

Kinematic Analysis of Olympic Sprint Performance: Men's 200 Meters

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Selected kinematic variables in the performance of the Gold and Silver medalists and the eighth-place finisher in the men's 200-meter sprint final at the 1984 Summer Olympic Games were investigated. Cinematographic records were obtained for all track running events at the Games, with the 200-meter performers singled out for initial analysis. In this race, sagittal view filming records (100 fps) were collected at the middle (125-meter mark) and end (180-meter mark) of the performance. Computer-generated analysis variables included both direct performance variables (body velocity, stride rate, etc.) and upper and lower body kinematics (upper arm position, lower leg velocity, etc.) that have previously been utilized in the analysis of elite athlete sprinters. The difference in place finish was related to the performance variables body horizontal velocity (direct), stride rate (direct), and support time (indirect). The critical body kinematics variables related to success included upper leg angle at takeoff (indirect), upper leg velocity during support (direct), lower leg velocity at touchdown (direct), foot to body touchdown distance (indirect), and relative foot velocity at touchdown.

Through a coordinated effort by sports scientists, performance data in the form of filmed results were collected in a number of sports during the 1984 Summer Olympic Games. These data present a unique opportunity to investigate the true "elite" athlete, performing at peak performance level during an intense competitive situation.

To record performance in athletics, all running performances with the exception of the marathon were filmed at various stages of each performance. In each instance, basic biomechanical methods were used to ensure the possibility of the most complete analysis possible with the external restrictions imposed on the data collection.

The purpose of this study was to utilize the data collected on the Olympic sprint (100m-400m) events to demonstrate the analysis potential of the data collected during the 1984 Games. The analysis approach is intended only as an example, however; with the available literature results it represents one that is economical in usable results.

To date, both qualitative and quantitative sprint studies have investigated the activity in two major areas: *direct performance descriptors* and *upper and lower body*

kinematics. Direct performance descriptors are those variables most often used to describe a sprinter's overall performance (i.e., horizontal velocity, stride rate, etc.). Although these variables give little insight regarding how a performer is physically producing the performance, they are critical in determining the level and nature of the effort. Upper and lower body kinematics include those movement patterns that actually produce the performance (i.e., upper arm angular velocity, lower leg angular position, etc.). If the proper results in this category are analyzed, insight can be gained into how the direct performance descriptors are produced.

Regarding direct performance descriptors, the greatest factor dictating success in sprinting is the maximum horizontal velocity that an individual is able to achieve. Although Northrip, Logan, and McKinney (1974) claim that the theoretical maximum velocity for the human body during a running event would be about 40 ft/s (12.9 m/s), in typical sprint studies to date the reported maximum horizontal velocities reached by any of the subjects tested have been between 8.85 and 9.49 m/s (Armstrong, Costill, & Gehlsen, 1984; Luhtanen & Komi, 1978; Mann & Sprague, 1980). Only in recent study involving elite sprinters in competition (Herman & Mann, 1985) have velocity results (10.78 m/s) remotely approached this estimate.

Vertical kinematics have virtually been ignored in sprint performance. Only Herman and Mann (1985) have reported on the maximum vertical velocity in elite sprinters ($M = .67$ m/s), finding the better performers minimizing the result and producing it late in the ground phase. Instead, a greater emphasis has been placed on the amount of total body vertical displacement. Fenn (1930) calculated this to be 6.0 cm in the subjects he tested, whereas Luhtanen and Komi (1978) reported a value of 6.7 cm.

A number of variables that describe a sprinter's performance (stride rate and stride length, support and nonsupport time) have frequently been the focus of previous investigations. Sinning and Forsyth (1970) and Hoshikawa, Matsui, and Miyashita (1973) both found that increases in running velocity were accompanied by a combination of increases in stride length and stride rate, with stride rate becoming the more important factor at higher running velocities. In both studies, however, the subjects were tested on a motorized treadmill which enabled them to run only at a maximum of 6.6 m/s and 8.33 m/s, respectively. In a study that investigated maximum sprint effort (9.3 m/s), Luhtanen and Komi (1978) found that stride length leveled off at high velocities, whereas stride rate continued to increase.

