Biomechanics of the Sprint Start

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Introduction

In track and field athletics, sprint races cover a range of distances from 60m up to 400m. Under the International Amateur Athletic Federation (IAAF) rules such races start from a crouched position in blocks. There are three main types of crouched positions: the bullet, the medium and the elongated positions (Hay, 1993). A crouched start is more effective than a standing start as it places the sprinter in a position to move the centre of gravity rapidly well ahead of the feet and thus the runner must accelerate very quickly or else fall (Adrian & Cooper, 1995). The start, however, must not be thought of as a separate part of the whole race. It is an integral part of the total race and consequently is not distinct from the entire sprinting event. Stampf (1957:53-54), cited in Barlow & Cooper (1972:27), commented that:

"The important thing is to reach top speed as quickly and smoothly as possible, and this can only be done if the rhythm of the stride begins actually in the starting blocks."

Movement from the set position in the sprint start must not only be fast and forceful but should permit the sprinter to rapidly take up a mechanically efficient running position (Barlow & Cooper, 1972).

Hay (1993) has commented that of all the sports techniques that have been subjected to biomechanical analysis, few have been more thoroughly examined than the sprint start. Scientific research on sprint starting dates back as far back as 1927 when Bresnahan investigated the difference between starting from holes dug in the ground and starting from blocks. Research has dealt with many factors that affect the sprint start such as the angle of the blocks, the block spacing, the forces exerted against the blocks, and the body position during the "set" phase of the sprint start.

A Description of the Sprint Start

The sprint start is a motor skill. Magill (1993:7) refers to a motor skill as "…an action or a task that has a goal and that requires voluntary body and/or limb movement to achieve the goal". Specifically, the sprint start could be categorised as a gross, continuous, closed motor skill. It is a "gross" skill in that it involves large musculature and the precision of movement is not as important to the successful execution of the skill as it is for fine motor skills. It can be considered "continuous" because the performer determines the beginning and end points of the skill and they are not specified by the skill itself. On the open-closed continuum the sprint start is closer to the closed anchor point than the open, since it takes place under fixed, unchanging, environmental conditions (Magill, 1993).

A starter gives three commands to start a sprint race. These are "On your marks"; "Set" and then "Go" or else a gun is fired. When the athlete hears the initial command, "On your marks", he/she moves forward and adopts a position with the hands shoulder width apart and just behind the starting line. The feet are in contact with the starting blocks and the knee of the rear leg is in contact with the track. On hearing the command "Set" the athlete raises the knee of the rear leg off the ground and thereby elevates the hips and shifts the centre of gravity up and out. Then on the command "Go" or when the gun is fired the athlete reacts by lifting the hands from the track, swinging the arms vigorously and driving with both legs off the blocks and into the first running strides. See Appendix 2 for a list of coaching points for the "On your marks", "Set", and "Go" phases of the sprint start.

Purpose of the Sprint Start and It's Objectives

The purpose of the sprint start is to facilitate an efficient displacement of the athlete in the direction of the run. It enables the sprinter to start the race with his/her body sloping as required for acceleration (McNeill Alexander, 1992). Bunn (1955:105), cited in Barlow and Cooper (1972:27-28), stated that:

"In starting, the emphasis is upon getting away from the mark as quickly as possible, and then into a position that will be favourable to developing the desired pace in the shortest distance".

The objectives of the sprint start can be seen below. The overriding principle is that it allows the athlete, if executed properly, to leave the blocks on balance and with maximum velocity.

1. To establish a balanced position in the blocks.
2. To obtain a body position where the centre of gravity is as high as is practical and slightly forward of the base of support.
3. To apply force against the blocks in a line through the ankle, knee and hip joints, the centre of the trunk and head.
4. To apply this force against the blocks and through the body at an angle of approximately 45°.
5. To establish the optimum knee joint angles in both the front and rear leg.
6. To clear the blocks on balance and with the greatest possible velocity.

Adapted from Richburg (1990) and Tellez & Doolittle (1984)

Types of Sprint Start: Which is the Most Effective?

There are three types of sprint start:

1. Bunch or bullet start
2. Medium start
3. Elongated start

According to Hay (1993) the main difference between these three starts lies in the longitudinal distance between the toes of the front foot and the toes of the rear foot when the athlete is in the "On your marks" position. This distance can be referred to as the toe-to-toe distance or the inter-block spacing.

When an athlete adopts the bunch or bullet start the toes of the rear foot are approximately level with the heel of the front foot (Hay, 1993). Both feet are placed well back from the starting line (Warden, 1986). Hay has indicated that the toe-to-toe distance is between 25 and 30 cm. In the elongated start, the athlete places the knee of the rear leg level with or slightly behind the heel of the front foot. The toe-to-toe distance in this case is between 60-70cm (Hay, 1993). Finally, the medium start involves the knee of the rear leg being placed opposite a point in the front half of the front foot (Hay, 1993). This results in a toe-to-toe distance of 40 to 55cm.

