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Kinematic analysis of the block startand 20-metre acceleration phase in two highly-trained sprinters: A case report

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Keywords

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Kinematic analysis of the block start and 20-metre acceleration phase in two highly-trained sprinters: A case report

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INTRODUCTION

There is a wide range of factors to consider during the block start. Expert coaches claim that the actual block start begins with the “on your marks” command [1, 2]. Many scientists have tried to determine which of the numerous factors are crucial for this particular part of the sprint. Some of them have focused on examining lower extremities in regard to reaction times, starting block spacing, feet-to-block distances, acceleration or 20-m all-out sprint runs [3, 4, 5, 6]. Harland and Steele [3] showed that, in order to achieve a combination of high force power and high maximum force, the sprinter should position his/her rear knee in the ”set” position between 90° and 130° of flexion, with the hips moderately high. Such a setting allows leaving the starting block at a low angle (40° to 45°) which eventually minimises potential horizontal breaking forces [3]. The study of Čoh, Tomažin and Štuhec [4], which was based on a 2-D kinematic analysis, revealed a definite correlation between the optimal set position and the maximal block velocity during the start and acceleration out of the blocks. Their findings suggest that the first ten steps are crucial in order to achieve a satisfactory velocity. Kugler and Jahnsen [5] utilized a three-dimensional force plate and infrared photoelectric photocells. They revealed that athletes with superior acceleration performance placed their feet further at initial contact or prolonged their ground contact time. During their research with the use of an optical measurement system with infrared light barriers, Klaus et al. [6] demonstrated that stride length and ground contact times can greatly differ depending on the current training programme. Babic et al. [7] utilised a photocell measurement system and they observed that high-level athletes reduced ground contact as well as lengthened their stride, especially in the acceleration phase.

Each discipline usually has more than one formula for achieving success. In sprinting, one particular principle does seem to stand out – a constant need to uphold the symmetry of motion. Recent findings of Trivers et al. [8] suggest that elite athletes (the Jamaican national team) have a very high association between the right and the left knee and the ankle symmetry and their sprinting performance. Findings presented by Pappas, Paradisis and Vagenas [9] imply that even young athletes display rather small individual asymmetries in the lower limb biomechanical parameters, such as flight time, acceleration or velocity. Korhonen et al. [10] indicate that professional athletes, regardless of age, provide repeatable and symmetric values of their strides especially during the acceleration phase (the first part of the distance) and further on.

For each and every professional athlete, developing individual technique is critical for success. In this study, we simultaneously analysed kinematic variables of numerous body segments during sprint block starts with the use of inertial sensors. Admittedly, similar research has been done up to date, but with the use of the popular video-motion analysis method rather than using inertial sensors. For instance, such studies were carried out by Bezodis et al. [11], Debaere et al. [12, 13], or Slawinski [14, 15]. Moreover, in contrast to other studies, we collected data during a real training session in the tapering phase of the competition period and obtained an actual picture of the block start technique which is not a standard way of testing athletes.

The aim of this study was to identify the most optimal values of individual kinematic characteristics in highly-trained sprinters during block clearance combined with a 20-m acceleration phase.

MATERIAL AND METHODS

SUBJECTS

Two male sprinters, members of the Polish national team, were tested. The athletes' age, height, weight and career length were 28 and 21 years, 187 and 189 cm, 90 and 95 kg, 13 and 6 years, respectively. Their personal best performances were 6.83 and 6.97 s (60 m), 10.33 and 10.39 s (100 m), 20.56 and 20.90 s (200 m). Before the study, they gave their informed consent. This study was part of a project which was approved by the Ethics Committee at the Poznan University of Medical Sciences.

STUDY DESIGN

The study was conducted during the competitive phase of the annual training cycle in which athletes developed speed and technique. Each athlete utilised his own running equipment, i.e. sportswear and spiked shoes. The data collection took place on a standard outdoor 400-m track in the stadium of the Central Sports Centre OPO "Cetniewo" (Poland) between the 2nd and 6th of August 2015, during a typical training session for speed and technique. Weather conditions were conducive to speed and technique development with an average temperature of 26°C and a maximal wind speed of 10 km/h (wind speed and direction were provided by the National Institute of Meteorology Website – http://instytutmeteo.pl/).

The measurements took place during a typical speed workout of the national team during a weekly microcycle. The session commenced with a 45-minute warm-up, which included jogging, stretching, band stretching, skips and preliminary 40–60-meter "run-throughs" at increasing speed. The stretching and band stretching is said to be a successful and desired way of pre-run preparation; such an impact was verified by Coh et al. [16]. The warm-up was followed by 4 block starts and 20-m all-out sprint runs separated by 5-min recovery intervals. Each athlete performed his block starts individually. A standard starting pistol was used for signalling the block start. Each trial was performed with the use of starting blocks, and their set up was executed by the athletes themselves in a manner that best suited them.

