The Rotation Over The Bar In The Fosbury-Flop High Jump

Prior articles and research have firmly established Jesus Dapena in the forefront in the area of track & field biomechanics. Track Coach is very pleased to present this outstanding work on the high jump, a piece that will be of great benefit to anyone coaching the event. The focus on correcting technical problems should have an immediate impact on the coach. Do not be deceived by the title. . . this article is very practical and immediately helpful.

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A high jump can be broken down into three phases: run-up, takeoff and bar clearance. After takeoff, the center of gravity (e.g.) follows a fixed path called a parabola. The parabola should reach the maximum possible peak height. As the e.g. travels along the parabola, the body should rotate around the e.g. in a way that will al- low the successful clearance of a bar set as high as possible.

In a Fosbury-flop, the rotation consists of a "twist" (a rotation around the longitudinal axis of the body) which turns the back of the athlete toward the bar, and a "somersault" (a rotation around a transverse axis) which makes the shoulders go down and the knees go up (Dapena, 1988).

The combination of these two motions produces a twisting somersault rotation which leads to a face-up layout position at the peak of the jump. Combined with an arched configuration of the body, this position allows the athlete to clear a bar set at a height that is near the maximum height reached by the c.g. (Dapena, 1980a, 1980b).

Some high jumpers are unable to perform the necessary somersault and! or twist rotations correctly. This can limit the effectiveness of the bar clearance and therefore the result of the jump.

The most frequent problems in the rotation of a Fosbury-flop high jump are due to insufficient amounts of somersault or twist rotation after takeoff. An insufficient amount of somersault rotation (sometimes misleadingly described as "stalling") makes it difficult for the legs to clear the bar; an insufficient amount of twist rotation produces a tilted position of the athlete at the peak of the jump, with the hip of the lead leg lower than the hip of the takeoff leg.

To a great extent, the rotation over the bar is produced, by the angular momentum of the athlete. To understand the nature of the problems that can occur in the bar clearance, it is necessary to have "a clear concept of what angular momentum is, and how it affects the rotation.

ANGULAR MOMENTUM

Angular momentum (also called" "rotary momentum") is a mechanical factor that makes the athlete rotate. In general terms, the larger the angular momentum, the faster the rotation. High jumpers need to have the right amount of angular momentum in order to perform in the air the rotations necessary for a proper bar clearance. Angular momentum cannot be changed after the athlete leaves the ground; the athlete has to obtain the angular momentum during the takeoff phase, through the forces that the takeoff foot makes on the ground.

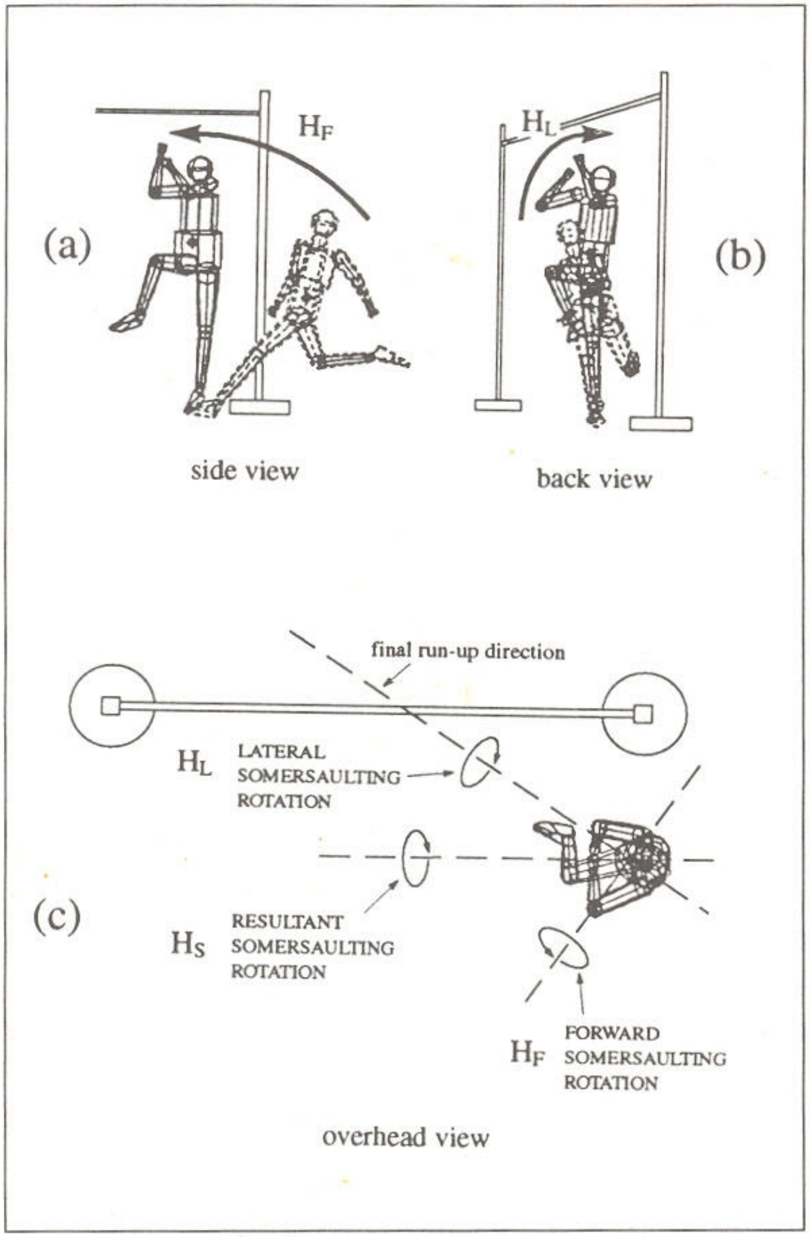
As mentioned before, the airborne motions of a Fosbury-flop can be described roughly as a twisting somersault. We will look first at the somersault rotation, and later at the twist.

THE SOMERSAULT ROTATION

The somersault rotation can be broken down into two parts: a forward somersaulting component and a lateral somersaulting component (Dapena, 1980b, 1988).

Forward somersaulting angular momentum

During the takeoff phase, the athlete produces angular momentum about a horizontal axis perpendicular to the final direction of the run-up (see Figure 1a and the sequence at the top of Figure 2). This is called the forward somersaulting angular momentum (HF). In the last step of the run-up, the high jumper thrusts the hips forward, and this makes the trunk have a backward lean at the start of the takeoff phase (i.e., at touchdown, the instant when the takeoff foot lands on the ground). Then the trunk rotates forward during the takeoff phase, and is vertical at the instant that the foot leaves the ground.



