KINEMATIC TRENDS IN ELITE SPRINTERS

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During the 1982 and 83 outdoor track and field seasons, selected Olympic caliber *men* (*n*>15) and *women* (*n*>20) sprinters (100m - 400m) were filmed in up to five top level competitions. These athletes were subsequently biomechanically analyzed under a grant from the United States Olympic Committee. The purpose of this effort, termed the Elite Athlete Project, was to provide feedback to the involved athletes regarding their strengths, weaknesses, and potential areas of performance improvement.

For the purpose of obtaining the critical kinematic data, the sprinters were filmed, using a high-speed camera (100 fps), oriented to record each performer in the sagittal plane. The camera was positioned to record the performer at maximum speed, on the straight. The filmed results were digitized, computer processed, and analysed with interest focused on those kinematic patterns that have previously been identified as indicators of the quality of sprint performance. The variables selected for presentation were derived from internal research (Mann and Sprague, 1980, Mann, 1981, Mann and Sprague, 1982; Mann and others, 1982; Sprague and Mann, 1983), selected external research (Armstrong and Costill, 1984; Atwater, 1982; Bates and Haven, 1973; Bunn, 1972; Cavagna and others, 1971; Deshon and Nelson, 1964, Dillman, 1971; Elftman, 1940, Fenn, 1930; Hay, 1978; Hoffmann, 1971; Hoffmann, 1972; Kuntz and Kaufmann, 1981; Luhtanen and Komi, 1978, Mann and Hagy, 1980, Mehrikadze and Tabatschnik, 1982; Sinning and Forsythe, 1970), and input from the involved coaches as the project progressed.

To rate the kinematic performance of each sprinter, it was necessary to identify certain total system as well as individual segment results. Results such as stride rate or stride length were selected to indicate how the total system was integrating the contributions of the segments toward performance. Individual results such as upper leg orientation at specific positions or lower leg rotational speed during selected phases were chosen to denote how the body parts contribute to performance. The examples presented in this section are for the elite athlete male 100 meter performers examined to date, however, except where indicated, the trends can be expanded to cover all sprinters.

STRIDE RATE AND STRIDE LENGTH (TOTAL BODY RESULT)

The speed at which a sprinter moves his legs (stride rate) and how far each stride covers (stride length) determines the success of the performance. An ideal situation includes a high stride rate coupled with a large stride length. The following two graphs show the average stride rate (Figure 1) and stride length (Figure 2) for all male 100 meter elite athletes investigated to date. In addition, values indicating magnitude and direction of results deemed good and poor are indicated. On both graphs, results shifted toward the poor category indicate a weakness in the sprint performance, while results shifted toward the good category can be beneficial if the corresponding value is not decreased. Thus, a high stride rate is good, but only if stride length is maintained at an acceptable level. Likewise, a large stride length is beneficial, but only if an acceptable stride rate is maintained.

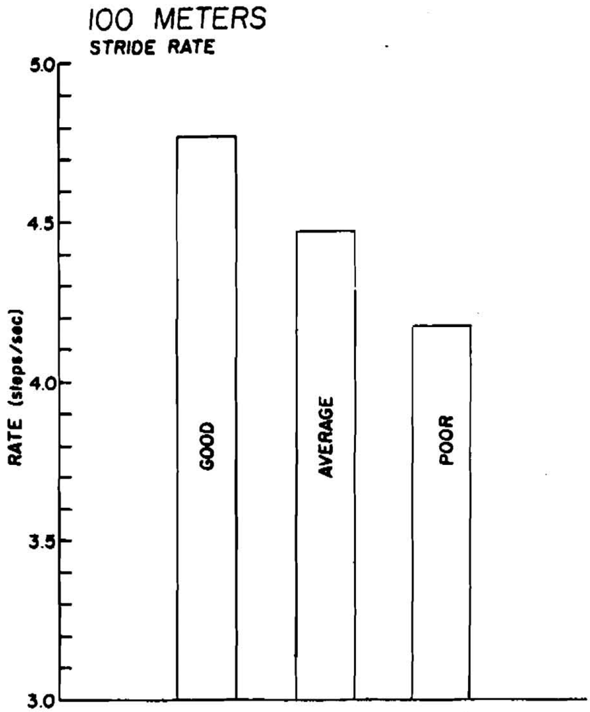

Figure 1. Stride rate trends for male, elite athlete 100 meter sprinters.