These findings were later supported by Mehrkadez and Tabatschnik (1982) utilizing performance data collected on leading Soviet sprinters. Kunz and Kaufmann (1981), using a small group of world-class sprinters ($n = 3$), found a combination of greater stride length, higher stride rate, and a significantly shorter ground support time for the sprinters when compared to a group of decathletes ($n = 16$) performing a maximal sprint effort. In a similar study contrasting collegiate sprinters and marathoners running at a maximal sprint, Armstrong, Costill, and Gehlsen (1984) found that the sprinters demonstrated a superior stride length, but did not differ significantly in stride rate. Comparing collegiate-level sprinters and elite-level sprinters, Herman and Mann (1985) found a significant difference in the stride rate (elite higher) and support time (elite lower). However, no significant differences were found in stride length or nonsupport time.

Concerning upper and lower body kinematics, no area of sprinting has been quantitatively analyzed less than the contribution of the upper body (arms). Bunn (1972) and Hay (1978) both qualitatively discussed the role of the arms in sprinting as that of balanc-

ing the action of the hips. Furthermore, Bunn claimed that a vigorous backswing of the arms causes the legs to stride further and help maintain velocity when the legs fatigue. The results of a kinetic analysis of sprinting by Mann (1981), however, showed a minimal amount of muscular contribution by the shoulder and elbow joints. Furthermore, no relationship could be established between arm motion and sprinting performance. These results indicated that the role of the arms in sprinting is more to maintain balance than to set the sprint cadence or combat fatigue. Recent kinematic work by Herman and Mann (1985) further supports this conclusion.

A number of lower body kinematic results have been investigated in depth. In examining upper leg results, several authors have attempted to relate the angle between the upper legs at touchdown to sprinting performance. Kunz and Kaufmann (1981) found this angle to be smaller (0° to 20°) in better sprinters. However, Armstrong, Costill, and Gehlsen (1984) were unable to support this finding. Regarding more conventional results, Bunn (1972) and Hay (1978) both stated that at takeoff the hip should be extended through as great a range as possible, and that failure to complete extension is one of the most common faults in sprinting. Kunz and Kaufmann (1981), however, found that world-class sprinters had less upper leg extension at takeoff than did a group of decathletes when performing a maximal sprint.

Although little work has been done with upper leg angular velocity, Herman and Mann (1985) found the results prior to and during ground contact to be highly correlated to increase sprint performance from the collegiate to the elite level. Upper leg velocity during recovery, however, was not a factor.

As with upper body results, data on lower leg action has focused on displacement results. Qualitatively, it has been readily agreed upon (Bunn, 1970; Deshon & Nelson, 1963; Fenn, 1930; Hay, 1978; Sinning & Forsyth, 1970) that, during the recovery portion of the stride, the lower leg should be flexed to the point at which the foot almost touches the buttocks. This, along with large upper flexion (high knee lift), would enable the leg to recover more rapidly and prepare for the next stride. Armstrong, Costill, and Gehlsen (1984), however, found no significant difference in the minimum lower leg recovery angle between collegiate sprinters and marathoners when both groups sprinted maximally. Likewise, Herman and Mann (1985) found no differences between collegiate and elite sprinters in this angle during the recovery portion of the stride. A significant difference was found at the takeoff position, however, where the elite sprinters demonstrated a smaller amount of knee extension. This contrasts with the increased knee extension results subjectively expected by Bunn (1972) and Hay (1978), or the lack of significance found by Armstrong, Costill, and Gehlsen (1984) when comparing marathoners and sprinters.

