Kinematic analysis of the sprint start and acceleration from the blocks

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By Milan Coh, Katja Tomazin

ABSTRACT

The start and acceleration from the blocks directly affect results in the sprint events. In this study, the major kinematic parameters of these phases of the race were analysed. The subject of the study was the best Slovenian male sprinter, who was making his preparations for the 2006 IAAF World Indoor Championships. The study showed the following to be the key factors for performance in the two phases: the distance between the starting blocks, block velocity, block face angle, the length of the first step, the path of the vertical rise in the body' centre of mass in the first three metres, the contact phase/flight phase index in the first ten steps and the ratio between the length and frequency of steps. As the study was on only one athlete, the results cannot be generalised. However, they may contribute to explaining phenomena related to sprinting at the highest level.

AUTHORS

Milan Coh is a professor of Track and Field in the Faculty of Sport at the University of Ljubljana, Slovenia.

Katja Tomazin is an assistant for Track and Field in the Faculty of Sport at the University of Ljubljana, Slovenia.

Introduction

The sprint start and acceleration from the blocks are two extremely important phases directly affecting results in the 60m, 100m, 200m and 400m events. It is no coincidence that many authors have delved into the biomechanical factors of these two race phases in an effort to explain the phenomenon of sprint velocity (HOSTER 1981; MERO, LUHTANEN, KOMI 1983; MORAVEC, RUZICKA, SUSANKA, NOSEK 1988; TELLEZ, DOOLITTLE 1984; MERO 1988; COPPENOLLE, DELECLUSE 1989; COPPENOLLE, DELECLUSE, GORIS, DIELS, KRAAYENHOF 1990; BRÜGGEMANN, GLAD 1990; MERO, KOMI 1990; GUISSARD, DUCHATEAU, HAINAUT 1992; DELECLUSE, COPPENOLLE, DIELS, GORIS 1992; KORCHEMNY 1992; SCHOT, KNUTZEN 1992; MCCLEMENTS, SANDERS, GANDER 1996; HARLAND, STEELE 1997). The results of the studies and their applicability depend on the relevance of the sample of subjects, the research technology used and a critical evaluation of the findings. The development of modern biomechanical technologies adds to the accuracy of measuring and analysing the key performance factors in sprint velocity. The sprint start and acceleration from the blocks are the first two derivatives of sprint velocity. TELLEZ and DOOLITTLE (1984) showed that the two phases account for 64% of the total result in the 100m.

Studies (TELLEZ, DOOLITTLE 1984; MERO 1988; COOPENOLLE 1989; COPPENOLLE ET AL. 1990; SCHOT, KNUTZEN 1992; KORCHEMNY 1992; GUISSARD, DUCHATEAU, HAINAUT 1992; HARLAND, STEELE 1997) concur that the efficiency of the sprint start depends primarily on the block positioning, the body's centre of mass (CM) in the set position, the reaction time and the block velocity (defined as the resultant velocity of the body's CM at the moment the foot brakes contact with the front block) leading to the acceleration from the blocks. The optimal relationship between the sprint start and acceleration is a specific motor problem in which the athlete has to integrate – in terms of space and time – an acyclic movement into a cyclic movement.

Acceleration is the phase of sprint races where the kinematic parameters of the stride are changing most dynamically. Owing to these changes, the velocity of the athlete's body's CM increases. This phase is a complex cyclic movement defined predominantly by the increase of the frequency and length of strides, the duration of the contact and flight phases and the position of the body's CM at the moments of ground contact. All of the above parameters are interdependent and each is conditional on the central movement regulation processes, biomotor abilities, energetic processes and morphological characteristics of the athlete (CAVAGNA, KOMAREK, MAZZOLENI 1971; MANN, SPRAGUE 1980; BUHRLE ET AL. 1983; MORAVEC ET AL. 1988; MERO, KOMI 1990; COPPENOLLE ET AL. 1990; MERO, KOMI, GREGOR 1992; LOCATELLI, ARSAC 1995; MÜLLER, HOMMEL 1997).