MEASUREMENTS

A wireless portable 3D inertial MyoMotion system (Noraxon Inc., USA) was used, based on 3D accelerometers and 3D gyroscopes, providing linear acceleration and angular velocity variables. The data were transmitted via Bluetooth to a laptop computer. The equipment was put on during a routine break after the warm-up in order to avoid any disruptions in the training flow. The athletes were equipped with a set of sixteen 3D sensors attached to the head (1 unit), upper and lower extremities including hands and feet (12 units) and the torso (3 units). The placement of each specific sensor was carried out according to the manufacturer's instructions (Figure 1), i.e.: the head sensor in the centre of occipitofrontalis area, the upper thoracic sensor at 7th cervical vertebrae, the lower thoracic sensor between 1st lumbar vertebrae and 12th thoracic vertebrae, the pelvic sensor precisely between the sacrum and lumbar vertebrae, the arm sensor (2 units) at the peak of biceps brachii, the forearm sensor (2 units) on flexor digitorum, the hand sensor (2 units) on metacarpal bones, the thigh sensor (2 units) on the bottom of rectus femoris, the shank sensor (2 units) in the centre of tibialis anterior and the feet sensors (2 units) in the centre of flexor digitorum brevis. Using these sensors, angle values of joints were displayed in degrees (°), time units for each phase in seconds (s) and accelerations body segments in Gals (G = 1 cm/s^2 = 0.01 m/s^2).

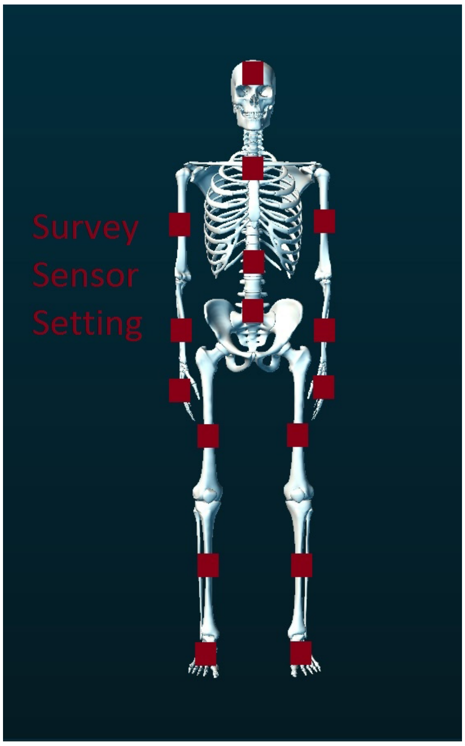

Fig. 1. Body sensor placement

The gathered data was analysed using a specialised software package MR 3.6 (Noraxon Inc., USA). The research focused on changes in joint angles as well as acceleration of body segments. Angle values were equal to the differences between current body positioning and that from standing calibration. Data recording started with the “on your marks” command. Sprint times were measured automatically to the nearest 0.01 s using photocells (Brower Timing TC-System, USA). Athlete 1 carried out 5 valid attempts and Athlete 2 carried out 4 valid attempts. The above mentioned inertial system, consisting of motion units, three-dimensional accelerometers, ensured high precision and accuracy and a minimal impact on the athlete’s exertion. Such systems are very reliable and utilised by scientists worldwide for the analysis of various movement patterns, among others by Lee et al. [17], Duffield et al. [18], Bergamini et al. [19] and Roland-Jimenez and Cuesta-Vargas [20]. Main hardware specifications included: full scale of angle ranges ±515°, full scale of accelerations ±16 g, internal sampling rate 800 Hz, and the minimal time sampling no smaller than 1 millisecond (ms). Studies using biomechanical analysis have been suggested as welcome and necessary by Graham and Harrison [21] as well as by Ozsu [22].

A standing calibration (Figure 2) was carried out before each trial, during which a standing straight posture was maintained. The upper limbs were straight and hanging freely along the torso, with palms directed inwards and finger tips towards the ground. Feet were apart from each other with toes directed forward (Figure 2). SafeLineFix adhesive surgical tape (Mercator Medical JSC., Poland) was applied to prevent any sensor displacement and fixed in such a manner that no movement restrictions were imposed on the participants. Additionally, each trial was monitored and recorded by two HD Pro Webcam C920 cameras (Logitech SA, Switzerland), as a tool supporting the analysis of the data provided by the inertial MyoMotion system. Camera 1 was placed directly beside the starting line, showing the athlete from the right side. Camera 2 was placed behind the athlete. In the post-run analysis, camera image helped to visually determine a desired body position for its kinematic description.

