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 identily 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).

AGE(years)	HEIGHT(cm)	WEIGHT(kg)	60M DASH(sec)	100M DASH(sec)
19	182	71	6.69	10.45
22	175	65	7.04	10.94
27	175	64	6.84	10.64

Each subject performed three trials. Statistical analysis (ONEWAY ANOVA - SPSSPC Software Program) was performed in order to highlight significant differences lor 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 Fvalue, 0.05.

High values of horizontal hip velocity indicate a good performance in the execution of the task. Although all the subjects tested were top ranking athletes, significant differences were observed in the horizontal velocity of the hip during the three fundamental phases of the initial starting movement, these phases are: release from the starting blocks (RS) (F), impact (I) (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 distance betwcen the leet at the moment of being "ready" fluctuates betwcen 21 and 30 cm, of which' the take-olt can be considered a "narrow" type (1,4). The distance between the hand and anterior foot is between 46 to 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 equivilent between the 1st and 2nd phase of take-off and between the second phase of take-off and impact with a slight priority to the 1st phase (40 versus 37 cm). The vertical displacement of the hips reflects.the pushing action of the lower extremities and exhibits very low values (2cm betwecn the take-off of the two legs from the blocks and 4 cm during the first stride) for the maintenance and increase in horizontal velocity. The elevation of the trunk can be estimated from the vertical height of the markers that are placed on the shoulder. This occurs very clearly in the RS phase, with very similar values for all three subjects (mean 30 cm), while in the following phases a noticible reduction occurs, 6 cm in the flight phase and 7 cm in the weight bearing phase). The transversal displacement during the fust stride is greater in reference to the feet (mean 8 cm) and less evident for the hips (2 cm).

JOINT ANGULAR DISPLACEMENT

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 blocks), I (impact), and PO (push-off from the ground after impact). The posterior 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 and in horizontal velocity of the hip) demonstrated diverse 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 the other two athletes seems more productive and efficient.

LINEAR AND ANGULAR VELOCITY

The linear velocity of the hip 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 (r with push off velocity = .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 arc not directly related to the performance (r = .21 .42). 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 in the successive phases.

The angular velocities of the three lower extremity articulations can give useful information about the extensor action 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 dilferences between 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 = .89). The peak angular velocity of the hip at the take-off of the weight bearing leg after impact also 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 (N);- the force impulse (N*sec);- 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 diverse betwecn the subjects evaluated in the three components and in the torque with the ground. The values were superior for the fastest athlete.

The horizontal push-olf force was significantly different amongst the athletes only pertaining to the fust

VARIABLE NAME						
Horizontal Distances(cm)	Gen Mean	Stand. Dev.	Mean Sub A	Mean Sub C	Mean Sub P	F <
Toe-to-Toe at "ready"	26	4,1	30	21	29	0,0001
Hand-Anterior Foot at "ready"	53	7,6	46	63	52	0,0025
First Stride Length	138	8,6	136	130	148	0,0140
Horizontal Displacements(cm)						
Hip:1st - 2nd Take Off	40	7,3	45	31	44	0,0100
Hip:2nd Take Off - Toe Impact	37	10	31	39	42	n.s.
Vertical Displacements(cm)						
Shoulder:1st - 2nd Take Off	30	3,1	31	29	30	n.s.
Shoulder:2nd Take Off-Toe Impact	5	4,3	1	-1	9	0,0006
Shoulder:Toe Impact - Take Off	7	4,7	9	11	3	0,0006
Hip:1st - 2nd Take Off	2	2,4	4	2	-1	0,0060
Hip:2nd Take Off - Toe Impact	4	1,5	5	3	3	n.s.
Transversal Displacements (cm)						
Hip:2nd Take Off - Toe Impact	2	3,8	3	5	-2	n.s.
Toe:2nd Take Off - Toe Impact	8	5,5	6	15	4	0,0180