LUHTANEN and KOMI (1980) divided the contact phase of the sprint stride during acceleration into a braking phase and a propulsion phase. The sum of the two parts constitutes the total contact time. Owing to the changing biomechanical conditions, the activity index (contact time/flight time) also changes during this phase: total ground contact times decrease and flight phases increase. Stride length depends on body height and/or leg length and the force developed by the extensor muscles of the hip (*m. gluteus maximus*), knee (*m. vastus lateralis, m. rectus femoris*) and ankle joint (*m. gastrocnemius*) in the contact phase. Execution of the contact phase is one of the most important generators of sprint velocity efficiency (MERO, KOMI 1987; LEHMANN, VOSS 1997). The contact of each stride has to be as short as possible and have an optimal ratio between the braking phase and the propulsion phase. Stride frequency depends on the functioning of the central nervous system and is largely genetically predetermined (MERO, KOMI, GREGOR 1992). The higher the frequency, the shorter the stride length, and vice versa. The efficiency of the acceleration from the blocks is, in fact, defined by an optimal ratio between the length and frequency of the athlete's strides.

The aim of our study was to identify and analyse the most relevant kinematic parameters that positively contribute to the efficiency of the start and acceleration from the blocks in one selected athlete, a world-class sprinter. Cutting-edge biomechanical technology was used for analysing this phenomenon. The objects of the study were the set position from the point of view of the height of total body CM, the reaction time at the front and rear blocks, the block velocity, the block face angle, the velocity of the total body CM in the first three metres and the kinematic parameters of the acceleration in the first ten steps. A 20m block-start sprint test was carried out to assess acceleration efficiency. The kinematic parameters of the start were analysed by means of a high-speed digital camera with a frequency of 200 frames/sec. The measurements of the acceleration parameters were made by means of the Opto Track technology and an infra-red photo cell system. This enabled the quantification of the key biomechanical parameters of movement in the start and acceleration, the identification of potential errors based on these data and the search for optimal solutions.

The study is based on the measurements of one sprinter who is presently in the world's top class. Owing to the sophisticated methodology and technology of the measurement procedure, there are relatively few biomechanical studies of this type in the professional literature. The findings of the study cannot be generalised; nevertheless, the results have an influential cognitive value in the objectification of two key phases of sprint races.

Methods

The study subject was M.O., a member of the national team of the Republic of Slovenia competing in the 100m (age: 27, body weight: 76.7kg, personal record: 10.15s). The biomechanical measurements were carried out in February 2006 during which period the athlete was preparing for the 11th IAAF World Indoor Championship in Moscow. At the said championship M.O. placed an excellent fourth in the 60m final and set a new national record of 6.58s.

The kinematic measurements of the start and acceleration phase were carried out in the sports hall of the Track and Field Centre of Slovenia in Siska, Ljubljana, under constant and optimal climatic conditions. The 2-D kinematic analysis of the start was performed with the high-speed camera Mikrotron Motion Blitz Cube Eco-1 and the Digital Motion Analysis Recorder, which is able to capture 6 seconds of movements at a frequency of 1,000 frames/second with a resolution of 640 x 512 pixels. This study was made using a frequency of 200 frames/sec. The area was calibrated with two referential cubes with 1m sides. The processing and analysis of the data obtained were carried out using the Ariel Performance Analysis System (APAS). The method of automatic digitalisation was applied, using high-contrast passive markers. The seven-segment anthropometric model (foot, shank, thigh, trunk, upper arm, forearm and head – according to DEMPSTER via MILLER and NELSON: Biomechanics of Sport, Lea & Febiger, Philadelphia, 1973) was also used. The co-ordinates of the nine digitised points thus obtained and a tenth point that was calculated on their basis (the total body CM) were smoothed with a digital filter set at 12Hz.

The new technology OPTO-TRACK Microgate was applied for analysing the kinematic parameters of the acceleration. The measuring system is based on interconnected rods (100cm x 4cm x 3cm) fitted with optical sensors and a computer program for data storage and processing. Each rod is fitted with 32 sensors – photocells, arranged at a 4cm distance from another and 0.2cm above the ground. The length of the interconnected rods was 20m. The rods were distributed along the width of the athletic track (1.22m). The measuring chain enabled the measurement of the following sprint parameters: contact time, flight time, stride length, stride frequency, velocity in each stride and change of velocity. In addition to the OPTO-TRACK measuring system, the infrared photocell timing system (BROWER) was also used to time the performance. The subject performed the 20m block-start sprint test five times, with 12-minute breaks between each effort. The SPSS software package was used for statistical data processing.