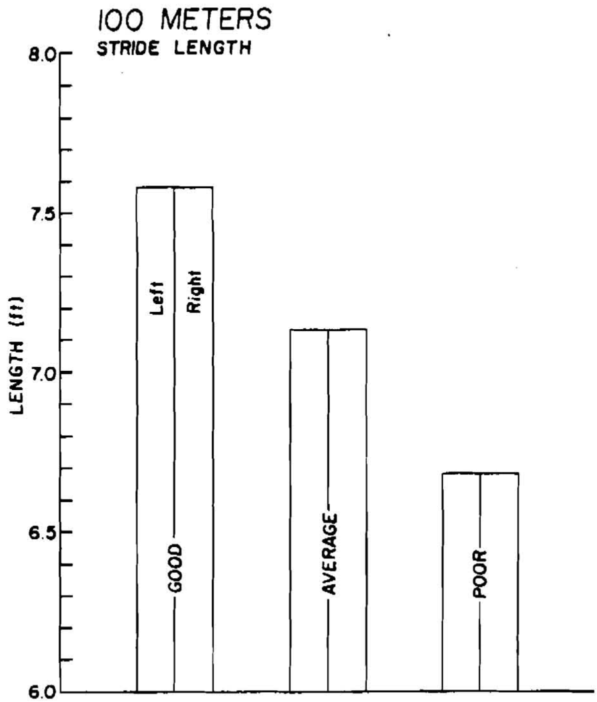

Figure 2. Stride length trends for male, elite athlete 100 meter sprinters.

The most recent research on sprinting indicates that, in the short sprints (100-200), improvement in stride rate and length is done primarily during ground contact. Moreover, it appears that improvement in stride rate is the means by which the better sprinters improve their performance. Thus, the superior elite athlete 100-200 meter sprinter will maintain an acceptable or slightly above average stride length, while producing an excellent stride rate. In the longer sprint (400 m), where economy of energy expenditure becomes a factor, improvement in performance appears to be accomplished through a more balanced increase in both stride rate and length. Regardless of the type of sprint event, both results are improved by increasing leg strength so that the necessary ground forces can be produced more quickly, and improving running mechanics so that less energy is wasted while on the ground and in the air. The segment results that follow will discuss these concepts in greater detail.

One final factor can affect stride rate and length results. If a performer is unusually tall or short, the results may be misleading. Although the results presented in Figures 1 and 2 are not corrected for height, if an athlete is not of average sprinter build, the results should be standardized to height.

TOTAL BODY VERTICAL SPEED (TOTAL BODY RESULT)

Although the performer must project the body vertically (upward) during the sprint, excessive vertical motion is not wanted. Figure 3 shows good, average, and poor levels of vertical speed for all of the male 100 meter elite athletes analyzed to date. The better sprinters tend to produce just enough vertical speed to allow time to complete leg recovery and prepare for the next ground contact, while directing more effort toward maintaining horizontal speed.

