A Closer Look At The Shape Of The High Jump Run-Up

Thanks to some video analysis done by Iiboshi and his team, new information can now be plugged into the method for drawing the path of the high jumper's footprints on the ground. The original article by Dapena on this subject was in issue #131 of Track Coach. *From this I gather elite jumpers have an unusual sense of finding the right spot to jump from. No matter what the differences are . . . they get the run-up to work. It is similar to Finnish javelin throwers, who may differ in the first part of the run, but who all seem to know what to do in the last two steps.*

The path of the footprints in a high jump run-up can be idealized as a straight line perpendicular to the bar, followed by a circular arc which ends at the takeoff (Figure 1). Such a path is defined by the position of the takeoff foot (its x and y coordinates), the angle between the bar and the final direction of the footprints' path (f), and the radius of the curve (r).

A method for drawing the path of the footprints on the ground was described in previous papers. (See Dapena, et al., 1993; Dapena, 1995a.) However, the numerical values needed for the implementation of this method were based on limited information.


ALLSPORT/TONY DUFFY

1996 Olympic champion Charles Austin.

Recent work by Iiboshi, et al. (1994) provides data that can help us to improve the design of the run-up. They used a special video analysis technique to measure the footprint locations of the top eight men and seven of the top eight

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women in the high jump finals of the 1991 World Championships. The last successful jump was analyzed for each athlete, with the exception of Heike Henkel, who had to be studied in a successful jump in which the bar was set 5 cm below her winning height. The Japanese research team also collected other data, such as the final speed of the run-up (v) and the final direction of motion of the center of gravity (c.g.) at the end of the run-up.

FITTING A CURVE TO THE FOOTPRINTS

(NOTE: This paper will refer to athletes that take off from the left foot; to make the text applicable to athletes who take off from the right foot, the words "right" and "left" should be interchanged.)

We used a computer program to fit an arc of a circle to the footprint locations reported by Iiboshi, et al. (1994). There are many ways to fit a circle to the footprints of a high jump curve; we decided to use the circle that passed through the takeoff footprint and made the best possible fit with the second, third and fourth footprints before the takeoff. Notice that we ignored the next to last footprint (i.e., we used footprints 0, -2, -3 and -4, skipping footprint -1). The reason for this was that many jumpers seem to plant the right foot in the next-to-last support outside the general curve, and therefore the inclusion of this footprint would have a misleading effect on the shape of the fitted curve.

Figure 2 shows the footprints of the 15 athletes analyzed at the 1991 World Championships and the circular arc that we fitted to the curve of each run-up. The arc was continued backward up to the point where it was perpendicular to the bar; from there, the path was extended backward along a straight line.