Of all lower body kinematic results, foot variables have received the closest scrutiny. Deshon and Nelson (1963) found that efficient running was characterized by placement of the foot as closely beneath the center of gravity as possible. Kunz and Kaufmann (1981) supported this conclusion by comparing world-class sprinters to poorer performers. In regard to foot velocity, Fenn (1930) and Hay (1978) stated that, in order to avoid horizontal braking at touchdown, the foot should be moving backward relative to the body center of gravity with a horizontal velocity at least equal to that at which the body center of gravity is moving forward. Payne, Slater, and Telford (1968), however, found that even when the foot was placed beneath the center of gravity its backward velocity was still not great enough to prevent unwanted braking. The importance of all these variables was underscored by Herman and Mann's (1985) recent work on elite sprinters.

Methods

The data acquired for this study were collected during the 1984 Summer Olympic Games. Data reduction and analysis followed procedures that were previously developed for the investigation of elite-class sprinters (Mann, Herman, Johnson, Schultz, & Kotmel, 1982-1983; Herman & Mann, 1985).

Data Collection

The potential subjects consisted of all sprint (100-400m) finalists in the 1984 Summer Olympic Games. For the purposes of this analysis, investigation was limited to the first (Gold), second (Silver), and eighth-place finishers in the 200 meters for men.

All potential subjects were filmed during the finals of the Olympic Games Track Events between August 4 and August 9. The finals in the 200 meters for men occurred on August 8. Filming was done at ground level with two Locam, motor-driven, 16mm cameras which were equipped with Angineaux 12-120mm lenses. Both cameras were positioned to film the sagittal view of the subjects, with a filming rate of 100 frames per second. Film speed was corroborated with an internal 100 cycle/second pulse generator contained in the camera. One camera was positioned at the 125-meter mark, approximately 10 meters into the beginning of the straightaway, to capture the nonfatigue portion of each subject's performance. The second camera was placed at the 180-meter mark to record the fatigue portion of the race. Both cameras were positioned to produce a field of view sufficient to record two complete sprint strides for the performer in the lane closest to the camera. A one-meter multiplier was filmed in each of the eight lanes to allow for proper scaling during data reduction.

Data Reduction and Analysis

The displacement data were reduced from the film using an Altek digitizer interfaced into a DEC Rainbow 100 computer. The results were then sent to a DEC VAX 11/750 computer for processing. The body parameters of interest were then generated with the aid of a program developed by Mann (1979).

The direct performance descriptors stride rate, support time, and nonsupport time were calculated directly off the film record. Stride rate was measured by determining the number of frames between two consecutive touchdown points and dividing this result by the frame rate. Similarly, support time was calculated by determining the number of frames from touchdown to takeoff and nonsupport time by determining the number of frames from takeoff to touchdown.

The remaining direct performance descriptors were identified from the processed digitized results. Horizontal velocity was defined as the average velocity during the entire stride, while vertical velocity was defined as the maximum positive (upward) velocity produced during the stride. Stride length was determined as the distance between consecutive touchdown points of the centers of gravity of the alternating feet. In each of the direct performance descriptors, results were averaged over at least two strides.

Figure 1 illustrates the upper body kinematic variables that were investigated in the study. The variables included (a) minimum and maximum upper arm angle, (b) total

