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SMALL DETAILS WITH GREAT EFFECTS ON SPEED RUNNING

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Abstract. *In sprint events, the start is a special issue, which has led us to conduct a more in-depth study of some biomechanical aspects that, on the one hand, may have permissive effects on performance or, conversely, may have a restrictive influence, depending on the stance adopted by the sprinter when getting into the "set" position for the block start. Ensuring optimal angles at the joints of the body segments enables the runner to quickly react when the starter's gun is fired, but especially to achieve the most efficient flexion-extension sequence of the lower limb joints (hip-knee-ankle) concurrently with providing the necessary balance that allows focusing attention on the sound of the gun. Carefully watching how the block start positions are approached, it has been found that no two athletes have the same stance at the "set" command and the same dynamics of the first steps. The different approaches to the speed running technique are mainly dependent on each athlete's morpho-functional characteristics, which will leave their mark on efficiency and specific training sessions. There are many situations in which some say that only a particular position allows them "to feel that they push best the starting block", while others try to imitate the start positions of certain sprinters they have seen in various television broadcasts just because they have noticed something special in their performance as compared to other athletes, but without understanding the degree of efficiency of those movements.*

Keywords: *speed running, starting block, push-off angle, reaction time, sprint running.*

Introduction

Tracking the progress of performance in the last period, we draw the conclusion that nowadays top results can only be achieved if the athlete masters the correct technique in the smallest details. For this reason, it is more and more often said that currently the details, even the smallest ones, make the difference in major competitions.

Milanese et al. (2014) suggest that coaches and athletes should pay more attention to the rear knee angle throughout the training process in order to reach high horizontal velocity at the "set" command in the starting block and acceleration phases.

According to Harland and Steele (1997), several variables have been studied regarding the block start, and research indicates that the adoption of a medium block spacing is preferred, with front and rear knee angles in the "set" position at about 90° for the front leg and 130° for the rear leg, from where the sprinter should be able to develop a high level of maximum force, especially in the horizontal direction.

Otsuka et al. (2015) highlight that the widened stance width in the "set" position during the block start phase, but this time from the left and right sides, "affects the hip joint kinematics and rear hip power generation during the block start phase but has no effect on the block-induced power when considering sprinting performance during the whole block start phase" (p. 12). Nagahara and Ohshima (2019) show that the location of the centre of pressure can influence the sprinter's performance regardless of the starting block location and angle.

In sprint events, the start is a special issue, which has led us to study some biomechanical aspects that may have either permissive or restrictive effects on performance, depending on the stance adopted by the sprinter when getting into the “set” position for the block start and the dynamics of the first steps.

Ensuring optimal angles at the joints of the body segments enables the runner to quickly react when the starter’s gun is fired, but especially to achieve the most efficient flexion-extension sequence of the lower limb joints (hip-knee-ankle) concurrently with providing the necessary balance that allows focusing attention on the sound of the gun.

After completion of the starting block phase, the technical efficiency of the running step decisively influences the final performance in sprint races.

Carefully watching how the start positions in the starting blocks are approached, it has been found that no two athletes have the same stance at the “set” command.

In most cases, the arguments are not based on biomechanical rules but only on subjective sensations, athletes saying that only a particular position allows them “to feel that they push best the starting block”, while others try to imitate the start positions of certain sprinters they have seen in various television broadcasts just because they have noticed something special in their performance as compared to other athletes, but without understanding the degree of efficiency of those movements, or maybe because an athlete crossed the finish line first on the last TV transmission.

The start is the beginning of the run and is very important in speed events, especially in indoor short-distance races or in the 100-meter race.

The stance adopted at the “set” command is represented by a series of motor gestures that, when correctly performed, help to both overcome the zero inertia and start accelerating due to the action of impulsive forces, which also include the length of reaction time.

During the start, all muscle groups should be engaged in their most efficient sequence. For the sprint event, the starting block phase has been addressed in many experimental biomechanical studies that mostly focus on the position that technically corresponds to the “set” command.