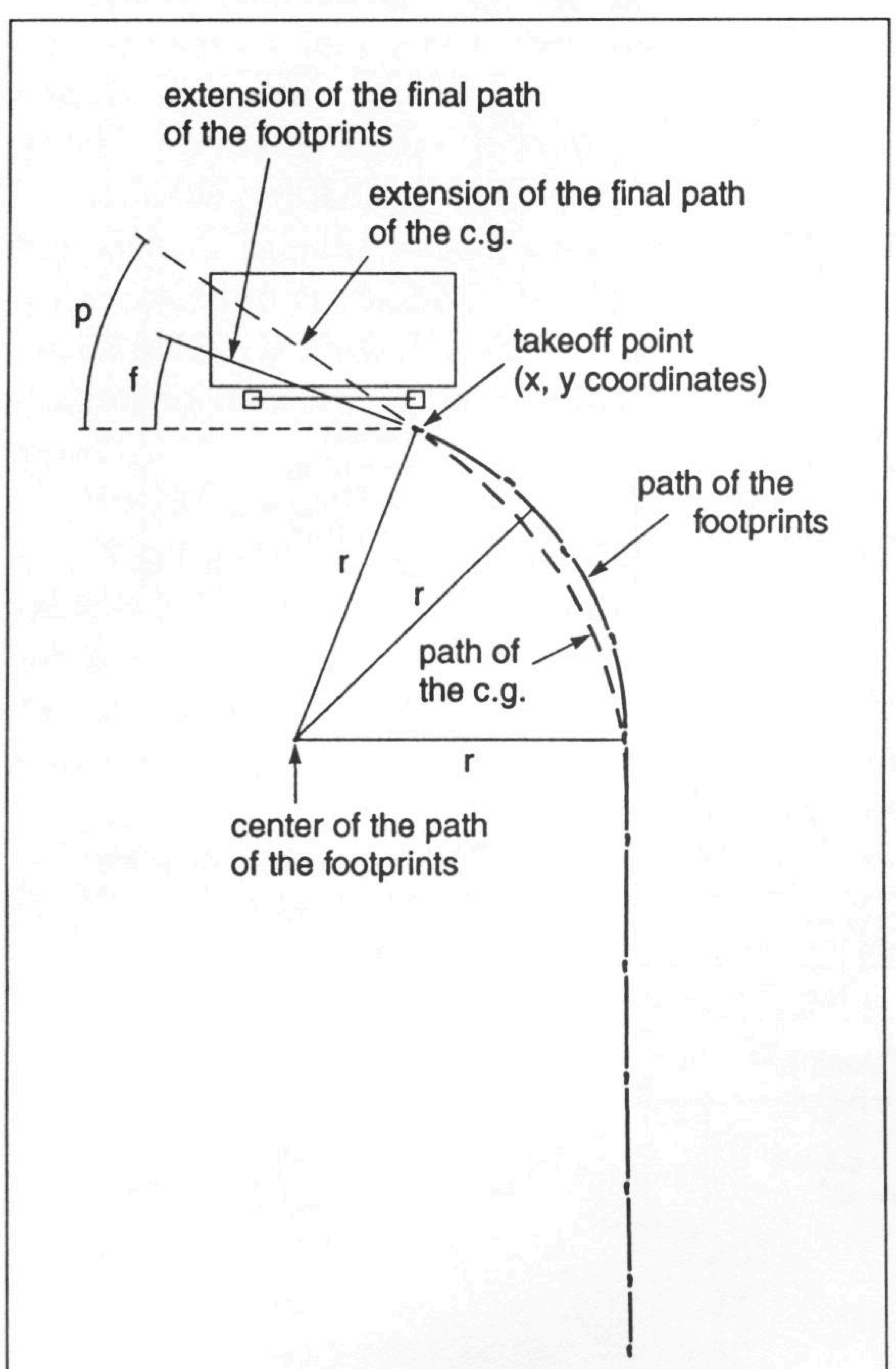


Figure 1

The drawings show that all the jumpers in the sample followed very closely the modeled circular path in the last steps of the run-up (although, as expected, in several jumps the next-to-last footprint was clearly outside the general curve). About half of the jumpers (e.g., Austin, Kovacs) used a strict "straight line plus circular arc" approach, and their footprints followed very closely not only the curved section, but also the straight section of the path modeled by the computer. The remaining jumpers (e.g., Drake, Henkel) started the straight section of the run-up somewhat farther outward than predicted by the computer model, and later converged into the final circular path.

In some jumpers (e.g., Drake, Kostadinova) the second type of run-up may have served to produce a more gradual transition from the straight section of the run-up to the final part of the curve, which should make the transition more comfortable. The disadvantage is that this run-up is obviously more complicated than the first type, and may therefore lead to more inconsistency.

In other jumpers (e.g., Grant, Kemp) the second type of run-up seemed to be the result of the opposite reason: a sudden change in the direction of running at the start of the curve (essentially, a kink in the path at footprint -5) before settling into the final curvature of the run-up. This does not seem advisable, because the sudden change in direction may interfere with the run-up speed; it may also lead to inconsistency.

The fitted curves allowed us to calculate the radius (r) and the final direction (f) of the curve for each jumper. These values are shown in Figure 2.

RELATIONSHIP BETWEEN THE RUNNING SPEED AND THE RADIUS OF THE CURVE

The proportion between the square of the running speed and the radius of the curve used by an athlete determines how much the athlete will lean. This can be expressed by the formula $q=v^2/r$; the larger the value of q, the greater the lean. This means that an increase in v while keeping the radius constant will increase q, and the athlete will lean more; an increase in r while keeping the running speed constant will decrease q, and the athlete will lean less. If an athlete wants to achieve a given

