BIOMECHANICAL STUDIES IN THE HIGH JUMP AND THE IMPLICATIONS TO COACHING

By Jesus Dapena

The author presents an easy to follow biomechanical interpretation of the Fosbury high jump technique, based on cumulative information on elite high jumpers obtained from research carried out at the Indiana University, USA, and the world by former Soviet authorities, Dyatchkov and Ozolin. The article appeared originally in Track & Field Quarterly Review, George D. Gales, editor, Vol 92, No. 4, winter 1992. Re-printed with permission from Modern Athlete and Coach.

A high jump can be divided into three parts:

- The run-up phase which serves as a preparation for the takeoff phase
- The takeoff phase, the most important part of the jump, and
- The flight or bar clearance phase.

The purpose of the run-up is to set the appropriate conditions for the beginning of the takeoff phase. During the takeoff phase the athlete exerts forces that determine the maximum height that the center of gravity (CG) will reach after leaving the ground and the angular momentum (also called "*rotary momentum*") that the body will have during the bar clearance.

The only voluntary movements that can be made after leaving the ground are internal compensatory movements, for example:

- One part of the body can be lifted by lowering another part.
- One part of the body can be made to rotate faster by making another part slow down its rotation.

The run-up serves as a preparation for the takeoff phase, the most important part of the jump. The bar clearance technique is less important. Most bar clearance problems actually originate in the run-up or in the takeoff phase.

GENERAL CHARACTERISTICS OF THE RUN-UP

Most jumpers who use the Fosbury flop technique have a curved approach run. The typical length of the run-up for experienced jumpers is about 10 strides.

- The first part of the run-up usually follows a straight line, perpendicular to the plane of the standards, and
- The last four or five strides follow a curve.

One of the main purposes of the curve is to make the jumper lean away from the bar at the start of the takeoff phase.

PROGRESSION OF THE RUN-UP

To start the run-up, some athletes walk a few steps and then start running, others make a standing start.

- In the early part of the run-up the athlete should follow a gradual progression in which each stride is a little bit longer and faster than the previous one.
- After a few strides the high jumper should be running pretty fast, with long, relaxed strides, very similar to those of 400/800m runners.
- In the last two or three strides of the run-up the athlete should gradually lower the hips. It must be stressed here that this lowering of the hips has to be done without a significant loss of running speed.

HORIZONTAL VELOCITY AND HEIGHT OF THE CG AT THE END OF THE RUN-UP

The takeoff phase is defined as the period of time between the instant when the takeoff foot first touches the ground (touchdown) and the instant when it loses contact with the ground (takeoff). During the takeoff phase the takeoff leg pushes down on the ground. In reaction, the ground pushes up on the body through the takeoff leg with an equal and opposite force. The upward force exerted on the athlete changes the vertical velocity of the center of gravity from a value that is initially close to zero to a large upward vertical velocity. The vertical velocity of the athlete at the end of the takeoff phase determines how high the center of gravity will go after the athlete leaves the ground. To obtain a large vertical velocity at the end of the takeoff phase the vertical force exerted by the athlete on the ground should be:

- As large as possible, and
- Exerted for as long as possible.

A fast approach run can help the athlete to exert a larger vertical force on the ground. This can happen in the following way:

- When the takeoff leg is planted ahead of the body at the end of the run-up, the knee extensor muscles try to resist against the flexion of the leg, but the leg is forced to flex anyway, because of the forward momentum of the jumper.

- In this process the extensor muscles of the knee of the takeoff leg are stretched. It is believed that this stretching produces a stimulation of the muscles, which in turn aids the forceful extension of the takeoff leg in the second half of the takeoff phase.

Therefore, a fast run-up is good or increasing the vertical force exerted during the takeoff phase.

To maximize the time during which the vertical force is exerted on the body it is necessary for the center of gravity to go through a long vertical range of motion during the takeoff phase. This can be achieved by making the center of gravity:

- Low at the start of the takeoff phase, and

- High at the end of it.

The center of gravity of most high jumpers is reasonably high by the end of the takeoff phase, but it is difficult to have the center of gravity in a low position at the start of the takeoff phase. This is because in that case the body has to be supported by a deeply-flexed non-takeoff leg during the next-to-last stride, and this requires a very strong non-takeoff leg. It is also difficult to learn the appropriate neuromuscular patterns that will permit the athlete to pass over the deeply-flexed non-takeoff leg without losing running speed. It is possible to achieve an approach run that is fast and low in the last strides, but this requires a considerable amount of effort and training.