Slawinski et al. (2010) investigated the joint angular velocity and the kinetic energy of different segments in eight elite sprinters. Then, Slawinski et al. (2013) experimentally determined the effects of using joint angles in the “set” position during the block pushing phase, and their results showed that better synchronisation of the upper and lower limbs could lead to increased efficiency of the block pushing phase.

The research by Bezodis et al. (2015) suggests that sprinters should be encouraged to maximise extension at the hip joints during the block phase, which would result in higher block power production. The same researchers, Bezodis et al. (2010), demonstrate in another study conducted on a sample of 12 sprinters that the athletes’ morphological characteristics should be taken into account to increase their performance.

Studies have also been conducted regarding the morpho-functional activity of the body and its effects on the production of greater power during the starting block phase.

Mero et al. (2006) and Brazil et al. (2017) present a new perspective on the joint biomechanics in the starting blocks during sprinting but also on the contribution of lower limb joints to energy production in leg extensors.

The *purpose* of this paper is to highlight some biomechanical aspects that may have either permissive or restrictive effects on performance, depending on the stance adopted by the sprinter when getting into the “set” position for the block start. In order to develop the current research, we studied and made several kinograms that we considered to be most relevant to the block start, acceleration and sprint running for two athletes, Shelly-Ann Fraser-Pryce and Usain Bolt. This choice was determined by the fact that both of them are part of the elite and world-class sprinters.

Ciacci et al. (2017) have suggested that the start kinematics is only partially affected by the gender of sprinters, but an important role is played by their level of performance. Their study was performed on a sample of 20 sprinters (10 male and 10 female athletes).

In sprint events, the start is initiated from the blocks where the athlete places their feet apart so as to ensure the most comfortable and balanced position when the starter’s gun is fired. Theoretically, the block spacing should allow the synchronisation of maximum leg extension in the first starting block with the maximum point of swinging forward the rear block foot. There is another version but only for hurdle runners, with the front block closer to the starting line while displacing the rear block even much to the rear in order to produce the power and speed needed to reach the first hurdle within seven steps.

The block spacing in the position corresponding to the “on your marks” command will be established depending on both the height of the athletes and their balance in the “set” position.

To choose the block start position, we should keep in mind that:

- the time to push the first starting block is directly proportional to the distance between blocks and the extent of the flexion adopted at the knee joints and pelvis;

- the time to push the front starting block is longer as the pelvis is lower and the front block is closer to the starting line;

- the higher the pelvis rises above shoulder level, the wider the thigh-leg angles, which ensures the acceleration of body mass inertia as a result of the hip joint extension;

- the closer the distance between the arms to shoulder width, the greater the distance between the athlete’s torso and the track, thus ensuring a larger space for the efficient leg movement with an optimal range of motion;

- the more the arm strength allows displacing the shoulder projection over the starting line, the easier the task of breaking the acceleration (0) by stretching the strong muscles of the back.

The position presented in Figure 1 (Petrescu & Petrescu, 2016) shows that lowering the heel more than the minimum level allowed by the current construction of the starting blocks leads to some changes that make the sprint start more efficient, for example:

- increased opening of the angles at the hip joints and automatically the knee joints, thus enhancing their extension speed;

- increased speed and range of motion of the ankle joint extension;

- decreased arm pressure at the “set” position, an aspect that we consider important for the moment of focusing attention on the sound of the starter’s gun.