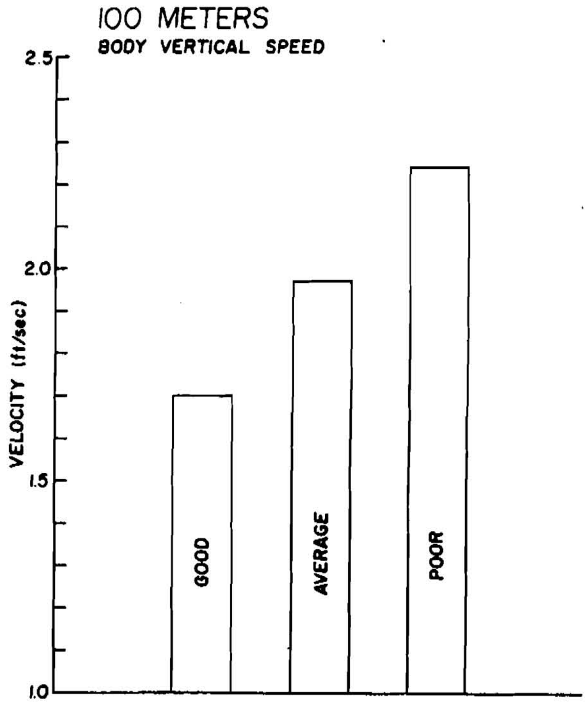

Figure 3. Total body maximum vertical speed trends generated by male, elite athlete 100 meter sprinters.

LOWER ARM MOTION (INDIVIDUAL SEGMENT RESULT)

Contrary to popular belief, the forearm (lower arm) does not maintain the same angle with the upper arm during sprinting. The angle normally ranges from a minimum at full front or full back position, to a maximum at the midpoint of the arm swing during each stride. Figure 4 indicates the average lower arm motion for the elite athlete 100 meter men sprinters analyzed to date. In addition, results indicating the performance levels deemed good and poor are also indicated. As indicated in the Figure, average (or even insufficient) arm action is not a problem. Excessive arm action, however, signals that the sprinter may be producing uneconomical motion, as well as overstriding.

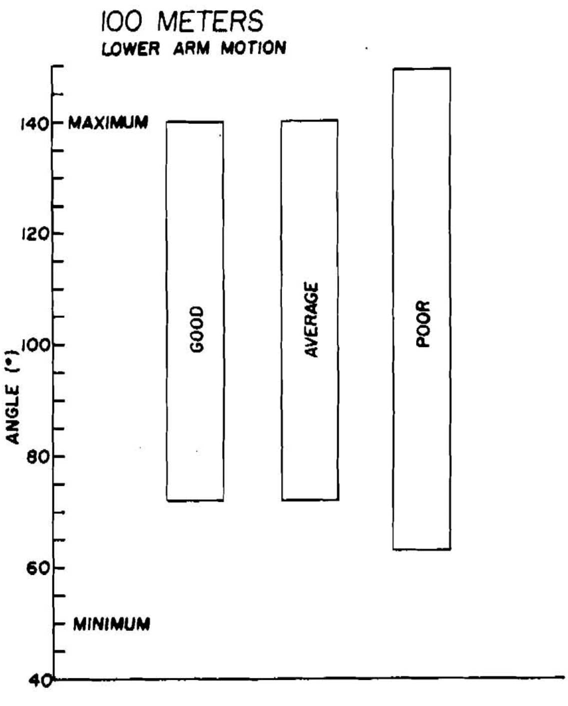

Figure 4. Lower arm range of motion trends for male, elite athlete 100 meter sprinters. The result identified is the angle formed between the arm (upper arm) and forearm (lower arm), with 180 degrees indicating full extension.

UPPER ARM MOTION (INDIVIDUAL SEGMENT RESULT)

The motion of the arm (upper arm) can tell much about the quality of a sprinter. The upper arm normally comes in front of the body to about 45 degrees in relation to the trunk, then rotates to a maximum position in back of the body of about 80 degrees during each stride. Figure 5 indicates the typical upper arm motion for all male 100 meter elite athletes investigated to date. For comparison, the performance shifts indicating beneficial or unwanted range of motion are also indicated. As in lower arm motion, although insufficient arm action is usually not a problem, excessive arm action indicates that the sprinter may be producing uneconomical motion and denotes overstriding in the performance.

