The energetics of middle distance running

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The study of records in sports, as pointed in the 1920s by A.V. Hill, is a fascinating source of information. However, the study of records was often based on statistical approaches, which do not allow us to draw any sound information as to the underlying physiology. Here I address the problem from a physiological point of view and show that the individual best performances in middle distance running can be predicted with fair accuracy as follows. Individual best performances in middle distance running can be predicted as follows. I) The metabolic power (E'r) required to cover any given distance d in the time tp is the product of the energy cost of running per unit of distance (Cr) and the speed (v=d/tp): E'r = Cr d/tp. Therefore, II) the shortest time (fastest speed) over any given d is achieved when E'r is equal to the maximal metabolic power of the subject (E'rmax). III) Between 50 s and 15 min, E'rmax decreases with increasing exercise duration (te): E'rmax = f(te), the precise function being defined analytically by the maximal oxygen consumption (VO2max) and the amount of energy derived from complete exploitation of anaerobic stores (AnS). Hence, IV) best performance times for any given distance and runner can be obtained as the time values for which E'rmax = E'r, provided that Cr, VO2max and AnS are known. Cr during track running was determined on 16 amateur and 24 elite middle distance runners on whom VO2max was also measured and AnS assumed from published data. For both groups, and for distances between 0.8 and 5.0 km, best performance times were slightly shorter (4.1 and 1.6 % on average), but not significantly different, than actual best times. In the above study it was assumed that, in the initial phase of the run in which the acceleration takes place, Cr is the sum of the value for constant speed running plus a kinetic energy term. This was estimated from the average speed and the efficiency of muscle contraction, assumed = 0.25. This problem is here addressed further. In the initial phase of a run on flat terrain from a stationary start, the biomechanics of running is equivalent to that of running uphill at constant speed, the slope (Equivalent Slope, ES) being dictated by the forward acceleration. The energy cost of uphill running (Cru) is rather well known, up to slopes of about 45 %. Therefore, the energy cost of accelerated running (Csr) was estimated from ES, as calculated from the forward acceleration measured over the initial 30 m of an all-our 100 metres run on 12 medium level sprinters, and on the basis of Cru. The instantaneous metabolic power (Pmet) was also estimated from the product of the instantaneous Csr and the corresponding speed. Peak and average values over 30 m (± 1 SD, n = 12) were: 10.7 ± 0.59; 43.8 ± 10.4 for Csr (J/(kg m)) (to be compared to about 3.8 for constant speed running on flat terrain) and 61.6 ± 4.7; 91.9 ±20.5 for Pmet (W/kg). The efficiency of transformation of metabolic into kinetic energy ( k) was also estimated from these data. Indeed, the rate of kinetic energy change (E'c) can be obtained from the first derivative of the speed versus time curve (E'c = dv2/(2 dt)). Hence, at any given time, the ratio of E'c to the corresponding Pmet yields the overall efficiency of kinetic energy production: k = E'c/Pmet. k increased from 0.09 at the very onset of the run (0.25 s after the start) to about 0.26 in the time frame from 1 to 2 s, decreasing progressively thereafter, to attain zero after about 4.5 s, when v reached a constant value. Because of the way in which k was calculated, these data mirror the efficiency of uphill running at constant speed as a function of the slope, in which case the external work is performed against gravity. They do show, however, that in the initial few strides k is rather low, presumably because of an unfavourably low speed of muscle shortening, in spite of the very steep ES which could be expected to yield k close to 0.25, as is the case for running at slopes ≥ 25 %. As the speed increases, but ES is still high enough to limit the mechanical energy losses due to the acceleration and deceleration of the centre of mass in the vertical and horizontal plane with each stride, k is not far from the optimal efficiency of muscle contraction (0.25). With greater forward speed and lesser ES, the energy waste with each stride to accelerated and decelerate the runner's centre of mass increases. This, coupled with the concomitant increase of internal work performance, inevitably leads to smaller and smaller ks.