(a)
H_F
side view
(b)
H_L
back view
final run-up direction
H_L
LATERAL
SOMERSAULTING
ROTATION
(c)
H_S
RESULTANT
SOMERSAULTING
ROTATION
H_F
FORWARD
SOMERSAULTING
ROTATION
overhead view

Figure 1

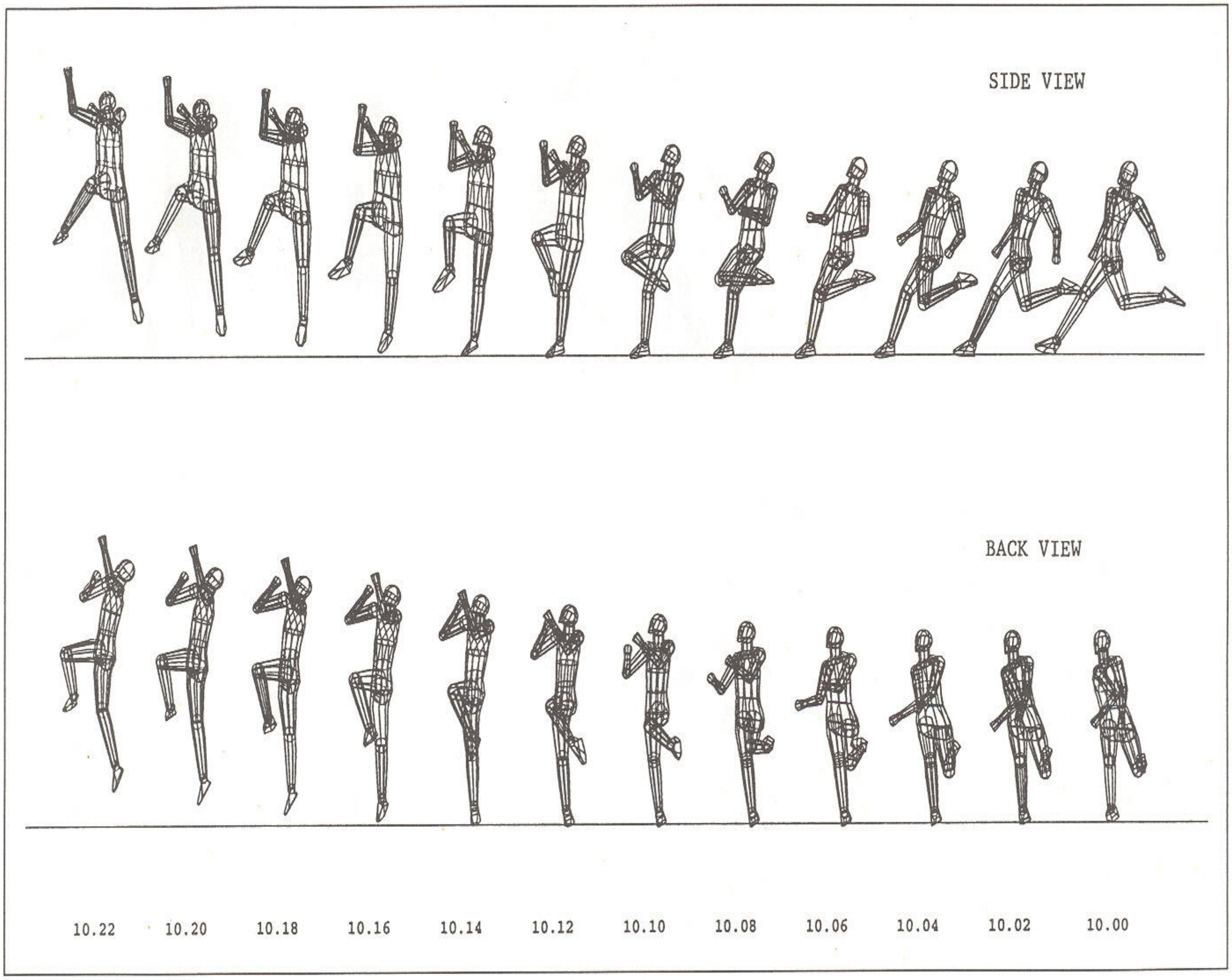


Figure 2

The angular momentum obtained by the athlete is related to the tilt angles of the trunk at the start and at the end of the takeoff phase: A larger change in the trunk tilt from a backward position toward the vertical during the takeoff phase is associated with the generation of a larger amount of for- ward somersaulting angular momentum (Dapena, 1988).

The forward somersaulting angular momentum can also be affected by the actions of the arms and of the lead leg. Wide swings of the arms and of the lead leg during the takeoff phase can help the athlete to produce a high parabola. However, in a view from the side (top sequence in Figure 3) they also imply strong backward (clockwise) rotations of these limbs, which can reduce the total forward somersaulting angular momentum of the body.

To decrease this problem, some high jumpers turn their back toward the bar in the last step of the run-up, and then swing the arms diagonally forward and away from the bar during the takeoff phase (see Figure 4). Since this diagonal arm swing is not a perfect backward rotation, it interferes less with the generation of forward somersaulting angular momentum.