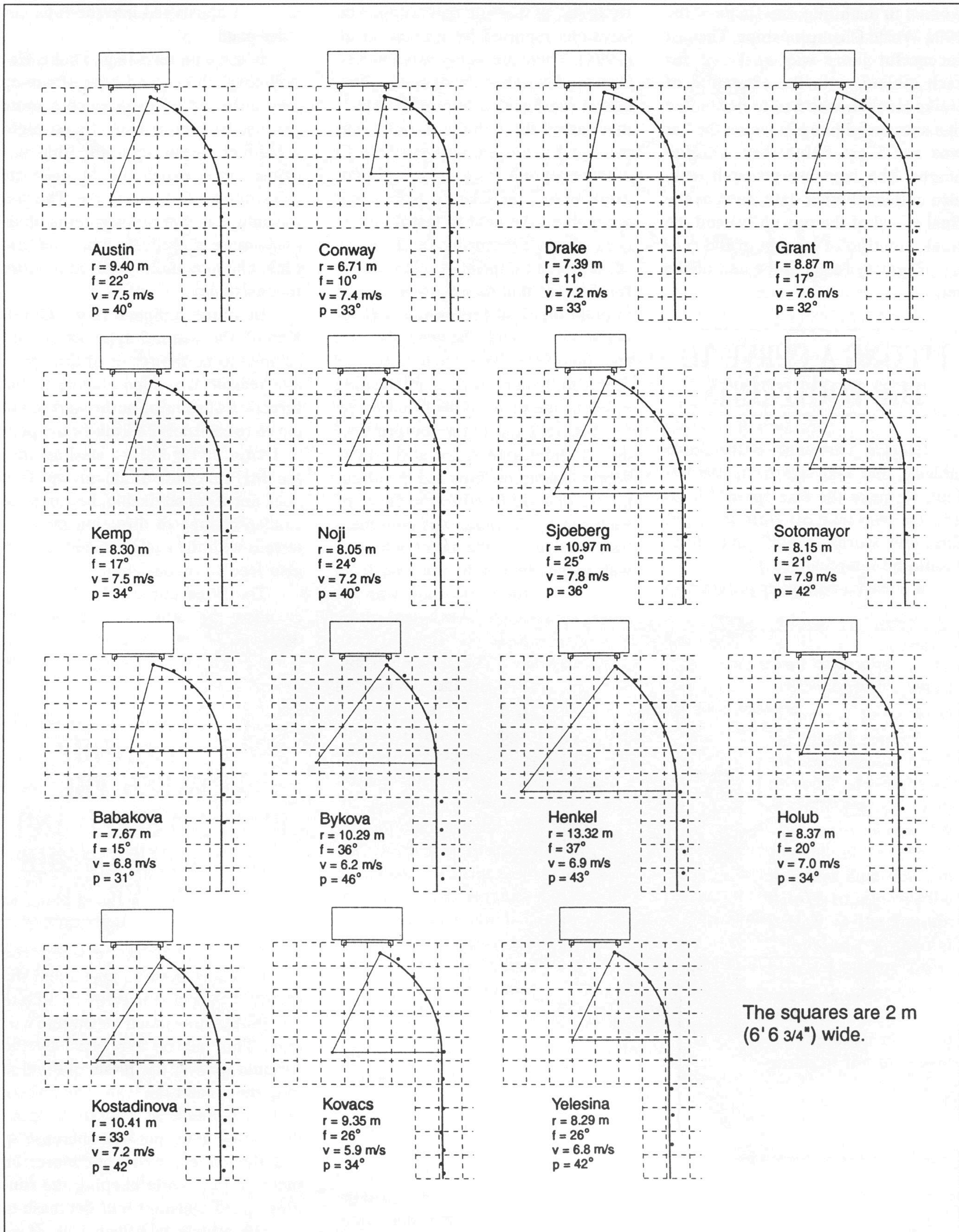

Austin
r = 9.40 m
f = 22°
v = 7.5 m/s
p = 40°
Conway
r = 6.71 m
f = 10°
v = 7.4 m/s
p = 33°
Drake
r = 7.39 m
f = 11°
v = 7.2 m/s
p = 33°
Grant
r = 8.87 m
f = 17°
v = 7.6 m/s
p = 32°
Kemp
r = 8.30 m
f = 17°
v = 7.5 m/s
p = 34°
Noji
r = 8.05 m
f = 24°
v = 7.2 m/s
p = 40°
Sjoeberg
r = 10.97 m
f = 25°
v = 7.8 m/s
p = 36°
Sotomayor
r = 8.15 m
f = 21°
v = 7.9 m/s
p = 42°
Babakova
r = 7.67 m
f = 15°
v = 6.8 m/s
p = 31°
Bykova
r = 10.29 m
f = 36°
v = 6.2 m/s
p = 46°
Henkel
r = 13.32 m
f = 37°
v = 6.9 m/s
p = 43°
Holub
r = 8.37 m
f = 20°
v = 7.0 m/s
p = 34°
Kostadinova
r = 10.41 m
f = 33°
v = 7.2 m/s
p = 42°
Kovacs
r = 9.35 m
f = 26°
v = 5.9 m/s
p = 34°
Yelesina
r = 8.29 m
f = 26°
v = 6.8 m/s
p = 42°
The squares are 2 m (6' 6 3/4") wide.

Figure 2

amount of lean, the ratio q between v^2 and r needs to have some particular value which will be different for each amount of lean.

If we knew the typical value of q for high jumpers, we would be able to use the running speed of any jumper to estimate the appropriate radius for the footprints of that jumper, using the equation $r=v^2/q$.

To check the value of q for each high jumper in the sample, we would need to divide the square of the average running speed of the athlete in the entire curve by the radius of the curve. Iiboshi, et al. (1994) did not measure the average running speed during the entire curve for the athletes shown in Figure 2, but they did report the final speed at the end of the run-up. We used the value of this reported speed to make a rough estimate of q for each jumper, using the formula $q=v^2/r$. The value of q was 6.8 ± 0.8 m/s² for the men, and 4.8 ± 1.0 m/s² for the women.

These results indicated that the men tended to lean more than the women. A greater lean requires the athlete to make larger horizontal forces on the ground during the curve. It is possible that the greater strength of the men allowed them to run with a greater lean without excessive discomfort to interfere with the run-up speed.

We can use the final run-up speed of a high jumper and the average value of q to estimate an appropriate radius for the jumper's run-up curve. This will not necessarily be the optimum radius for that individual, but it is useful as a rough guideline. For the men, the prediction equation is $r=v^2/6.8$; for the women, $r=v^2/4.8$. (These equations replace the one given in the previous papers, which was based on data from a single jumper.)