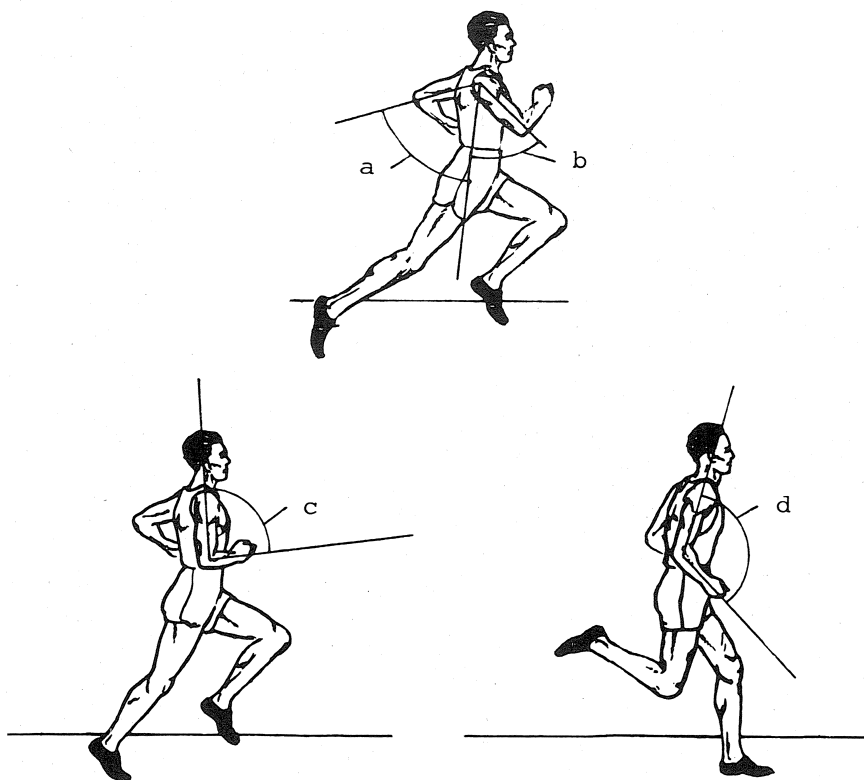


Figure 1 — Upper body kinematic variables: (a) minimum upper arm angle; (b) maximum upper arm angle; (c) minimum lower arm angle; (d) maximum lower arm angle. From these results, total upper and lower arm range of motion and average upper arm speed were determined.

upper arm angular displacement, (c) minimum and maximum lower arm angle, (d) total lower arm angular displacement, and (e) average upper arm angular speed averaged over the entire stride.

Figures 2 and 3 identify the lower body kinematic variables analyzed. The upper leg variables investigated (Figure 2) included (a) upper leg angular position at takeoff, (b) upper leg angular position at full extension, (c) upper leg angular position at full flexion, (d) upper leg angular recovery speed averaged over the entire nonsupport time, (e) upper leg angular velocity at touchdown, and (f) average upper leg angular velocity during ground contact. The lower leg variables of interest (Figure 3) included (a) lower leg angular position at takeoff, (b) minimum lower leg recovery angle, (c) lower leg angular position when the ankle crosses the opposite knee, and (d) lower leg angular velocity at touchdown.

The position and velocity results of the upper and lower legs combine to dictate the position and velocity of the touchdown foot at ground impact. The two variables selected for presentation included (a) horizontal distance from the body center of gravity to the foot center of gravity, and (b) horizontal velocity of the foot, with respect to the body center of gravity.