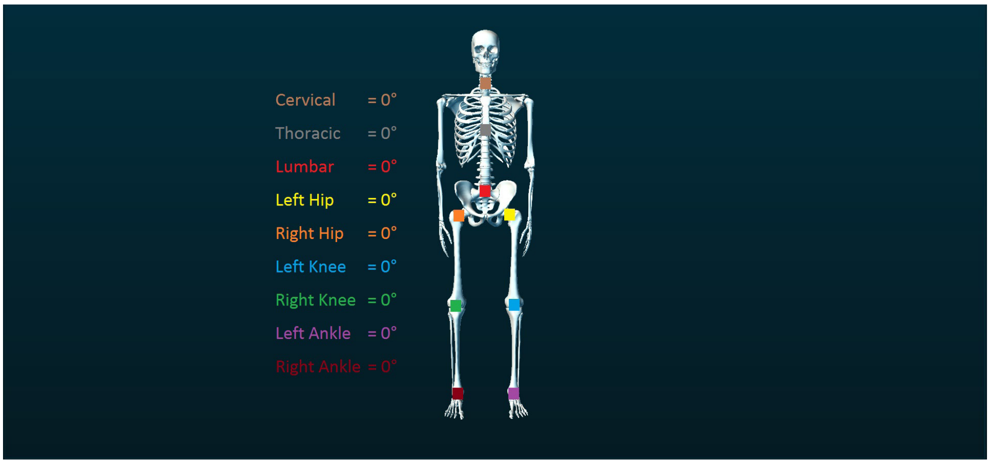

Fig. 2. Joints with corresponding neutral angles (zero degree) after successful calibration

DATA ANALYSIS

After each attempt, a brief data analysis was conducted followed by a quick short report. The whole data with its raw content was stored on a hard drive. Upon arriving at the laboratory, a full analysis and report were carried out. A thorough kinematic analysis was applied from the very moment the athletes stabilised their position after the “set” (Figure 3) command, until each athlete reached the moment of block clearance (Figure 4; the judgement was based on the avatar positioning that was displayed by the software). Subsequently, 10 steps of the 20-metre sprint were analysed (step count was verified with the help of the software avatar display).

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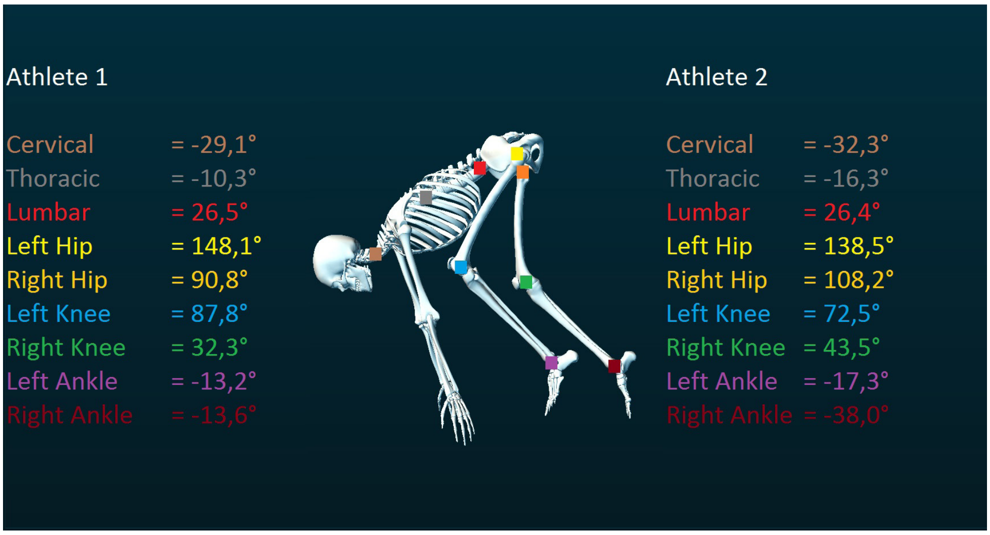

Fig. 3. Joint angles during “Set” command from best attempts

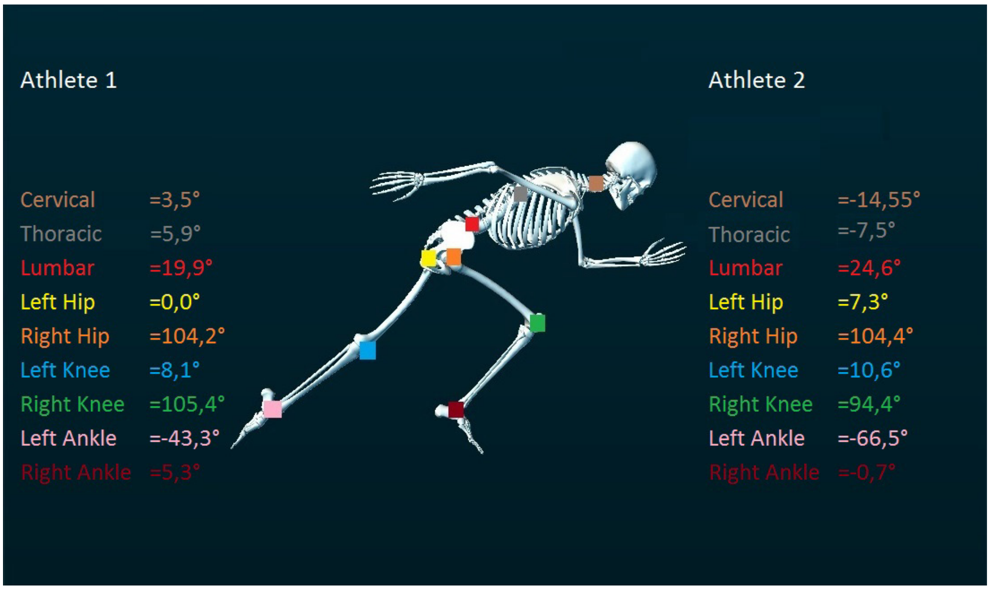

Fig. 4. Joint angles during block clearance phase.