Let’s say that an athlete has learned how to run fast and low. A new problem could occur: The athlete could actually be too fast and too low. If the takeoff leg is not strong enough, it will be forced to flex excessively during the takeoff phase, and then it may not be able to make a forceful extension in the final part of the takeoff phase. In other words, the takeoff leg may “*buckle*” under the stress, resulting in an aborted jump. There is an optimum combination of run-up speed and center of gravity height and this optimum may not be the same for different athletes. So, how can an athlete find this optimum combination?

The optimum should be expected to be either:

- At the present speed and height that the athlete has at the end of the run-up, or

- At a faster speed and/or lower height than the athlete has now.

Therefore, an athlete should learn how to run faster and lower. They try jumping using a run-up that is faster and lower than the athlete's usual run-up. If the athlete jumps well with the new run-up, a run-up that is still faster and lower should be tried. This process should be repeated until the run-up becomes fast and low enough to make the takeoff leg buckle, or at least to reduce the height that the athlete is able to jump. When this point is reached, it means that the athlete has gone beyond the optimum combination of speed and center of gravity height. The jumper should then experiment with run-ups that are somewhat slower and/or higher than the one that produced the buckling or the worsening of the jumps, and look for the combination that leads to the best jumps.

Important caution: The use of a faster and lower run-up will put a greater stress on the takeoff leg, and thus it may increase the risk of injury if the leg is not strong enough. Therefore, the adoption of a faster and lower run-up may require some extra strengthening of the takeoff leg to withstand the increased impact that will be produced when the takeoff leg is planted at the end of a faster and lower run-up.

ARM ACTIONS

The actions of the arms during the takeoff phase are very important for the outcome of the jump. As the arms are accelerated upward during the takeoff phase, they exert by reaction a compressive force downward on the trunk. This force is transmitted through the takeoff leg to the ground. The increased downward vertical force exerted on the ground evokes by reaction an increased upward vertical force exerted by the ground on the athlete. This leads to a greater vertical velocity by the end of the takeoff phase and consequently to a higher jump.

For a good arm action both arms should swing forcefully forward and up during the takeoff phase. The arms should not be too flexed at the elbow during the swing - a good elbow angle seems to be somewhere between 90 degrees of flexion and full extension.

In some athletes the arm nearest to the bar is forward instead of backward at the start of the takeoff and this limits the vertical range of motion available to it during the takeoff phase. Although the arm can still be used with moderate effectiveness for a really strong action it would have to be back at the start of the takeoff phase. The athletes with the strongest arm actions usually bring both arms back during the final one or two strides of the run-up, as this allows the arm nearest to the bar to swing more actively during the takeoff phase. The learning of a doublearm technique takes some time and effort, but it should help most athletes to jump higher.

TAKEOFF TIME

The duration of the takeoff phase is influenced by several factors. Some of them are beneficial for the jump and others are detrimental. Short takeoff times go together with a strong action of the takeoff leg (good), but they also go together with weak arm actions and with a high center of gravity at the start of the takeoff phase (bad). In sum, takeoff times are informative, but the length of the takeoff time by itself does not necessarily indicate good or bad technique.

HEIGHT AND VERTICAL VELOCITY OF THE CENTER OF GRAVITY AT THE END OF THE TAKEOFF PHASE

The peak height that the center of gravity will reach over the bar is totally determined at the end of the takeoff phase. It is determined by the height of the centre of gravity and by its vertical velocity at the end of the takeoff phase.

At the instant that the takeoff foot loses contact with the ground the center of gravity of a high jumper is usually at a height somewhere between 70 percent and 75 percent of the standing height of the athlete. This means that tall high jumpers have a built-in advantage. Their center of gravity’s will generally be higher at the instant they leave the ground.

The vertical velocity of the center of gravity at the end of the takeoff phase determines how much higher the center of gravity will travel beyond the takeoff height after the athlete loses contact with the ground.

PEAK HEIGHT OF THE CENTER OF GRAVITY AND OUTCOME OF THE JUMP

- If an athlete can’t clear the bar when the center of gravity goes 6cm higher than the bar, we consider this to be a very ineffective bar clearance technique.

