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Research article

USAIN BOLD – BIOMECHANICAL MODEL OF SPRINT TECHNIQUE

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Abstract. *The aim of this research was to determine which kinematic parameters generate the maximum sprint speed of the world's fastest sprinter, Usain Bolt. The biomechanical parameters of a double sprint step, using a 2D kinematic analysis under conditions of the realization of its maximum velocity were analyzed. The APAS computer system was used for the kinematic analysis. The data was recorded with three digital cameras CASIO EX-F1 with a frequency of 300 Hz, while the cameras were connected to one another and synchronized. The measurements were performed at the international athletics competition IAAF World Challenge in Zagreb, Croatia. Bolt reached a maximum speed of 12.42 m·s^{-1} in the section between 70 and 90 meters. His average stride length in this section was 2.70 m at an average frequency of 4.36 strides/s. His average contact time was 0.86 s and the average duration of his flight phase was 0.145 s. He developed a maximum vertical ground reaction force of 3956.74 N. This force corresponds to 4.1 times the weight of the athlete. The ratio between his braking and propulsion phase was 37.3% : 62.7%, which is a good indicator of an economical running technique. The maximum speed of Usain Bolt is a combination of optimal anthropometric characteristics, motor abilities, and an extremely rational technique of sprinting gait.*

Key words: *athletics, technique, sprinting gait, 2D kinematic analysis*

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INTRODUCTION

Usain Bolt is one of the greatest athletes in the history of athletics. During the 12th International Association of Athletics Federations (IAAF) World Championships in Athletics in Berlin in 2009 he set a new world record in the 100m sprint, resulting in one of the most remarkable achievements in the world of athletics. He broke the previous record by 0.11 seconds, with a headwind of -0.3 $m \cdot s^{-1}$. His phenomenal results were subjected to numerous media analyses, debates, and discussions as well as some in depth scientific biomechanical studies. Though these studies are rare, they analyze and explain Usain Bolt's achievements indirectly on the basis of the approximation of certain physical and time dynamic models (Erikson, Kristiansen, Langangen, & Wehus, 2009; Beneke & Taylor, 2010; Beneke, Taylor, & Leithauser, 2011; Taylor & Beneke, 2012; Mackala & Mero, 2013; Gómez, Marquina, & Gómez, 2013). The purpose of the current research project was figuring out the selected objective biomechanical parameters of the technique of a double sprint step, using a 2D kinematic analysis under conditions of the realization of its maximum velocity. Genetic, motor and biomechanical factors strongly influence the 100m sprint result (Čoh, Tomažin, & Štuhec, 2006). Usain Bolt (age: 25, height: 1.96 m, weight: 95 kg, BMI: 24.7) is a sprinter with an incredible genetic potential, which shows in the optimal combination of an excellent running technique, extreme motor abilities, and morphological characteristics. At the World Championships in Athletics in Berlin in 2009, he set the world record of 9.58 seconds, he developed a speed of 44.72 $km \cdot h^{-1}$ (12.42 $m \cdot s^{-1}$) in the section between 60 and 80 meters (20m split = 1.61 s). That was the highest absolute velocity ever achieved by a sprinter. His mechanical efficiency during running is based on his relative strength, muscle coordination, the optimal frequency of his strides, exceptionally short ground contact time, and extreme length of his stride, which is a consequence of his height (196 cm) (Beneke & Taylor, 2010; Graubner & Nixdorf, 2011; Gómez et al., 2013). Usain Bolt is one of the highest sprinters in the history of athletics (Charles & Bejan, 2009). He participated at the IAAF World Challenge in Zagreb in 2011. This presented an opportunity for a biomechanical analysis of the model of the running technique of this great Jamaican athlete.

The aim of this research was to determine which kinematic parameters generate the maximum sprint speed of the world's fastest sprinter, Usain Bolt.

METHODS

Experimental design

The biomechanical analysis of the technique of Usain Bolt's sprinting gait at maximum velocity was performed at the international competition IAAF World Challenge (Zagreb, Croatia, 2011), at the athletic stadium "Mladost". The weather conditions were optimum, the outside temperature reaching 23^{o} C, with a wind speed of +0.1 $m \cdot s^{-1}$. We acquired permission for the performance of biomechanical measurements from the Technical Delegate and the Organizing Committee of the European Athletics. The track was covered from the start to the finish line with 3 high-speed cameras Casio – digital camera EX-F1 (Casio Computer Co., Ltd., Tokyo, Japan) that were connected to one another and synchronized (Figure 1). The cameras had a frequency of 300 Hz with a 720 x 576 pixel resolution. The section between 60 and 90 meters was calibrated with the two reference frames in the size of 2m x 2m x 2m, taking into account eight points of the calibration frame.