RESULTS

The kinematic variables are displayed in Tables 1, 2, 3 and 4. Performance range of the measured attempts varied between 3.08 and 3.12 s for Athlete 1 and 3.06 – 3.13 s for Athlete 2. Both athletes had a strict conduct of behaviour regarding body positioning during the block start ("set" position) and they tried to emulate this style as best as possible across all attempts. Athlete 1 achieved approximately 145°, 95, 90, 42° in the left hip, the right hip, the right knee and the left knee, respectively, and Athlete 2 obtained approximately 135°, 105°, 75°, 45° in the left hip, the right hip, the right knee and the left knee, respectively (Table 1). However, upper limb joints were excluded from final analysis due to lack of association with performance. They were applied due to the sheer purpose of better data recording (more sensors equals more thorough data readings).

Table 1. Detailed angular characteristics of the "set" position

Cervical	Lumbar	Thoracic	Left Hip	Right Hip	Left Knee	Right Knee	Left Ankle	Right Ankle
Athlete 1								
Best performance = 3.08 s (Trial 4)								
-29.1	26.5	-10.3	148.1	90.8	87.8	32.2	-13.2	-13.6
Worst performance = 3.12 s (Trial 2)								
-27.0	28.9	-14.6	149.2	96.7	91.7	42.0	-10.5	-9.7
Athlete 2								
Best performance = 3.06 s (Trial 3)								
-32.7	36.4	-16.3	138.5	108.2	72.5	43.5	-17.3	-38.0
Worst performance = 3.13 s (Trial 1)								
-29.4	34.6	-23.2	138.5	105.0	78.3	46.4	-16.4	-27.4

The block clearance phase provided interesting data (Table 2). There were clear differences between the worst and the best attempts: 110.6° vs 121.1° (right hip), 96.5° vs. 106.4° (right knee) for Athlete 1 and 109.0° vs 118.4° (right hip), 99.7° vs 105.1° (right knee) for Athlete 2. No such situation took place in regard to angles in the ankle, thoracic, cervical, and lumbar body segments. The fact of striking importance is that the athletes had extremely repeatable results as regards the time of the block clearance phase: 0.32 s vs 0.34 s and 0.32 s vs 0.33 s for Athletes 1 and 2, respectively.

Table 2. Detailed angular characteristics at the moment of block clearance

Cervical	Lumbar	Thoracic	Left Hip	Right Hip	Left Knee	Right Knee	Left Ankle	Right Ankle
Athlete 1								
Best performance = 3.08 s (Trial 4) Block clearance = 0.32 s – Running time = 2.76 s								
3.6	14.2	7.2	3.6	110.6	9.6	96.5	-53.9	13.2
Worst performance = 3.12 s (Trial 2) Block clearance = 0.34 s – Running time = 2.78 s								
4.0	18.2	-0.5	4.7	121.1	4.3	106.4	-53.7	14.3
Athlete 2								
Best performance = 3.06 s (Trial 3) Block clearance = 0.34 – Running time = 2.72 s								
-13.4	23.8	-5.2	3.3	109.0	7.8	99.7	-56.8	0.6
Worst performance = 3.13 s (Trial 1) Block clearance = 0.35 – Running time = 2.78 s								
-11.3	22.1	-3.3	10.8	118.4	0.8	105.1	-58.2	-1.2

As to the 20-metre acceleration phase, the findings mentioned below indicate that a more deviating stride, i.e. one with an undesirable angle asymmetry between the left and the right side, resulted in overall movement hampering, which was associated with weaker 20-metre performance (Table 3, 4).

