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BIOMECHANICAL MODEL OF THE SPRINT START

1. INTRODUCTION

Sprint start and block acceleration are two extremely important phases directly generating results in a 60m, 100m, 200m and 400m sprint. It is no coincidence that many authors have delved into biomechanical factors of these two phases to explain the phenomenon of sprint velocity (Coppenolle, Delecluse, Goris, Diels, & Kraayenhof, 1990; Bruggemann & Glad 1990; Mero & Komi, 1990; Guissard, Duchateau, & Hainaut, 1992; Schot & Knutzen, 1992; Mc Clements, 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 results. The development of modern biomechanical technologies adds to the accuracy of measuring and analysing the key performance factors in sprint velocity. Sprint start and block acceleration are the first two derivatives of sprint velocity where the athlete tries to assume maximal block velocity. The study (Tellez & Doolittle, 1984) showed that the two phases account for 64% of the total result for a 100m sprint. Studies (Coppenolle et al., 1990; Schot & Knutzen 1992; Korchemny, 1992; Guissard, Duchateau, & Hainaut) concur that the efficiency of the sprint start depends primarily on the block positioning, the TBCG in the set position, the block time and the block velocity followed by block acceleration. The optimal coherence between the sprint start and block 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.

Block acceleration is that phase of the sprint where the kinematic parameters of the sprint step are changing most dynamically. Owing to these changes the block acceleration of the TBCG of the athlete increases. Block acceleration is a complex cyclic movement defined predominantly by the progression of the frequency and length of steps, the duration of the contact and flight phases and the total body centre of gravity position at the moment 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 (Buhrle et al. 1983; Moravec et al., 1988; Mero & Komi, 1990; Coppenolle et al., 1990; Mero, Komi, & Gregor 1992; Locatelli & Arsac, 1995).

Luhtanen and Komi (1980) divided the contact phase of the sprint step in block acceleration into a braking phase and a propulsion phase. The sum of both parts constitutes the total contact time. Owing to the changing biomechanical conditions, the contact phase/flight phase index also changes. Total ground contact times are decreasing and flight phases are increasing. The length of the step 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 (Lehmann & Voss, 1997). The contact phase has to be as short as possible with an optimal ratio between the braking phase and the propulsion phase. Step 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 step length, and vice versa. The efficiency of block acceleration is in fact defined by an optimal ratio between the length and frequency of the athlete's steps.

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 block acceleration in one athlete, namely a world class sprinter. The currently available, cutting-edge biomechanical technology was used for analysing this phenomenon. The subject of the study was the set position from the point of view of the height of total body centre of gravity (TBCG), the block time at the front and rear blocks, the block velocity, the block face angle, the velocity of the TBCG in the first three metres and the kinematic parameters of the block acceleration in the first ten steps. A 20m low-start sprint test was carried out to assess block 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 block 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 start and block acceleration, an 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 objectivisation of the two key phases of sprint running.

2. METHODS

2.1. Subjects: The study involved M.O., a member of the national team of the Republic of Slovenia for the 100 m sprint (aged 27, body mass 76.7 kg, personal record in 100m sprint: 10.14 sec.). The biomechanical measurements were carried out in May 2006 during which period the athlete was preparing for the European Athletics Championship in Geteborg 2006

2.2. Testing procedures The kinematic measurements of the start and block acceleration were carried out in the sports hall of the Track and Field Centre of Slovenia in Šiška, 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, that is able to capture 6 seconds of movements at a frequency of 1,000 frames/second at 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 1-metre sides. The processing and analysis of the data obtained were carried out by using the Ariel Performance Analysis System (APAS). The new technology OPTO-TRACK–Microgate was applied for analysing the kinematic parameters of block acceleration. The measuring chain enabled the measuring of the following sprint parameters: contact time, flight time, step length, step frequency, velocity in every step and change of velocity. In addition to the OPTO-TRACK measuring system, the infrared photocell timing system (BROWER) was also used in the block acceleration test in a 20m low-start sprint to measure the sprint time. The subject performed the 20m low-start sprint test five times, interrupted by 12-minute breaks. The SPSS software package was used for statistical data processing.

3. RESULTS AND DISCUSSION

The figures outlined in Table 1 suggest that the height of the total body centre of gravity (TBCG) in the set position was 54 ± 0.01 cm. The horizontal distance of projection of the TBCG from the start line was 32 cm. 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, also block acceleration. In such a position the mass 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 TBCG represents 32% of his standing height.

Table 1. *Kinematic parameters of the set position, sprint start and block acceleration in the first two steps*

Variable	**Unit**	**1**	**2**	**3**	**4**	**5**	**AS SD**
SET POSITION							
Distance between the TBCG and the start line	cm	32	33	33	32	32	32 ± 0.00
TBCG height	cm	54	53	54	54	54	54 ± 0.01
SPRINT START							
Block face angle	^{o}	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