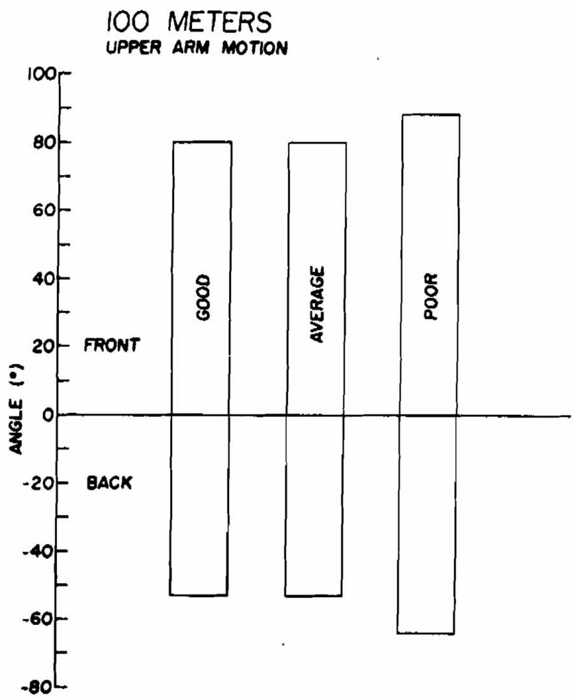

Figure 5. Upper arm range of motion trends for male, elite athlete 100 meter sprinters. The result identified is the angle formed between the trunk and arm (upper arm). Positive results indicate the upper arm is in front of the body, negative results indicate the upper arm is behind the body, and zero identifies the point when the upper arm is aligned with the trunk.

HORIZONTAL FOOT SPEED AT TOUCHDOWN (INDIVIDUAL SEGMENT RESULT)

When the foot contacts the ground in sprinting it is moving forward (horizontally) with respect to the ground, resulting in a braking action which slows the sprinter. The better sprinters tend to recover the foot so that it is not moving forward as quickly at touchdown, effectively decreasing the braking force. Figure 6 shows the good, average, and poor forward foot speed results at touchdown for all male elite athlete 100 meter sprinters analyzed to date. Although no sprinter has been able to recover the foot so that it is moving backward when it hits the ground, this should be the goal of every performer.

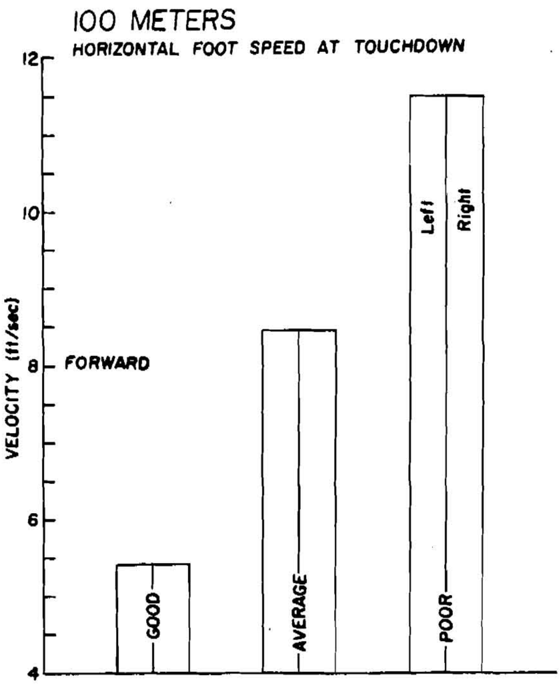

Figure 6. Horizontal foot speed at touchdown trends for male, elite athlete 100 meter sprinters.