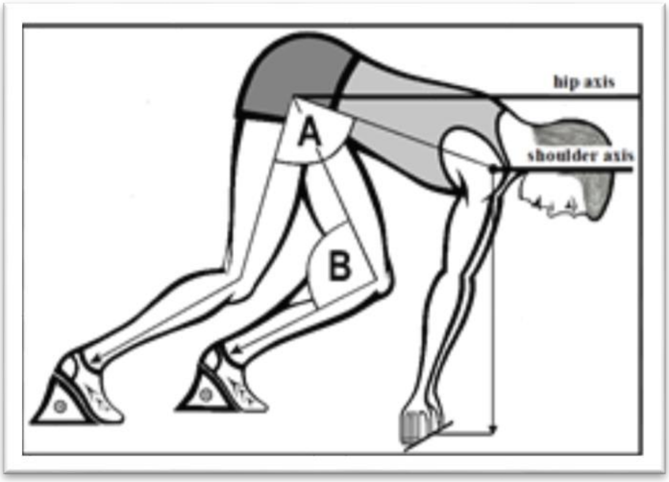

Figure 1. Position corresponding to the “set” command

We mention that Figures 1, 2 and 3 are adapted from Petrescu and Petrescu (2016).

Topic Addressed

Adopting the start position largely depends on the athlete’s morphological and functional qualities. These aspects determine how the starting blocks will be fixed, the distance from the starting line to the first starting block and the distance between the first and the second block.

In our opinion, the sprinter’s placement in the starting block:

- must ensure the optimal block spacing according to the athlete’s morpho-functional characteristics so that when the leg ends pushing the first starting block, the knee of the foot placed in the rear block reaches its maximum point of swinging forward;
- the closer the first starting block to the starting line, the farther the second starting block will be placed from the starting line;
- the foot placed in the second starting block will thus counterbalance the forward tilt of the body mass over the starting line;
- the stronger the athlete’s back muscles, the closer the first starting block can be placed to the starting line;
- the adopted position must ensure the highest possible pressure of the heels against the starting blocks in order to completely eliminate the rebound phase that occurs during the push-off. Such an approach ensures pre-tension in both the lower limb extensors and the torso (back) muscles so that the vigorous forward “plunge” performed by the athlete at the sound of the gun is as effective as possible;
- this forward plunge generated by the vigorous extension of the gluteal and back muscles causes the hands to lift from the arm support on the ground, triggering the forward projection of the athlete’s body mass.

However, there are opinions according to which an individual possessing greater strength in the muscular chains of the triple leg extension should close more the angles at the knee and hip joints in order to use that strength, which we do not consider quite correct.

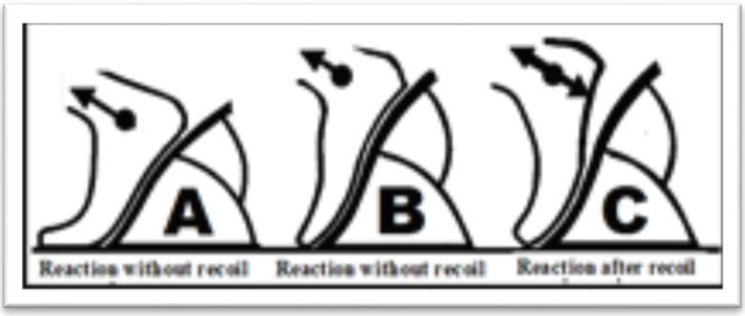

Figure 2. Foot placement in the starting block

To counter the heel rebound, some runners place their feet in the blocks so that, at the "set" command, the tips of their shoes "catch the plaid" (Figure 2 A). This approach also ensures better balance in the "set" position, allowing the runner to focus only on the sound of the starter's gun. It is recommended for those who do not have enough strength in their arms. This position, besides better balance and a balanced distribution of body weight between the four support points of the position corresponding to the "set" command, ensures the forward imbalance of the body weight over the arms, countering the heel rebound during the push-off (also see Figure 1).

Opinions on the sprint running dynamics are different, and some explanations are presented by Korchemny (1992), who recommends focusing on:

- a one- or two-leg starting effort;
- a vector of effort in the 45^0-50^0 range;
- vigorous arm movements.

