THE EVOLUTION OF HIGH JUMPING TECHNIQUE: BIOMECHANICAL ANALYSIS

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Over the years, high jumping technique has improved through changes in the run-up, the takeoff and the bar clearance. The straddle technique used a fast run-up and strong free limb actions during the takeoff to increase the generation of lift. The production of the angular momentum needed for the bar clearance in the Fosbury-flop technique (which replaced the straddle) is in conflict with the use of strong free limb actions during the takeoff. Fosbury-flop high jumpers compensate by using a faster run-up. Some athletes are able to generate more lift with the faster run-up and weaker free limb actions of the Fosbury-flop, while others can generate more lift with the slower run-up but stronger free limb actions of the straddle. Therefore, both techniques should be in use today. However, the straddle has disappeared, because the Fosbury-flop is much easier to learn.

KEY WORDS: biomechanics, high jump, history, straddle, fosbury-flop

INTRODUCTION: There was no high jumping event in the ancient Greek Olympic Games. This sport event seems to have its origin with the Celts (Tailteann Games). But modern high jumping began in Germany in the late 18th century. It started as a physical education activity for children (Figure 1). It developed into a competitive sport in England in the 19th century, and soon afterward spread to Canada and to the United States. *Mechanical considerations:* To clear a high jump bar, it is necessary to drive the center of mass (c.m.) of the athlete to the largest height possible. It is also necessary to move the body in the air in a way that will allow the athlete to clear a bar set as close as possible to the peak height reached by the c.m. For a given peak height reached by the c.m., lowering some parts of the body allows other parts to go higher. This is the mechanical principle that has improved the effectiveness of the bar clearance over the years. *Evolution of the bar clearance:* Techniques have progressed considerably since the beginning of modern high jumping in the late 18th century. Every new technique was named after an improvement in the bar clearance. If a high jumper remains in a straight vertical position after taking off from the ground, the height of the bar that the feet will be able to clear will be far below the peak height of the c.m. The simplest improvement over this is a technique in which the athlete flexes at the hips and knees to adopt a squatting position at the peak of the jump (Figure 1). We could call this the "legs-up" technique. Since the peak height of the c.m. can't be changed after the athlete leaves the ground, the lifting of the legs is accompanied by a lowering of the trunk. This technique greatly increases the height of the bar that can be cleared. The next technique in the evolution of high jumping was the "scissors", in which the legs are lifted over the bar in alternation one after the other. The advantage of the scissors technique is that parts of both legs are below the level of the bar at the peak of the jump (Figure 2). This increases the height of the pelvis, and therefore the bar height that can be cleared. The scissors was followed by the "Eastern cut-off" technique (sometimes called the Lewden scissors in Europe). In the Eastern cut-off the athlete rotates the trunk into a horizontal position at the peak of the jump (Figure 3). This lowers the trunk, and therefore lifts the pelvis higher than in the simple scissors technique. The result is a higher bar clearance. A disadvantage of the Eastern cut-off is that it requires tremendous flexibility.

Figure 1. The legs-up technique. (after GutsMuth, 1797)

Figure 2. The scissors technique. (after Riefenstahl, 1936)

The Eastern cut-off was succeeded by the "Western roll" technique (Figure 4). In the Western roll the athlete cleared the bar on his/her side, with the takeoff leg tucked under the rest of the body. This technique probably did not improve much the effectiveness of the bar clearance in relation to the Eastern cut-off. However, it also did not require very much flexibility. Thus, the contribution of the Western roll was to provide a reasonably effective bar clearance for a larger number of high jumpers. The Western roll was followed by the "straddle" technique (Figure 5). In the straddle the athlete cleared the bar face-down, with the body stretched along the bar. The straddle allowed parts of the legs to be lower than the bar at the peak of the jump. This allowed the pelvis to rise to a greater height in relation to the position of the c.m., and therefore it improved the effectiveness of the bar clearance.

