KINEMATIC AND DYNAMIC ANALYSIS OF SPRINT START


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INTRODUCTION

The sprint from the starting blocks has an important influence on the sprint performance trials in track and field events. The purpose of this study was to quantify the parameters that are commonly used in this field of practice and to identify the variables that influence the sprint start movement by means of kinematic and dynamic analysis. Statistical analysis of these variables was performed in order to explain the differences that are observed in the execution of this specific task amongst three top ranking athletes.

METHODS

Data acquisition was performed by means of an optoelectronic system (ELITE Motion Analysis System, BTS, Milan, Italy, two 3D cameras, 100 Hz) and a piezoelectric force platform (Kistler Instruments AG, Winthertur, CH, Type 9281b, sampling rate 500 Hz). The ELITE software package includes programs for the acquisition of kinematic and dynamic data, 3D reconstruction, filtering, and calculation of kinematic and dynamic variables.

MATERIALS

Three top ranking elite athletes participated in this study (each subject's data is summarized in table 1). Each subject performed three trials. Statistical analysis (ONEWAY ANOVA - SPSSPC Software Program) was performed in order to highlight significant differences for F 0.05.

RESULTS

Three groups of variables were defined in order to obtain a detailed description of the movement pattern of sprint starting: 1) linear and joint angular displacement (Table 2); 2) linear and joint angular velocities (Table 3); 3) dynamic parameters of impact and push-off from the ground (table 4).

The following statistics are listed in the tables:

1) variable description; 2) general mean value; 3) individual mean value; 4) standard deviation (9 trials performed by three subjects); 5) ANOVA F value, 0.05.

High values of horizontal hip velocity indicate a good horizontal velocity of the initial starting movement. These phases are: release from the starting blocks (RS) (F), impact (F) (F), and push-off from the ground after impact (PO) (F), these phases are indicative of performance variables.

Many factors regarding the position of the body segments in space (linear and angular displacements) and ground reaction force components significantly affect the performance described by the above mentioned variables. Therefore, it is interesting to identify the kinematic and dynamic variables, related to the performance variables, which show significant statistical differences between the subjects.

LINEAR DISPLACEMENT

The distances on the three coordinate axes between selected points of the body are listed in table 1 with reference to the following events: ready, release of the posterior foot (first foot) from the starting block, release of the anterior foot (second foot), impact and push-off during weight bearing.

The distances between the feet at the moment of being "ready" fluctuates between 21 and 30 cm, on which the take-off can be considered a "narrow" type (1.4). The distance between the hand and the anterior foot is between 46 and 63 cm. These two parameters seem to be linked to a technical choice of the individual, the shorter athlete has the starting blocks closer to the body and the taller athlete has a greater distance between his hands and the anterior foot. It is interesting to observe the displacement of the hip that occurs almost equivalent between the 1st and 2nd phases of take-off and between the second phase of take-off and impact.
The joint angle values of the anterior and posterior lower extremities (hip, knee ankle) were studied in the positions of RS (release from the starting block), IMP (impact), and PO (push-off from the ground after impact). The anterior ankle was more open in subject C (the slowest) during the "ready" phase because of his more extended body position. With the exclusion of the platform push-off phase the angular values of the posterior knee did not show significant differences amongst the three subjects. It is interesting to note that subject C (the slowest in agonistic performance) demonstrated different positions in respect to the other two athletes as far as the joint angle of the leg at the "ready" phase and in various defined phases of push-off from the ground. Therefore, the action of the other two athletes seems more productive and efficient.

LINEAR AND ANGULAR VELOCITY

The linear velocity of the hips and the velocity from the tips of the feet was evaluated as an index of performance. The horizontal velocity showed three growing peaks in the phases of posterior take-off (1.70 m/sec), anterior take-off (3.08 m/sec) and Push-off (4.36 m/sec). As mentioned before, these performances demonstrated significant differences amongst the three subjects in relation to the agonistic performance in the 60 m with push-off velocity (r = .92) and 100 meter dash (r = .90).

The tips of the feet horizontal velocity peaks demonstrated a significant difference between the subjects even if they are not directly related to the performance (r = .21). The vertical velocity of the hips provides useful information on the raising of the pelvis after the push-off phase. The observed athletes demonstrated different behaviors during the elevation of the hips in two moments:

- push-off of the anterior leg from the starting block
- push-off on the weight bearing leg after impact.

Subject A tended to rise up more quickly from the starting blocks while the other two subjects did so in the successive phases.

The angular velocities of the three lower extremity articulations can give useful information about the extension and flexion which favors the recovery of the limb during one stride. As far as the peak angular velocity of the hip it can be observed that the significant differences amongst the three subjects in relation to their performances are the extension of the anterior leg that takes-off from the starting blocks (r = .90) and its successive flexion (r = .80). The peak angular velocity of the hip at the push-off of the weight bearing leg after impact was significantly different amongst the three subjects and seem to be in relation to the performance (r = .92).

As far as the peak velocity of the knee, significant differences were noted only in the extension movement during the stride phase.

DYNAMIC DATA OF WEIGHT BEARING AFTER IMPACT

In this phase, as proposed by Mero (2), there are two distinct phases: impact and push-off. In the horizontal component impact graphs of two subjects it is observed force vectors opposite to the motion of the athletes.

