MECHANICAL ENERGY DIFFERENCES BETWEEN WALKING AND RUNNING AT DIFFERENT VELOCITIES ON A TREADMILL

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INTRODUCTION: Starting with Fenn's study of sprint running (Fenn, 1930), there have been many studies on the energetics of running and walking. Even so, there still remains room for discussion. Cavanagh (1990) described a variation from 170 to 1700 W in power output for the same movement (running at 3.6 m/s) calculated by six different authors. These differences occurred mainly due to different procedures for energy calculation and generated data that are not comparable (Corrêa, 1996). The purpose of this investigation was to describe, analyze, and compare the mechanical energy curves (total, internal and external energies) for six subjects while walking and running on a treadmill, using the same procedure for energy calculation.

METHODS: Six male subjects were filmed with two video-cameras (Sony-50Hz) while walking at 1.5 m/s and running at 3.0 and 4.0 m/s on a treadmill. After a manual digitizing process, a 3D analysis was performed from the kinematics. The analysis was based on a 13 segment model, represented by 17 markers placed on: ear, and right and left shoulders, elbow, wrist, hip, knee, ankle, heel and front foot extremity. Positions of segmental centers of gravity, segmental weights, and moments of inertia were estimated on the basis of tables devised by Dempster (1955); the segmental lengths were estimated as a percent of body height (Drillis & Contini, 1966), both as revised by Winter (1979). The components of mechanical energy were calculated at each instant of time, using the equations described by Zatsiorsky *et al.* (1987). From the different forms of mechanical energy, we have calculated the potential, kinetic and rotational energy at each instant of time, and the internal, external and total energy for the whole body.
The potential energy (E_{pot}) for the whole body, as a result of a multi-segment unit, was calculated as

$$E_{\text{pot}} = \sum_{i=1}^{n} m_i g\, h_i = m g\, h_{C.G}$$

where m_i was the mass (kg) of the ith segment, h_i the respective height (m) of the center of gravity and g the gravitational acceleration (g = 9.81 m/s^2).The summation of the potential energy of the n segments was equal to the potential energy of the body's center of gravity.
The kinetic energy (E_{kin}) for the whole body was defined as:

$$E_{\text{kin}} = \sum_{i=1}^{n} \tfrac{1}{2} m_i v_i^{\,2} = \tfrac{1}{2} m v_{C.G}^{\,2} + \sum_{i=1}^{n} \tfrac{1}{2} m_i v_{i,C.G}^{\,2}$$

where the velocity v_i (m/s) of the ith segment was relative to the velocity of the body's center of gravity ($v_{i,c.g.}$), and the others designations were as described above.

The rotational energy was obtained from:

$$E_{\text{rot}} = \sum_{i=1}^{n} \tfrac{1}{2} I_i \, \omega_i^{\,2}$$

where ω_i (rad/s) was the angular velocity and I_i (Kg·m^2) the rotational moment of inertia about the mass center of the ith segment.
The total body energy (E_{tot}) of a multi-segment system at each instant of time was obtained according to the following definition:

$$E_{tot} = \underbrace{mgh + \tfrac{1}{2}\, m v_{C.G}^2}_{\text{External}} + \underbrace{\sum_{i=1}^{n}\left(\tfrac{1}{2}\, m_i\, v_{i,C.G}^2 + \tfrac{1}{2}\, I_i\, \omega_i^2\right)}_{\text{Internal}}$$

RESULTS AND DISCUSSION: As we expected, the pattern of the curves for the total energy in walking and running were in agreement with the literature and energy change was, on the average for six subjects, 2.5 times greater in running than in walking. In order to better understand the differences between the curves for walking and running we further observed the curves of internal and external energy for both forms of locomotion (Figure 1).

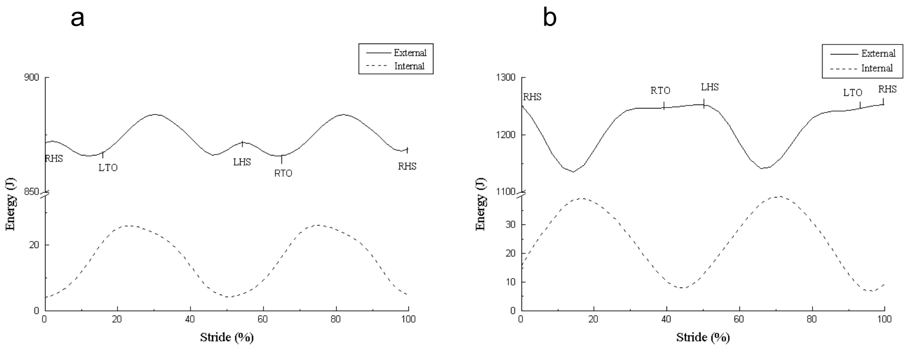

FIGURE 1 - INTERNAL AND EXTERNAL ENERGY CURVES FOR WALKING AT 1.5 M/S (A) AND RUNNING AT 3.00 M/S FOR ONE SUBJECT.

In relation to the differences between walking and running, the following observations were made: a) in walking the greatest contribution to the total change derived from the internal energy, while in running it derived from the external energy; b) the internal and external energy were in phase when walking, and in opposition when running. It means that for walking the subject needed more energy for the movement of arms and legs than for forward movement, while for running it was the opposite; and for running the contribution of the external energy to the total change was three times greater than the contribution of the internal.