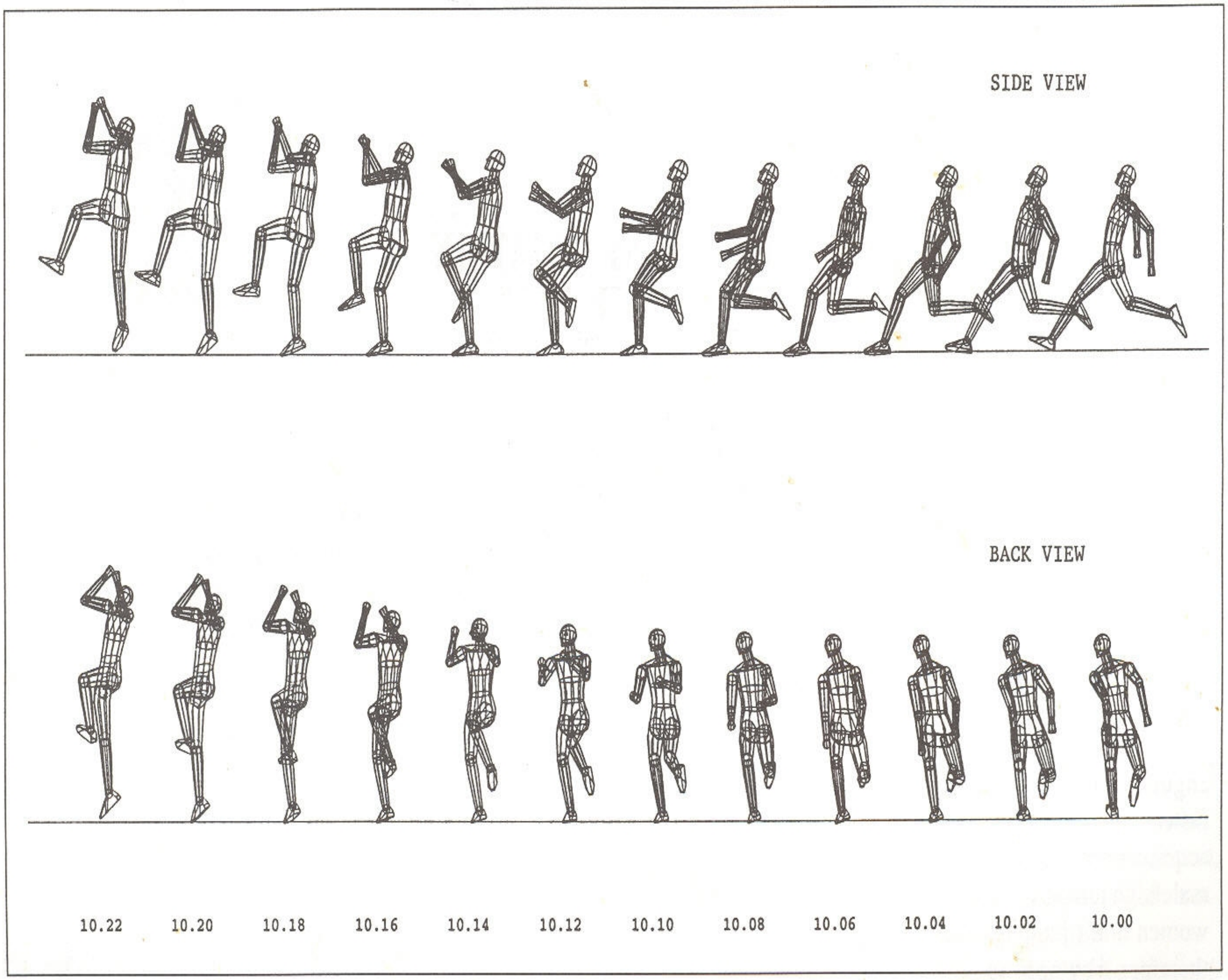


Figure 3: Direct Forward Arm Swing

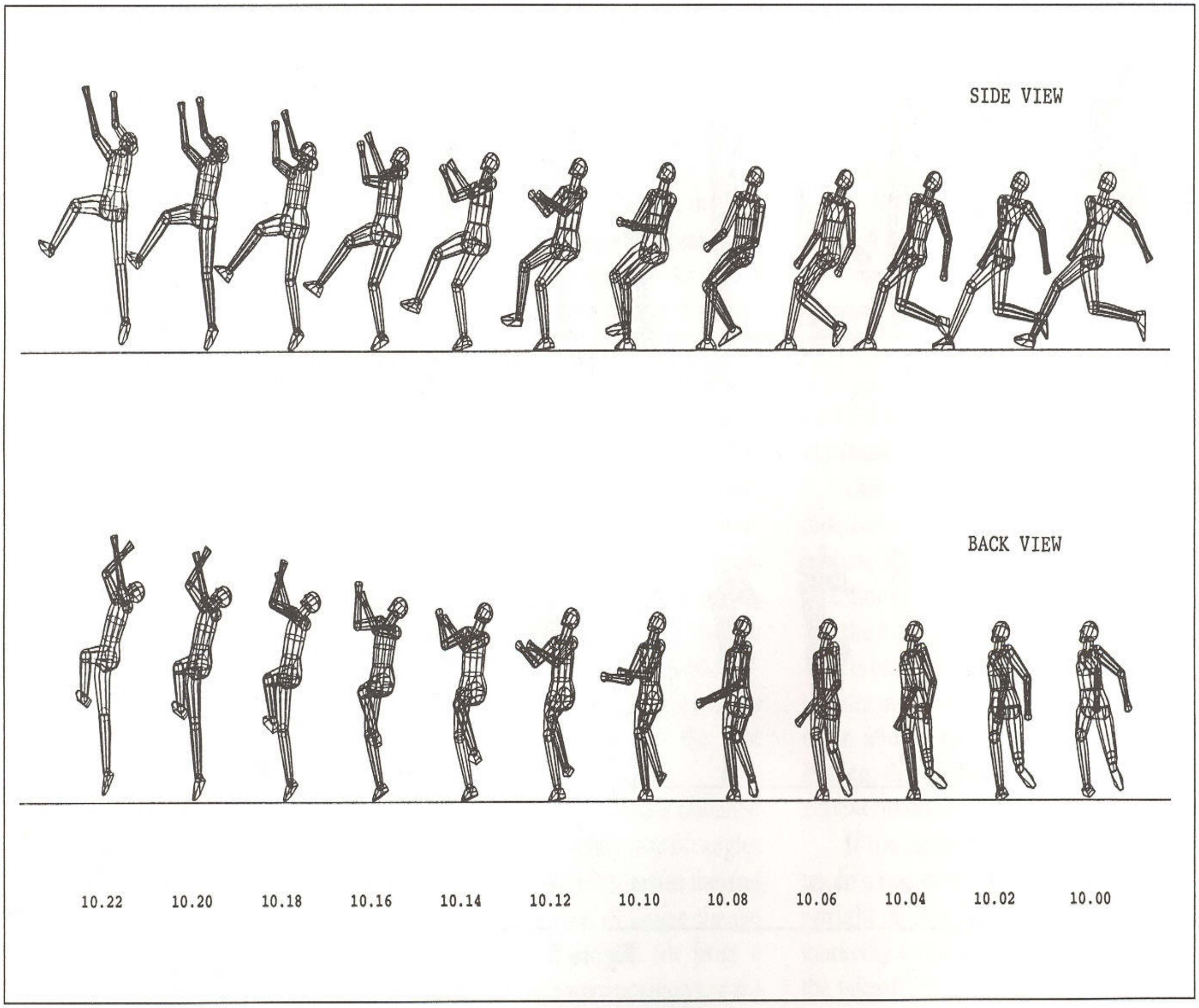


Figure 4: Diagonal Arm Swing

Lateral somersaulting angular momentum

During the takeoff phase, angular momentum is also produced about a horizontal axis in line with the final direction of the run-up (see Figure 1b and the bottom sequence in Figure 2). This is called the lateral somersaulting angular momentum (HL). In a rear view of an athlete who takes off from the left leg, this angular momentum component produces a clockwise rotation. If the jumper used a straight run-up, in a rear view the athlete would be upright at touchdown and leaning markedly toward the bar at the end of the takeoff phase. Since a leaning position at the end of the takeoff would result in the generation of less lift, the production of angular momentum would thus cause a reduction in the maximum height reached by the c.g. at the peak of the jump.

However, if the athlete uses a curved run-up, the initial lean of the athlete to the left at the start of the takeoff phase will allow the athlete to be upright or only slightly past the vertical at the end of the takeoff (see Figure 1b and the bottom sequence in Figure 2). Therefore the curved run- up, together with the generation of lateral somersaulting angular momentum, contributes to the generation of more lift than if a straight run-up were used.

Large changes from left to right in the tilt angle of the trunk during the takeoff phase are generally associated with larger amounts of lateral somersaulting angular momentum at the end of the takeoff (see Dapena, 1988).

The bottom sequence in Figure 4 shows that in an athlete who takes off from the left leg a diagonal arm swing is associated with a clockwise motion of the arms in a view from the back. Therefore, a diagonal arm action not only interferes less with the generation of forward somersaulting angular momentum, but also contributes more to the generation of lateral somersaulting angular momentum.

High jumpers usually have a larger amount of the lateral component of somersaulting angular momentum than of the forward component. The sum of these two components adds up to the required total (or "resultant") somersaulting angular momentum, Hs (Figure 1e).

In general, athletes with more angular momentum tend to rotate faster. Female high jumpers tend to acquire more angular momentum than male high jumpers. This is because the women don't jump quite as high, and therefore they need to rotate faster to compensate for the smaller amount of time that they have available between the takeoff and the peak of the jump.

THE TWIST ROTATION

The twist rotation is generated in part by swinging the lead leg up and somewhat away from the bar during the takeoff, and also by actively turning the shoulders and arms during the takeoff in the desired direction of the twist. These actions create angular momentum about a vertical axis. This is called the twisting angular momentum, HT, and most high jumpers have no difficulty obtaining an appropriate amount of HT. However, we will see later that the actions that the athlete makes in the air, as well as other factors, can also significantly affect whether the high jumper will be perfectly face-up at the peak of the jump, or tilted with one hip lower than the other.

ADJUSTMENTS IN THE AIR

After the takeoff is completed, the parabolic path of the e.g. is totally determined, and there is nothing that the athlete can do to change it. How- ever, this does not mean that the paths of all parts of the body are determined. What cannot be changed is the path of the point that represents the average position of all the body parts (the e.g.), but it is possible to move one part of the body in one direction by moving other parts in the opposite direction.