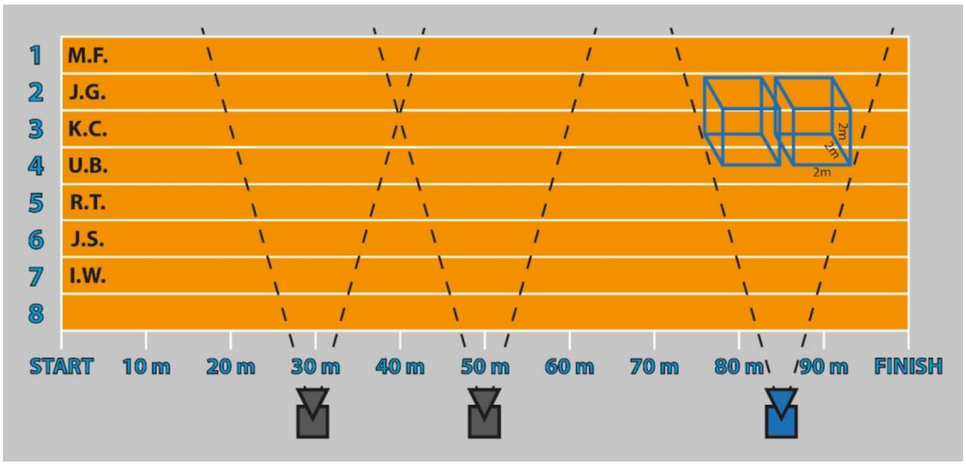


Fig. 1 Positioning of the cameras and the calibration area of the measuring protocol of the kinematic analysis of Usain Bolt's 100m sprint

In the first phase the dynamics of the velocity of all 7 finalists/competitors in terms of average velocity, number of strides, average frequency, and the average stride length in a 100m sprint was analyzed. The data was acquired on the basis of the videos of 6 official television cameras and 3 digital cameras Casio EX-F1 (Figure 1). The competitors' reaction time (RT) in the sprint start was acquired from the official measuring team of the competition (TIMING, Ljubljana). The kinematic parameters of Usain Bolt's sprinting gait were analyzed over 85 meters of the athletic track during his maximum velocity. During data processing we used the APAS computer system (Ariel Performance Analysis System) for the 2D kinematic analysis. We performed the digitalization of a 15-segment model of the body of the athlete who was defined with 17 reference points (Winter, 2005). The coordinates of the points were smoothed using a digital filter with a frequency of 14 Hz. We filmed with a frequency of 300 Hz, while the digitalization of the points was done with 100 Hz. The center of mass (CM) was calculated from the digitalized points on the basis of anthropometric tables (Winter, 2005). The analysis included 21 kinematic parameters of the technique of the sprinting gait: stride length, duration of the contact phase, duration of the flight phase, stride frequency, duration of the braking phase, duration of the propulsion phase, height of the CM, horizontal velocity of the CM in the braking phase, horizontal velocity of the CM in the propulsion phase, horizontal velocity in the maximum amortization phase, vertical velocity of the CM in the braking phase, vertical velocity of the CM in the propulsion phase, vertical velocity in the maximum amortization phase, angle of the ground leg, angle of the toe off, angle of the knee of the ground leg in initial contact and terminal stance, angle of foot inclination in the sagittal plane, average horizontal velocity of the foot of the swinging leg, angular velocity of the thigh of the swinging leg, and horizontal movement of the CM in the contact phase of gait. All processed data are presented descriptively, in tables and figures.