Table 3. Detailed angular characteristics of the 20-meter acceleration phase

Angles	Cervical	Lumbar	Thoracic	Left Hip	Right Hip	Left Knee	Right Knee	Left Ankle	Right Ankle
Athlete 1									
Best performance = 3.08 s (Trial 4) Block clearance = 0.32 s – Running time = 2.76 s									
Absolute Minimum	-10.0	5.0	-2.4	-14.8	-22.4	0.1	1.3	-63.3	-64.3
Averaged Minimum	-5.2	11.7	-1.2	-8.2	-16.9	12.3	3.4	-58.1	-62.6
Absolute Maximum	8.0	35.2	11.0	120.4	111.3	135.4	113.9	21.6	23.1
Averaged Maximum	7.0	33.6	9.9	112.3	102.2	126.6	107.6	14.9	15.7
Absolute Range of Motion	18.0	30.3	13.4	135.1	133.8	135.3	112.6	84.9	87.4
Average Range of Motion	12.2	21.9	11.0	120.5	119.2	114.3	104.2	73.0	78.3
Worst performance = 3.12 s (Trial 2) Block clearance = 0.34 s – Running time = 2.78 s									
Absolute Minimum	-7.7	9.3	-8.1	-8.3	-17.5	15.2	2.0	-52.9	-79.1
Averaged Minimum	-1.8	16.9	-4.6	-0.7	-11.0	17.8	9.4	-47.5	-63.3
Absolute Maximum	13.9	33.0	6.0	118.8	115.7	138.6	129.0	28.3	22.4
Averaged Maximum	12.4	31.8	4.2	116.5	111.5	128.1	111.1	24.1	18.0
Absolute Range of Motion	21.6	23.7	14.1	127.1	133.3	123.4	126.9	81.2	101.5
Average Range of Motion	14.2	14.8	8.8	117.2	122.6	110.2	101.7	71.7	81.3
Athlete 2									
Best performance = 3.06 s (Trial 3) Block clearance = 0.34 – Running time = 2.72 s									
Best	-20.6	-1.4	-2.9	-7.6	-13.7	-3.5	-0.6	-84.3	-65.0
Worst	-11.6	-1.4	-9.2	-13.4	-16.5	2.1	-14.1	-70.1	-59.9
Averaged Minimum	-16.7	3.5	-0.6	2.5	-4.2	5.0	3.4	-64.6	-57.6
Absolute Maximum	4.07	27.33	18.4	124.6	116	141.2	140.9	41.82	26.68
Averaged Maximum	0.9	24.6	16.4	117.8	112.9	133.1	133.5	6.8	16.2
Absolute Range of Motion	24.7	28.7	21.3	132.2	129.7	144.7	141.5	126.1	91.7
Average Range of Motion	17.6	21.1	16.9	115.4	117.2	128.2	130.2	71.5	73.9
Worst performance = 3.13 s (Trial 1) Block clearance = 0.35 – Running time = 2.78 s									
Absolute Minimum	-11.6	-1.4	-9.2	-13.4	-16.5	2.1	-14.1	-70.1	-59.9
Averaged Minimum	-11.0	4.2	-6.4	1.6	-6.3	8.5	0.9	-58.9	-54.4
Absolute Maximum	8.9	31.3	12.8	122.6	113.5	141.3	135.5	46.8	14.0
Averaged Maximum	4.2	29.2	12.0	117.6	108.3	131.7	132.6	15.2	1.7
Absolute Range of Motion	20.5	32.7	22.0	136.1	130.0	139.1	149.6	116.9	73.9
Average Range of Motion	15.2	25.0	18.4	116.0	114.6	123.2	131.7	74.0	56.1

Table 4. Angular absolute and percentage asymmetry between the right and left lower limbs during the 20-meter sprint after a block start. Best and worst performance were compared. The angle of the right limb is a reference value

Unit	Hip		Knee		Ankle		Sum	
	Best	Worst	Best	Worst	Best	Worst	Best	Worst
Athlete 1								
Degree	1.1	4.4	9.7	8.4	6.8	11.8	17.6	24.6
%	0.9	3.6	9.3	8.3	8.7	14.5	18.9	26.4
Athlete 2								
Degree	1.8	2.6	2.0	9.5	2.4	18.1	6.2	30.2
%	1.5	2.3	1.5	7.2	3.3	32.3	6.3	41.7

Such hampering can be noticed during the worst attempt of Athlete 1, where the sum of asymmetries between both sides in terms of average range of motion exceeded 24° (26.4%). During his best attempt the sum of deviations reached less than 18° (18.9%). Athlete 2 had both the best and the worst observed analogous asymmetry: 6.2° (6.3%) and 30.2° (41.7%), respectively. This is even more visible when we compare the biggest single fluctuations in one specific body segment during the best and the worst 20-metres performance. Prime examples are those of Athlete 2, where his best performance had only 2.4° (3.3%) deviation while his worst attempt reached an asymmetry of 18.1° (32.3%).

Detected fluctuations seemed to have a serious impact on 20-metres acceleration (Table 4). If we take a closer look at trial 3 (fastest) and trial 1 (slowest), we can observe that the ranges of acceleration between these attempts differed greatly: 12.16 G vs 13.52 G and 15.68 Gvs 14.84 G, respectively.