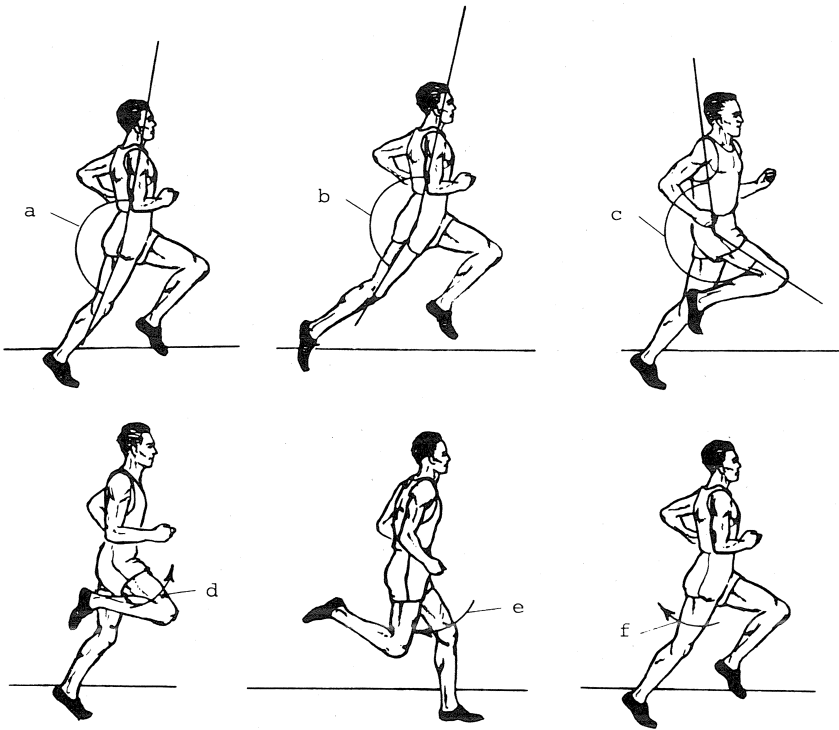


Figure 2 — Upper leg kinematic variables: (a) angular position at takeoff; (b) angular position at full extension; (c) angular position at full flexion; (d) average angular speed during recovery; (e) angular velocity at touchdown; (f) angular velocity during ground contact.

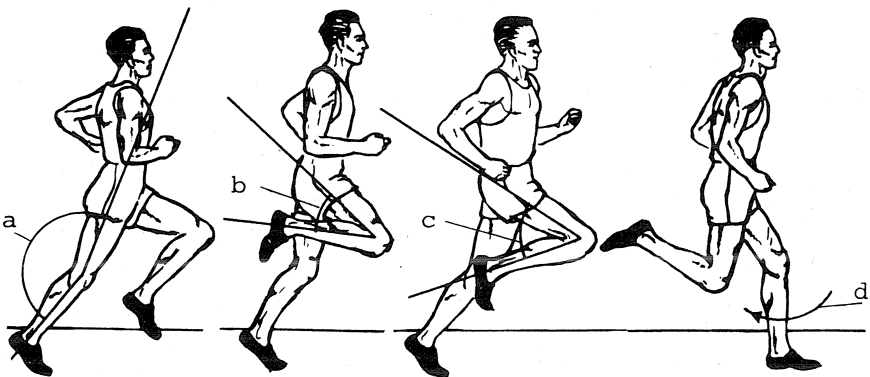


Figure 3 — Lower leg kinematic variables: (a) angular position at takeoff; (b) minimum recovery angle; (c) angular position at opposite angle cross; (d) angular velocity at touchdown.

As in the case of the direct performance descriptors, all kinematic results were averaged over at least two strides. The specific results were selected since extensive information has been gathered on these results for elite athletes (Mann et al., 1982-1983). The variables were originally chosen due to their importance as indicated by previous research, as well as coaches' input. Since the initial selection, variables have been altered, deleted, or added as data provided greater insight into the importance of the possible variables.

Results and Discussion

The results for the direct performance descriptors for the three 200-meter sprinters are presented in Table 1. All results are averaged over the maximum number of strides available. In addition, both nonfatigue and fatigue values are presented. Table 2 presents the results for the upper body kinematics, while Table 3 identifies the lower body kinematics. The format in these tables is the same as in Table 1.

As in the earlier sections, this section will focus first on the effects (direct performance variables), followed by the visible causes (upper and lower body kinematics).

Direct Performance Variables

Although the direct performance variables do not indicate how the elite sprinter uses the body to produce a successful performance, they do provide insight concerning the critical phases of the activity. It is obvious that the horizontal velocity value is the cumulative result that determines quality of performance. The velocity results listed in Table 1 indicate that, as expected, success in producing this result correlated directly with place

Table 1
Direct Performance Descriptors

Variable ^a	Gold	Performer	
		Silver	8th
Horizontal velocity (m/s)	10.21/10.82	9.93/10.39	9.29/9.96
Vertical velocity (m/s)	.570/.825	.565/.733	.764/.718
Stride length (m)	2.38/2.48	2.38/2.49	2.31/2.38
Stride rate (step/s)	4.30/4.35	4.17/4.17	4.01/4.17
Support time (s)	.10/.10	.11/.11	.13/.12
Nonsupport time (s)	.13/.13	.13/.13	.12/.12

^aResults are averaged over at least two strides. In each case, nonfatigue results are followed by fatigue values.