Figure 3. The Eastern cut-off technique. (after Riefenstahl, 1936)

In the 1936 Olympic Games at Berlin, the scissors, Eastern cut-off, Western roll and a primitive version of the straddle were all used by one medalist or another in the men's and women's competitions. During the 1940's and early 1950's, the straddle gradually replaced the Western roll, and became the standard technique. *Improvements in the run-up and takeoff:* While the straddle was replacing the Western roll, more important innovations were occurring in the run-up and takeoff. Some athletes used a fast run-up. This allowed them to put the muscles of the takeoff leg in fast eccentric conditions during the takeoff phase, which in turn allowed the athlete to exert a larger vertical force on the ground. Other athletes ran with the c.m. in a low position in the final part of the run-up. This allowed them to have available a long vertical range of motion for the c.m. during the takeoff phase, which increased the height of the jump. Some athletes noticed that a vertical position of the body at the end of the takeoff increased the height of the jump. This was also due to an increased vertical range of motion during the takeoff phase. Other jumpers moved their arms into a backward position in the last steps of the run-up, and then threw them strongly forward and upward during the takeoff phase. This allowed the takeoff leg to exert a larger force against the ground. Still others kicked forward and upward with the lead leg during the takeoff phase, with a motion similar to a soccer kick (Figure 6). This "straight lead leg" action had the same purpose as the double-arm action, but with an enhanced effect due to the larger mass and length of the leg. Today we know that all these actions are advantageous for the generation of lift in a high jump. However, this was not clear in the 1940's and early 1950's. There were disagreements about what was advantageous and what was detrimental. As a result, only a small number of high jumpers incorporated one or another of these elements into their techniques, and nobody used all of them. *The Russian revolution:* The United States dominated the men's high jump event during the first half of the 20th century. Following this tradition, in 1956 Charles Dumas raised the world record to 2.15 m, and then proceeded to win the Olympic Games at Melbourne.

Figure 4. The Western roll technique. (after Riefenstahl, 1936)

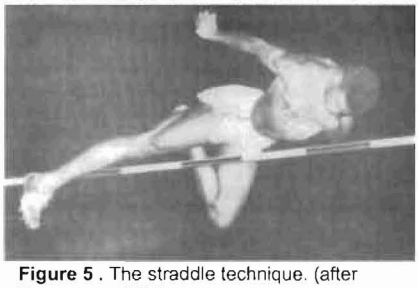

Figure 5 . The straddle technique. (after Berenguer, 1964)

Figure 6. Double-arm and straight lead leg actions.