HORIZONTAL FOOT DISTANCE FROM THE BODY AT TOUCHDOWN (INDIVIDUAL SEGMENT RESULT)

To sprint properly, the foot must touchdown in front of the body. This is a very important action since it increases the stride length, as well as giving the leg a greater range of motion to produce the necessary vertical speed and maintain the forward motion while on the ground. On the other hand, the farther out the sprinter lands, and the greater the range of motion of the ground leg, the longer the ground time. Thus, a tradeoff situation occurs since sufficient leg range of motion is needed to produce the necessary ground forces and produce an acceptable stride length, while the ground time must be reduced to a minimum to maximize stride rate.

The most recent research on sprinting indicates that the better elite athlete 100-200 meter sprinters are favoring a decrease in ground time over an increase in leg range of motion. Thus, they are actually minimizing the horizontal touchdown distance in an effort to minimize the ground time (and maximize stride rate). This surprising result raises a number of questions concerning how the better sprinters are minimizing this touchdown distance. As shown by the stride length results (see Figure 2), they are not sacrificing stride length in an effort to minimize ground time. From the available data, it is evident that the sprinters are minimizing ground time in two ways:

1. Properly preparing the ground leg for touchdown (this will be discussed in the leg motion and speed results).

2. Developing sufficient leg strength to generate the necessary velocity changes during a shorter ground time. It must be realized that the biggest problem in sprinting is to stop the downward fall of the body and produce upward projection into the next airphase. To accomplish this, large vertical forces must be produced during ground contact. This combination of force and time, which is termed impulse, amounts to about 50 ft/s for both average and elite sprinters. The difference is that the average sprinter exerts about 400 pounds of force for .125 seconds of ground contact (400 * .125=50), while the elite sprinter exerts about 500 pounds of force for .10 seconds of ground contact (500 *.10=50). Thus, the elite sprinters decrease ground time (which increases stride rate) without affecting the other performance results (like stride length) by having greater leg strength.

To minimize the touchdown distance, and get the most out of this action, the sprinter must be very strong in the hamstring and gluteal muscles since these are needed to pull the body over the touchdown point during the initial portion, of ground contact. More than any other factor, the strength of these muscles dictate the success of a sprinter.

Figure 7 shows the average horizontal distance the foot is in front of the body at touchdown for all male 100 meter elite athletes analyzed to date. In addition, those results constituting good and poor performance values are indicated. It is a tradeoff between the need to decrease ground time (to increase stride rate) and the need to produce the necessary ground forces (to maintain stride length). Thus, a small touchdown distance is good, as long as the rest of the sprint stride does not suffer. A good indicator of whether a performer can handle the touchdown distance is the stride length result (see Figure 2). If the stride length is at least average, then the touchdown distance is acceptable. On the other hand, if the touchdown distance is large, then either the sprinter does not have sufficient leg strength, or is not preparing properly for ground contact (this will be discussed in subsequent sections).

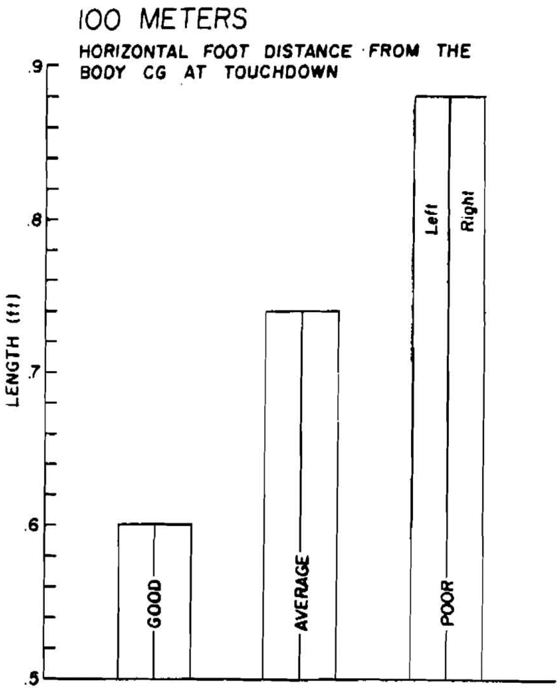

Figure 7. Trends produced for horizontal foot distance from the body (center of gravity) at touchdown for male, elite athlete 100 meter sprinters.