Table 2
Upper Body Kinematics

Variable ^a	Performer		
	Gold	Silver	8th
Upper arm displacement (deg)	135/133	124/124	118/130
Lower arm displacement (deg)	87/84	91/84	67/91
Upper arm angle (deg)			
maximum	80/80	75/76	81/86
minimum	- 55/ - 53	- 47/ - 48	- 37/ - 44
Lower arm angle (deg)			
maximum	153/153	148/146	122/150
minimum	66/69	57/62	55/59
Upper arm average speed (deg/s)	525/740	500/558	490/572

^aResults are averaged over at least two strides. In each case, nonfatigue results are followed by fatigue values.

finish. Additionally, since the velocities at the end of the race did not decrease, fatigue was not a factor in these performances. During peak performance competitions, this minor decrement in performance in elite short (100-200m) sprinters has been a common trend (Mann et al., 1982-1983). Due to the length of the race, this trend is not surprising; however, it emphasizes the importance of sprint endurance, innate ability, and proper mechanics in the short sprints.

In elite athlete sprinters, it has been found that better performers minimize the maximum vertical velocity and produce the result very close to the takeoff point. In less successful sprinters, or when fatigue sets in, maximum velocity increases and occurs before the takeoff point (Herman & Mann, 1985). In both the Gold and Silver Medal results (Table 1) both of these trends were produced.

The remaining direct performance variables, which go into producing the horizontal velocity, indicate the critical phase of the successful sprint performance. As the stride length/stride rate results of Table 1 indicate, the major difference between the place finishes (especially Gold and Silver) was in stride rate. This result is supported in general by numerous researchers, and specifically Mehrikadze and Tabatschnik (1982) and Herman and Mann (1985), who found increase in stride rate as the significant difference when investigating the quality of elite sprinters.

The support/nonsupport results of Table 1 indicate where the Gold medalist produced the critical stride rate advantage. It is evident that a decreased support time was the means by which the difference was generated. This conclusion was again supported by Herman and Mann (1985), who found a significant decrease in support time, with no relationship evident in nonsupport time, as sprint performance increased.

Table 3
Lower Body Kinematics

Variable ^a	Performer		
	Gold	Silver	8th
Upper leg position (deg)			
takeoff	167/167	170/164	167/160
full extension	165/164	168/162	158/157
full flexion	237/240	235/242	239/241
Upper leg velocity (deg/s) ^b			
touchdown	-228/-153	-200/-157	-228/-150
during support	-429/-472	-378/-481	-328/-419
during recovery ^c	301/344	257/313	308/420
Lower leg position (deg)			
takeoff	157/157	156/165	158/156
minimum recovery angle	38/35	43/45	37/35
at angle cross	44/45	54/53	50/46
Lower leg velocity (deg/s) ^d			
touchdown	-330/-424	-115/-165	-150/-329
Foot distance from body (m)			
touchdown	.217/.276	.284/.286	.327/.309
Foot velocity (m/s) ^e			
touchdown	-7.93/-7.18	-5.84/-5.22	-6.47/-7.20

^aResults are averaged over at least two strides. In each case, nonfatigue results are followed by fatigue values.

^bPositive results indicate flexion, negative results indicate extension.

^cSince this result is an average of velocities in both directions, it is a nondirectional speed result.

^dNegative results indicate flexion.

^eNegative results indicate foot is moving backward in relation to the body center of gravity. For the foot to be moving backward with respect to the ground, the velocity would have to exceed the forward velocity of the performer.

Upper and Lower Body Kinematics

Despite the infatuation of the coaching profession with the arm action in sprinting, there is no research support to indicate that the upper limbs play a significant role in dictating the quality of the performance. Of the results presented in Table 2, the only apparent differences occurred in the upper arm results. The Gold medalist generated greater upper arm velocity; however, it was necessary due to the greater upper arm range of motion. The velocity results indicate that the arms were working well within their capabilities and were simply being employed for balance during the stride.