Table 5. Accelerations from the 20-m all-out sprint in two athletes

	Athlete 1				Athlete 2			
Acceleration	Head	Pelvis	Left Shank	Right Shank	Head	Pelvis	Left Shank	Right Shank
	Best performance = 3.08 s (Trial 4) Block clearance = 0.32 s – Running time = 2.76 s				Best performance = 3.06 s (Trial 3) Block clearance = 0.34 – Running time = 2.72 s			
Minimum	-5.56	-2.62	-5.89	-4.05	-5.34	-2.92	-5.88	-4.05
Maximum	4.38	6.28	6.27	9.47	3.93	5.79	6.29	9.47
Range	9.94	8.90	12.16	13.52	9.27	8.71	12.17	13.52
	Worst performance = 3.12 s (Trial 2) Block clearance = 0.34 s – Running time = 2.78 s				Worst performance = 3.13 s (Trial 1) Block clearance = 0.35 – Running time = 2.78 s			
Minimum	-5.64	-3.73	-4.77	-7.31	-6.99	-2.93	-6.68	-6.54
Maximum	5.92	3.86	8.22	8.42	3.96	4.90	9.00	8.40
Range	11.56	7.59	12.99	15.73	10.95	7.83	15.67	14.84

Taking the block clearance phase into consideration (Table 6), similar results are present. Differences observed during the block clearance phase equalled to 5.71 G and 9.06 G (trial 4 – fastest) vs 7.54 G and 11.81 G (trial 2 – weakest). Inspecting Athlete 2, there were significant disparities between his fastest and weakest attempts (trial 3 and 1 respectively). The values observed during those trials equalled to 6.19 G and 9.58 G (fastest) vs 6.11 G and 10.79 G (slowest).

Table 6. Accelerations during block clearance phase

	Athlete 1				Athlete 2			
Acceleration	Head	Pelvis	Left Shank	Right Shank	Head	Pelvis	Left Shank	Right Shank
	Best performance = 3.08 s (Trial 4) Block clearance = 0.32 s – Running time = 2.76 s				Best performance = 3.06 s (Trial 3) Block clearance = 0.34 – Running time = 2.72 s			
Minimum	-1.89	-0.45	-0.53	-3.02	-2.71	-0.32	-0.88	-2.74
Maximum	1.55	3.89	5.18	6.04	1.37	3.12	5.31	6.84
Range	3.44	4.34	5.71	9.06	4.08	3.44	6.19	9.58
	Worst performance = 3.12 s (Trial 2) Block clearance = 0.34 s – Running time = 2.78 s				Worst performance = 3.13 s (Trial 1) Block clearance = 0.35 – Running time = 2.78 s			
Minimum	-1.67	-0.79	-1.24	-5.39	-3.74	-0.48	-0.91	-4.57
Maximum	2.07	3.11	6.30	6.42	2.46	2.89	5.20	6.22
Range	3.74	3.9	7.54	11.81	6.2	3.37	6.11	10.79

DISCUSSION

The purpose of this research was to identify individual kinematic characteristics during block clearance and 20-metre acceleration phase in two highly-trained sprinters. The fastest attempts were picked as the model block starts and compared to the worst attempts. The main criteria of judgment were the angular and acceleration values and asymmetry present in individual body segments (assuming an asymmetry equal to 0 was ideal), as well as the sum of all the asymmetries present in hip, knee and ankle flexions (criteria for the average range of motion from all of the strides).

BODY POSITIONING DURING THE “SET” COMMAND

Our findings seem to correspond with angle ranges presented by Bezodis et al. [11, 23] in professional sprinters, especially in regard to the rear knee angle (78° and 95°). According to their findings, a specific leg extension (typically individual for each athlete) is also responsible for the overall outcome of the run. Our findings indicate that Athlete 1 was trying to achieve a “classical” 90°angle in his rear (left) knee while positioning himself during the “set” command. According to Harland and Steele [3] as well as Barret [2], such behaviour is extremely beneficial for the run outcome. However, his right leg’s knee positioning varied greatly throughout all the trials between 32.2° vs 42.0°. Despite these knee angle differences, he did manage to keep a very stable left hip angle range 148.1° vs 149.2° with a slightly fluctuating right hip angle 90.8° vs 96.7°.

When we take a closer look at the upper body angles during the “set” position, we can observe small differences between the best and the worst trials. Lumbar angles equalled to 26.1° vs 30.0°, cervical -24.9° vs -30.5° and thoracic -9.5 vs -16.5°, respectively. There seems to be no pattern in regard to ankle angles, with the exclusion of favouring a deeper dorsiflexion of the right ankle. All of the above indicates that there is an overall specific pattern (for each athlete individually) for body positioning during the “set” command. Athlete 1 tried to mirror this pattern as best as possible during each block start.

Angle values achieved in the rear knee by Athlete 2 also corresponded with findings presented by Bezodis et al. [11, 23]. Athlete 2 during the “set” position managed to maintain an even greater control and stability and the angles measured during the fastest and weakest trials were 72.5° vs 78.3° in his left knee and 43.5° vs 50.4° in his right knee, respectively. He continued to exhibit such stability in regard to hip angles: 133.3° vs 138.5° on the left side and 102.0° vs 108.2° on the right side, respectively. The upper body of this athlete had a little more fluctuations between the repetitions than in Athlete 1, but we can still find a pattern for each segment. Cervical angle values equalled to -38.6° vs -28.0°, lumbar angle 34.6° vs 36.9° and thoracic angle 22.0° vs -16.3°. When analysing ankle dorsiflexion, there was a greater difference on the right side (-38.0° vs -22.9°), than on the left (-18.2° vs -12.9°). This general pattern is also visible and quite characteristic of this particular sprinter.