Using this principle, after the shoulders pass over the bar the high jumper can raise the hips by lowering the head and the legs. For a given height of the e.g., the farther the head and the legs are lowered, the higher the hips will be lifted. This is the reason for the typical arched position on top of the bar.

To a great extent, the rotation of the high jumper in the air is also determined once the takeoff phase is completed, because the angular momentum of the athlete cannot be changed in the air. However, some alterations of the rotation are still possible. By slowing down the rotations of some parts of the body, other parts of the body will speed up as a compensation, and vice versa. This is called rotational action and reaction.

For instance, the athlete shown in Figure 5a slowed down the counter-clockwise rotation of the takeoff leg shortly after the takeoff phase was completed by flexing at the knee and extending at the hip (t = 10.34 - 10.58 s). In reaction, this helped the trunk to rotate faster counterclockwise, and therefore contributed to produce the horizontal position of the trunk at t = 10.58 s. Later, from t = 10.58 to t = 10.82 s, the athlete slowed down the counterclockwise rotation of the trunk, and even reversed it into a clockwise rotation; in reaction, the legs simultaneously increased their speed of rotation counter- clockwise, and thus cleared the ~ bar (t = 10.58 - 10.82 s). (NOTE: To facilitate comparisons among jumps, in our laboratory the time t = 10.00 seconds is arbitrarily assigned to the instant when the takeoff foot first makes contact with the ground to start the takeoff phase.)

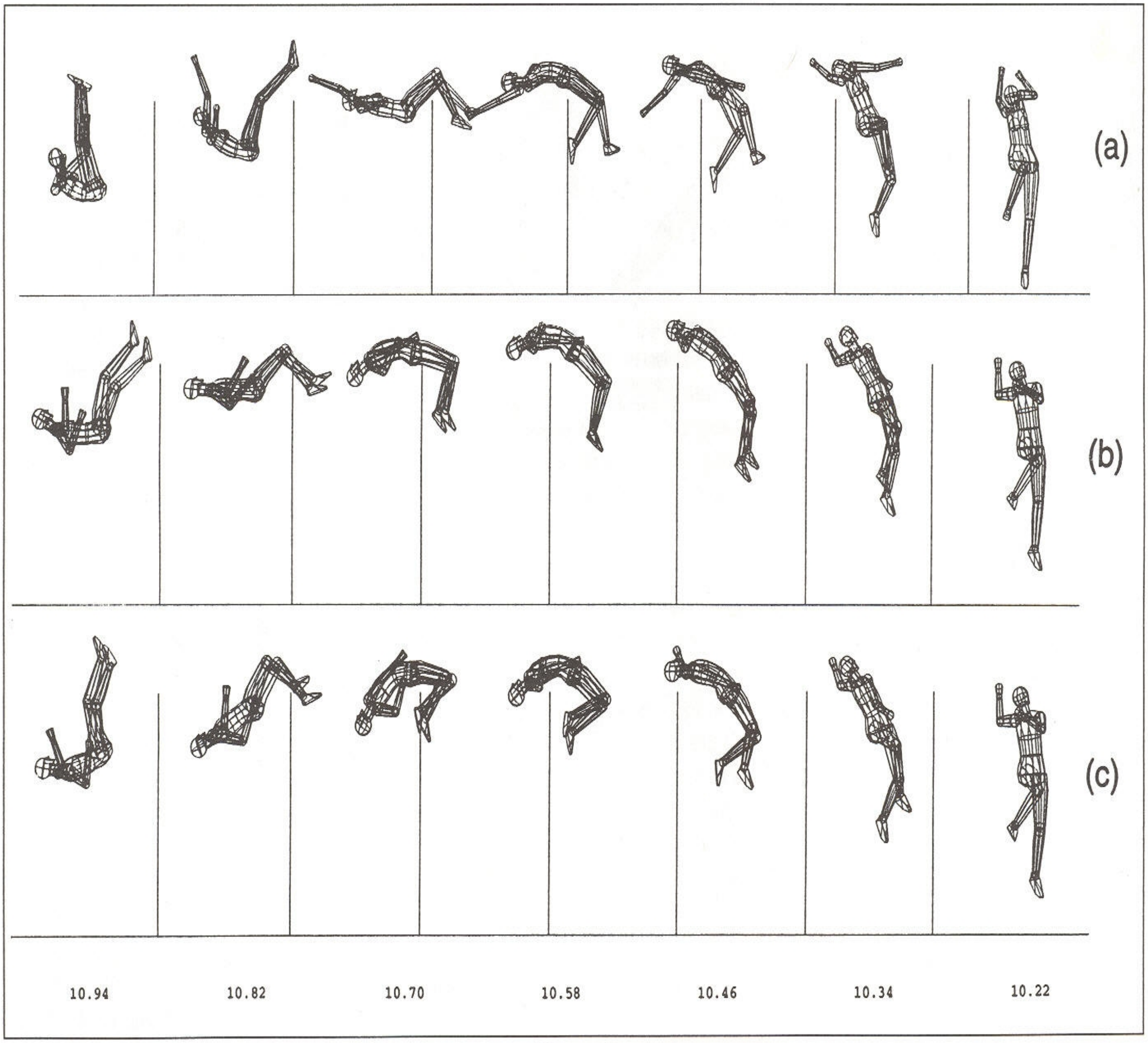


Figure 5

The principles of action and reaction just described both for translation and rotation result in the typical arching and un-arching actions of high jumpers over the bar: the athlete needs to arch in order to lift the hips, and then to un-arch in order to speed up the rotation of the legs. As the body un- arches, the legs go up, but the hips go down. Therefore, timing is critical. If the body un-arches too late, the calves will knock the bar down; if the body un- arches too early, the athlete will "sit" on the bar and will also knock it down.

Another way in which rotation can be changed after takeoff is by altering the "moment of inertia" of the body. The moment of inertia (you should think of it as a single long word, "moment-of-inertia") is a number that indicates whether the various parts that make up the body are close to the axis of rotation or far from it.

When many parts of the body are far from the axis of rotation, the moment of inertia of the body is large, and this decreases the speed of turning about the axis of rotation. Conversely, if most parts of the body are kept close to the axis of rotation, the moment of inertia is small, and the speed of rotation increases. This is what happens to figure skaters in a view from overhead when they spin: As they bring their arms closer to the vertical axis of rotation, they spin faster about the vertical axis.

In high jumping, rotation about a horizontal axis parallel to the bar (i.e., the somersault) is generally more important than rotation about the vertical axis, but the same principle is at work. The jumps shown in Figures 5b and 5c both had the same amount of somersaulting angular momentum. However, the athlete in Figure 5c somersaulted faster: Both jumpers had the same tilt at t = 10.22 s, but at t = 10.94 s the athlete in Figure 5c had a more back- ward-rotated position than the athlete in Figure 5b.

The faster speed of rotation of the jumper in Figure 5c was due to his more compact body configuration in the period between t = 10.46 sand t = 10.70 s. It was achieved mainly through a greater flexion of the knees. This configuration of the body reduced the athlete's moment of inertia about an axis parallel to the bar, and made him somersault faster.