There are many cases in which athletes focus their attention only on pushing the starting blocks and fail to properly coordinate their first steps, and this aspect can be observed even in athletes with good physical development. In this phase, a great pressure is exerted on the joints, which is why athletes who lack elastic (eccentric) strength need more time to recover from the pressure of the first steps, which has a negative influence on acceleration. For the sprint start, several technical ways of starting can be approached, for example: - short choppy strides; - long strides or power drive by progressively increasing frequency; - active first stride similar to the depth jump with rebound, and then actions similar to uphill running where the stride length and frequency are concurrently increased. (Korchemny, 1992)

Debaere et al. (2013) demonstrated the specifics of the sprint technique during the transition from the starting block to acceleration and sprint running in the case of well-trained sprinters.

In the study by Bradshaw et al. (2007), it was shown that the consistent generation of higher horizontal velocity during the sprint start led to more stable and faster post-block steps.

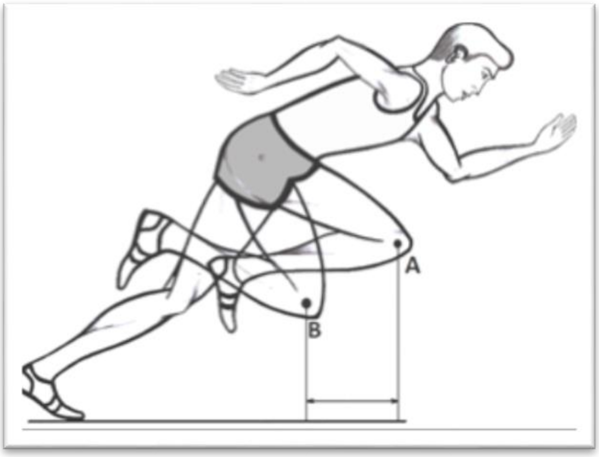

Figure 3. First step after the sound of the starter's gun

In Figure 3, we can notice that the heel of the push-off leg is lowered well below the angle of about 100^0-110^0, as much as the current starting blocks allow it. We mention this because, from our personal experience, we can say that the starts performed without using the starting blocks are technically more efficient than those using these blocks.

A technical error with negative effects on the efficiency of the first step, which is also transferred to the first 4-5 steps, consists in the fact that the flexion of the calf on the thigh occurs faster than the flexion of the thigh on the pelvis. This error, which seems minor at first sight, causes a difference of about 1.5 m less in step 7/8 compared to an athlete of the same value but with correct execution. For a better understanding, the sequences are presented in Figure 4.

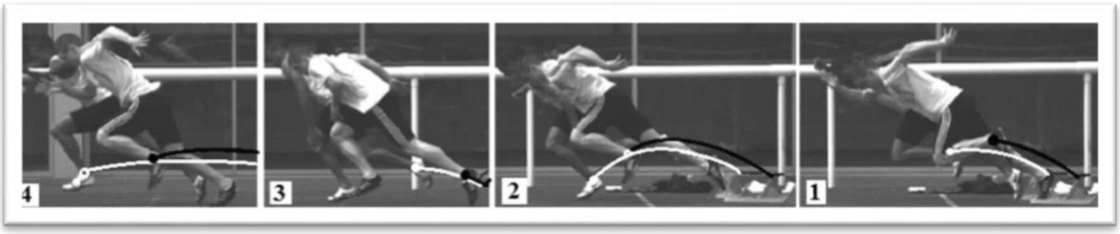

Figure 4. Comparative sequences of two different executions of the first two steps

In the economy of the block start, an important biomechanical aspect refers to the way in which ground contact is achieved. Ideally, the shock absorption time should be reduced as much as possible. Contact with the running track should be done with the foot in dorsiflexion so that the heel "just" does not touch the ground.

For a better understanding, we present some sequences with the former world champion Shelly-Ann Fraser-Pryce, whose performance is closest to what we have stated above.

Figure 5. Fraser-Pryce's first post-block steps (sequences processed after Shelly-Ann Fraser-Pryce, Block start slow motion, World Championships, 2011)

In Figure 5, sequence 1, it can be seen that, by the position adopted at the "set" command, the knee angles exceed the value of 90^0; the rear leg is moved forward by actively pulling the tip of the foot forward and reaching the surface of the track in maximum dorsiflexion.