Athlete 1 seemed to have a lesser degree of angular differences between the sides during the “set” position (i.e. the left to the right knee angle 87.8° vs 32.3° in the best sprint and 91.7° vs 42.0° in the worst sprint) than Athlete 2 (72.5° vs 43.5° and 78.3° vs 46.4°, respectively). The main difference was the entire body setup which both of them exhibited after the “set” command. As a side note for possible future research, it was quite noticeable that Athlete 1 was far more leaned forward than Athlete 2, because of the left knee and left hip positioning. The athletes varied here from each other by approximately 15°. We reckon that this may be a result of a personal code of conduct during the said phase. Considering all of the data explained above, the observations done during positioning after the “set” command did not provide clear and unequivocal evidence that the asymmetry during this phase was sure to guarantee if the 20-metre acceleration phase was successful or not (Athlete 1 had a bigger side difference during the best attempt, while Athlete 2 quite the opposite). The slowest attempts had very similar angular values as the fastest ones. The athletes did put a large amount of focus when positioning this particular joint. It may suggest that they wanted to be very certain that their block ejection was as best as possible and/or they wanted to ensure that their leading leg would have the best possible positioning support. Both of the athletes had a consistent pattern regarding their position of the hip of their rear leg. Similar observations have been reported by other scientists as well, for instance Ozsu [22] and Coh [16]. It seems that there is more than one particular standard model of body setting replicated during each trial by the athletes. Sprinters worldwide do seem to have their own code of conduct during this said phase, but each of them carries it in a distinct way (behaviour during entering the block and/or angles preserved while at it).

BLOCK CLEARANCE PHASE

Data provided in Table 2 indicate that the athletes had no or very little discrepancy between the fastest and slowest attempts when taking left ankle, right ankle, thoracic, lumbar or cervical angles at the moment of block clearance into consideration. Athlete’s 1 juxtaposition for the above equalled to -53.9° vs -53.7°, 13.2° vs 14.3°, 3.6° vs 4.0°, 14.2° vs 18.2° and 7.2° vs -0.5°, and for Athlete 2 it was -56.8° vs 58.2°, and -0.6° and -1.2°, 13.4° vs 11.3°, 23.8° vs 22.1° and -5.2° vs -3.3°, respectively.

It was not difficult to pin-point a presence of angle differences that took place between the trials during block clearance phase. Taking a closer look on the comparison of the worst vs the best attempts for the following joints, 110.6° vs 121.1° (right hip), 96.5° vs. 106.4° (right knee) for Athlete 1 and 109.0° vs 118.4° (right hip), 99.7° vs 105.1° (right knee) for Athlete 2, we could come to a conclusion that in those trials that had the right hip angle further than 110° and the right knee angle further than 100°, the block clearance phase lasted longer. The above seems similar (with some exclusions) to findings provided by Bezodis et al. [11], meaning that the desired front hip angle varies around 110°, whereas the front knee angle should oscillate around 70°. According to Debaere et al. [13], the control of propulsion is heavily connected with those two abovementioned joints. Aerenhouts et al. [24] also support the view that an appropriate technique applied in this phase determines the performance. Furthermore, according to Debaere et al. [12], during the transition phase, the sprinter actively prepares for a more forward leaning position, which corresponds with the above mentioned values in specific joints.

Another important fact to consider was the time of block clearance for each athlete. According to Harland & Steele along with Čoh et al. [3, 4], block clearance time and acceleration is key to a successful run. Neither of our athletes had a difference of great magnitude between the attempts; still it did differ them from each other. Athlete 1 needed 0.32 s and 0.34 s while Athlete 2 needed 0.32 s and 0.33 s during their best and worst trials, respectively. One hundredth of a second is more than enough to win or lose a gold medal, still the repeatability of the block clearance performance was sufficient.

It comes to no surprise that the differences are also present in regard to acceleration (Table 6). Athlete 1 had the left to the right shank acceleration values equal to 5.71 G and 9.06 G (trial 4 – the best) vs 7.54 G and 11.81 G (trial 2 – the worst). Athlete 2 had a bit smaller differences than his partner, equalling 6.19 G and 9.58 G vs 6.11 G and 10.79 G in the best and the worst trials, respectively. It is vital to comprehend that not only maximum acceleration during block clearance is the most important factor, but also the accompanying deceleration may prove fatal for the performance itself. For instance, Athlete 1 had the best overall acceleration in his right leg accompanied by his overall greatest deceleration during his worst attempt: +6.42 G vs -5,39 G. A point of notice is that no significant discrepancies were noticed in regard to head and pelvis accelerations in the best to the worst attempts comparison, 3.44 G vs 4.34 G and 3.74 G vs. 3.9 G for Athlete 1 and 4.08 G vs 3.44 G and 6.2 G vs 3.37 G for Athlete 2, respectively.