However, this situation was about to change. In 1957, Yuri Stepanov of the Soviet Union broke Dumas' world record with a jump of 2.16 m. It was found out later that Stepanov had used a "built-up" takeoff shoe with a very thick sole. This increased the vertical range of motion of the c.m. during the takeoff phase, and thus gave an advantage to the jumper. But the rules current at the time did not limit the thickness of the sole, and therefore Stepanov's jump was legal. The International Amateur Athletic Federation soon changed the rules, and limited the maximum thickness of the shoe sole to 13 mm. However, the rule was not made retroactive, and Stepanov's record was allowed to stand. In 1960 things seemed to go back to "normal". John Thomas reclaimed the world record for the United States, and raised it to 2.23 m. He was the overwhelming favorite for the gold medal at the Olympic Games to be held at Rome later that year. The Stepanov incident seemed a brief anomaly, the result of the built-up shoe. But surprisingly, Thomas was relegated to third place in the Olympic Games at Rome by two athletes from the Soviet Union, Robert Chavlakadze and Valeri Brumel. And by 1963 Brumel had raised the world record to 2.28 m. It became clear that there was more to Russian high jumping than Stepanov's built-up shoe. These results were the product of Vladimir Dyachkov's work. Dyachkov was the Soviet Union's national coach. He had studied films of the world's best high jumpers for many years. Through his analyses, he was able to figure out the advantages and disadvantages of the various techniques used by high jumpers. He acquired a particularly good understanding of the advantages provided by the run-up and takeoff improvements that had been gradually introduced during the 1940's and 1950's. Before Dyachkov, one or another of these advantageous technique elements had shown up sporadically in the techniques of various high jumpers; Dyachkov incorporated practically all of them into the technique of every one of his athletes. *The dive straddle:* A new variant of the straddle appeared around 1960. It was called the "dive straddle" (Figure 7). In this technique, at the peak of the jump the athlete's trunk was set at an oblique angle with respect to the bar. This allowed the athlete to drop the head and upper trunk below the level of the bar at the peak of the jump. This raised the hips and the rest of the body, and therefore allowed the athlete to clear a higher height than with the older ("parallel") straddle. Dyachkov adopted this bar clearance technique for his jumpers. Through the efforts of Dyachkov, in the mid-1960's there was consensus about the technique that should be used for high jumping: A fast and low run-up, with preparation of the arms in the last one or two steps, followed by a double-arm action and straight lead leg action that ended in a vertical position of the athlete at the end of the takeoff. The athlete crossed the bar using the dive straddle technique. It is important to point out that not all high jumpers adapted well to this technique. Some were not able to combine effectively a straight lead leg action with the impulse of the takeoff leg. These bent-lead-leg jumpers were quite frustrated, incapable of jumping properly. *The Fosbury-flop:* A completely new technique appeared in the mid-1960's. It was invented independently by several different jumpers who took advantage of the increased safety provided by foam-rubber landing mats. Today this technique is called the "Fosbury-flop" (Figure 8). In 1968, Dick Fosbury won the American University (NCAA) Indoor and Outdoor Championships using this technique. He made the bar clearance on his back, with his body horizontal and perpendicular to the bar. Fosbury surprised everyone by winning the 1968 Olympic Games in Mexico City. Until the 1968 Olympic Games, there had been little information on this jumping style, but the Games were

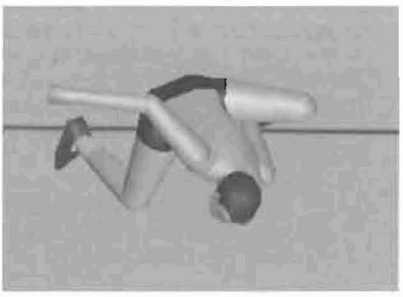

Figure 7. The dive straddle technique.

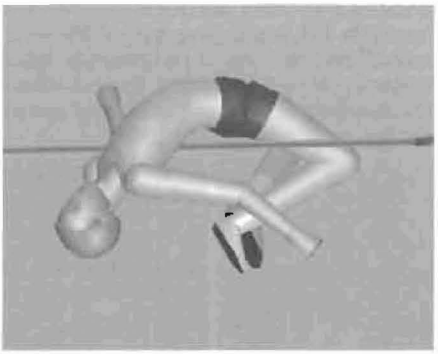

Figure 8 . The Fosbury-flop technique.