The question now arises as to which of these three types of starting positions will produce the best sprinting results. Firstly there is a need to examine what is meant by the term impulse. In order to clear the starting blocks on the command "Go" the athlete must produce a force over a certain time period. The product of this force (F) and the time (t) is known as the impulse of the force.

$$\text{Impulse} = F \times t$$

A useful relationship, impulse-momentum relationship, can be obtained by substitution as follows:

F = ma.....m = mass.....a = average acceleration
However, a = (vf - vi)/t.....vf = final velocity.....vi = initial velocity

Therefore, F = m(vf - vi)/t
Or, F = (mvf -mvi)/t
Hence, Ft = mvf - mvi

This equation states that the impulse of the force is equal to the change in momentum that it produces. When an athlete is in the starting blocks his/her initial momentum is zero (mvi = 0). In addition, the mass of the athlete is constant and because of this the velocity of the athlete on leaving the blocks is directly proportional to the magnitude of the impulse exerted on the blocks but opposite in direction. The greater the impulse exerted the greater the velocity of the athlete. As Warden (1986) notes, exerting a high force for a long period of time produces speed from the crouch start.

So which of the three types of crouch starts will allow the athlete to be in the anatomically best position to produce the highest possible force in the longest practicable time? The bunch start limits the impulse that can be exerted against the blocks because the athlete is only in contact with the blocks for a relatively short time period and thus has less time to exert forces against them. With the elongated start, the athlete has a far greater amount of time over which he/she can exert force against the blocks. This type of start however, does not allow a very great force to be generated because of the athlete's body position in the set phase. The medium start is a compromise between the fast clearance produced by the bullet start and the greater amount of time provided by the elongated start (Warden, 1986). It allows the highest possible force to be produced for the longest practicable time. Therefore it facilitates the athlete in producing the greatest impulse and leaving the blocks with the highest velocity.

Research findings exist to support this. Henry conducted a study in 1952 that investigated the effects that four different inter-block spacings had on the performance of the crouch start. He attempted to find out which type of crouch start was most effective. Reaction time as well as performance times to 10 yd and 50 yd of the 18 subjects were all recorded. Force-time graphs of the leg thrust during each start by the subjects were also obtained. From his results, see Table 1.

Henry concluded that:

1. Use of the 11 inch (28 cm) bunch stance results in clearing the blocks sooner but with less velocity than secured from medium stances, resulting in significantly slower time at 10 and 50 yards.
2. The highest proportion of best runs and the smallest proportion of poorest runs result from starting with a 16-inch stance (41cm). A 21 inch (53 cm) is nearly as good. Both of these are medium stances.
3. The experimental results are, in general, consistent with theoretical expectations and apply to sprinters differing in ability and skill.

This experiment illustrated the point that "…the time lost from starting with the blocks in the medium or elongated position will be more than regained in the first few yards due to the greater block velocity as compared with the bunch start" (Henry, 1952:304). Sigerseth and Grinaker (1963) conducted a similar study and their findings supported those reported by Henry that the medium start offers an advantage to the sprinter over that provided by the elongated or bunch starts. Sigerseth and Grinaker also concluded that the largest number of fastest sprints were made from the medium starting position, the next largest number from the bunch starting position and the smallest number from the elongated starting position (see Table 2). This supports the fact that there is a definite relation between a good starting impulse and a fast start (Henry, 1952).

Table 1: Time and Velocity Characteristics of Crouch Starts Using Various Block Spacings (Mean Values)				
Block Spacing	11in.(28cm)	16in.(41cm)	21in.(53cm)	26in.(66cm)
Time on blocks (that is, time from the gun to front foot leaving)	0.345 s	0.374 s	0.397 s	0.426 s
Block Velocity (that is horizontal velocity as athlete leaves blocks)	6.63 ft/s (2.02m/s)	7.41 ft/s (2.26 m/s)	7.50ft/s (2.29 m/s)	7.62ft/s (2.32 m/s)
Time to 10 yd (9.1m)	2.070 s	2.054 s	2.041 s	2.049 s
Time to 50 yd (45.7m)	6.561 s	6.479 s	6.497 s	6.540 s
Adapted from data in Henry (1952)				

Table 2: Number of Fastest Sprints Made from Three Starts			
Yards Sprinted	Bunch Start	Medium Start	Elongated Start
10	5	17	6
20	7	16	5
30	11.5	10	6.5
40	9	13.5	5.5
50	12.5	13.5	2
Totals	45	70	25
Adapted from Sigerseth and Grinaker (1963)			