RELATIONSHIP BETWEEN THE FINAL DIRECTIONS OF THE PATHS OF THE C.G. AND OF THE FOOTPRINTS

The sketch in Figure 1 shows that the c.g. travels directly over the footprints during the straight part of the run-up. However, in the transition to the curve the body tilts toward the left. The tilt is maintained during the curve, and the c.g. follows a path that is somewhat closer to the center of the curve than the footprints. At the end of the curve, the paths of the c.g. and of the footprints converge, and this puts the c.g. more or less directly above the left foot by the end of the takeoff.

A consequence of the convergence of the two curves is that the final angle of the c.g. path (p) is always larger than the corresponding angle of the footprints' path (f). Iiboshi, et al. (1994) reported the value of angle p for each of the jumpers shown in Figure 2. Using the values of f which we computed from the fitted curves, we were able to calculate the difference between angles p and f: $15 \pm 5°$.

In the previous papers (Dapena, et al., 1993; Dapena, 1995a) the difference between angles p and f was used to produce a table that showed for several values of the final direction of the run-up (angle p, which indicates the final path of the c.g.) a distance called "j". This distance is necessary for the calculation of the direction of the center of the curve relative to the takeoff point (see Figure 3), and therefore it is ultimately needed for drawing the path of the footprints on the ground. The newly calculated difference between angles p and f leads to a modified table for the calculation of j (Table 1).

Table 1

final direction of the run-up (angle p)	final direction of the footprints' path (angle f)	value of distance j
25°	10°	1.75 m
30°	15°	2.70 m
35°	20°	3.65 m
40°	25°	4.65 m
45°	30°	5.75 m
50°	35°	7.00 m

PRACTICAL IMPLICATIONS

To draw the path of the footprints on the ground, we strongly advise the reader to follow the detailed instructions given in the previous paper (Dapena, 1995a), but using the new formulas to estimate the radius of the curve ($r=v^2/6.8$ for the men; $r=v^2/4.8$ for the women), and the new table to estimate the value of distance j. (If you are unable to find the previous paper, please contact *Track Coach* editor Mr. Kevin McGill, Box 259, Boxford, MA 01921, USA, for a free copy.)