To maintain the impulse vector in the optimal direction and create a space between the torso and the running track, which allows performing the steps with optimal range of motion, the torso should be slightly tilted (Bergamini et al., 2013) at the hip joint and thus the pelvis remains at a higher level, which helps to maximally exploit the stride length without reducing its frequency.

From the second step, ground contact is already made almost on the whole foot and is maintained like this until the acceleration phase is completed (Figure 6).

Figure 6. Fraser-Pryce's landing after the 5th step and exiting to the 6th step (sequences processed after Shelly-Ann Fraser-Pryce, Block start slow motion, World Championships, 2011)

This way of approaching the dynamics of the first 7-8 steps, specifically up to about 10 m, meets the conditions for preserving the force actions that are suggestively explained by Gagea (2006), who states that, when starting a movement produced by muscle contraction, the active force tends to be preserved in the form of inertial force.

Completion of the block start is followed by the sprint running that, in order to become as efficient as possible, should be analysed according to the principle that we live under the influence of gravity throughout our lives.

We present below a biomechanical analysis of Usain Bolt's running technique that, in biomechanical terms, can be considered to be closest to "perfection", which is why he may be the best example for such an analysis.

In this regard, we made a kinogram of Bolt's running step.

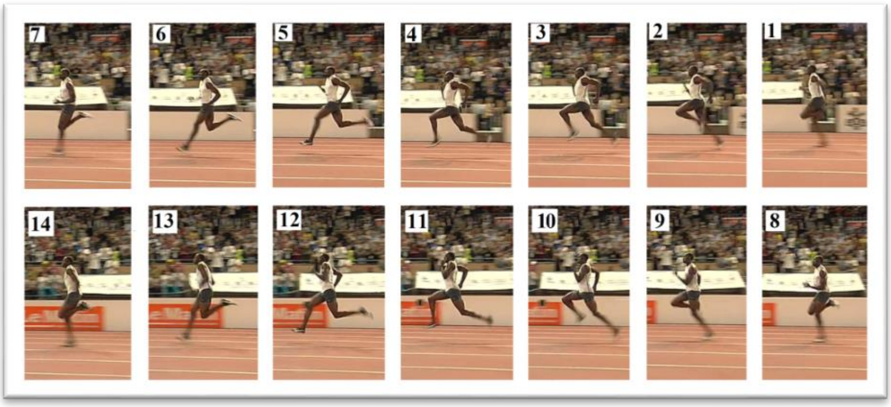

Figure 7. Kinogram of Usain Bolt's double running step (sequences processed after Usain Bolt - Lausanne, 2008)

The sequential analysis of Usain Bolt's running step (Figure 7) at the point of maximum effort reveals that sequence 1 (corresponding to the vertical moment with support on the right foot) and sequence 8 (corresponding to the vertical moment with support on the left foot) are almost identical ("in the mirror").

Analysing these two sequences in terms of dynamics of the body segment movements during the running steps, it is noted that they are almost identical as regards the specific phases of the swinging segments and the execution speed of the "scissoring" (all being performed with maximum range of motion by the swinging segments) but also the support moments.

After the vertical moment (Figure 7, sequence 2, corresponding to the moment of support on the right leg, and sequence 9, corresponding to the moment of support on the left leg), the upper limb segments have a compensatory action in the direction opposite to that in which the lower limbs swing in order to ensure optimal balance. The vertical moment is followed by the drive (push-off) phase and its completion, thus making the transition to the next phase, i.e., the flight phase (Figure 7, sequence 3, for the right leg, and sequence 10, for the left leg).

In Figure 7, the knee of the left swinging leg (sequence 2) and the knee of the right swinging leg (sequence 9) are vigorously pushed forward, reaching the maximum point of the swing and thus shortening the pendulum motion and decreasing the high speed of this motion.

