BIOMECHANIC EVALUATION OF RUNNING PERFORMANCES

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INTRODUCTION

Running is the final result of a very complex coordination involving a lot of different anatomical-physiological contributions which are jointly provided by the neuro-muscular, the cardio-vascular, the respiratory and the metabolic systems. Given the obvious difficulty of performing a complete and detailed evaluation of all the variables associated with running, useful information for practical applications is often obtained by analyzing the movement itself as an integrated descriptor of the whole process of coordination. However, even when only kinematic and dynamic aspects of running are taken into account, the large number of the available measures makes the study of correlation between variables very difficult to manage and to interpret. The aim of this study is to present a simple method for quantitative and synthetic description of the running performance and to show some preliminary results obtained through such a multivariable integration involving both kinematic and dynamic data.

EQUIPMENT AND METHOD

The equipment adopted to measure the required kinematic data and ground reaction forces is essentially composed by two main units: the ELITE System (Ferrigno et al., 1989) which is an opto-electronic based 3-D motion analyzer, and a Kistler force plate. According with the ELITE hardware features, various small reflective hemispheres were preliminary placed on the runner's skin to mark suitable body reference points. In this application, only six passive markers were used to identify three anatomical landmarks (the anterior-superior iliac spine, the heel and the fifth metatarsal head) and the approximated position of the axis of flexion/extension of the hip, the knee and the ankle joints. The subject was then asked to run along a straight pathway about 30 m long at the four step cadences that are corresponding, by his own interpretation (and capability), to jogging, long and middle distance running and sprinting. After about two thirds down the starting line, the force plate was located flush with the floor and centered with respect to the calibrated volume where the kinematic measures had to be taken. The acquired 3-D coordinates of the markers and the ground reaction forces were then processed in order to obtain the angular velocities and the reactive moments (Boccardi et al. 1981) at the lower limb joints, and the x and y velocity of the hip. Although the raw data were collected in 3-D, the analysis has been performed along the athlete's sagittal plane and during the stance-phase only in order to simplify the processing of the moments which have been computed without taking into account the anthropometric and inertial parameters of each athlete. The computed variables are:

- the RMS reactive power (P.), developed at the lower limb joints with respect to the body mass, computed as follows:
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Ground reaction forces

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<table>
<thead>
<tr>
<th>Trials</th>
<th>Pr</th>
<th>Ekx</th>
<th>$\sigma_x$</th>
<th>$\sigma_y$</th>
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<tbody>
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<td>Jogger</td>
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<td>8.580</td>
<td>366.155</td>
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<tr>
<td></td>
<td>2</td>
<td>9.810</td>
<td>499.556</td>
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<td></td>
<td>3</td>
<td>17.927</td>
<td>766.660</td>
<td>0.563</td>
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<tr>
<td></td>
<td>4</td>
<td>19.686</td>
<td>926.397</td>
<td>0.659</td>
</tr>
<tr>
<td>Runner</td>
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<td>8.573</td>
<td>297.509</td>
<td>0.183</td>
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<tr>
<td></td>
<td>2</td>
<td>14.665</td>
<td>619.570</td>
<td>0.355</td>
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<tr>
<td></td>
<td>3</td>
<td>22.957</td>
<td>920.922</td>
<td>0.515</td>
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<tr>
<td></td>
<td>4</td>
<td>25.236</td>
<td>1627.398</td>
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<td>282.205</td>
<td>0.166</td>
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<tr>
<td></td>
<td>2</td>
<td>16.822</td>
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<tr>
<td></td>
<td>3</td>
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<td>0.391</td>
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<td></td>
<td>4</td>
<td>26.219</td>
<td>1593.473</td>
<td>0.510</td>
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</table>
RESULTS AND DISCUSSION

The results obtained showed different results for the three subjects. While the third subject showed the best performance, the following two cases stand out:
- In the middle range of velocities, the curves for energy consumption and metabolic energy expenditure are roughly parallel.
- At slow velocities (from slow to moderate), the runner showed a better efficiency, while the jogger was more efficient at faster speeds (from slow to moderate).
- The fast runner, who is the best performer, shows the highest efficiency at the fastest velocity, by far.

However, the need for a synthetic approach, one that considers the velocity (or energy expenditure) at a given point in time, is evident, particularly when considering the runner's ability to maintain a consistent and regular pattern of movement.

REFERENCES
- Boccardi S., Pedotti A., Etienne at the Lower Limb, J. Biomechanics, 1996
- Ferrigno G., Borghese, Motion Analysis, ISPRS
\[ P_r = m^{-1} \left( \sum_i (P_i^2) \right)^{1/2} \]
\[ P_i = \left( T^{-1} \int_T (M_{r,i} \omega_i \cdot \delta t) \right)^{1/2} \]

where \( T = t_f - t_i \) is the stance-phase duration, \( M_{r,i} \) is the reactive moment around the \( i \)-th joint, \( \omega_i \) is the angular velocity around the \( i \)-th joint, \( m \) is the athlete's body mass.

- The kinetic energy \( E_{kx} \) along the progression direction, computed as:
\[
E_{kx} = 0.5 \ m \ v_{x}^2
\]
where \( v_{x} \) is the mean velocity along the progression direction of the hip joint marker which is supposed to represent the body center of mass.

- The standard deviations \( a_i \) and \( c_i \) from the mean values of the hip joint velocity along the advancing \( (v_x) \) and the vertical \( (v_y) \) directions.

RESULTS AND DISCUSSION

The results obtained by testing three different subjects are shown in the Table. The three subjects had different running characteristics: one is just a jogger, the second is an amateur runner while the third is a professional long jumper. The two diagrams showing \( P_r \) and \( E_{kx} \) could arouse the following two considerations:

- in the middle range of running velocities (from point 2 to point 3) the three subjects provide \( P_r \) and \( E_{kx} \) curves having just a slight different trend. The amplitude shift among the three curves of power are roughly confirmed also in the curves referring to the energy;

- at slow velocities (from point 1 to point 2) the jogging trained subject provides the best performance given that his \( E_{kx}/P_r \) ratio is more advantageous with respect to the other two subjects. The less advantageous ratio is given by the long jumper;

- at fast speeds (from point 3 to point 4) \( E_{kx}/P_r \) ratio turns in favor of the long jumper while the jogger is following after the runner. A very large improvement of the above ratio is obtained, at the fastest velocity, by the runner.

However, the need of a good efficiency in the conversion of power into energy suggests the study of the velocity (or energy) deviations with respect to the mean vertical and horizontal values. The diagrams of \( a_i \) and \( c_i \) show that, for all the three subjects, a characteristic progression speed occurs. In fact the intersection of the \( a_i \) and \( c_i \) curves, where the vertical dissipation of movement equals the horizontal one, points out for each subject a typical advancing velocity which is changing as the runner ranking. Of course, this finding is worth being further investigated but the regularity with which it arises is quite surprising and, if confirmed by other results, it may represent a synthetic performance index to monitor the running capabilities of a subject.

REFERENCES