Mechanical Energy States during Running

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Summary. Changes in total mechanical work and its partitioning into different energy states (kinetic, potential and rotational) during a step cycle of running were investigated on six well trained athletes who ran at the test speeds of 40, 60, 80, and 100% (9.3 ± 0.3 m/s) of maximum. Cinematographic techniques were utilized to calculate the mechanical energy states as described by Norman et al. (1976), using a 13 segment mechanical model of a runner as the basis for the computations. The data showed that both the kinetic and rotational energy increased parabolically but the potential energy decreased linearly with increases in running velocity. The calculated power of the positive work phase increased quadratically with running speed. During the phase when the runner was in contact with the ground, the applied calculations gave similar increases for the positive and negative works, and the power ratio (\(\frac{\bar{W}_{pos}}{\bar{W}_{neg}}\)) stayed the same at all measured speeds. Therefore, it is likely that the method used to calculate the various mechanical energy states did not reflect accurately enough the physiological energy costs at higher running speeds. It may, however, be quite acceptable for estimating the mechanical energy states during walking and slow running, in which case the role of negative work is less and consequently the storage and utilization of elastic energy is small.

Key words: Mechanical energy — Work efficiency — Positive and negative work — Running mechanics.
(1976) re-examined the concept of mechanical efficiency in treadmill running and introduced a term of "pseudomechanical work" obtained from the film analysis. Applying the methods of Norman et al. (1976) the present study was designed to investigate the mechanical work in normal level running utilizing a large range of running speeds.

Methods

Six national level track and field athletes (two sprinters, two jumpers, one decathlete and one thrower) were used as subjects. Each subject ran short distances on a tartan type track of an indoor hall at the following instructed constant velocities: 40 ± 10, 60 ± 10, 80 ± 10 and 100% of their maximum speeds. The subjects practiced several times to become acquainted with the desired speeds. Electronic timing was used to assist the correct pacing. The actual speeds varied slightly from these desired speeds and they were: 3.9 ± 0.7, 6.4 ± 0.4, 8.0 ± 0.2 and 9.3 ± 0.3 m/s. Table 1 gives the physical characteristics and the test running velocities for each subject.

Each run was filmed with a Locam 51-0003 camera set to operate at 100 frames per second. In the subsequent film analysis with a Vanguard analyzer the mechanical model of the runner was assumed to consist of 13 segments with the head and trunk forming one segment. The individual segment parameters were obtained using the standards given by Dempster (1955). The necessary X-Y coordinates were punched onto paper tape for subsequent computer analysis. The segmental landmarks were marked on the skin with black and white tapes.

The final computations of the desired parameters were performed for one step cycle, which in this study was a period between the highest positions of the center of gravity (C.G.) of the two consecutive flights.

The total work (positive and negative) performed by the runners at each running speed was calculated through the kinetic, rotational and potential energy series using the methods and formulas developed by Norman et al. (1976) as follows:

\[ W = \sum_{j=1}^{n} \sum_{i=1}^{13} |\Delta m_i g h_{ij}| + |\Delta \frac{1}{2} m_i v_{ij}^2| + |\Delta \frac{1}{2} I_i \omega_{ij}^2| \]

where:

- \( W \) = total work during the step cycle
- \( 13 \) = number of segments
- \( n \) = number of frames per cycle
- \( i,j \) = segment number, frame number
- \( m_i \) = mass of segment \( i \)
- \( g \) = gravitational constant, 9.81 m/s²
- \( I_i \) = segment \( i \) moment of inertia about mass center
- \( h_{ij} \) = segment \( i \) vertical position in frame \( j \)
- \( v_{ij} \) = segment \( i \) linear velocity in frame \( j \)
- \( \omega_{ij} \) = segment \( i \) angular velocity in frame \( j \)

Because of the great range (40–100%) of the running velocities the work done to overcome the air resistance was also adjusted by using the equivalent slope of Hill (1928).

The mechanical energy states were calculated with a Honeywell 1644 computer. The equations for segmental displacements were smoothed through the 9th degree polynomial fitting. The positive and negative work were calculated both for the total cycle and for the contact period. During the contact period the phase of negative work was taken from the first contact to the position where the C.G. had passed the vertical line over the point of ankle joint (Cavagna et al., 1964).