POSTERIOR LEG ANGLES	Gen Mean	Stand. Dev.	Mean Sub A	Mean Sub C	Mean Sub P	F <
"Ready":Ankle	116	15,6	111	136	101	0,0014
"Ready":Knee	139	3,2	139	139	135	n.s.
"Ready":Hip	129	16,6	107	141	137	0,0040
1st Take Off:Ankle	134	14,0	117	150	135	0,0003
1st Take Off:Knee	144	6,8	140	144	147	n.s.
1st Take Off:Hip	144	11,6	128	155	150	0,0001
2nd Take Off:Ankle	111	6,3	102	116	114	0,0005
2nd Take Off:Knee	110	4,7	114	106	111	n.s.
Platform Take Off:Ankle	139	12,6	130	147	138	n.s.
Platform Take Off:Knee	168	12,1	166	181	157	0,0100
Platform Take Off:Hip	196	20,4	156	216	190	0,0003
ANTERIOR LEG ANGLES						
"Ready":Knee	108	8,8	102	119	104	0,0100
"Ready":Hip	95	18,9	72	115	97	0,0017
1st Take Off:Ankle	111	2,7	107	114	109	0,0300
1st Take Off:Knee	115	6,4	109	122	115	0,0200
1st Take Off:Hip	119	14,6	100	136	117	0,0000
2nd Take Off:Knee	170	4,3	168	173	171	n.s.
Platform Take Off:Knee	87	7,9	79	94	83	n.s.

TABLE 2 - Linear distances and displacements of the markers and joint angular displacements

VARIABLE NAME	GEN MEAN	STAND. DEV	MEAN SUB.A	MEAN SUB.C	MEAN SUB.P	F <
LINEAR VELOCITY						
Horizontal Velocity (m/sec)						
Hip:1st Take Off	1,70	0,14	1,76	1,66	1,68	n.s.
Hip:2nd Take Off	3,08	0,33	3,M	2,69	3.32	0.02
Hip:Toe Touch down	3,23	0,26	3,08	3.03	3,58	0.01
Hip:Platform Take Off	4,36	0,49	5,43	3,96	4,40	0,0003
Front Toe:Peak Velocity	9.30	0,80	9,20	8,50	10,10	0,045
Back Toe:Peak Velocity	7,60	0,40	7,10	7,50	8,10	0,0004
Vertical Velocity (m/sec)						
Hip:2nd Take Off	0,17	0,32	059	0,02	-0.09	0,001
Hip:Platform Take Off	0,88	0.61	-0,38	1.44	0.73	0,0002
HIP Peak joint angular velocity (deg./sec.)						
Ant. Hip Exten.:Before 2nd Take Off	369	113	513	283	310	0,005
Ant. Hip Flex.:After 2nd T O.	648	252	979	444	521	0,002
Post. Hip Flex :Max After 1st T O.	565	122	401	655	639	0,0007
Post. Hip Exten Before Aat T.O.	694	195	450	903	649	0,001
KNEE Peak joint angular velocity (deg./sec.)						
Ant.Knee Exten.:Before 2nd Take Off	623	38	634	593	642	n.s.
Ant.Knee Flex.:Max After 2nd T.O.	827	94	947	783	752	0,0055
Pos.Knee Exten .Before touch down	570	89	518	676	517	0,025

Tab 3 - Linear velocity of markers and peak joint angular velocity.

VARIABLE NAME	GEN MEAN	STAND. DEV	MEAN SUB.A	MEAN SUB.C	MEAN SUB.P	F <
IMPACT FORCES						
Vertical Force (N)						
Max	837	136	961	712		0,01
Max % body weigth	1,2	0,21	1,37	1,03		0,05
Mean	578	54	617	538		n.s.
Horizontal Force (N)						
Max	-463	74	-522	-403		0,05
Max % body weigth	-0,68	0,09	-0,75	-0,61		n.s.
Mean	-237	28	-246	-228		n.s.
FORCES DURING PUSH-OFF OF FIRST STRIDE						
Vertical Force (N)						
2nd Max	1319	209	1510	1332	1115	n.s.
Mean	989	132	1089	990	839	n.s.
Orizontal Force (n)						
1st Max	532	148	611	586	331	0,08
1st Max % b.w.	0,79	0,23	0,87	0,89	0,53	n.s.
2nd Max	594	115	686	547	524	n.s.
Mean	433	112	533	391	344	n.s.
Duration (sec)	0,185	0,019	0,167	0,207	0,177	0,001

Tab. 4 - **Forces during** impact and **push-off of first** stride.

peak. In every **case, subject** A (with the best performance) showed superior dynamic values in **com** arisoa to the other subjects in the three directions and also **pertaining** to the torque **with** the ground. The &ration **of the** push-off phase which was **significant!** different **amongst** the **subjects** seemed to be **inversly related** (r = -.96) to **their** performance. **This final** Hta leads **us** to **think** that **subject A utilizized** the rapid **fibers better a**nd 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 **principlc** 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 sprint **starting** 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 obiained 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.

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