Results and interpretation

The figures outlined in Table 1 suggest that the height of the total body CM in the set position was 54 ± 0.01cm. The horizontal distance of the projection of the total body CM from the start line was 32cm. SCHOT and KNUTZEN (1992) defined this set position as a "medium start" type, offering elite competitors optimal conditions for generating block velocity. The higher the force impulse on the front block, the shorter the motor reaction time and the more efficient the execution of the first step and, consequently, the greater the acceleration from the blocks. In

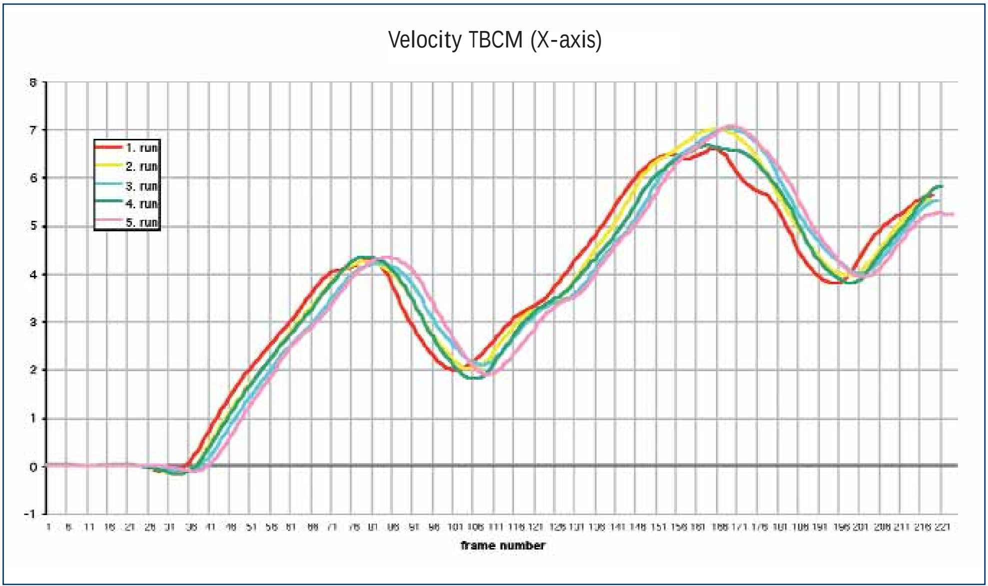

Figure 1: Velocity of total body CM in the first two steps of acceleration from the blocks

such a position, the weight is distributed evenly between the legs and arms. The set position of the sprinter in the blocks is individually conditioned and primarily depends on the athlete's anthropometric characteristics and motor abilities. The height of the subject's total body CM is at 32% of his standing height.

The time from the sound of the gun to the moment the foot leaves the rear block (i.e. the total reaction time) is 0.29 ± 0.01s. The total reaction time of the front lower extremity is 0.43 ± 0.02s. These values point to a certain deficit of the competitor. MERO and KOMI (1990) found shorter reaction times in elite sprinters, by 0.09s. The total reaction time is a result of a two-component ability defined by the 'pre-motor time' (i.e. time from the sound of the gun to the beginning of the EMG muscle activation) and the 'motor time' (i.e. time from the beginning of the EMG muscle activation to the moment the foot leaves the rear – front block). In the final 60m final at the IAAF World Indoor Championship in Moscow, M.O. had the fifth best reaction time – 155ms. Reaction time has been dealt with by many researchers (TELLEZ, DOOLITTLE 1984; MORAVEC ET AL. 1988; COPPENOLLE ET AL. 1990; BRÜGGEMANN, GLAD 1990; MERO, KOMI 1990; DELECLUSE ET AL., 1992; MARTIN, BUONCHRISTIANI 1995; MCCLEMENTS ET AL. 1996; FERRO ET AL. 2001). In most of these studies, no correlation could be established between the reaction time and the final time in a 100m. One study found that reaction time accounts for only 2-3% of the total result in a 100m race (BRÜGGEMANN, GLAD 1990). In the 60m, reaction time is more important. The winner of the 60m final in Moscow, L. S., recorded the shortest reaction time in absolute terms, 124ms. The ability to achieve a short reaction time involves a specific, genetically conditioned ability, which enables the rapid transmission of afferent and efferent nerve impulses, and, to some extent, it depends on the sprinter's competitive experience and anticipation.