RESULTS AND DISCUSSION

In the 100m sprint, stride length and frequency have to be coordinated to such an extent as to enable ground contact times to equal those of the flight phases within the shortest time possible. An overview of the parameters of the 100m sprint (Table 1) shows us that Usain Bolt achieved 9.85 seconds at the average stride length of 2.44 m, an average frequency of 4.16 strides/s, and an average velocity of 10.15 $m\cdot s^{-1}$. He reached a speed of 12.14 $m\cdot s^{-1}$ in the section between 70 and 90 meters. His reaction time was 0.194 seconds. Comparing his 100m sprint in Zagreb to his 100-meter world record in Berlin and his sprints at the Olympics in Beijing and London (Table 2) certain obvious differences can be noticed. In Zagreb, Bolt achieved a very long reaction time, a lower average frequency, and a longer average stride length. He achieved maximum velocity in the section between 70 and 90 meters and not between 60 and 80 as in Beijing, Berlin, and London. The differences are understandable since the competitions differ in importance, the sprinter's condition on the day of the competition, and the competition of other performers. He achieved the shortest reaction time (0.146 s), the lowest number of strides (40.92 strides), and the longest average stride (2.44 m) in Berlin in 2009, while he achieved the highest average frequency (4.28 strides/s) and the lowest initial acceleration time at 20 meters (2.70 s) in Beijing in 2008 (Mackala & Mero, 2013).

Table 1 Parameters of the finalists of the 100m sprint at IAAF World Challenge (Zagreb, 2011)

Parameter	Usain Bolt (JAM)	Kim Collins (SKN)	Richard Thompson (TRI)	Saidy Ndure (NOR)	Mario Forsythe (JAM)	Justin Gatlin (USA)	Ivory Williams (USA)
100 m (in s)	9.85	10.01	10.03	10.13	10.16	10.17	10.37
Reaction time (in s)	0.194	0.181	0.177	0.167	0.188	0.177	0.156
Average velocity (in $m\cdot s^{-1}$)	10.15	9.99	9.97	9.87	9.84	9.83	9.64
Number of strides (in n)	41.00	49.25	44.5	43.25	46.50	43.25	49-00
Average stride frequency (in strides/s)	4.16	4.92	4.44	4.27	4.58	4.25	4.73
Average stride length (in m)	2.44	2.03	2.25	2.31	2.15	2.31	2.04

The time of 9.85 s that Usain Bolt achieved at IAAF World Challenge in Zagreb is not his best time, though it is still extremely good. His maximum velocity in the section between 70 and 90 meters was 43.70 $km\cdot h^{-1}$ (12.14 $m\cdot s^{-1}$), which is only 1.02 $km\cdot h^{-1}$ worse than his absolute highest speed, achieved at the World Championships in Athletics in Berlin.

Table 2 Comparative analysis of the parameters of the sprint dynamics of Usain Bolt

Parameter	Beijing 2008*	Berlin 2009**	Zagreb 2011	London 2012*
100m (in s)	9.69	9.58	9.85	9.63
Reaction time (in s)	0.166	0.146	0.194	0.165
Average velocity (in $km \cdot h^{-1}$)	37.15	37.57	36.54	37.36
Maximum velocity (in $km \cdot h^{-1}$)	43.91	44.72	43.70	44.70
Maximum velocity (in $m \cdot s^{-1}$)	12.20	12.42	12.14	12.41
Section of maximum velocity (in m)	60 – 80	60 – 80	70 – 90	60 – 80
Point of maximum velocity (in m)	/	65.03	/	
Number of strides (in №)	41.51	40.92	41.00	41.30
Average stride frequency (in strides/s)	4.28	4.27	4.16	4.37
Average stride length (in m)	2.41	2.44	2.44	2.42
Speed at 99% (in m)	/	48.18	/	/

Legend: *El Pais (2013); **Hommel (2009)

On the basis of the kinematic analysis of the double sprint step in the section between 70 and 90 meters (Table 3), we established that his frequency was 4.36 strides/s, with a 2.70-meter stride length, a contact time of 0.086 seconds, and duration of the flight phase of 0.145 seconds. The kinematic analysis also portrayed a certain asymmetry when it came to Bolt's stride length and frequency and the vertical oscillation of the CM. His left-foot stride is 0.046 m longer, in other words 1.2%. The difference in frequency of the left and right foot is 0.13 strides /s, meaning 2.8%. The flight phase is 10 ms longer when the toe off is done by the left leg. With the left toe off the vertical oscillation of the CM is 0.014 meters lower.