The technique used by the athlete in Figure 5c can be very helpful for high jumpers with small or moderate amounts of somersaulting angular momentum. In both jumps shown in Figures 5b and 5c the athlete had the same amount of angular momentum, the center of gravity reached the same peak height, and the bar was set at the same height. While the athlete in Figure 5b hit the bar with his calves (t= 10.82 s), the faster somersault rotation of the athlete in Figure 5c helped him to pass all parts of the body over the bar with some room to spare.

In the rare cases in which a high jumper has a very large amount of angular momentum, the technique shown in Figure 5c could be a liability, because it might accelerate the rotation so much that the shoulders will hit the bar on the way up. For athletes with a very large amount of angular momentum, it will be better to keep the legs more extended on the way up to the bar, following the body configuration pattern shown in Figure 5b. This will temporarily slow down the backward somersault, and thus will help to prevent the athlete from hitting the bar with the shoulders on the way up to the bar. (Of course, the athlete will still need to arch and un-arch with good timing over the bar.)

PROBLEMS IN THE EXECUTION OF THE TWIST ROTATION

It was pointed out earlier that the twist rotation in high jumping is produced in part by the twisting component of angular momentum, HT. But it was also mentioned that other factors could affect whether the jumper would be perfectly face-up at the peak of the jump (Figure 6a), or tilted to one side with one hip lower than the other (Figure 6b). One of the most important of these factors is the proportion between the sizes of the forward and lateral components of the somersaulting angular momentum. Let's see how this works.

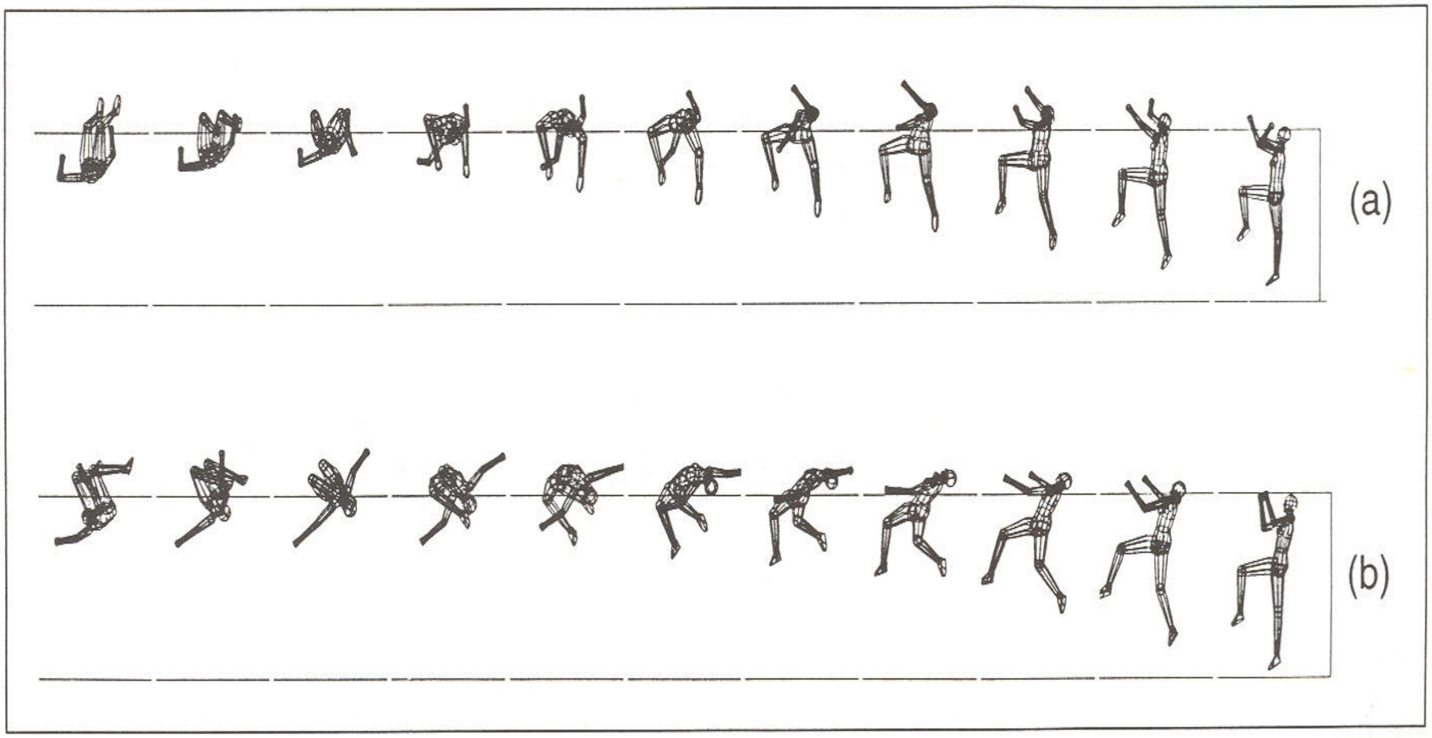


Figure 6

Figure 7 shows sketches of a hypothetical high jumper at the end of the takeoff phase and after three pure somersault rotations in different directions (with no twist), all viewed from overhead. For simplicity, we have assumed that the final direction of the run-up was at a 45° angle with respect to the bar. A normal combination of forward and lateral components of somersaulting angular momentum would produce at the peak of the jump the position shown in image b, which would require in addition 90° of twist rotation to generate a face-up orientation. If instead an athlete generated only lateral somersaulting angular momentum, the result would be the position shown in image a, which would require only about 45° of twist rotation to achieve a face-up orientation; if the athlete generated only forward somersaulting angular momentum, the result would be the position shown in image c, which would require about 135° of twist rotation to achieve a face-up orientation.