M.O.'s block velocity was 4.18 ± 0.19m/s^{-1}. A comparison of the results of some other studies (MERO 1988; COPPENOLLE ET AL. 1989; MERO, KOMI 1990) involving elite sprinters reveals that the block velocity of

Table 1: Kinematic parameters of the set position, start and first two steps of acceleration from the blocks

Variable	Unit	1	2	3	4	5	AS SD
Set position							
Distance between the total body CM and the start line	cm	32	33	33	32	32	32 ± 0.00
Height of total body CM	cm	54	53	54	54	54	54 ± 0.01
Sprint start							
Reaction time – right foot	s	0.275	0.285	0.295	0.285	0.305	0.29 ± 0.01
Reaction time – left foot	s	0.405	0.420	0.440	0.410	0.440	0.43 ± 0.02
Block face angle	°	41.0	39.4	41.1	42.3	39.3	40.8 ± 1.19
Vertical block velocity	m/s^{-1}	0/85	0/78	0/74	0/91	0/83	0/77 ± 0/14
Horizontal block velocity	m/s^{-1}	4/27	4/08	3/95	4/28	4/19	4/11 ± 0/17
Block velocity – resultant	m/s^{-1}	4/36	4/15	4/02	4/37	4/28	4/18 ± 0/19
Acceleration – Step 1 (Braking phase)							
Vertical velocity	m/s^{-1}	-0/89	-0/89	-0/86	-0/96	-0/92	-0/89 ± 0/04
Horizontal velocity	m/s^{-1}	1/99	2/02	2/10	1/82	1/91	2/00 ± 0/12
Velocity – resultant	m/s^{-1}	2/18	2/21	2/27	2/05	2/12	2/19 ± 0/09
Acceleration – Step 1 (Propulsion phase)							
Vertical velocity	m/s^{-1}	1/12	0/91	0/97	1/23	0/93	0/99 ± 0/16
Horizontal velocity	m/s^{-1}	4/48	4/39	4/45	4/22	4/59	4/41 ± 0/13
Velocity – resultant	m/s^{-1}	4/62	4/48	4/56	4/40	4/68	4/52 ± 0/12
Acceleration – Step 2 (Braking phase)							
Vertical velocity	m/s^{-1}	0/31	0/35	0/36	0/36	0/32	0/33 ± 0/04
Horizontal velocity	m/s^{-1}	6/00	6/07	6/14	5/96	5/95	5/98 ± 0/12
Velocity – resultant	m/s^{-1}	6/20	6/08	6/15	5/97	5/96	6/03 ± 0/15
Acceleration – Step 2 (Propulsion phase)							
Vertical velocity	m/s^{-1}	0/05	0/10	0/43	0/41	0/53	0/24 ± 0/25
Horizontal velocity	m/s^{-1}	5/75	5/91	6/15	6/06	6/21	6/00 ± 0/17
Velocity – resultant	m/s^{-1}	5/75	5/91	6/17	6/07	6/24	6/05 ± 0/18
TBCM acceleration							
Velocity of the total body CM at 3m	m/s^{-1}	4/49	4/60	4/41	4/47	4/56	4/52 ± 0/07
Rise of the total body CM at 3m	m	0/68	0/66	0/67	0/68	0/68	0/67 ± 0/01