In the long sprint (400 m), the endurance demands eliminate the trend toward a decreased touchdown distance. Instead, the endurance sprinters increase the touchdown distance, thus increasing the leg range of motion while on the ground, which allows a decreased energy expenditure for speed maintenance. Although this approach does not allow maximum speed to be produced, since the long sprinters are not running at top sprinting speed, this tradeoff of economy for decreased speed is acceptable.

It must be emphasized that, while an insufficient distance is unwanted in the 400 meter sprint, an increased distance is beneficial only as long as the performer is strong enough to handle the increase. A good indicator of whether the performer can handle the touchdown distance can be found in the result of the horizontal foot speed at touchdown (see Figure 6). If the speed at touchdown is kept small, then the touchdown distance is acceptable (or could even be increased). If the foot is not recovering fast enough, the additional length benefit is offset by the braking action caused by the foot moving forward rapidly at touchdown.

UPPER LEG ANGULAR MOTION (INDIVIDUAL SEGMENT RESULT)

There are three critical, quantifyable positions for the upper leg during sprinting; 1) the position at takeoff, 2) the full extension position, and 3) the full flexion position. Figure 8 shows good, average, and poor upper leg results for all of the elite athlete 100 meter male sprinters analyzed to date. The better 100-200 meter sprinters tend to minimize upper leg extension at takeoff and full extension (in Figure 8, this results in a larger angle) to decrease the ground time (and increase stride rate), while the long sprinters (400 m) tend to maximize upper leg extension to increase leg range of motion (and increase efficiency). Both short and long sprinters tend to maximize upper leg flexion at full flexion (in Figure 8, this results in a larger angle). It must be emphasized, however, that a very good angle at one position is only beneficial if the other results are acceptable. Poor results here commonly indicate a lack of leg strength (indicated by excessive extension at takeoff), or an inability of a performer to properly recover the leg (indicated by insufficient flexion at full flexion). For instance, the elite athlete women sprinters tend to overemphasize the takeoff and full extension positions, while underemphasizing the full flexion position. The small benefit gained by a greater emphasis on the push off of the ground is offset by the inability of the leg to produce full recovery and complete preparation for the next ground contact.

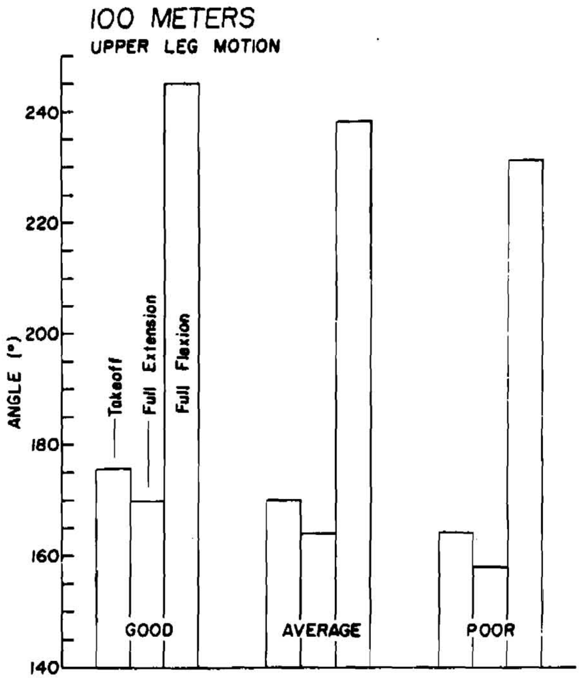

Figure 8. Thigh (upper leg) angular motion trends for male, elite athlete 100 meter sprinters.