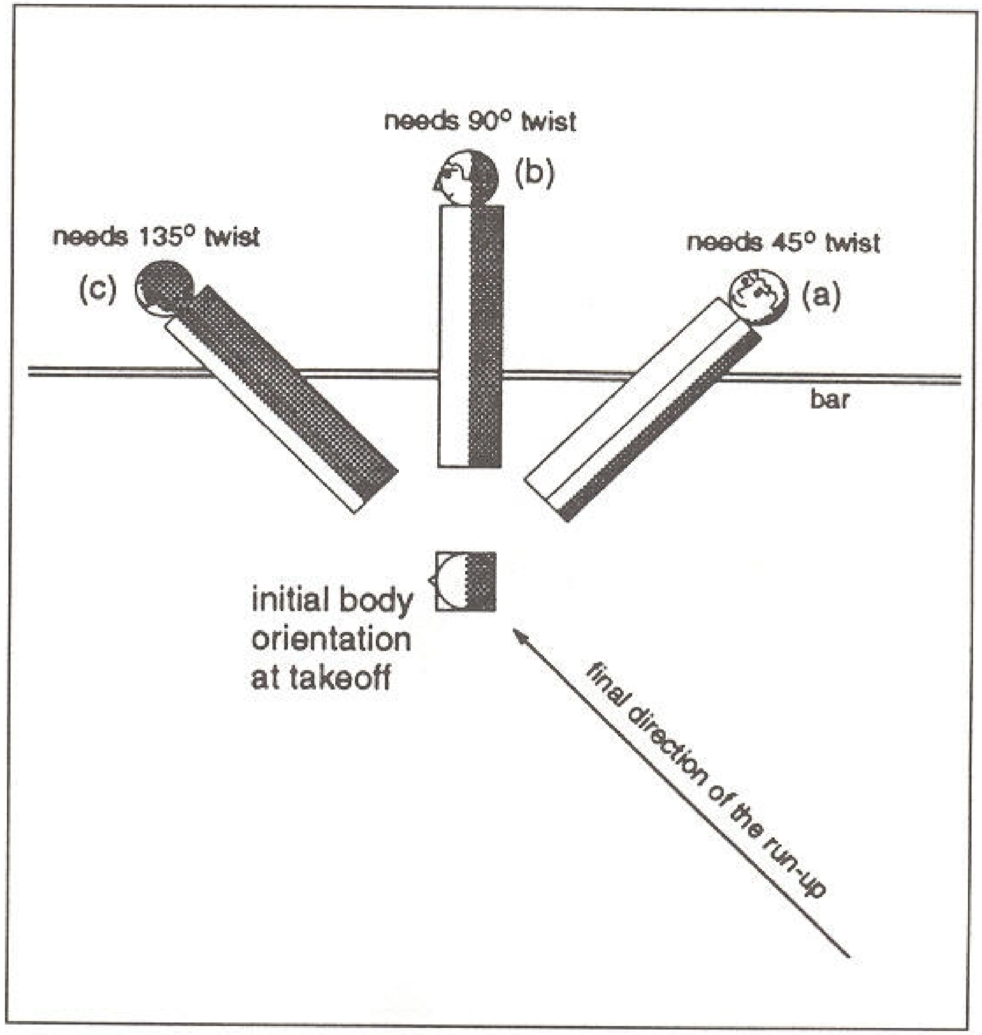


Figure 7

It is very unusual for high jumpers to have only lateral or forward somersaulting angular momentum, but many jumpers have much larger amounts of one than of the other. The example shows that jumpers with particularly large amounts of forward somersaulting angular momentum and small amounts of lateral somersaulting angular momentum will need to twist more in the air in order to be face up at the peak of the jump. Otherwise, the body will be tilted, with the hip of the lead leg lower than the hip of the takeoff leg.

Conversely, jumpers with particularly large amounts of lateral somersaulting angular momentum and small amounts of forward somersaulting angular momentum will need to twist less in the air than other jumpers in order to be perfectly face up at the peak of the jump. Otherwise, the body will be tilted, with the hip of the take- off leg lower than the hip of the lead leg. (This last problem does not occur very often.)

Another point that we have to take into account for the understanding of the twist rotation is that, while the twisting component of angular momentum (RT) is a major factor in the generation of the twist rotation, it is generally not enough to produce by itself the necessary face-up position on top of the bar. In addition, the athlete also needs to use rotational action and re- action about the longitudinal axis of the body to increase the amount of twist rotation that occurs in the air.

As we have seen, in a normal high jump the athlete needs to achieve about 90° of twist rotation between takeoff and the peak of the jump. Only about half of it (about 45°) is produced by the twisting angular momentum; the other half (roughly another 45°) needs to be produced through rotational action and reaction. Rotational action and reaction is sometimes called "catting" because cats dropped in an upside-down position with no angular momentum use a mechanism of this kind to land on their feet.

It is difficult to see the amount of twist rotation that occurs through catting in a high jump, because it is obscured by the simultaneous somersault and twist rotations produced by the angular momentum. If we could "hide" the somersault and twist rotations produced by the angular momentum, we would be able to isolate the catting rotation, and see it clearly.

To achieve that, we would need to look at the high jumper from the viewpoint of a rotating camera. The camera would need to somersault with the athlete, staying aligned with the athlete's longitudinal axis. The camera would also need to twist with the athlete, but just fast enough to keep up with the portion of the twist rotation produced alone by the twisting component of angular momentum. That way, all that would be left would be the rotation produced by the catting, and this rotation is what would be visible in the camera's view.

It is impossible to make a real camera rotate in such a way, but we can use a computer to calculate how the jump would have appeared in the images of such a camera if it had existed. This is what is shown in Figure 8.

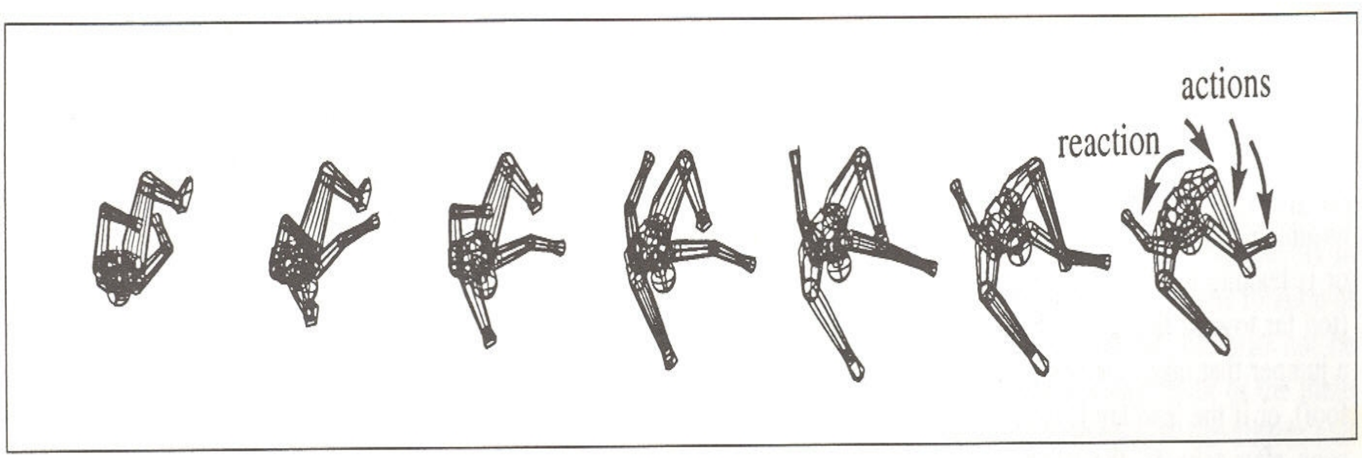


Figure 8

The sequence in Figure 8 covers the period between takeoff and the peak of the jump, and progresses from left to right. All the images are viewed from a direction aligned with the longitudinal axis of the athlete. (The head is the part of the athlete nearest to the "camera".)

As the jump progressed, the camera somersaulted with the athlete, so it stayed aligned with the athlete's longitudinal axis. The camera also twisted counterclockwise with the athlete, just fast enough to keep up with the portion of the twist rotation produced by the twisting component of angular momentum.

Figure 8 shows a clear counter-clockwise rotation of the hips (about 45°) between the beginning and the end of the sequence. This implies that the athlete rotated counterclockwise faster than the camera, i.e., faster than the part Of the twist rotation produced by the twisting component of angular momentum.

The counterclockwise rotation of the hips visible at the end of the sequence is the amount of twist rotation produced through catting alone. It occurred mainly as a reaction to the clock- wise motions of the right leg, which moved toward the right, and then back- ward for the arch. (These actions of the right leg are subtle, but never the less visible in the sequence.) In part, the counterclockwise catting rotation of the hips was also a reaction to the clockwise rotation of the right arm.

Without the catting, the twist rotation of this athlete would have been reduced by an amount equal to the approximately 45° of counterclockwise rotation visible in the sequence of Figure 8. The athlete shown in Figure 8 is the same one shown in Figure 6a. Without the catting actions, the hips would have been about 45° short of the level position seen in Figure 6a at the peak of the jump: the right hip would have been lower than the left hip.