The body contributions that dictate the level of success in sprinting are those produced by the lower limbs and supporting structures. The upper and lower leg angular mo-

tions, and the resulting foot positions and speed, determine the degree of horizontal and vertical body acceleration during ground contact. It is these accelerations that produce and maintain the critical direct performance descriptors previously discussed.

The most consistent success factor identified in the sprint results of elite athletes (Herman & Mann, 1985; Mann et al., 1982-1983) is the action of the upper leg. To terminate the nonproductive latter portion of ground contact, the better sprinters end ground contact early and quickly begin leg recovery. As Table 3 indicates, both the Gold and Silver medalists accomplished this goal in both the nonfatigue and fatigue conditions. This abbreviated leg extension is one major factor in decreasing the critical ground contact time. During the recovery phase, all three sprinters produced similar full extension, followed by excellent flexion (high knee) positions. This flexion result is critical in initiating the production of upper leg velocity into and during ground contact.

As the upper leg velocity results of Table 3 indicate, although all three performers produced comparable results at touchdown, a major difference in this race was produced due to the ability of the medalists to increase the leg speed to a greater degree during the support phase. Since these velocity results have been identified as additional factors by which the critical ground time can be reduced (Mann et al., 1982-1983), it is evident that the success of the medalists was due in large part to the ability to produce this result.

While large upper leg recovery speed is a beneficial performance variable (Mann et al., 1982-1983), none of the three performers showed superiority in this result. The same conclusion can be made for all three lower leg position results. In the takeoff position (where ground contact can be decreased by a minimum result) and the two angles identified during recovery (where moment of inertia can be reduced and recovery speed enhanced with minimum results), all three sprinters generated typical elite sprint values.

Although lower leg velocity results are extremely variable in nature, a large result at touchdown can be as beneficial as a superior upper leg velocity in decreasing horizontal braking and ground time (Mann et al., 1982-1983). As the lower leg velocities of Table 3 indicate, the Gold medalist gained a significant edge with a superior result in this variable.

The upper and lower leg results dictate, to a large degree, the position and velocity of the foot at ground contact. Thus, as shown in Table 3, the superiority in the leg results demonstrated by the Gold medalist produced a beneficial small touchdown distance and large relative foot velocity. It should be noted that none of the sprinters were able to produce a foot velocity that approached their sprinting velocity. Thus, the touchdown foot of all three sprinters was moving forward in relation to the ground at impact, producing initial horizontal braking. Although no sprinter can avoid this, the better performers minimize the braking both prior to and after ground contact.

Conclusions

From the filmed results of the 1984 Summer Games, it is evident that the factors that dictate superior performance can be identified. In the analysis of three 200-meter sprinters, the overall results clearly demonstrate the superiority of the more successful performers. In summary, the difference in performance stemmed from the following:

1. Higher horizontal velocity
2. Greater stride rate

3. Shorter support time
4. Large upper leg angle (less extension) at takeoff
5. Higher upper leg velocity during support
6. Higher lower leg velocity at touchdown
7. Smaller foot to body touchdown distance
8. Higher relative (to the body) foot velocity at touchdown.

In relating cause to effect, the higher lower leg velocity at touchdown produced the superior foot results, thus decreasing the amount of initial horizontal braking during ground contact. This superior foot placement, coupled with upper leg strength, allowed the successful sprinters to increase the upper leg velocity during ground contact. The overall efficiency of the ground mechanics permitted a shortened ground leg range of motion. All of these factors produced the winning edge: a shortened ground time, greater stride rate, and higher horizontal velocity.

It is hoped that the availability of the films from the Games will produce expanded results on these data, as well as results from the remaining sprint and distance events. Such biomechanical data on elite performances of this nature offer the possibility of greater understanding of the nature of high performance human locomotion.

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