UPPER LEG ROTATIONAL SPEED (INDIVIDUAL SEGMENT RESULTS

Upper leg rotational speed is critical in recovering the leg after takeoff (extension, flexion, then extension), preparing the leg for ground contact and, finally, continuing the extension rotation during ground contact. Figure 9 shows good, average, and poor results for the average absolute rotation speed of the upper leg during recovery, the extension speed at touchdown, and the average extension speed during the ground phase for all of the elite athlete 100 meter male sprinters analyzed to date. The better sprinters tend to maximize the leg recovery and touchdown rotation speeds, while maintaining or actually increasing (larger than touchdown) leg speed during ground contact. As in upper leg position (Figure 8), these values are directly related to the quality of the upper leg strength, as well as sprinting mechanics.

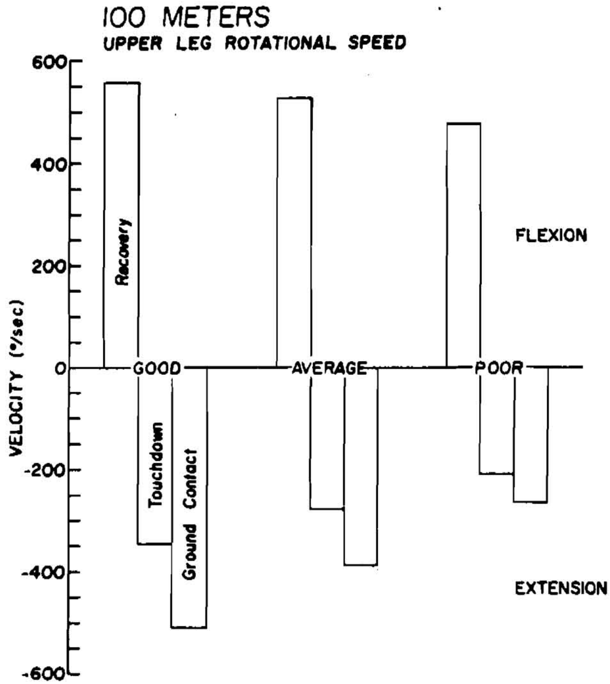

Figure 9. Thigh (upper leg) rotational speed trends for male, elite athlete 100 meter sprinters.

Of all the upper leg results, the upper leg speed at touchdown is the most critical since it affects both the amount of forward braking (see HORIZONTAL FOOT SPEED AT TOUCHDOWN) and the amount of ground contact time. Since decreasing ground time is the means by which elite 100-200 meter sprinters maximize stride rate, and limiting force and energy production is one means by which elite 400 meter sprinters economize their running action (see STRIDE RATE AND STRIDE LENGTH and HORIZONTAL FOOT DISTANCE FROM THE BODY AT TOUCHDOWN), properly preparing the leg for touchdown is a critical movement.

LOWER LEG ANGULAR MOTION (INDIVIDUAL SEGMENT RESULT)

There are three critical positions for the lower leg during sprinting; 1) the position at takeoff, 2) the maximum flexion during recovery, and 3) the position when the ankle crosses the opposite leg during recovery. The following graph (Figure 10) shows good, average, and poor results for takeoff, maximum flexion, and the point where the ankle crosses the opposite leg for all of the elite athlete athlete 100 meter male sprinters analyzed to date. The better 100-200 meter sprinters tend to minimize lower leg extension at takeoff (on Figure 10, this results in a smaller angle) to minimize the ground contact time (and increase stride rate), while the 400 meter performers tend to maximize extension to increase leg range of motion (and efficiency). Regardless of the type of sprint, the superior performer minimizes the lower leg angle during both recovery and as the ankle passes the opposite leg (on Figure 10, again a smaller angle) to make the task of recovering the leg both faster and easier. Poor results here, as in the upper leg (see UPPER LEG MOTION), commonly point to a lack of leg strength (indicated by excessive extension at takeoff), or an inability to properly recover the leg (indicated by insufficient flexion during recovery).