- If the center of gravity needs to go between 3 to 6cm higher than the bar to clear it, we consider this a reasonable bar clearance technique.

- If the athlete is able to clear the bar when the centre of gravity goes no higher than 2cm over the bar (or if the center of gravity passes under the bar), we consider this a very effective bar clearance technique.

The most usual reasons for an ineffective bar clearance are:

- Taking off too close or too far from the bar

- Insufficient amount of somersaulting angular momentum
- Poor arching, and
- Bad timing of the arching/un-arching process.

TAKEOFF DISTANCE

The distance between the toe of the takeoff foot and the plane of the bar and the standards is called the “takeoff distance”. The value of this distance is very important, because it determines the position of the peak of the jump relative to the bar:

- If an athlete takes off too far from the bar, the center of gravity will reach its maximum height before crossing the plane of the standards and the jumper will probably fall on the bar.
- If the athlete takes off too close to the bar, there will be a large risk of hitting the bar while the center of gravity is on its way up, before reaching its maximum height.

Different athletes usually need different takeoff distances. The optimum value for the takeoff distance of each athlete is the one that will make the center of gravity of the jumper reach its maximum height more or less directly over the bar. It will depend primarily on the final direction of the run-up and on the amount of residual horizontal velocity that the athlete has left after the completion of the takeoff phase. In general:

- Athletes who travel more perpendicular to the bar in the final strides of the run-up will also travel more perpendicular to the bar after the completion of the takeoff phase. They will need to take off farther from the bar.
- Athletes who run faster in the final strides of the run-up will generally have more horizontal velocity left after takeoff, thus they will travel through larger horizontal distances after the completion of the takeoff phase than slower jumpers and will also need to take off farther from the bar in order for the center of gravity to reach its maximum height directly over the bar.

High jumpers need to be able to judge after a miss whether the takeoff point might have been too close or too far from the bar. This can be done by paying attention to the time when the bar was hit.

- If the bar was hit a long time after the takeoff, this probably means that the bar was hit as the athlete was coming down from the peak of the jump, implying that the athlete took off too far from the bar. In that case the athlete should move the starting point of the run-up slightly closer to the bar.

- If the bar was hit very soon after the takeoff, this probably means that the bar was hit while the athlete was still on the way up toward the peak of the jump, implying that the takeoff point was too close to the bar. In that case the athlete should move the starting point of the run-up slightly farther from the bar.

ANGULAR MOMENTUM

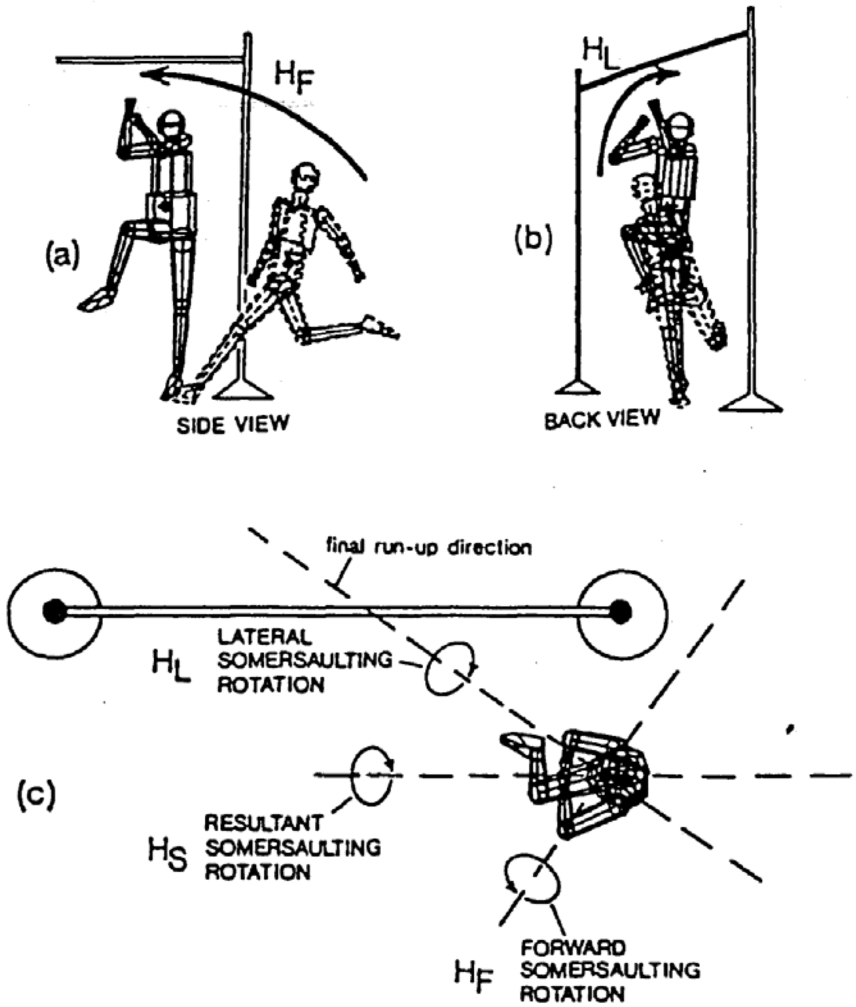
In order to perform a proper layout over the bar the athlete needs to rotate after leaving the ground. For this rotation, the jumper needs a certain amount of *angular momentum* (also called *rotary momentum*). Practically all of this angular momentum is produced during the takeoff phase. No angular momentum can be obtained after the athlete leaves the ground.