20-m all-out sprint of the acceleration phase

All of the data for each of the body segments should be analysed in a complex manner. First and foremost, an inspection ofeach joint has to be made separately (both sides, if applicable), then their conjunctions with other neighbouring body areas, and lastly the totality of all the measured segments. First of all, let us focus our attention on stride consistency. Both athletes achieved the best results only when their stride was very stable as regards the average range of motion between sides. The best performance (Table 3; 3.06 s, Athlete 2, Trial 3) had the smallest range of discrepancies between the left and the right side, namely 115.4–117.2° in hips, 128.2–130.2° in knees, and 71.5–73.9° in ankles. *Ipso facto* an average range of 3° in all of these joints indicates that the stride symmetry was near perfect. The best run performed by Athlete 1 (3.08 s, Trial 4) revealed a similar angle range in hips (120.5–119.2°), knees (114.3–104.2°) and ankles (73.0–78.3°). Despite being less divergent than Athlete 2, these results had still the best consistency through all of his trials.

In order to underline the importance of the movement symmetry let us also focus on the weakest attempts of each participant. In Athlete's 1 trial number 2 (3.12 s) the angles range in hips, knees and ankles were 117.2–122.6°, 110.2–101.7 and 71.7–81.3°, respectively. The worst trial of Athlete 2 was the very first one (3.13 s), angle range in hips, knees and ankles reached 116.0–114.6°, 123.2–131.7° and 74.0–56.1°, respectively. Even though hip ranges do not seem to stand out, the conjunction of all three pairs should be still taken into consideration. During their slowest attempts, both athletes had more than 20° difference in those body segments, which is roughly at least 50% greater than the differential observed during the fastest runs. According to Trivers et al. [8], not only stride symmetry is important, but also body symmetry is influential for sprinting performance.

If we take a closer look at accelerations, we can come to very similar conclusions. Attempts which are far less successful seem to have a higher fluctuation rate in the acceleration range between the left and the right side and between the head and pelvis. The least effective trial carried out by Athlete 1 was trial 2. The differences in this attempt between both sides (the left and the right shank) equalled 2.74 G, while the differences from trial 4 (fastest) reached 0.83 G and were thrice as small as during the slowest attempt. The analysis of the head to pelvis differential provides similar findings, where the fastest and slowest trials of Athlete 1achieved 1.04 and 3.97 G, respectively. We can also observe similar findings while analysing Athlete 2. His fastest trial 3 had a difference range between both sides (the left and the right shank) equal to 1.35 G as well as a difference range between head and pelvis equal to 0.56 G. The slowest attempt had a more stable side fluctuation: 0.84 G but, at the same time, the discrepancies between his head and pelvis reached 3.12 G. Based on this study, we can speculate that the safe margin which should not exceed about 1.40 G. In short, the asymmetry proves to be crucial for sprint performance.

As regards the running time, both Athletes did perform less perfectly in the block clearance and the acceleration phases simultaneously as concerns their best vs worst attempts, equalling to 0.32 s and 2.76 s vs 0.34 s vs 2.87 s for Athlete 1 and 0.34 s and 2.72 s vs 0.35 s and 2.78 s for Athlete 2, respectively (Tables 1–6). Athlete 1 made mistakes with a greater magnitude than his partnerbut surprisingly managed to carry out a trial with the best overall block clearance time: 0.32 s. Both of them had the same time of running during the acceleration phase when inspecting the worst of their attempts. During the fastest attempts Athlete 2 performed at a much better rate (2.72 s vs 2.76 s) than his teammate.

LIMITATIONS AND STRENGTHS

As stated above, the quantity of attempts and the number of athletes that participated in this study does not allow us to draw far-reaching conclusions. Further study with a greater number of sprinters representing similar (international) level is needed. What is more, such a study should be applied at least 3–4 times per year to track changes in the sprinting technique. Also, an accurate wind measurement device is advisable.

When considering the strengths of this experiment, it included elite national athletes which were capable of applying greater forces and thus carry out attempts of an international level. The athletes were measured during their tapering phase just before the world championships (Beijing 2015), thus providing important, reliable and valuable data from an actual outdoor training session. The equipment utilised during this study was specifically designed for human movement analysis. Its size and wireless capabilities limited the influence on the workout itself.

CONCLUSIONS

Fast block clearance and stride symmetry seem to be the key factor affecting sprint performance during the 20-metre acceleration and block clearance phase. At the moment of block clearance, rear hip and front knee angles should not exceed 110° and 100°, respectively. Greater stride asymmetry is associated with lower acceleration during the block clearance phase. Similar dependencies can be found regarding accelerations for each specific body segments. Based on our measurements, one can assume that the overall asymmetry in the said joints in the joints of a lower limb should not exceed ~20° and the asymmetry in one particular joint section should not exceed ~10°.

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