Table 3 Kinematic parameters of Usain Bolt's sprinting gait

Parameter	Right leg	Left leg	Average R/L leg
Stride frequency (in strides/s)	4.42	4.30	4.36
Stride length (in m)	2.68	2.72	2.70
Braking phase of gait (in %)	34.60	40.00	37.30
Propulsion phase of gait (in %)	65.40	60.00	62.70
Contact phase (in s)	0.088	0.083	0.086
Flight phase (in s)	0.140	0.150	0.145
Vertical amplitude CM (in m)	0.055	0.041	0.045

Sprint speed is the product of stride frequency and length. The parameters are interdependent and individually determined by the processes of central control of movement, morphological characteristics, motor abilities, and metabolic processes (Mann & Sprague, 1980; Bruggemann & Glad, 1990; Mero, Komi, & Gregor, 1992; Donatti, 1995; Hunter, Marshall, & McNair, 2004). While stride length depends on height, the length of the legs, and the ground reaction force that is developed by the ankle, knee, and hip protractors (Mero et al., 1992; Novacheck, 1998; Hunter et al., 2004), the stride frequency depends on the function of the central nervous system on a cortical and subcortical level (Golhofer & Kyrolainen, 1991; Hunter et al., 2004). The relationship between both parameters is individually defined and automatized with each person. An increase in frequency results in a shorter stride length and vice versa. Maximum velocity is basically the outcome of an optimal combination of stride frequency and length. When Usain Bolt set the world record in the 100m sprint (9.58 s) his average frequency was 4.27 strides/s with an average stride length of 2.44 m (Graubner & Nixdorf, 2011). He was the first person in the history of athletics to run the distance of 100m in less than 41 strides. Other finalists of the 100m sprint at the World Championships in Athletics in Berlin had an average stride length of 2.29 m (Mackala & Mero, 2013). Bolt's speed is a consequence of a high frequency and an extremely long gait, both integrated into an economic and mechanically effective movement. In one of their studies, Charles and Bejan (2009) established that stride length is one of the main factors in sprint speed. The world record holders in the 100m sprint have gotten taller and heavier in the last 20 years (Brechue, 2011). A higher CM, which depends on the length of the lower extremities and height, apparently enables better conditions for the development of speed. The ground reaction force is at work for longer distances.

The analysis of Usain Bolt's sprint at the IAAF World Challenge in Zagreb in 2011 showed that the realization of maximum velocity appeared at a frequency of 4.36 strides/s and a stride length of 2.70 m in the section between 70 and 90 meters, which is highly untypical for him. This can probably be attributed to a poorer start and initial acceleration in that particular sprint.

The sprinting gait generates the basic mechanics of locomotion speed. The focus of our research work was the kinematics of this crucial structural element of the sprint. Contact time is one of the most important parameters of sprinting gait and also a parameter that is extremely time-limited (Mann & Sprauge, 1980; Luhtanen & Komi, 1980; Guissard & Hainaut, 1992; Mero et al., 1992; Taylor & Beneke, 2012). With top sprinters it lasts from 0.075 to 0.095 seconds. In this extremely limited time frame, the sprinter must develop a high ground reaction force that is generally three to four times greater than the value of body weight (Cavagna, Komarek, & Mazzoleni, 1971; Mann & Sprague, 1980; Ito & Suzuki, 1992; Donatti, 1995; Mero et al., 1992). The development of force is a consequence of the connection of the eccentric and concentric muscle contraction, called the stretch shortening cycle (Nicol, Avela, & Komi, 2006), which has to be as short as possible. With Usain Bolt the average contact time is 0.086 s, measured on the basis of high-frequency videos (Figure 2).

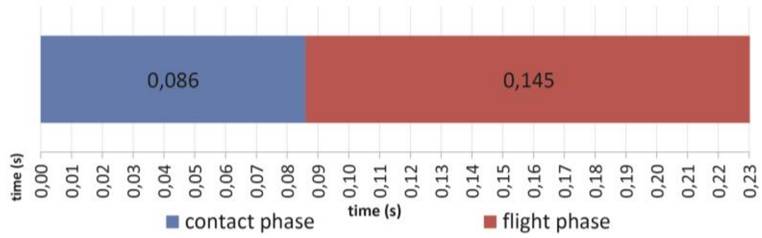


Fig. 2 The ratio of the contact and flight phase of Usain Bolt's sprinting gait

On the basis of ground contact time, the duration of the flight phase, and the sprinter's body mass, we used the formula (Taylor and Beneke, 2012):

$$F\ max = mass \cdot g\ \pi/2 \cdot [tf\ \ / tc + 1]$$

to calculate the maximum vertical ground reaction force that amounts to 3956.74N.