OTHER CONSIDERATIONS

The jumps shown in Figure 2 used a wide range of values for the radius of the curve (between 6.71 m and 13.32 m). If the path of the footprints had had the same final direction (angle f) in all these jumps, the distance between the right standard and the straight part of the run-up (measured outward from the standard) would have needed to have a vari-

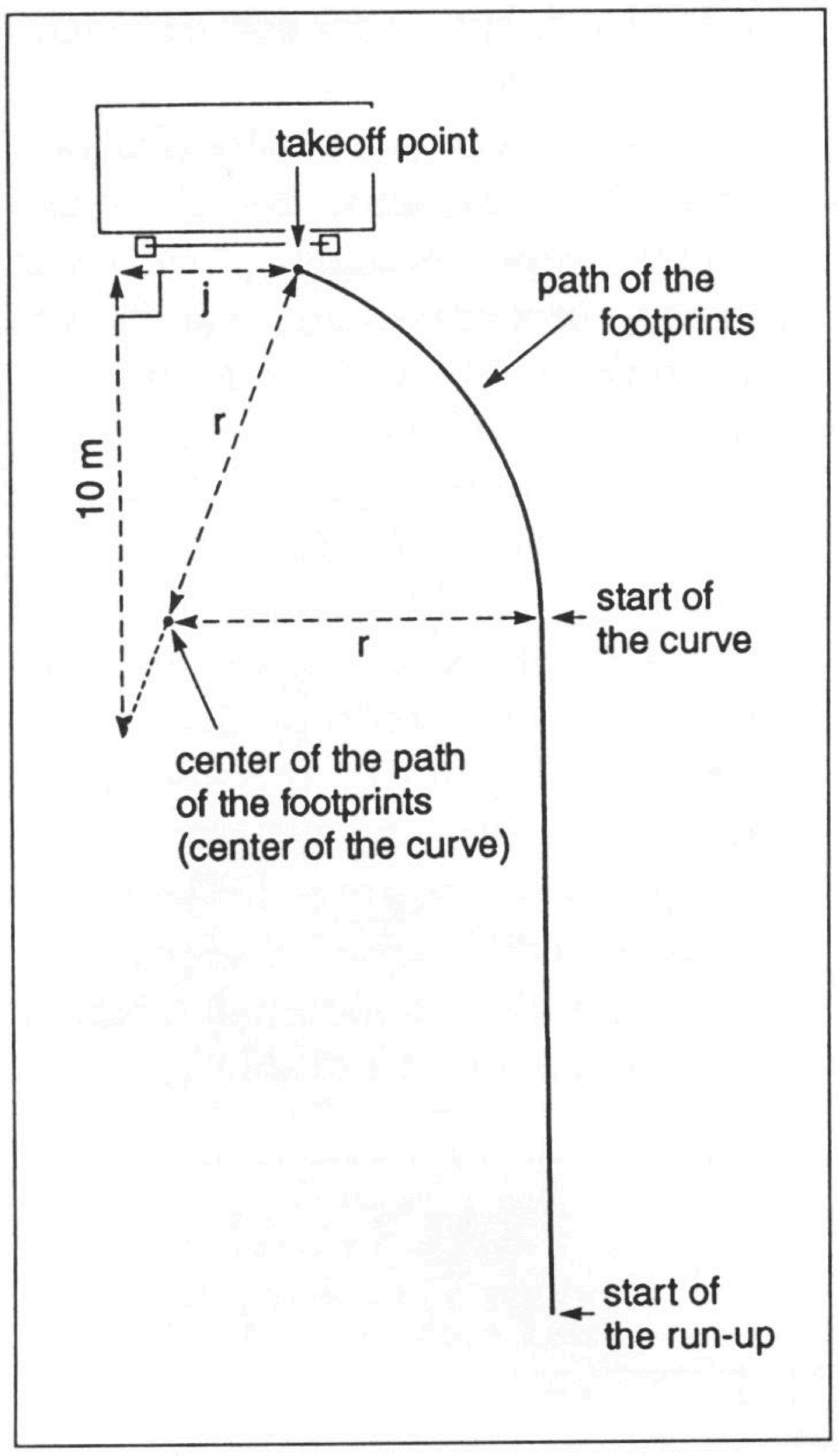


Figure 3

ability of about 4 meters. This is demonstrated by the hypothetical run-ups shown in Figure 4a. However, Figure 2 shows that the distance from the right standard to the straight part of the run-up was actually constrained between approximately 4 and 6 meters for all the jumps, a variability range of only 2 meters.