Completion of the push-off and transition to the flight phase performed by the right foot (Figure 7, sequence 3) and the left foot (Figure 7, sequence 10) are all the more efficient as the swinging leg acts faster forward, with the knee swinging forward in maximum flexion.

The compensatory arm actions performed after completion of the support leg push-off are opposite to the swinging leg, and in the final phase, the fist's vertical plane of the arm that swings backwards should not exceed the elbow's vertical plane towards the rear. The arm swing is an important aspect for shortening the support duration due to the vector produced by the inertia of their masses that, if correctly oriented, generate ascending vectors.

The optimal flight height is also favourably influenced by the efficiency of the way in which the inertias generated by the swinging segments act and add up to the strength of the support leg (push-off, impulse).

To efficiently add up the inertias generated by the swinging segments (arms and leg), they should reach the maximum point of swinging forward together with the impulse completion.

The efficiency of the running step results from maintaining the high flight trajectory tuned with the running steps, which contributes to developing the inertia accumulated by the athlete's body mass on the push-off completion, to which is added the inertia generated by the swinging leg at the maximum point of the forward and upward swing at the same time with the impulse completion.

Maintaining the height of the GCM (general centre of mass) trajectory will result in lower ground support contact, which will automatically increase the frequency of running steps.

The arm on the side opposite to the support leg acts at the backward vertical moment as a long pendulum, and in the forward swing phase, as a short pendulum.

During leg "scissoring" in the flight phase, the leg that has just completed the push-off begins to perform rapid flexion at the knee joint reaching the maximum point of flexion when the knee moves ahead of the support leg, and in the next phase, it accelerates its forward and upward swing, the thigh being horizontal on impulse completion.

The better the maximum point of the knee's forward swing is synchronised with the impulse completion, the more efficient the running step.

The compensatory inertias generated by the swinging segments should be efficiently used in the running step, mainly to maintain the height of the GCM trajectory.

These two aspects will automatically reflect in the shortening of ground support time and frequency index (both aspects influence the reduction of the final time). In other words, all the running sequences respect the pendulum law and the law of mass inertia compensation for each segment involved in the movement performed.

In the movement specific to physical activity, regardless of the sport concerned, the efficiency of all technical executions depends on how the upper and lower limbs act according to the principle of mechanical laws but especially the pendulum law.

The interaction between the inertias of each swinging segment of the body during the execution of different technical sequences can be deduced from Figure 8, where the sequences through which the short pendulum passes under the action of gravity run twice as fast as the sequences through which the long pendulum passes.

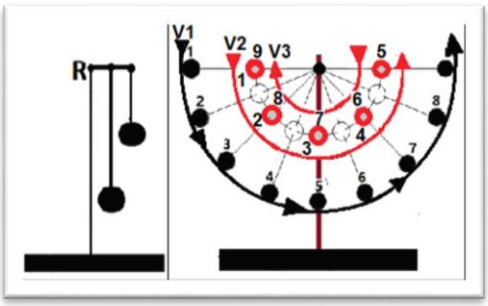

Figure 8. The comparative action of two pendulums whose length ratio is 1/2

It is observed that the two pendulums whose length ratio is 1/2, which both start in the same point, have angular velocities proportional to the lengths of their own arms.

If we extrapolate this principle to the block start, acceleration and sprint running phases, the leg that completes the push-off begins the "scissoring" motion simultaneously with the flexion of the calf on the thigh, while the leg that has completed the swing stretches for ground contact as close as possible to the GCM projection on the ground or to the running step.

For maximum efficiency of the leg "scissoring" in the flight phase, the direction (trajectory) in which the inertias of the masses of swinging segments (arms and legs) act proves to be important. Specifically, on ground support, all the swinging segments must act forwards and upwards so as, together with the impulsive force, to impart the body mass as much forward and upward inertia as possible, and in the second part of the flight phase, when the ascending inertia of the same swinging segments becomes equal to gravity, they will act downwards and backwards in terms of antigravity to maintain the body mass inertia forward.