televised live, world-wide. The high jumpers and coaches in the audience were able to see the new technique in great detail. It became clear that the bar clearance was not the only difference between the "standard" dive straddle and the Fosbury-flop: Fosbury's run-up was curved, and his arm and lead leg actions during the takeoff phase were weaker than in the straddle. The day after the Mexico high jump final, practically every high jumper in the world tried the new technique. They readily adopted Fosbury's curved run-up (even though they did not know why --or if-- the curve was needed), but most of them added a double-arm action and a straight lead leg, since these were regarded as basic elements for any high jumping technique. However, this did not work: They found it impossible to attain at the peak of the jump the desired face-up position, perpendicular to the bar. These athletes had to give up on the Fosbury-flop. On the other hand, the bent-lead-leg high jumpers adapted to the Fosbury-flop with little trouble. This led to the separation of the world's high jumpers into two groups: those who used the straddle and those who used the Fosbury-flop. The straddlers cleared the bar face-down, used strong double-arm and straight lead leg actions during the takeoff phase, and their run-up was straight and fast. The Fosbury-floppers cleared the bar face-up, their arm and lead leg actions during the takeoff phase were weak, and their run-up was curved and even faster than in the straddle. *Questions about the Fosbury-flop:* The Fosbury-flop raised obvious questions: What advantages did the curved run-up provide? Was the bar clearance more effective than in the straddle? Why was it so difficult to do a Fosbury-flop with a straight lead leg? And how could a technique that used a bent lead leg be good? Answering these questions is what I set out to do in my research. *The curve:* There were several theories about the curved run-up. According to one of them, the curve allowed the athlete to use centrifugal force to generate more lift. According to another theory, the curve allowed the athlete to start during the run-up the rotation needed for the bar clearance. This would allow the athlete to concentrate exclusively on the generation of lift during the takeoff. The first theory made no sense at all. Centrifugal force is a horizontal force, and therefore can't provide lift. The second theory had more potential, but ultimately it was also proved wrong. In my research, I found that almost all the angular momentum in a Fosbury-flop is generated during the takeoff phase, and not during the run-up. The curve was useful in two ways: (a) It allowed the athlete to be in a low position at the end of the run-up without having to run with very bent knees; (b) the curve made the athlete lean away from the bar at the time that the takeoff foot was planted, and this permitted the generation of angular momentum during the takeoff without having to lean into the bar by the end of the takeoff. *Bar clearance and takeoff height:* The bar clearance is about 5-7 cm more effective in the Fosbury-flop than in the dive straddle. However, the Fosbury-flop has a *dis*advantage of similar magnitude in the height

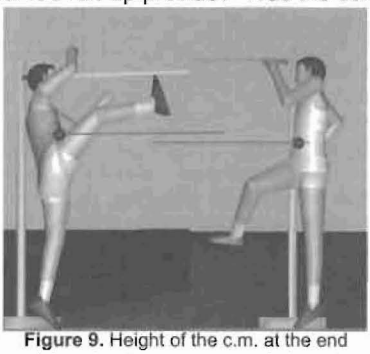

Figure 9. Height of the c.m. at the end of the takeoff in the straddle (left) and in the Fosbury-flop.

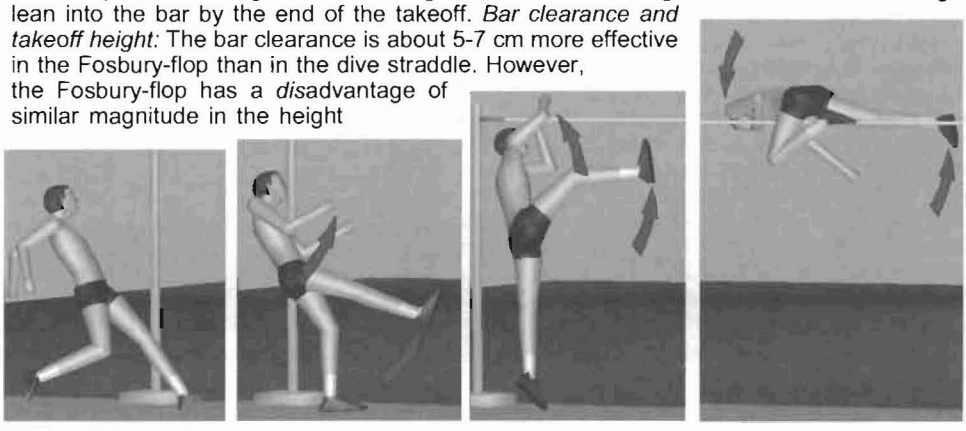

Figure 10. Rotation in the straddle.