Some jumpers emphasize the twisting angular momentum more; others tend to emphasize the catting more. If not enough twisting angular momentum is generated during the takeoff phase, or if the athlete does not do enough catting in the air, the athlete will not twist enough in the air, which will make the body be in a tilted position at the peak of the jump, with the hip of the lead leg lower than the hip of the takeoff leg. This will put the hip of the lead leg (i.e., the low hip) in danger of hitting the bar. .

There are other ways in which problems can occur in the twist rotation. If at the end of the takeoff phase an athlete has too much backward lean, or is leaning too far toward the right (too far toward the left in the case of a jumper that takes off from the right foot), or if the lead leg is lowered too soon after takeoff, the twist rotation will be slower. These mechanical effects are due to interactions between the somersault and twist rotations that are too complex to explain here.

According to the previous discussion, a tilted position at the peak of the jump in which the hip of the lead leg is lower than the hip of the takeoff leg can be due to a variety of causes: an insufficient amount of twisting angular momentum; a much larger amount of forward than lateral somersaulting angular momentum; insufficient catting in the air; a backward-tilted position of the body at the end of the takeoff phase; a position that is too tilted toward the right at the end of the takeoff phase (toward the left in the case of jumpers taking off from .the right foot); premature lowering of the lead leg soon after takeoff.

CORRECTING PROBLEMS IN THE SOMERSAULT ROTATION

If a jumper often "stalls" during the bar clearance, and therefore finds it difficult for the legs to clear the bar successfully, the problem can be solved through changes in the actions that the athlete makes in the air or through changes in the actions that the athlete makes while still on the ground.

Corrections in the air

One possible solution is to arch more during the bar clearance, putting a special emphasis on a very marked flexion of the knees' (see Figure 5c). Such a body configuration can be very compact in a view along the bar, and it will increase the speed of the somersault rotation.

Some high jumpers try to speed up the somersault rotation by spreading the knees far apart during the bar clearance. Keeping the knees far apart also makes the body more compact in the view along the bar, and therefore helps the athlete to somersault faster.

However, there is an important problem with such a technique. By keeping the knees far apart, the knees have to cross the bar almost immediately after the hips. This leaves very little time for the athlete to execute the un-arching, and therefore usually leads to an ineffective bar clearance. Keeping the knees far apart is not an advisable technique. Arching more aggressively, together with a marked flexion of the knees, is a much better solution to a slow somersault rotation.

Corrections on the ground

If an improved arch and a very marked flexion of the knees does not solve the problem, this means that the somersaulting angular momentum of the athlete is probably so small that it is necessary to make changes in the run-up and takeoff to increase it. Ideally, the athlete should be subjected to a detailed 3D biomechanical analysis, to determine the source of the problem and the best solution for it. However, such an analysis is not available to most high jumpers. Therefore, we have to look for a solution using video taping and qualitative analysis.

The coach should videotape the athlete from two different positions:. (a) from the back, with the camera pointing along the final direction of the run-up, and (b) from the side, with the camera pointing perpendicular to the final direction of the run-up.

The final direction of the run-up is the direction in which the c.g. is traveling during the last step of the run-up, immediately before the take- off foot is planted on the ground (Dapena, 1980a, 1988). It is about 10-15 degrees more perpendicular to the bar than the line joining the last two footprints.

For most high jumpers, the final direction of the run-up will be at an angle of about 40 degrees with respect to the bar. This should be accurate enough for our purposes here.

Figure 9 shows the approximate positions in which the camera should be placed for the back and side views, assuming a final run-up angle of 40 degrees. In the qualitative analysis, the video images have to be observed using stop-action single-frame advance.

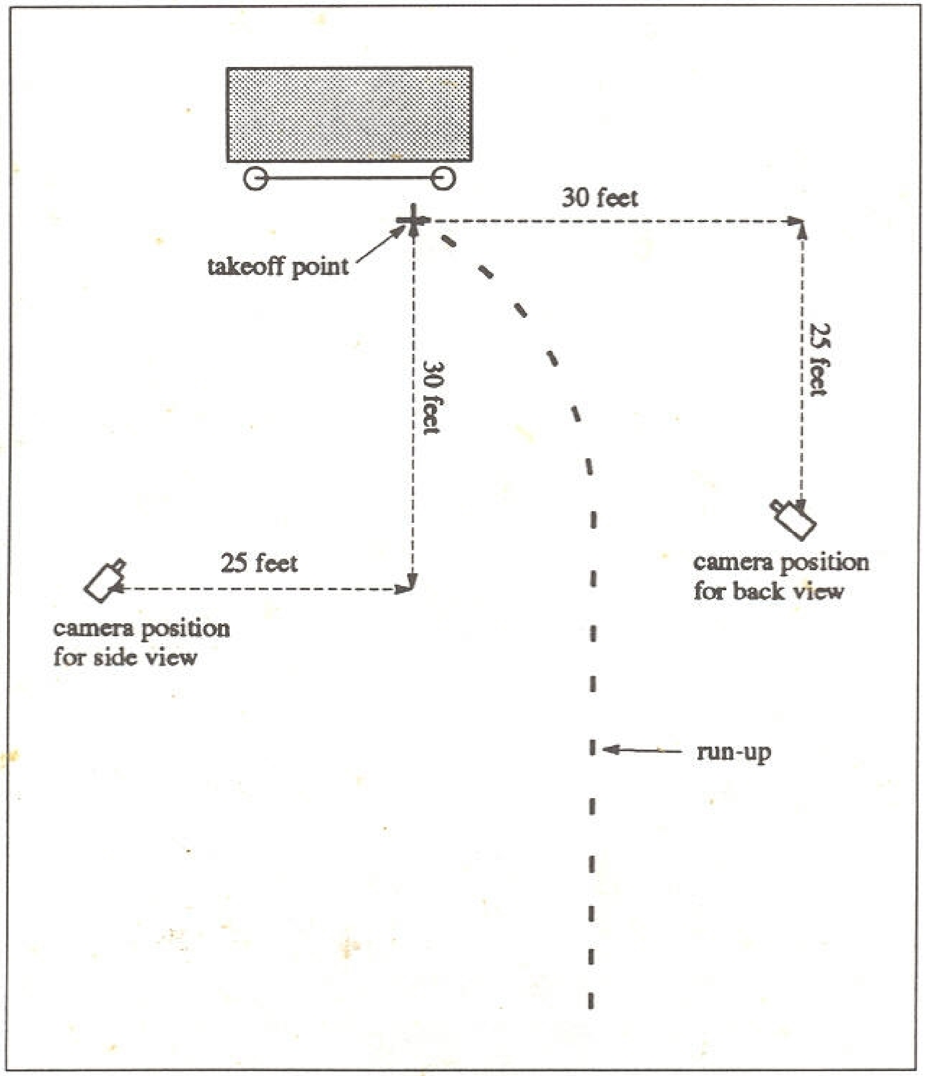


Figure 9

Back view

In the video images showing the back view, the longitudinal axis of the trunk (i.e., the line going from the base of the neck to the midpoint between the hips) should be leaning about 15 degrees away from the bar at the start of the take- off phase, and it should not be tilting toward the bar more than 10 degrees beyond the vertical at the end of the takeoff phase. The most typical problems are the following three:

1. An athlete who does not have enough lean away from the bar at the start of the takeoff phase, and then stays within the allowable 10 degrees of lean toward the bar at the end of the take- off. This athlete will not be able to generate a large enough amount of lateral somersaulting angular momentum, which will probably lead to problems in the bar clearance.
2. An athlete who does not have enough lean away from the bar at the start of the takeoff phase, and then decides to rotate beyond the allowable 10 degrees of lean toward the bar

at the end of the takeoff. This athlete may be able to generate the necessary amount of lateral somersaulting angular momentum to produce a good rotation over the bar, but the c.g. will not reach a very high height after takeoff because of the excessive lean toward the bar at the end of the takeoff. Also, this jumper could have problems hit- ting the bar on the way up.