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 ± 0.01 sec. The total reaction time of the front lower extremity is 0.43 ± 0.02 sec. These values of reaction times point to a certain deficit of the competitor in this element. Mero and Komi (1990) found shorter reaction times of elite sprinters, namely by 0.09 sec. The total reaction time is a result of a two-component ability defined by the 'premotor 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 run at the World Indoor Championship in Moscow M.O. had the fifth best reaction time – 155 ms. Reaction time has been dealt with by many researchers (Coppenolle et al., 1990; Bruggemann & Glad, 1990; Mero & Komi, 1990; 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 100-metre run. Reaction time accounts for only 2-3% of the total result in a 100-metre run (Bruggemann & Glad, 1990). The reaction time in the 60m sprint is more important. The winner of the final 60m sprint in Moscow, L. Scott (USA), recorded the shortest reaction time in absolute terms, namely, 124 ms. This involves a specific, genetically conditioned ability enabling the rapid transmission of afferent and efferent nerve impulses which, to some extent, depends on the sprinter's competitive experience and anticipation. The resultant of the velocity of the sprinter (M.O.) at the moment his foot broke contact with the front block, which is defined by block velocity, is 4.18 ± 0.19 $m.s^{-1}$. 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 our subject was 0.18 $m.s^{-1}$ higher. This exceptional capability of 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 in the TBCG in the first three metres of block acceleration is 0.67 ± 0.01 m, suggesting that the athlete's trunk during the run is leaned 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 block acceleration is mainly seen in the velocity parameters of the sprinter's TBCG in the first two steps (Table 1). At the end of the first step (propulsion phase) the horizontal velocity of the TBCG was 4.41 ± 0.13 $m.s^{-1}$ and at the end of the second step 6.00 ± 0.17 $m.s^{-}$

^{1}, showing an increase in velocity of more than 1.5 m.s^{-1}. In the first two steps the projection point of the TBCG is located behind the foot's ground contact point. It is not until the third and fourth steps that the TBCG projection point moves in front of the foot's ground contact point. The consequence of the TBCG 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 ± 1.34 cm long, the velocity in the braking phase is 2.00 ± 0.12 m.s^{-1}. Horizontal velocity decreased by 45.3% in view of the velocity in the propulsive phase of the first step. The length of the second step is almost identical to that of the first step (103.8 ± 3.42 m.s^{-1}). Nevertheless, 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.

Block acceleration is one of the most complex segments of the development of sprint velocity (Mero, Luhtanen, & Komi, 1993; Luhtanen & Komi, 1980) characterised by the most manifest changes in the dynamic and kinematic structure of the running technique. The step length and frequency increase, the contact phases shorten and the flight phases lengthen. In the first ten steps the athlete's step length increased by 46.9%. The ground contact time of the first step was 177.2 ± 7.73 ms. In view of the total step time (contact + flight times) the contact phase accounted for 77.4%. Similar values were identified on a sample of elite sprinters (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 contact phase/ flight phase index is subject to change. The contact phases are becoming shorter and the flight phases longer. The athlete's contact phase time equals the flight phase time in the eighth step. This is the end of the first phase of block acceleration and the beginning of the second phase of pick-up acceleration, representing the transition to maximal velocity. The step length stabilises in the ninth step (189.0 ± 2.12 m) and the contact time (CT = 103.40 ± 5.22 ms) is shorter than the flight phase time of the sprinting step for the first time (FT = 104.80 ± 7.76 ms). The subject's best result of all five sprints was 2.98 sec. In this sprint he took 12 steps at an average frequency of 4.4 Hz and with a step length of 166 cm . 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 in the seventh step. 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 block acceleration to the maximal velocity of the athlete occurred in passing from the seventh to the eighth step. In his least successful attempt (3.19 sec.), this transition was only executed between the tenth and the eleventh steps.

4. CONCLUSION

The study pointed to the indisputable correlation between the start and block acceleration. The basis is an optimally set position guaranteeing the maximal block velocity of the sprinter. The transition from the block velocity to block 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 block acceleration generates the time aspect of the contact/flight index in the first ten steps. Step 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 centre of gravity has to rise gradually in a vertical direction so as to enable the maximisation of the horizontal component of block velocity. The results of the study cannot be generalised, however, they may contribute valuably to explaining the sprint phenomenon at the highest level of competitive performance.

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Abstract

The study analysed and identified the major kinematic parameters of the phases of sprint start and block acceleration that influence the results of sprint running. The biomechanical measurements and kinematic analysis were performed on the best world's best sprinters during his preparation for the European Athletics Championship in Geteborg 2006. In this competition Matic Osovnikar won the bronze medal in a 100-metre run set the Slovenian national record with 10.14 s. The kinematic parameters of the sprint start were established on the basis of a 2-D kinematic analysis, using a high-speed camera with a frequency of 200 F/s. The measurements of block acceleration were made by means of the OPTO TRACK technology and an infra-red photo cell system. The athlete performed five, 20m low-start sprints in constant and controlled measurement conditions. The subject of the study was the set position from the point of view of the height of the total body centre of gravity (TBCG), the block time at the front and rear blocks, block velocity, the block face angle, the velocity of the TBCG in the first three metres and the kinematic parameters of block acceleration in the first ten steps. The study showed the following were the key performance factors in the two phases of sprint running: medium start block distance, block velocity, low block face angles, first step length, low vertical rise in the TBCG in the first three metres of block acceleration, contact phase/flight phase index in the first ten steps and the optimal ratio between the length and frequency of steps.

Key words: *Sprint start, block acceleration, technique, kinematics, top sprinter, new technology*