted the amount of work involved in performing a movement, s/he would use a model that calculated the changes in the energy of the segments. A prime example of this type of model is Winter's internal work (W_{wb}) equation (1978) which attempted to quantify the internal work of locomotion. However, this model has some basic flaws. As pointed out by Williams and Cavanagh (1983) a model with unlimited between segment energy transfer will fail in certain situations. Unfortunately, a model that limits between segment energy transfers will also fail in certain situations, making any limitation to energy transfer arbitrary. Even more importantly, Aleshinsky (1986, part IV) mathematically established that the energy-based model is only valid under certain restricted conditions.

Despite its limitations, many variations on this model abound. Researchers have attempted to incorporate various biological factors in this model. Unfortunately, none of these factors are directly measurable with the result that different numeric estimates have been used to represent the same factors. The conclusion reached by Williams (1985) was that a consensus on a "best" energy-based model does not exist.

Attention has now turned to alternative methods for calculating the work involved in movement. Aleshinsky (1986, part V) established the mathematical validity and recommended the use of integrating joint powers to find work. He overcame the traditional limitation of this approach, the mutual cancellation of positive and negative work values, by proposing that the absolute value of the powers be integrated. Although in theory a better model, little research has been done using it. Chapman et al. (1987) used this model in their study examining normal versus modified runs, but only one subject was used, and the results were somewhat ambiguous. In this study we use a similar procedure to Chapman's to examine the sensitivity of the absolute power equation. The question under examination was: Is the absolute power approach sensitive enough to detect the differences between normal efficient running and the forced inefficiencies of the modified running?

METHODS

Nine trained runners were filmed (100 fps, Locam camera) as they ran across a Kistler force plate. They performed five normal runs (Norm) followed by four modified runs: exaggerated knee flexion (EKF), overstriding (OS), stiff knees (SK) and exaggerated arm swing (EAS). Analysis of the data was performed using custom software. Internal work for both the energy and joint power approaches was calculated using the following equations.

Energy approach: Absolute work = $$\sum_{n=1}^{N}\left|\sum_{s=1}^{S}\Delta E_{s,n}\right| - \sum_{n-1}^{N}\sum_{s=1}^{S}\Delta E_{s,n}$$

Power approach: Absolute power = $$\sum_{n=1}^{N}\sum_{j=1}^{J}\left|P_{j,n}\right| - \sum_{n=1}^{N}\sum_{j=1}^{J}P_{j,n}$$

where: N is the number of frames in the cycle of motion,
S is the number of body segments, J is the number of joints,
P_j is the power of the j^{th} net moments of force and
ΔE_s is the change of the s^{th} segment's mechanical energy.

For both equations the first term represents the total work and the second term represents the external work.

The internal work values were divided by the running velocity to obtain a "biomechanical cost" value. For each subject the mean biomechanical cost of the normal runs (from the absolute power method) was compared to each of the modified runs using a planned comparison with a Bonferroni corrected alpha level.

RESULTS AND DISCUSSION

As expected, the absolute power approach was quite sensitive. In most cases the differences between the efficient normal runs and the inefficient modified runs were detected. For example there was a significant difference between the mean normal run and each modified run for the runner depicted in Figure 1.

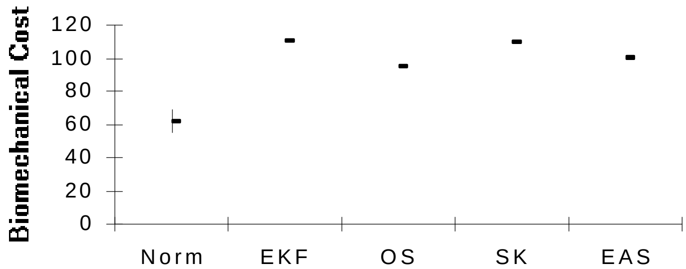

Figure 1 Comparison of biomechanical costs

In some cases where differences weren't detected it was possible that the modified run was not sufficiently different from the normal run for a statistical difference to exist. For example, for the runner in Figure 2 all of the modified runs except exaggerated arm swing were significantly different than the normal runs. It is possible that this is the result of a large arm swing in her normal running style.

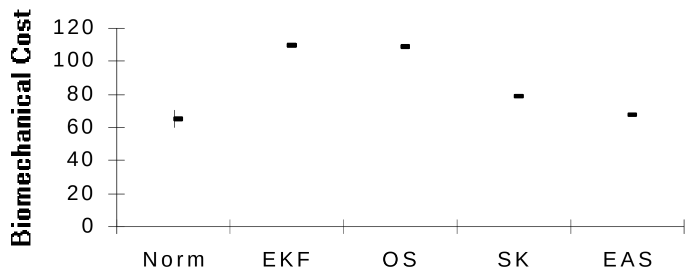

Figure 2 Comparison of biomechanical costs

One interesting result was that the variance in the energy approach was approximately 10 times greater than that of the absolute power approach, with increased variability being indicative of decreased reliability.

Also of interest was the difference in the pattern of the energy values in this study compared to Chapman's. In Chapman's study the energy values for the modified runs were all less than the value for the normal run, whereas in this study they tended to be greater than the value for the normal run.

CONCLUSION

The absolute power approach proved sensitive enough to detect the inefficiencies present in the modified running as compared to efficient normal running. As well, the energy approach was shown to be less reliable than the absolute power approach.

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