Table 2: Kinematic parameters of acceleration from the blocks at 20 metres

Variable	Unit	1	2	3	4	5	AS	±	SD
20m	s	3/08	2/98	3/07	3/03	3/19	3/07	±	0/08
Step number	n	12	12	12	12	12	12/00	±	0/00
Step frequency	Hz	4/5	4/4	4/6	4/6	4/6	4/54	±	0/09
Step length	cm	165	166	162	163	163	163/80	±	1/64
Ground contact time	ms	125	126	126	126	129	126/40	±	1/52
Flight time	ms	96	100	93	95	87	94/20	±	4/76
Activity index – contact/flight		1/30	1/26	1/35	1/32	1/48	1/34	±	0/11
Step one									
Length	cm	103	103	103	103	106	103/60	±	1/34
Ground contact time	ms	172	178	184	167	185	177/20	±	7/73
Flight time	ms	62	37	56	55	43	50/60	±	10/26
Step two									
Length	cm	99	105	108	102	105	103/80	±	3/42
Ground contact time	ms	142	179	154	154	166	159/00	±	9,04
Flight time	ms	86	80	80	92	74	82/40	±	6/84
Step three									
Length	cm	133	136	130	130	133	132/40	±	2/51
Ground contact time	ms	141	129	135	129	148	136/40	±	8/17
Flight time	ms	80	92	86	80	73	82/20	±	7/16
Step four									
Step length	cm	136	140	143	136	133	137/60	±	3/91
Ground contact time	ms	130	130	130	136	130	131/20	±	2/68
Flight time	ms	110	92	104	92	98	99/20	±	7/82
Step five									
Step length	cm	158	155	158	158	158	157/40	±	1/34
Ground contact time	ms	111	129	123	123	117	120/60	±	6/84
Flight time	ms	86	86	93	87	92	88/80	±	3/42
Step six									
Step length	cm	155	164	164	161	158	160/40	±	3/94
Ground contact time	ms	117	130	129	123	117	123/20	±	6/26
Flight time	ms	99	98	92	98	105	98/40	±	4/62
Step seven									
Step length	cm	171	177	180	174	177	175/80	±	3/42
Ground contact time	ms	129	117	117	123	117	120/60	±	5/37
Flight time	ms	86	111	111	93	105	101/20	±	11/23
Step eight									
Step length	cm	177	192	186	183	183	184/20	±	5/45
Ground contact time	ms	117	111	105	117	110	112/00	±	5/10
Flight time	ms	111	117	117	104	111	112/00	±	0/09
Step nine									
Step length	cm	186	189	192	189	189	189/00	±	2/12
Ground contact time	ms	99	98	104	111	105	103/40	±	5/22
Flight time	ms	92	111	111	105	105	104/80	±	7/76
Step ten									
Step length	cm	186	196	199	196	196	194/60	±	4/98
Ground contact time	ms	117	105	111	110	110	110/60	±	4/28
Flight time	ms	104	123	123	111	117	115/60	±	8/17

our subject was 0.18m/s^{-1} higher. This exceptional capability for generating a high velocity following block clearance is a consequence of exerting high impact force in the horizontal direction, the good co-ordination of the base of support (hands), effective action of the rear lower extremity and low block face angle, measuring only 40.8 ± 1.19°. A low block face angle guarantees the athlete a high horizontal start velocity and adequate vertical block velocity used to balance the effects of gravity. An average vertical rise of the total body CM in the first three metres of block acceleration is 0.67 ± 0.01m, suggesting that the athlete's trunk is leaning forward strongly with respect to the horizontal line. Thus, the horizontal component of velocity is maximised.

The quality of the transition from the sprint start to acceleration is mainly seen in the velocity parameters of the sprinter's total body CM in the first two steps (Table 1, Figure 1). At the end of the first step (propulsion phase) the horizontal velocity of the total body CM was 4.41 ± 0.13m/s^{-1} and at the end of the second step it was 6.00 ± 0.17m/s^{-1}, showing an increase in velocity of more than 1.5m/s^{-1}. In the first two steps, the projection point of the total body CM is located behind the foot's ground contact point. It is not until the third and fourth steps that the total body CM's projection point moves in front of the foot's ground contact point. The consequence of the total body CM position in the first two steps is manifested in a reduction of velocity in the braking phase of the running step. In the first step, which is 103.6 ± 1.34cm long, the velocity in the braking phase is 2.00 ± 0.12m/s^{-1}. Horizontal velocity decreased by 45.3% in view of the velocity in the propulsive phase of the first step. The velocity of the second step is almost identical to that of the first step (103.8 ± 3.42m/s^{-1}) but the reduction of velocity in the braking phase is substantially lower (1.2%) compared to the first step. The critical point is the propulsion phase in the first step following clearance of the block. It may be established that the subject of our study executes an overly long first step, resulting in the negative reaction force of the ground, which is exerted in the opposite direction of the movement.

The results in Table 2 show that the average result of the subject in a 20m block-start sprint was 3.07 ± 0.08m/s^{-1}. The average contact time in the first ten steps of the acceleration was 126.40 ± 1.52ms and the flight time 94.20 ± 4.76ms. The activity index was 1.34 ± 0.11, suggesting that the contact phases lasted 25% longer on average than the flight phases in the first ten steps.