The bar clearance technique of a Fosbury flop can be described roughly as a *twisting backward somersault*. The *twist*, that makes the athlete turn the back to the bar during the ascending part of the flight path, is generated mainly by:

- Swinging the lead leg up and somewhat away from the bar during the takeoff phase, and also

- The active turning of the shoulders in the desired direction of the twist before the end of the takeoff phase.

These actions create angular momentum about a vertical axis (H_T). Most athletes have no difficulty obtaining an appropriate amount of H_T.



ANGULAR MOMENTUMS IN THE TAKEOFF PHASE
HF = forward angular momentum (a), lateral angular momentum (b), resultant component (c)

The *somersault*, which will make the shoulders go down while the knees go up, results from two different components:

1. Forward somersaulting angular momentum (H_F)

During the takeoff phase, angular momentum is produced about a horizontal axis perpendicular to the final direction of the run-up (see Figure 1a). This forward rotation is similar to the one that is produced when a person hops off from a moving bus while facing the direction of motion of the bus. After the feet hit the ground the tendency is to rotate forward and fall flat on one's face. This can be described as *angular momentum* produced by checking of a linear motion.

The forward somersaulting angular momentum can be affected by the arm and lead leg actions. Wide swings of the arms and of the lead leg can help the athlete to jump higher, but they also generally imply backward rotations of these limbs, which can reduce the forward somersaulting angular momentum of the body.

2. Lateral somersaulting angular momentum (H_L)

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). From a rear view of an athlete who takes off from the left leg, this angular momentum component appears as a clockwise rotation. If the jumper made use of a straight run-up, in a rear view the athlete would be upright at touchdown and leaning toward the bar at the end of the takeoff phase. The production of angular momentum would thus cause a reduction in the vertical range of motion of the center of gravity during the takeoff phase. However, if the athlete uses a curved run-up, the initial lean of the athlete is toward the left at the end of the takeoff phase (see Figure 1b). This favors a large vertical range of motion of the center of gravity during the takeoff phase and thus permits greater lift than if a straight run-up were used. One of the main purposes of the curve of the approach run is to achieve this lateral lean at the end of the run-up, i.e., at the start of the takeoff phase.

The sum of the forward and lateral somersaulting angular momentum components adds up to the required total (or "*resultant*") somersaulting angular momentum, H_S (Figure 1c). In general, athletes with more angular momentum will tend to rotate faster.

ADJUSTMENTS IN THE AIR

The rotation of an athlete is determined primarily by the angular momentum the athlete has during the airborne phase, but there are other factors that can also have some effect on the rotation.

- By speeding up the rotation of some parts of the body, other parts of the body will slow down as a compensation, and vice versa.

- Another way in which rotation can be changed is by altering the "*moment of inertia*" of the body.

When many parts of the body are far from the center of gravity, we say that the "moment of inertia" of the body is large and this decreases the speed of rotation. Vice versa, if all parts of the body are kept close to the center of gravity, the moment of inertia of the body is small and the speed of rotation is increased. This is similar to what happens to figure skaters when they spin. As they get their arms closer to the body, they spin faster.