The small variability in the position of the straight part of the run-up in spite of the large variability in the radius of the curve implied that the athletes in the sample tended to make systematic changes in the final angle of the footprints as they made changes in the radius.

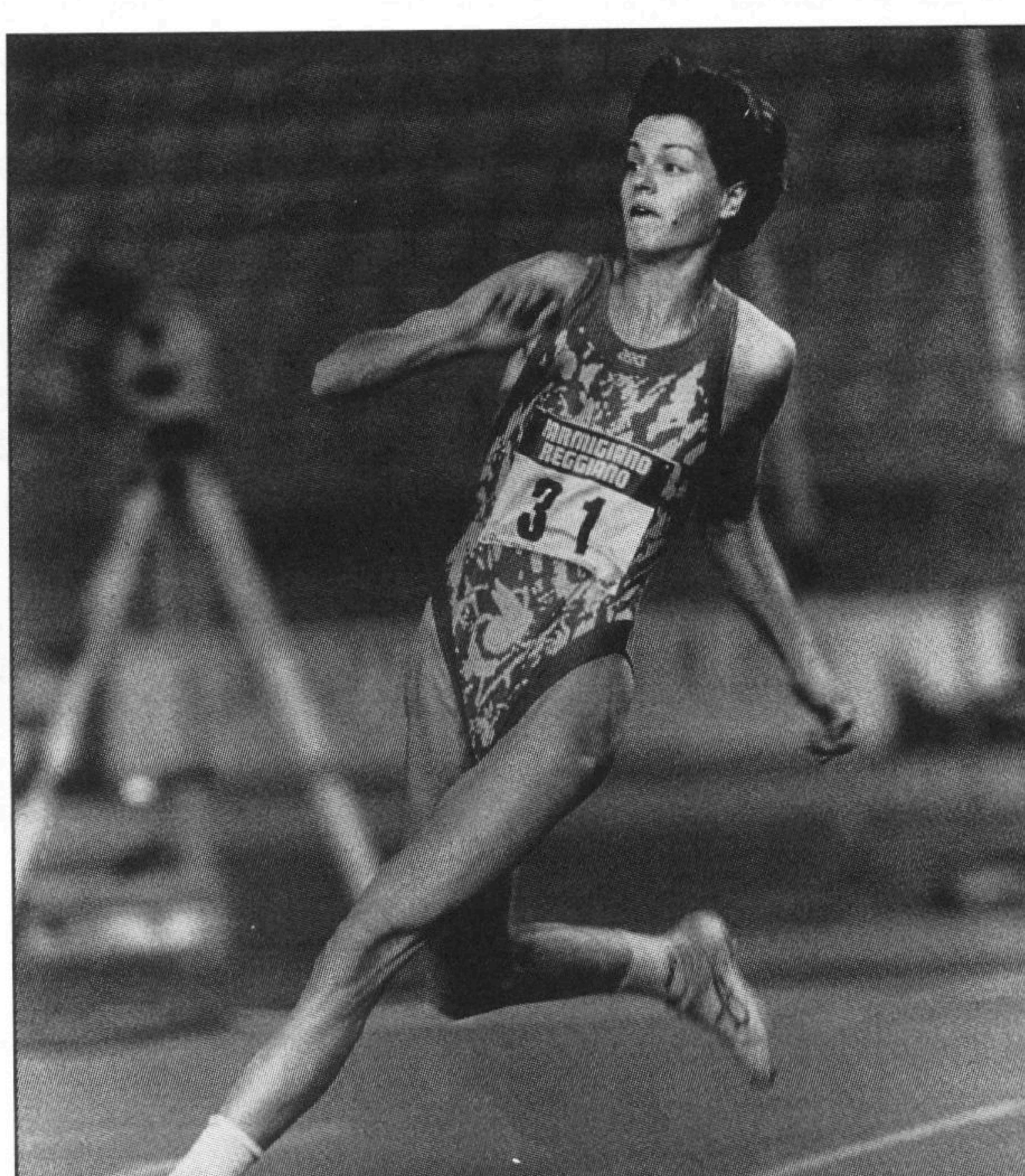
This can be understood better with the help of Figure 4b. The straight parts of the three hypothetical run-ups shown in this drawing were all at the same distance from the right standard (5 meters). Each run-up used a different radius, but still they all ended up at the same takeoff point. The differences between the three run-ups started with differences in the starting point of the curve. By traveling deeper toward the plane of the standards before starting the curve, the athlete can use a smaller radius, and still reach the same takeoff point. However, the final angle of the footprints' curve will also be smaller (i.e., the final path of the footprints will be more parallel to the bar).