of the c.m. at the end of the takeoff, due to the lower positions of the arms and of the lead leg in relation to the straddle (Figure 9). So to a great extent these two factors cancel each other out. *Straight lead leg versus bent lead leg:* It is very difficult to execute a proper Fosbury-flop using the straddle's straight lead leg. The reason is that the double-arm and straight lead leg actions of the straddle are "backward" rotations (counterclockwise in a view from the right). Such actions favor the generation of the counterclockwise rotation that is generally needed in the air for a straddle bar clearance (Figure 10). But they would not be desirable in the Fosbury-flop, because a proper Fosbury-flop bar clearance requires the execution of a "forward" rotation in the air, clockwise in the view from the right (Figure 11). This is why Fosbury-flop high jumpers need to use weaker actions of the arms and of the lead leg during the takeoff. *Run-up speed:* Fosbury-flop high jumpers can use a bent lead leg and still obtain a good height in the jump due to the fact that they compensate for the weaker lead leg with a faster run-up. If the athlete runs fast enough, the arm and lead leg actions become less important. In effect, what counts is the *combination* of the run-up speed and the actions of the swinging limbs. For Fosbury-fl p jumpers, the optimum is at a combination of very fast run-up speed and relatively weak arm and

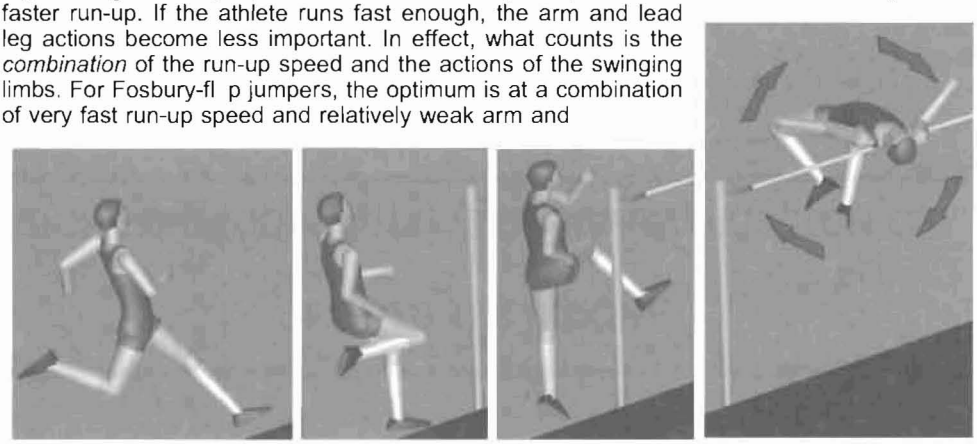

Figure 11. Rotation in the Fosbury-flop.

lead leg actions. For the straight lead leg straddle high jumpers, the optimum is at a combination of slightly slower run-up speed but stronger arm and lead leg actions. *Leg muscles:* It is not clear why one of these two techniques is not good for everyone. The reason probably lies in physiological differences in the muscles of the takeoff leg. In the Fosbury-flop the takeoff leg flexes quickly, and then extends quickly. In the straddle the takeoff leg flexes more slowly, stays near maximum flexion for a longer time, and then extends more slowly than in the Fosbury-flop. Some people's muscles seem to be better suited to one kind of leg action than to the other. *Choosing between straddle and Fosbury-flop:* The choice of arm and lead leg actions was a high jumper's first decision. This choice then determined what kind of bar clearance worked best for that individual: For the athletes with the weaker free-limb actions, the Fosbury-flop type of bar clearance; for the athletes with the stronger free-limb actions, the straddle type of bar clearance. Ultimately, the Fosbury-flop is the best technique for some jumpers, and the straddle for others. Therefore, we should expect both techniques to be in use today. However, they are not. Only the Fosbury-flop is in use; the straddle has disappeared. The crucial factor was that the Fosbury-flop was much easier to learn than the straddle. Consequently, all high jumpers today use the Fosbury-flop technique, even though the straddle would be better for some of them.