In conclusion, it appears that the medium start offers an advantage to the sprinter. It allows the sprinter to exert a high force against the blocks for the longest practicable time. This in turn produces the maximum impulse and hence the athlete clears the blocks with the greatest possible velocity as compared with the elongated or bunch start. This is true because as already explained the velocity of the athlete on clearing the blocks is directly proportional to the impulse exerted against them. Studies by Henry (1952) and Sigerseth and Grinaker (1963) support the medium start as being the one that offers the most advantage to the sprinter. McFarlane (1981:36) has noted that:

"The medium start has been proven superior over both the bunch and elongated starting positions in providing the compromise needed to allow for a fast acceleration of the centre of gravity, good forward lean and the maximum impulse."

Since the medium starting position is the most effective it is the one that novices should be encouraged to use when learning the starting technique (Faithful, 1986; Hay, 1993; McNab, 1972; Sigerseth and Grinaker, 1963; Tellez and Doolittle, 1984; Warden 1986). In this research study, therefore, the medium starting position will be taught to and imaged by the novice subjects.

Biomechanical Analysis of the Strint Start

As noted previously, the sprint start has been the focus of much research over the past number of decades. The "set" position (Baumann, 1976; Mero, Luhtanen and Komi, 1983; Mero, 1988), reaction time (Baumann, 1976; Henry, 1952; Payne & Blader, 1970) and force-time characteristics (Baumann, 1976; Henry, 1952; Mero et al., 1983, Mero, 1988) have been the variables commonly investigated. The aspect that is relevant for review in this thesis is the "set" position.

Two studies in particular researched the position of the athlete during the "set" phase of the sprint start: Mero et al. (1983) and Mero (1988). Mero et al. (1983) conducted a biomechanical study on 25 male subjects of varied abilities. Force production, reaction time and "set" position data were collected and analysed. Of particular interest here is the "set" position data. Each subject performed 3 runs over a 10m distance on a tartan type indoor track. The fastest run of each subject was selected for film analysis. Every second frame from the set position up to the third contact phase was analysed using a Vanguard film analyzer, Summagraphics 10 digital board and HP 21MX computer. The mechanical model of the runner was assumed to consist of 14 rigid body segments and the segmental landmarks were marked on the skin with black ink.

The subjects were divided into three groups based on sprinting ability. The best sprinters (n=8) were placed in the first group and their mean 100m record time was 10.8 ± 0.30s. The results of the analysis of the best sprinters body positions in "set" can be seen in Table 3.

Table 3: Values of the Best Sprinters in "Set" Position	
Measures	Values *(Mero et al, 1983)
Front Ankle Angle (q1)	115 ± 9°
Rear Ankle Angle (q4)	106 ± 8°
Front Knee Angle (q2)	111 ± 9°
Rear Knee Angle (q5)	134 ± 14°
Front Hip Angle (q3)	41 ± 14°
Rear Hip Angle (q6)	80 ± 13°
Angle of the Trunk (q7)	29 ± 9°
Angle of the Arms(q8)	106 ± 7°
Height of the Centre of Gravity (h)	0.605 ± 0.037m
Horizontal distance of Centre of Gravity (f)	0.189 ± 0.089m

Mero conducted a similar study in 1988 and used eight experienced Finnish male sprinters with a mean 100m record time of 10.79 ± 0.21s. The methodology used was the same as his 1983 study. The results of the analysis of the eight experienced sprinters body positions in "Set" can be seen in Table 4. The values in Table 4 could be referred to as "optimal" values for the "set" position. However, the centre of gravity (C.G.) values, especially the C.G. horizontal distance, differed greatly from previous research. Mero (1988:96) specifically referred to this in the discussion and stated that "...in order to make it (sprint start) more efficient, the body C.G. should be positioned about 0.1m forward."

Table 4: Values of the Sprinters in "Set" Position [2]	
Measures	Values *(Mero, 1988)
Front Ankle Angle (q1)	94 ± 4°
Rear Ankle Angle (q4)	96 ± 8°
Front Knee Angle (q2)	96 ± 12°
Rear Knee Angle (q5)	126 ± 16°
Front Hip Angle (q3)	39 ± 7°
Rear Hip Angle (q6)	77 ± 9°
Angle of the Trunk (q7)	21 ± 7°
Angle of the Arms(q8)	104 ± 8°
Height of the Centre of Gravity (h)	0.57 ± 0.04m

Horizontal distance of Centre of Gravity (f)	0.29 ± 0.05m

In instances when a subject ran a distance in the same time from two of the starting positions, his performance was given one-half point.