3. An athlete who has a good amount of lean away from the bar at the start of the takeoff phase, but then decides to be very conservative in the rotation toward the bar, and does not have any lean at all toward the bar at the end of the takeoff, in the view from the back. This athlete will probably get a lot of lift from the ground, but the rotation over the bar will not be very good, and overall the result of the jump will probably be worse than if the athlete had allowed the trunk to rotate to a position 5-10 degrees beyond the vertical at the end of the takeoff.

If the athlete wants to generate a good amount of lateral somersaulting angular momentum, it will be necessary to have a good amount of lean away from the bar at the start of the takeoff phase. To achieve this, the curve of the run-up has to be. tight enough to provide the correct amount of lean toward the center of the curve (but it should not be so tight that the athlete has difficulty running fast).

Also, the athlete should lean with the whole body while running the curve. (Some high jumpers lean a lot with their legs, but keep the trunk vertical. That does not produce a proper lean of the trunk at the start of the takeoff phase.)

If an athlete is not leaning enough away from the bar at the start of the takeoff phase, the coach should first check whether the athlete is leaning with the whole body or only with the legs in the last steps of the run-up. If only the legs are leaning, the athlete has to learn how to lean with the whole body while running the curve. If that is not the problem, it will be necessary to tighten the radius of the run-up curve. See Dapena (1995) for instructions on how to change the shape of the run-up curve.

Side view

In the side view, the longitudinal axis of the trunk should be leaning backward about 15 degrees at the start of the take-off phase, and it should not go beyond the vertical at the end of the takeoff. The three typical problems that we saw in the back view can also occur in the view from the side:

1. An athlete who does not have enough backward lean at the start of the takeoff phase, and then does not go beyond the vertical at the end of the takeoff (in the side view). This athlete will not be able to generate a large enough amount of forward somersaulting angular momentum, which will probably lead to problems in the bar clearance.
2. An athlete who does not have enough backward lean at the start of the takeoff phase, and then decides to rotate beyond the vertical at the end of the takeoff, in the view from the side. This athlete may be able to generate the necessary amount of forward somersaulting angular momentum to pro- duce a good rotation over the bar, but the c.g. will not reach a very high height after takeoff because of the excessive forward lean at the end of the takeoff. Also, this jumper could have problems hitting the bar on the way up.

3. An athlete who has a good amount of backward lean at the start of the takeoff phase, but then decides to be very conservative in the forward rotation, and is still far from reaching the vertical at the end of the takeoff, in the view from the side. The rotation of this athlete over the bar will not be very good, and the result of the jump will be worse than if the athlete had allowed the trunk to rotate to the vertical at the end of the takeoff.

If the athlete wants to generate a good amount of forward somersaulting angular momentum, he/she will need to have a good amount of backward lean at the start of the takeoff phase. To achieve this, the trunk has to be perfectly vertical one step before takeoff. Then, the athlete has to thrust the hips clearly forward in the final part of the last step of the run-up, to produce a backward lean of the trunk at the start of the takeoff phase. During the takeoff phase, the athlete needs to allow the trunk to rotate forward, and reach the vertical at the end of the takeoff (in the view from the side).

The athlete may also want to adopt a diagonal arm action, because this will also help to generate a larger amount of forward somersaulting angular momentum. (See Figure 4, and read the last paragraph of the section on "Forward somersaulting angular momentum.")

If the amounts of forward and lateral somersaulting angular momentum generated during the takeoff phase are reasonably large, and if the athlete succeeds in generating this angular momentum without leaning excessively forward and toward the bar (in the side and back views, respectively), the somersault rotation over the bar should be good.

CORRECTING PROBLEMS IN THE TWIST ROTATION

If the hips are level during the bar clearance, the athlete does not need to make any changes in the twist rotation. However, if the hips are tilted over the bar, with the hip of the lead leg lower than the hip of the takeoff leg, it will be necessary to make changes to correct the problem. As with the somersault rotation, the changes can be introduced into the actions that the athlete makes in the air or into the actions that the athlete makes while still on the ground.

Corrections in the air

It may be possible to solve the problem through improved catting. For the simplest possible catting maneuver, the athlete should first extend the lead arm parallel to the bar, pointing toward the far standard, and then throw the arm directly downward toward the pit. This may solve the problem. If it doesn't, it will be necessary to incorporate the lead leg into the catting maneuvers.

To make the lead leg contribute to the catting, the athlete needs to keep the knee of the lead leg in a high position after takeoff. Then the knee should be opened outward, toward the bar, while keeping the knee high. Finally, the athlete should bring the knee backward for the arch.

Combined with the arm action described previously, this maneuver may be sufficient to correct the problem in the twist rotation.

Corrections on the ground

If the hips are still tilted over the bar after the introduction of the catting maneuvers just described, it will probably be necessary to make changes in the run-up and takeoff in order to correct the problem.

The key generally lies in the generation of an extra amount of lateral somersaulting angular momentum, but without getting an excessive lean toward the bar (in the back view) at the end of the takeoff. For this, it is crucial to acquire a very good lean toward the center of the curve during the run-up, and to lean with the whole body, not only with the legs. Then, during the take- off phase the athlete will be able to rotate through a wide angle toward the bar (and therefore generate a large amount of lateral somersaulting angular momentum), and still be only slightly beyond the vertical-not more than 10° beyond the vertical-at the end of the takeoff (in the view from the back).

As previously mentioned, an in- creased amount of lateral somersaulting angular momentum helps the hip of the lead leg to be higher at the peak of the jump, but an increased lean toward the bar (in the view from the back) at the end of the takeoff has the reverse effect: it tends to lower still further the hip of the lead leg at the peak of the jump, which would tend to worsen the problem. That is why it is so important for the athlete to generate a lot of lateral somersaulting angular momentum, but minimizing the lean toward the bar at the end of the take- off. The only way to achieve this is by having a very good lean toward the center of the curve at the end of the run-up. (Of course, an extra advantage of a more vertical position at the end of the takeoff is that it will also help the athlete to generate more lift.)

In some cases, an increase in the amount of lateral somersaulting angular momentum may not be sufficient to correct the problem in the twist rotation: it may actually be necessary also to ***reduce*** the amount of ***forward*** somersaulting angular momentum generated during the takeoff phase. That could be achieved through more active swings of the arms and of the lead leg during the takeoff phase (which always tend to interfere with the generation of forward somersaulting angular momentum).

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REFERENCES

Dapena, J. Mechanics of translation in the Fosbury-flop. Med. Sri. Sports Exerc. 12:37-44, 1980a.
Dapena, J. Mechanics of rotation in the Fosbury-flop. Med. Sri. Sports Exerc. 12:45-53,1980b.
Dapena, J. Biomechanical analysis of the Fosbury-flop. Track Technique 104:3307-3317;3333; 105:3343-3350, 1988.
Dapena, J. How to design the shape of a high jump run-up. Track Coach 131, Spring 1995.