This force corresponds to 4.1 times the weight of the athlete. The value of the maximum ground reaction force is somewhat larger than the value that was established by Taylor and Beneke (2012). Their research showed the value of 3600N of maximum vertical force in the case of Usain Bolt (body mass = 95 kg, tc = 0.091 ms, tf = 0.132 ms), 3250N with Tyson Gay (body mass = 73 kg, tc = 0.070 ms, tf = 0.132 ms) and 3590N in the case of Asafa Powell (body mass = 88 kg, tc = 0.080 ms, tf = 0.131 ms). Usain Bolt develops an extremely high vertical ground reaction force in a very short contact phase (tc = 0.086 ms). The approximation of the ground reaction force with 41 strides at a 100m sprint shows that the sum of maximum forces equals 162.2 kN. The sum of all ground contact times at a 100m sprint is 3.53 seconds and the sum of all flight times is 5.96 seconds [t 100 (s) = tc 3.53 s + tf 5.96 s = 9.49 s]. The ratio between the duration of the contact and flight phase is 41% : 59%. In the case of T. Gay this ratio amounts to 47% : 53% and in the case of A. Powell to 39% : 61%. U. Bolt can run a distance of 100m in 40.92 strides, T. Gay in 45.94 strides, and A. Powell in 44.45 strides (IAAF, 2011). On the basis of the comparative analysis of the three fastest sprinters in the world, we can discover that Usain Bolt's main advantage lies in the smaller number of strides, a somewhat lower frequency, a higher ground reaction force, and a higher average metabolic energy. In their research, Beneke and Taylor (2010) discovered that during the 100m sprint at the 12th IAAF World Championships in Berlin in 2009 the average metabolic energy that the finalists spent amounted to 72.5 W·kg^{-1}, while Usain Bolt reached 76.7 W·kg^{-1}.

The stance and flight duration, however, do not present a sufficient relevant criterion for the efficiency of the sprinting gait. What is important is the ratio between the duration of the braking phase and the duration of the propulsion phase (Mero et al., 1992). Usain Bolt's ratio between the braking and propulsion phase is 37.3% : 62.7%, which is a good indicator of an economical technique of maximum sprint velocity (Taylor & Beneke, 2012), Table 3. The braking phase lasts 0.030 seconds, whereas the propulsion phase lasts 0.056 seconds (Figure 3).

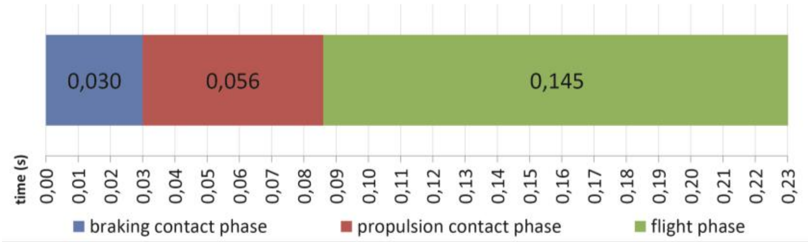


Fig. 3 The ratio between the braking and the propulsion contact phase of Usain Bolt's sprinting gait

The close position of the foot of the ground leg to the vertical projection of the CM plays a key role in the braking phase. With U. Bolt this distance is 0.34 m. The shorter the braking phase, the smaller the reduction of the horizontal velocity of the CM will be (Mann & Sprague, 1980; Novacheck, 1998; Hunter et al., 2004) (Figure 4). At the beginning of the contact phase, when the ground foot is placed on the ground, the horizontal velocity of the CM is 11.44 $m \cdot s^{-1}$, while it is 12.04 $m \cdot s^{-1}$ at the end of the contact phase. The reduction of horizontal velocity of the CM is 4.9%, which points to an extremely rational and efficient technique. But if we take into account only the braking phase (the placement of the foot on the ground until we reach the vertical movement of the sprinting gait) the reduction of velocity amounts only to 2.7%. It is obvious that Bolt minimizes the braking phase (decreasing speed) and maximizes the propulsion phase (increasing speed) of the sprinting gait.

The second important parameter of keeping the horizontal velocity of the CM in the contact phase is the position of the foot at the moment of first ground contact. The foot needs to be in the position of plantar flexion. The sprinter achieves this through a proper pre-activation of the ankle protractors and flexors i.e., m. gastrocnemius, m. soleus, m. tibialis (Komi, 2000). Pre-activation must be preprogrammed and stimulated with the help of higher centers of the central nervous system. It has to appear 40-60 ms before ground contact (Komi, 2000; Nicol et al., 2006). The position of Usain Bolt's foot points to his efficient pre-activation, which is seen in the angle between the longitudinal axis of the foot and ground. The angle is 19.5°. In the vertical phase (Figure 4) the angle between the longitudinal axis of the foot and the ground is 27.3°. The consequence of pre-activation is increased muscle stiffness, which enables an efficient resistance to the ground reaction force in the phase of initial contact.