The high jumpers in the sample did not follow exactly the pattern of variation shown in Figure 4b, because the distance between the right standard and the straight part of the run-up did fluctuate in the sample (see Figure 2). However, this fluctuation was rather small (about 1 meter in either direction around the 5-meter point), and therefore the basic relationships of the hypothetical jumps of Figure 4b were present in the jumps of Figure 2: the athletes who used a large radius (e.g., Henkel, Kostadinova) tended to have large values of f, while the athletes who used a small radius (e.g., Conway, Babakova) tended to have small values of f.

In theory, a high jumper should be able to try any combination of radius (r) and final angle of the footprints' path (f): for any given value of f, the jumper should be able to try a wide variety of values of r, as shown in Figure 4a; and for any given value of r, the jumper should be able to try a wide variety of values of f, as shown in Figure 4c. However, to a great extent this did not happen; the jumpers in the sample tended to follow a pattern similar to the one shown in Figure 4b, in which there was a positive correlation between the values of r and f.

It is not clear why the jumpers linked the values of r and f in this way, but we have come up with two possible theories:

The first theory is based on the relationship between the radius of the curve and the need for the generation of angular momentum. During the bar clearance, a high jumper needs angular momentum in order to make the appropriate rotations over the bar. This rotation can be broken down into a twist rotation and a somersault rotation (Dapena, 1995b). The twist rotation serves to turn the back of the athlete toward the bar; the somersault rotation makes the shoulders go down and the knees go up during the bar clearance. Taking into account the final direction of the run-up, the somersault rotation can be broken down into a forward somersaulting component and a lateral somersaulting component. One of the main purposes of the curved run-up is to favor the production of the *lateral* somersault-