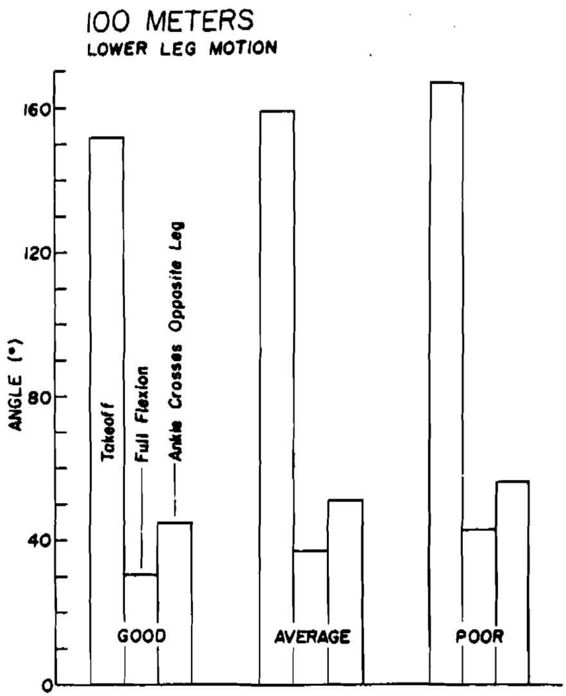

Figure 10. Leg (lower leg) angular motion trends for male, elite athlete 100 meter sprinters.

LOWER LEG ROTATIONAL SPEED (INDIVIDUAL SEGMENT RESULTS)

Lower leg rotational speed is critical as touchdown occurs since it contributes to the amount of braking (slowing down) that occurs during ground contact. Figure 11 shows the result for good, average, and poor rotational speeds of the lower leg at touchdown for all elite athlete 100 meter sprinters to date. The better sprinters are able to complete lower leg extension in sufficient time during the air phase to be able to produce a significant amount of lower leg flexion speed at touchdown. This results in a reduction in the forward braking force during the initial portion of ground contact.

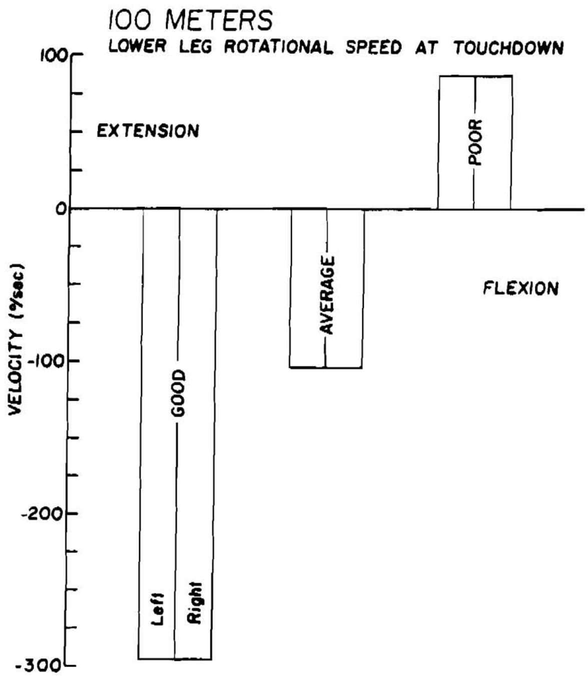

Figure 11. Leg (lower leg) rotational speed trends for male, elite athlete 100 meter sprinters.

SUMMARY

It appears that the action of sprint running is dominated by the goal of producing maximum horizontal body speed utilizing strength and proper movement mechanics. In the short sprints

(100-200 m), economy of energy expenditure is often sacrificed if greater speed can be produced. In the long sprint (400 m), however, this does not appear to be the case since endurance becomes a major factor. Regardless of the movement approach, the critical total body and individual segment performance results can be used to identify the quality of performance.

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