To better understand this mechanism, Figure 9 shows the actuation principle of two articulated pendulums that have the same mass, but their length ratio is 1/2.

In order for the swing of the two pendulums to have the same angular velocity but in different directions (like the "scissoring" motion in the flight phase of the running step), the point of rotation (R) of the system moves downwards along the long pendulum's arm so that the initial articulation point in A1 moves to point A2 during the swing. This distance (A1-A2) will depend on the range of motion and accuracy with which the "scissoring" presented above is performed and is proportional to the length of the lower limb segments.

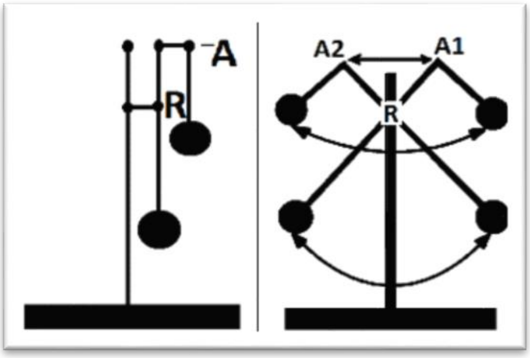

Figure 9. The short pendulum-long pendulum couple articulated at one end (A), with equal masses and the same angular velocity

Starting from the above and taking into account that the human body is multi-articulated, all the movement sequences respect the pendulum law and the law of mass inertia compensation for each segment involved in the movement performed.

In the movement specific to sport activity, regardless of the sport concerned, the efficiency of all technical executions depends on how the upper and lower limbs act according to the principle of mechanical laws but especially the pendulum law.

The mathematical model of speed running is generated by the alternate and successive triple extension of the lower limb joints during an explosive power action as a measure of the instantaneous maximum anaerobic power considered a measure of the take-off performance.

Biomechanical analyses highlight the interaction between the sequences that influence the push-off/block clearance and the transition to the first step, followed by the rapid acceleration of the next steps up to the maximum speed (Ionescu-Bondoc, 2018). In this regard, we can highlight those detail aspects that might have a good influence on athletic performance, but also some aspects that prove to be restrictive to increase performance in speed running.

Conclusion

In order for the start to be effective, the runner must ensure optimal angles at the triple extension of the lower limbs, which is necessary for the most efficient mobilisation of the muscle groups involved in the triple leg extension. The wider the angles at the knee joints, the more the back and thigh muscles (considered to be the strongest) are used efficiently, impulse completion being much better achieved by the ankle extensors that act after the runner's body mass has already accumulated an initial inertia close to the maximum one.

The higher the pressure on the heel as it goes down backwards, the lower the pressure on the arms, which can more easily leave the ground support.

Concurrently with meeting the requirements described for the "set" position, conditions are created to focus attention only on the quick reaction to the sound of the starter's gun.

For efficient running, the inertias of the swinging segments must act in the same direction as the vector generated by the push-off leg, namely forwards and upwards (Figure 7, sequences 2 and 3 for the right leg and sequences 9 and 10 for the left leg).

The inertias generated by the swinging arms, which abruptly stop at the end of impulsion, will generate an inertia that shortens the ground contact time of the push-off leg.

The efficiency of the inertias generated by the arm action (Figure 7, sequences 3 and 4 for the support on the right leg and sequences 10 and 11 for the left leg) acts on the elbow as a result of maintaining the fist's vertical plane ahead of the elbow's vertical plane (at an angle below 90º), which generates an upward-oriented inertial vector.

The inertial vector of each arm shortens the braking vector (represented by the distance between the GCM projection on the ground and the point of ground contact of the support leg).

At the vertical moment, the arm opposite to the support leg swings backwards almost stretched, while the arm opposite to the swinging leg swings forward as a short pendulum (Figure 7, sequences 1 and 14 for the right leg and sequences 2 and 7 for the left leg).

Authors' Contributions

Both authors have equally contributed to this study.

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