The parameter of the velocity of the swinging leg plays an important part in the economics of sprint speed (Figure 5). For an efficient sprinting gait we need to ensure a high horizontal velocity of the foot of the swinging leg in the contact phase and a high grabbing velocity. The swinging leg (thigh – tibia – foot) is the only segment in the braking phase that produces propulsion force (Lehmann & Voss, 1997; Novacheck, 1998; Hunter et al., 2004). Usain Bolt's average horizontal foot velocity is 16.76 $m \cdot s^{-1}$ in the braking phase and 23.42 $m \cdot s^{-1}$ in the propulsion phase. We can see that his horizontal foot velocity in the propulsion phase is almost two times higher than the horizontal velocity of the CM.

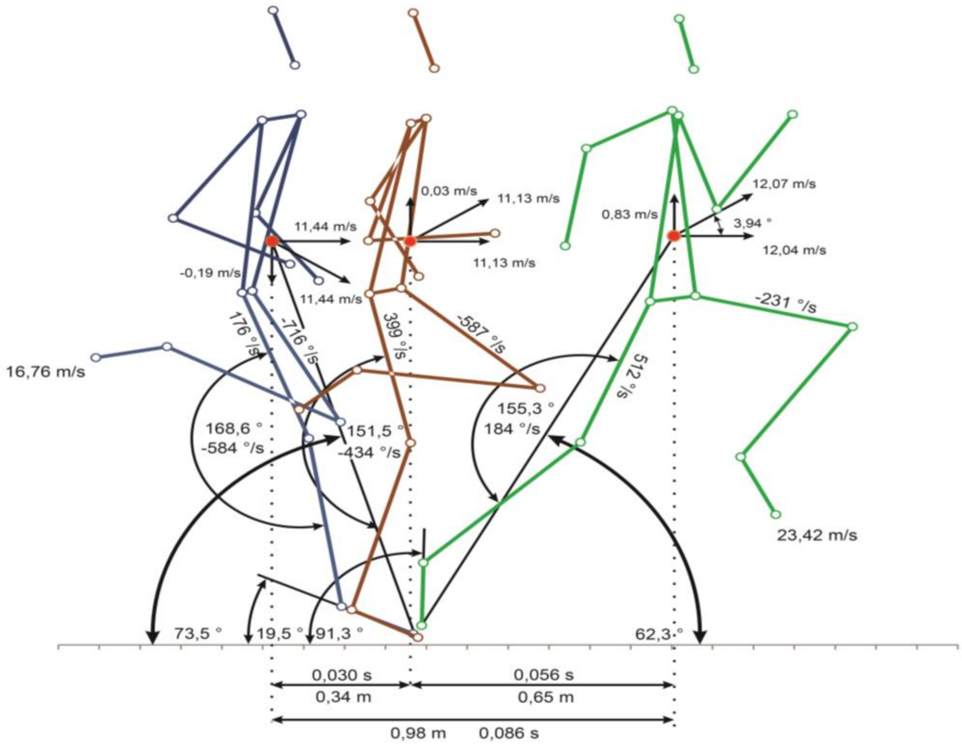
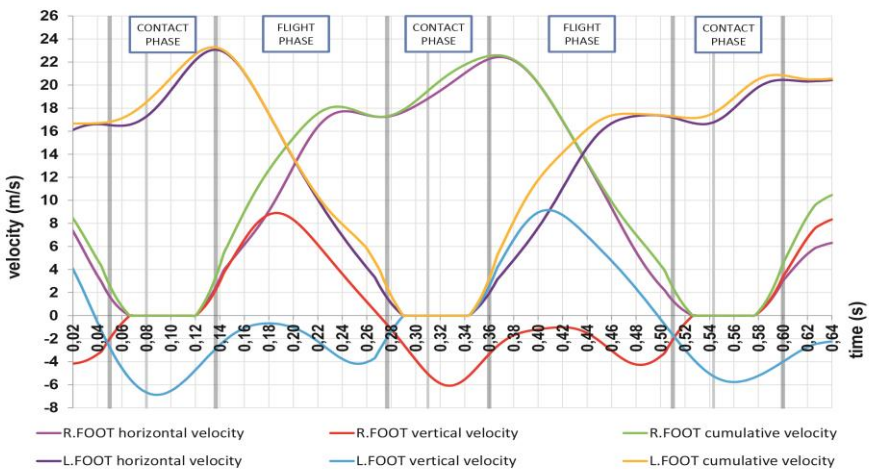