When we looked at the components of the external energy for both forms of locomotion, we noticed that in walking the components (potential and kinetic energy of the C.G).were out of phase (180^0), while in running they were in phase (Figure 2).

a b

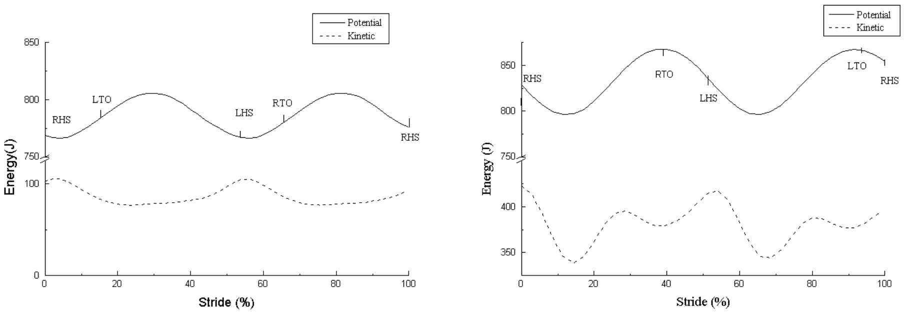

FIGURE 2 - COMPONENTS OF EXTERNAL ENERGY IN WALKING (A) AND RUNNING AT 3.00 M/S (B).

In practice, this means that in walking a change is possible between kinetic and potential energy, while in running one does not occur, and the greater the change between the components, the less need there is for muscular work to keep the velocity constant. That is the reason why for the same velocity the need for external energy is greater in running. The components of the internal energy (kinetic energy of the segments in relation to the CG and rotational) are in phase in walking and running, and in walking these changes are caused mainly by the acceleration and deceleration of the swing leg, while in running these changes occur during the support phase, due to vigorous movements of the segments in relation to the CG.

In Figure 3 we can see the curves for the total energy and for the external and internal energies in running at two different velocities - 3.0 and 4.0 m/s.

a b

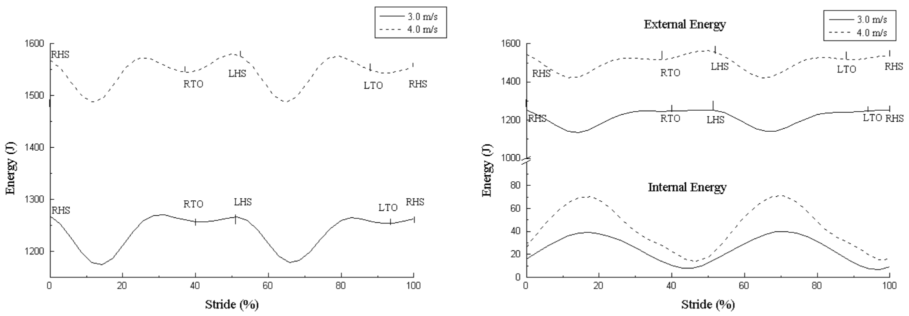

FIGURE 3 - TOTAL (A),INTERNAL AND EXTERNAL (B) ENERGIES FOR RUNNING AT 3.0 AND 4.0 M/S

Comparing the variations in the two velocities of running, the following conclusions were drawn: a) the average value of the absolute total energy at 3.0 m/s was 1237.9 J and at 4.0 m/s 1544.2 J; b) there was a linear correlation (r = 0.84)

between the change in velocity and the change in total energy for the six subjects; b) with the increase in velocity, the average increase in the total contribution of the change in internal energy was about 72% and of the external energy 36%.
In relation to the components of the external and internal energy (Figure 4), we concluded that a) there was no change in the contribution of the potential energy to the change in external energy; b) the increase in the internal energy was chiefly dependent on the increase in the kinetic energy.

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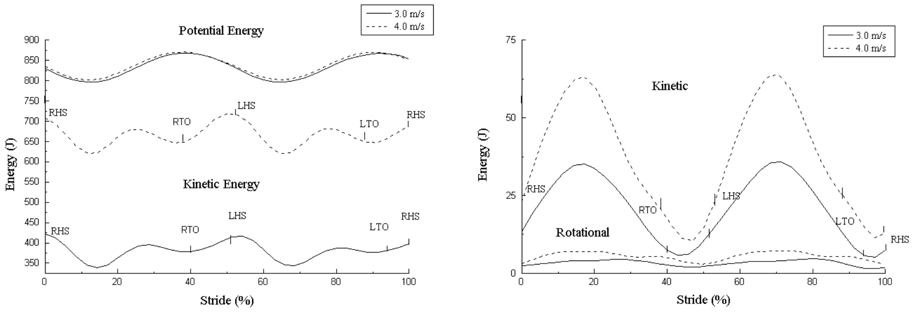

FIGURE 4 - COMPONENTS OF EXTERNAL (A) AND INTERNAL (B) ENERGIES IN RUNNING AT 3.00 AND 4.00 M/S.

CONCLUSION: Although the results related to the shape of the curves for mechanical energy for walking and running are already a matter of consensus in the field of biomechanics, it would appear that the numerical results are still open to broad discussion.

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