The acceleration phase is one of the most complex elements of the development of running velocity, characterised by the most manifest changes in the dynamic and kinematic structure of the running technique (MERO, LUHTANEN, KOMI 1993; LUHTANEN, KOMI 1980; DONATTI 1995; HUNTER ET AL. 2004). The stride length and frequency increase, the contact phases shorten and the flight phases lengthen. In the first ten steps the athlete's stride length increased by 46.9%. The ground contact time of the first step was 177.2 ± 7.73ms. In view of the total step time (contact + flight times) the contact phase accounted for 77.4%. Similar values were identified in a sample of elite sprinters (MERO 1988; MERO, KOMI 1990; HARLAND, STEELE 1997). In the second step, the ground contact time represented 65.8% of the total step time. Owing to the altering biomechanical conditions and the increasing velocity, the activity index is subject to change. The contact phases are becoming shorter and the flight phases longer (Tables 2 and 3). The athlete's contact phase time equals the flight phase time in the eighth step. This is the end of the first phase of acceleration (acceleration from the blocks) and the beginning of the second phase (pick-up acceleration), representing the transition to maximal velocity running. The step length stabilises in the ninth step (189.0 ± 2.12m) and the contact time (CT = 103.40 ± 5.22ms) is shorter than the flight phase time for the first time (FT = 104.80 ± 7.76ms).

Table 3: Ground contact and flight times during acceleration from the blocks

Variable	Unit	1	2	3	4	5	A		SD
20m	s	3/08	2/98	3/07	3/03	3/19	3/07	±	0/08
Ground contact time + flight time	ms	221	226	219	221	216	220/60	±	3/65
Ground contact time in %	%	56/56	55/75	57/53	57/01	59/72	57/31	±	1/50
Step one									
Ground contact time + flight time	ms	234	215	248	222	228	229/40	±	12/56
Ground contact time in %	%	73/50	82/79	74/19	75/22	81/14	77/37	±	4/28
Step two									
Ground contact time + flight time	ms	228	259	234	246	240	241/40	±	11/91
Ground contact time in %	%	62/28	69/11	65/81	62/60	69/16	65/79	±	3/35
Step three									
Ground contact time + flight time	ms	221	221	221	209	221	218/60	±	5/37
Ground contact time in %	%	63/80	58/37	61/08	61/72	66/96	62/39	±	3/21
Step four									
Ground contact time + flight time	ms	240	222	234	228	228	230/40	±	6/84
Ground contact time in %	%	54/16	58/55	55/55	59/64	67/01	58/98	±	5/00
Step five									
Ground contact time + flight time	ms	197	215	216	210	209	209/40	±	7/57
Ground contact time in %	%	56/34	60/00	56/94	58/57	55/98	57/57	±	1/68
Step six									
Ground contact time + flight time	ms	216	228	221	221	222	221/60	±	4/28
Ground contact time in %	%	54/16	57/01	58/37	55/65	52/70	55/58	±	2/24
Step seven									
Ground contact time + flight time	ms	215	228	228	216	222	221/80	±	6/26
Ground contact time in %	%	60/00	51/31	51/31	56/94	52/70	54/45	±	3/87
Step eight									
Ground contact time + flight time	ms	228	228	222	221	221	224/00	±	3/67
Ground contact time in %	%	51/31	48/68	47/29	52/94	49/77	50/00	±	2/21
Step nine									
Ground contact time + flight time	ms	191	209	215	216	210	208/20	±	10/08
Ground contact time in %	%	51/83	46/88	48/37	51/38	50/00	49/69	±	2/07
Step ten									
Ground contact time + flight time	ms	221	228	234	221	227	226/20	±	5/45
Ground contact time in %	%	52/94	46/05	47/43	49/77	48/45	48/93	±	2/62

Table 4: Dynamics of contact-flight phases, frequency and length of steps and velocity in block acceleration in a 20m run (2.98s)

Step	Ground contact time [s]	Flight time [s]	(Step) frequency [Hz]	Step length [cm]	Velocity of the total body CM [m/s]
1	---	---		103	---
2	0/178	0/037	4/7	105	4/88
3	0/179	0/080	3/9	136	5/25
4	0/129	0/092	4/5	140	6/33
5	0/13	0/092	4/5	155	6/98
6	0/129	0/086	4/7	164	7/63
7	0/13	0/098	4/4	177	7/76
8	0/117	0/111	4/4	192	8/42
9	0/111	0/117	4/4	189	8/29
10	0/098	0/111	4/8	196	9/38
11	0/105	0/123	4/4	208	9/12
12	0/104	0/111	4/7	214	9/95
13	0/105	---	---	---	---
A	0/126	0/100	4/4	166	7/62
SD	0/024	0/021	0/16	39/09	1/64