Fig. 4 The kinematic parameters of Usain Bolt's sprinting gait



Legend: R.FOOT – right foot, L.FOOT – left foot

Fig. 5 The horizontal velocity of the foot of the swinging leg in Usain Bolt's sprinting gait

The horizontal velocity of the foot of the swinging leg in the contact phase presents an important part in reassuring the horizontal speed of the sprinter's CM (Figure 6). With Usain Bolt, this element is at the highest possible level of the economics of movement. The thigh angular velocity of the swinging leg insures the velocity of the foot in a horizontal direction. In the vertical phase the speed is 587°/s. A study by Lehmann & Voss (1997) showed that sprinters with maximum velocity from 10.50 to 12.50 $m \cdot s^{-1}$ reach maximum angular velocity of 500 to 800°/s when it comes to the thigh of the swinging leg. They discovered a positive correlation between the thigh angular velocity and the absolute velocity of the sprinters. With Usain Bolt these values are somewhat lower on account of the specific length of the segments.

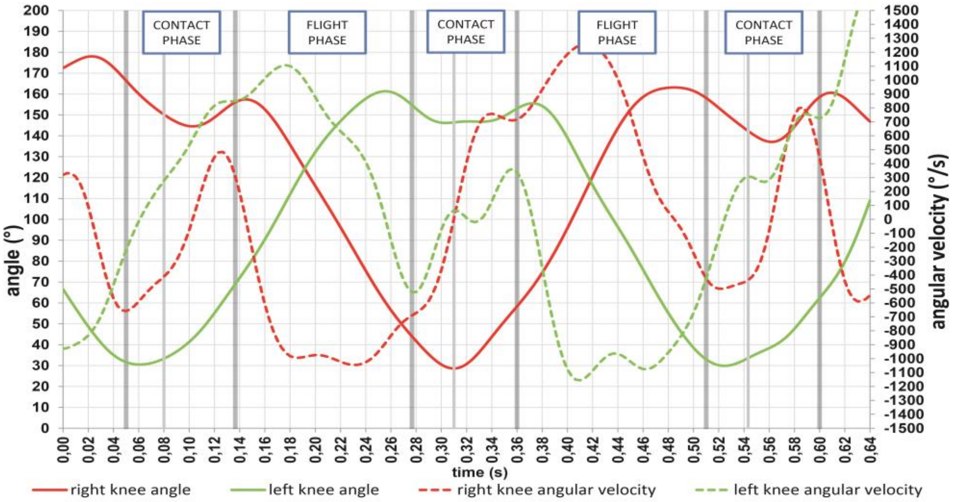


Fig. 6 Thigh angular velocities of the swinging leg in Usain Bolt's sprinting gait

Taylor and Beneke (2012) established that Usain Bolt's economy and efficiency are based precisely on a lower frequency and a longer stride. The force production is larger with an optimally longer contact phase and longer distances travelled during ground contact. With Usain Bolt the force works in an anterior-posterior direction at a distance of 0.98m during 0.086 seconds of contact time. In that time he can develop a greater impulse of force and with it a greater propulsion force and a more efficient mechanics of movement. The force in the anterior-posterior direction of the CM in the contact phase is defined by two parameters: the angle of the ground leg in the braking phase (73.5°) and the angle of toe off in the propulsion phase (62.3°).

An extremely important factor of the mechanics of the sprinting gait is the vertical oscillation of the CM (Figure 7).