In vertical and transverse directions, in the same point in time, force vectors are observed to be oriented in the same direction as to those of the push-off phase. These peaks were considered to be a dampening phase that prepares for the successive push-off. In the impact phase the following was measured:

- the maximum peak value in Newton or the percentual value in respect to body weight;
- the mean force value (Np), the force impulse (Npsec), the duration of the impact phase (sec);
- the delay of the peak in respect to the impact (sec).

In the push-off phase the same variables were evaluated while taking into consideration two peak forces: The first being characterized by a rapid increase in values and the second, with a less pronounced increase in which maximum values are reached. Out of the 62 dynamic and temporal values evaluated, 26 showed significant differences between the athletes.

The impact phase showed values that were significantly different between the subjects evaluated in the three conditions and in the torque with the ground. The values were superior for the fastest athletes.

The horizontal push-off force was significantly different amongst the athletes only pertaining to the first peak force...
TABLE 2 • Linear distances and displacements of the markers and joint angular displacements

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th>GEN MEAN</th>
<th>STAND. DEV</th>
<th>MEAN SUBA</th>
<th>MEAN SUBB</th>
<th>MEAN SUBC</th>
<th>MEAN SUBP</th>
<th>F &lt;</th>
</tr>
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<tbody>
<tr>
<td><strong>LINEAR VELOCITY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Horizontal Distance (cm)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Hip-to-Toe at 1st T.O.</td>
<td>1.70</td>
<td>0.14</td>
<td>1.76</td>
<td>1.66</td>
<td>1.68</td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td>Hip-to-2nd T.O.</td>
<td>3,08</td>
<td>1.38</td>
<td>3.04</td>
<td>2.69</td>
<td>3.32</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Hip-to-Toe Touch down</td>
<td>3.23</td>
<td>0.26</td>
<td>3.08</td>
<td>3.03</td>
<td>3.58</td>
<td>0.01</td>
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<tr>
<td>Hip-to-Platform Touch down</td>
<td>4.38</td>
<td>0.49</td>
<td>5.41</td>
<td>3.96</td>
<td>4.40</td>
<td>0.0003</td>
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<td>Front-to-Peak Velocity</td>
<td>3.02</td>
<td>0.64</td>
<td>3.70</td>
<td>2.48</td>
<td>4.04</td>
<td>0.0067</td>
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<tr>
<td>Back-to-Peak Velocity</td>
<td>7.60</td>
<td>0.46</td>
<td>7.10</td>
<td>7.50</td>
<td>8.10</td>
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<tr>
<td>Vertical Velocity (m/sec)</td>
<td>0.17</td>
<td>0.32</td>
<td>0.59</td>
<td>0.02</td>
<td>0.09</td>
<td>0.0011</td>
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<tr>
<td>Hip-to-Platform Touch down</td>
<td>0.88</td>
<td>0.61</td>
<td>0.88</td>
<td>1.14</td>
<td>0.73</td>
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<td>Ant. Hip Flex Before 2nd T.O.</td>
<td>1.17</td>
<td>0.13</td>
<td>1.13</td>
<td>1.29</td>
<td>1.13</td>
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<td>Post. Hip Flex Before 1st T.O.</td>
<td>1.64</td>
<td>0.22</td>
<td>1.65</td>
<td>2.11</td>
<td>1.91</td>
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<td>Ant. Knee Ext. Before 2nd T.O.</td>
<td>0.62</td>
<td>0.38</td>
<td>0.73</td>
<td>0.93</td>
<td>0.62</td>
<td>0.0001</td>
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<td>Ant. Knee Flex Max. After 2nd T.O.</td>
<td>0.82</td>
<td>0.94</td>
<td>0.94</td>
<td>1.04</td>
<td>0.94</td>
<td>0.0055</td>
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</tr>
<tr>
<td>Post. Knee Ext. Before touch down</td>
<td>0.70</td>
<td>0.89</td>
<td>0.78</td>
<td>0.91</td>
<td>0.78</td>
<td>0.0025</td>
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</tbody>
</table>

Tab3 • Linear velocity of markers and peak joint angular velocity.
peak. In every case, subject A (with the best performance) showed superior dynamic values in comparison to the other subjects in the three directions and also pertaining to the torque with the ground. The duration of the push-off phase which was significantly different among the subjects seemed to be inversely related ($r = -96$) to their performance. This final H1a leads us to think that subject A utilized the rapid fibers better and exhibited the shortest durations of weight bearing phase and the highest peaks for rapid propulsion coming up from the starting blocks.

**CONCLUSION**

By means of the method used it is possible to quantify spatial parameters (linear and angular), of static position and of the principle phases of movement during the 'break-away' from the starting blocks. From a study of three subjects it has been demonstrated how the 'ready' position can influence the successive movements.

The different performances in respect to hip horizontal velocity during the main phases of sprinting can be explained with the different results obtained by the athletes through the use of kinematic and dynamic parameters that have been proposed in this study. The method allows the study of individual subjects or the comparison of a group of individuals. To this matter it is possible to observe that many dynamic and common kinematic data is in accordance with the data obtained by Mero (2) and Schnaber and Singer (3). For a complete evaluation it is not enough to only take into account dynamic and kinematic parameters since these are related with other spatial (linear and angular) and temporal parameters that after all are more utilized and well known in the field of practice.

**Bibliography**

2) Mero A., Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. Res. Quart.: 59, 2, 1988