The subject's best result of all five sprints was 2.98s. In this effort he took 12 steps at an average frequency of 4.4Hz with an average step length of 166cm (Table 4). Compared to other sprints, the average step length was the highest, the flight phase the longest and the frequency the lowest. The activity index was 1.26. The contact phase time already equalled the flight phase time by the seventh step (Figure 2). From the eighth step onward the length of the step stabilised and the contact phase times were shorter than those of the flight phases. The transition from acceleration to the maximal velocity phase occurred in passing from the seventh to the eighth step. In his least successful attempt (3.19s), this transition was only executed between the tenth and the eleventh steps.

Conclusion

The start and acceleration are two indisputably important phases of sprint races, which is why training for these two components deserves special attention. To maximise the efficiency of training, the structure of these two phases has to be examined in detail. Both phases are strongly dependent on genetic, motor and biomechanical factors. The aim of this study was to explain the most important biomechanical parameters generating an efficient performance of the start and block acceleration. So far, such studies have usually been performed on samples of sprinters of medium quality and, in some cases, with inadequate accuracy of the measurement procedures. What we have here is a biomechanical analysis of one current world-class sprinter made on the basis of technology that meets the highest standards of biomechanical research.

This study pointed to the indisputable correlation between the start and acceleration. The practical aim for coaches and athletes is to achieve an optimal set position, which guarantees the maximal block velocity of the sprinter. The transition from the blocks to

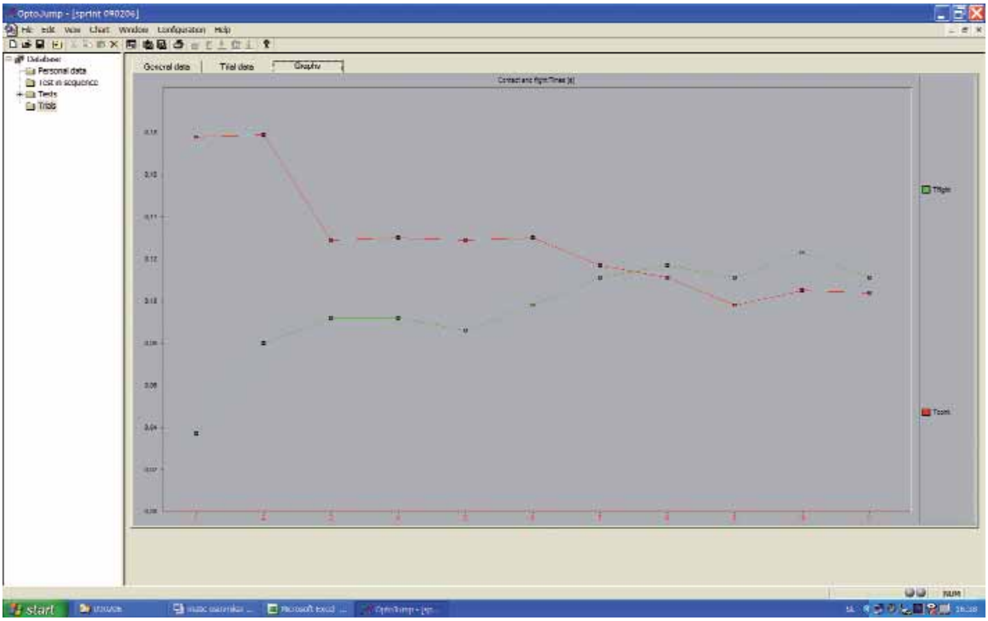

Figure 2: Activity Index (ground contact time / flight time) during acceleration from the blocks

acceleration depends on the execution of the first step, particularly the length of the step and positioning of the foot in the braking phase. The efficiency of the acceleration generates the time aspect of the activity index in the first ten steps. Stride length and frequency have to be co-ordinated to such an extent as to enable ground contact times to equal those of the flight phases within the shortest time possible. In the first three steps, the total body CM has to rise gradually in a vertical direction so as to enable the maximisation of the horizontal component of block velocity.

The results of this study cannot be generalised, however, they may contribute valuably to explaining phenomena of sprinting at the highest level of competitive performance.

Please send all correspondence to:
Milan Coh
Milan.Coh@fsp.uni-lj.si

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