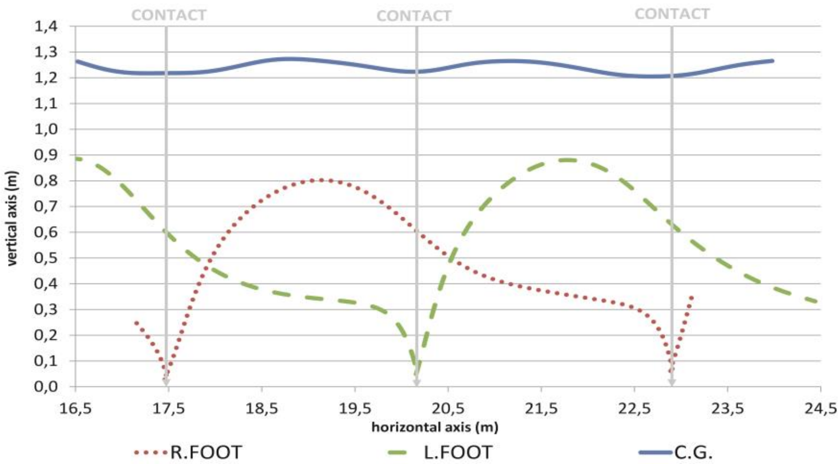


Fig. 7 The trajectory of movement of the CM in the vertical direction of Usain Bolt's double sprint step

The lowest position of the CM is in the phase of maximum amortization of the knee joint when the ground leg is in a vertical position. The angle of maximum amortization in the knee of the ground leg in the vertical position of Usain Bolt’s sprinting gait is 151^{o}. The vertical amplitude of the movement of the CM is 0.049m. The studies of several authors (Mann & Sprague, 1980; Mero et al., 1992) show that the oscillation amplitudes with the sprinters range from 0.06 to 0.12 m. The vertical oscillation of the CM of less than 5cm points to Usain Bolt’s biomechanically efficient and extremely rational running technique.

CONCLUSION

The current study analyzed the sprint technique of the fastest runner on the planet, a two-time world record holder, and two-time 100m Olympic champion Usain Bolt. On the basis of a 2D kinematic analysis, performed at the IAAF World Challenge (Zagreb, Croatia, 2011), we studied the biomechanics of the sprinting gait under conditions of maximum velocity in the section between 70 and 90 meters, with the velocity reaching 43.70 $km \cdot h^{-1}$ (12.14 $m \cdot s^{-1}$). The main parameters that define Bolt's sprinting achievements are the short duration of the contact phases, extremely long strides, optimal stride frequency, a high vertical ground reaction force, and rational mechanics of sprinting gait. The last parameter is seen in the ratio between the braking and the propulsion phase, the minimal reduction of horizontal velocity of the CM in the braking phase, the minimal amplitude of vertical movement of the CM, a high horizontal velocity of the foot of the swinging leg, the thigh angular velocity of the swinging leg, and the optimal position of the foot at the moment of contact with the ground. This study is one of the first attempts at objectifying Usain Bolt’s sprint technique using direct measurements and modern biomechanical methodology and technology. The study focuses on the segment of maximum velocity. We are aware of the fact that we should also have taken into account the sections of the initial phase of acceleration and the phase of deceleration to achieve a more objective and complex analysis. Therefore, this is one task that remains for further research.

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USAIN BOLT - BIOMEHANIČKI MODEL TEHNIKE SPRINTA

Cilj ovog istraživanja bio je da se utvrdi koji kinematički parametri generišu maksimalnu brzinu sprinta najbržeg sprintera na svetu, Usaina Bolta. Analizirani su biomehanički parametri dvostrukog sprintskog koraka, koristeći 2D kinematičku analizu u uslovima realizacije maksimalne brzine. Za kinematičku analizu korišćen je kompjuterski sistem APAS. Podaci su snimljeni sa tri međusobno povezane i sinhronizovane digitalne video kamere CASIO EX-F1 sa frekvencijom od 300 Hz. Merenja su sprovedena na međunarodnom atletskom natjecanju IAAF World Challenge u Zagrebu, Hrvatska. Bolt je dostigao maksimalnu brzinu od 12.42 m · s^{-1} *u deonici između 70-tog i 90-tog metra. Njegova prosečna dužina koraka u ovom delu bila je 2.70 m sa prosečnom frekvencijom od 4.36 koraka / s. Prosečno vreme kontakta bilo je 0.86 s, a prosečna dužina faze leta bila je 0.145 s. Razvio je maksimalnu vertikalnu silu reakcije podloge od 3956.74 N. Ova sila je 4.1 puta veća od težine aktuelnog sportiste. Odnos između faze kočenja i propulzije bio je 37.3% : 62.7%, što je dobar pokazatelj ekonomične tehnike trčanja. Maksimalna brzina Usain Bolta je kombinacija optimalnih antropometrijskih karakteristika, motoričkih sposobnosti i izuzetno racionalne tehnike sprintskog hoda.*

Ključne reči: *atletika, tehnika, sprintski hod, 2D kinematička analiza*