VICTOR SAILER/PHOTO RUN

1996 Olympic champion Stefka Kostadinova.

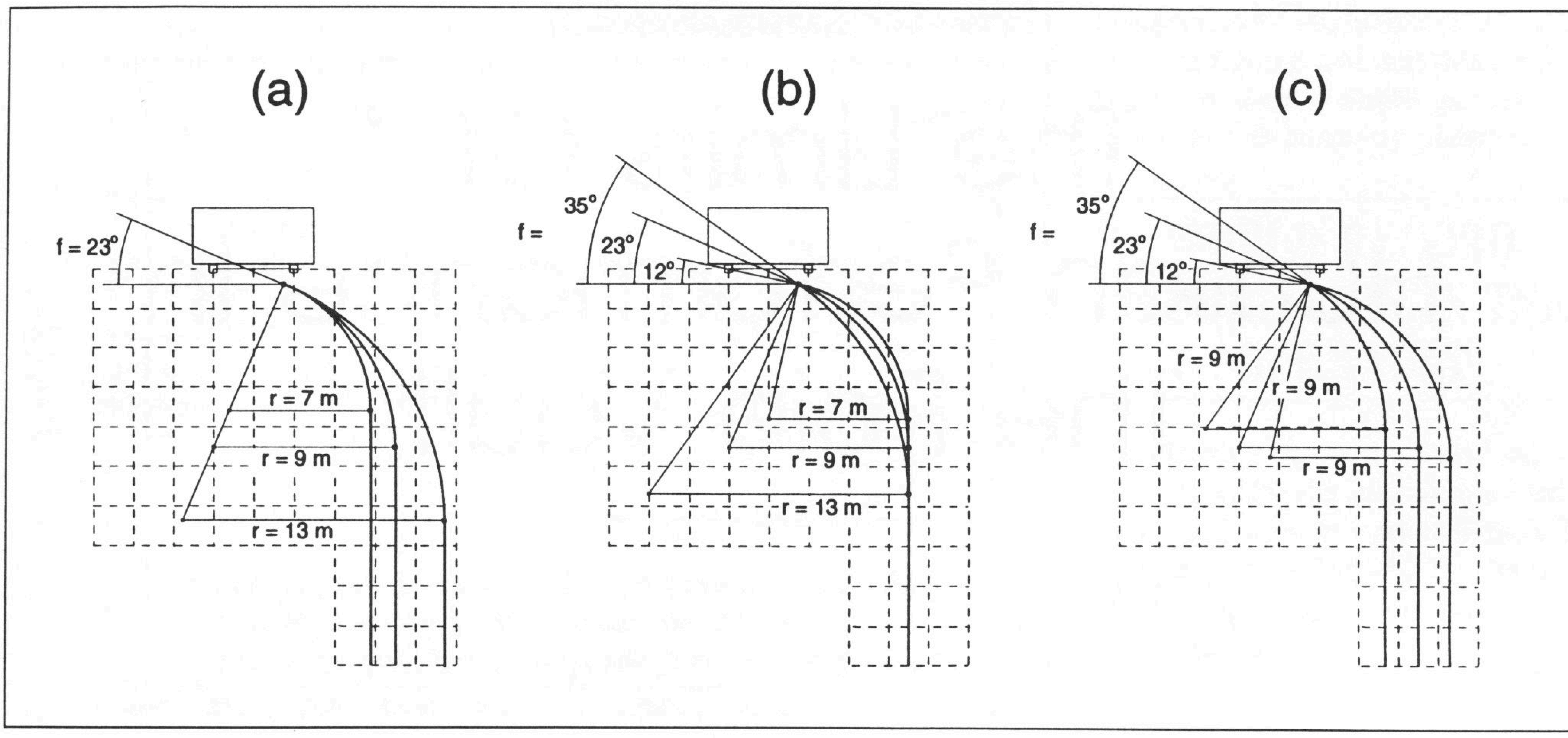


Figure 4

ing component of the angular momentum. (The other one is to lower the c.g. in the last steps of the run-up.)

The high jumpers who are traveling more parallel to the bar at the end of the run-up will tend to need a smaller amount of forward somersaulting angular momentum and a larger amount of lateral somersaulting angular momentum in order to produce a total somersault rotation that makes the longitudinal axis of the athlete be perpendicular to the bar at the peak of the jump. This means that, to some extent, we should expect athletes who are traveling more parallel to the bar at the end of the run-up to use tighter curves (smaller radius) in order to facilitate the generation of a larger amount of lateral somersaulting angular momentum during the takeoff. This may be part of the reason why the athletes who used smaller radius values tended to be those who were traveling more parallel to the bar at the end of the run-up (Figures 2 and 4b).

The second theory is that the high jumpers in the sample may not have fully explored all the possible options for the distance between the right standard and the straight part of the run-up. They may all be starting within the narrow range between 4 and 6 meters simply because the other high jumpers also start there. If this is the case, the jumpers are unnecessarily restricting the combinations of r and f that they can use.

For instance, let us assume that a jumper who is using the combination r=9 m and f=23° with the straight part of the run-up 5 meters out from the right standard (i.e., the middle path in Figure 4b) wishes to try a run-up with a 7-meter radius, but maintaining f at 23°. If this jumper keeps the straight part of the run-up at the 5-meter distance, it will be impossible to combine the 7-meter radius with a final angle of 23°; the athlete will have to change the final angle to 12° (see Figure 4b). However, if the jumper brought the straight part of the run-up to a distance of less than 4 meters from the right standard, the combination of a 7-meter radius with a final angle of 23° would be possible (Figure 4a).

If the second theory is correct, the next question would be, what drives the athletes' decisions within Figure 4b (or within Figure 2)? Do they decide to use a certain radius, and are then forced into a final angle that may or may not be desirable? Or do they decide to use a certain final angle, and are then forced into a radius that may or may not be desirable?

At this time, we do not know for certain the reasons for the linkage found between the radius of the curve and the final direction of the footprints in the finalists from the 1991 World Championships. However, we believe that coaches should feel free to experiment with a variety of combinations of r and f, even if some of those combinations take the straight part of the run-up out of the 4-6 meter range currently used by most high jumpers.

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