BIOMECHANICS OF ELITE HIGH JUMPERS

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INTRODUCTION

Our laboratory has been involved for the past two years in a study of top-class high jumpers sponsored by the U.S.O.C. and T.A.C. ("Elite Athlete Project"). The high jumpers are filmed during official competitions, using two cameras simultaneously. Computer programs are used to calculate 3D body landmark coordinates throughout the last strides of the run-up, the takeoff, and the bar clearance (Dapena et al., 1982), and later to calculate other kinematic and kinetic parameters of the jumps (Dapena, 1978, 1980a, 1980b) and to produce computer plots showing different views of stick-figure sequences of the jumps.

While the optimum high jumping technique is not known, a logical rationale may be followed to reach provisional conclusions about its characteristics (Dapena, 1980c). Part of this rationale is explained in the present paper.

THE TAKEOFF PHASE

The most important part of a high jump is the takeoff phase (Fig. 1). At the start of the takeoff phase the center of mass (c.m.) of the jumper usually has a large horizontal velocity (mean = 7.1 m/s in our sample). During the takeoff phase the ground pushes back on the athlete, reducing his horizontal velocity to about 3.8 m/s (Fig. 1a). This residual horizontal velocity gives the athlete the necessary horizontal displacement to reach the landing pit.

The vertical velocity at the start of the takeoff phase typically has a small negative value (-0.3 m/s). During the takeoff phase the athlete exerts a large downward force on the ground. The reaction to this force (Fig. 1b) gives the athlete a large upward vertical velocity by the end of the takeoff phase (about 4.4 m/s for jumps around 2.20 - 2.30 m). This vertical velocity component is the most important factor contributing to the height of the parabolic path that follows the takeoff, and consequently to the result of the jump.

In order to maximize the vertical velocity at the end of the takeoff phase, the jumper needs to receive a large vertical impulse from the ground. That is, the product of vertical force and time should be as large as possible.

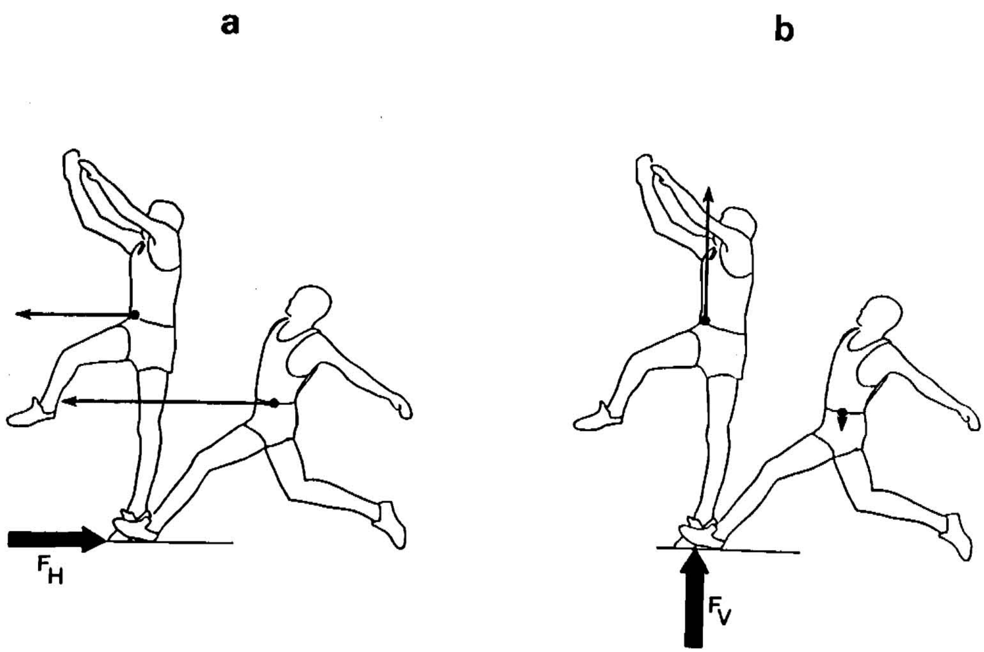

Figure 1

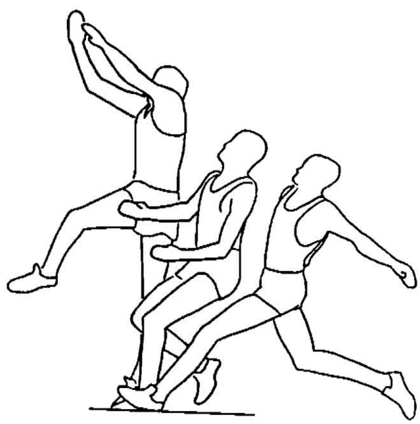

Figure 2

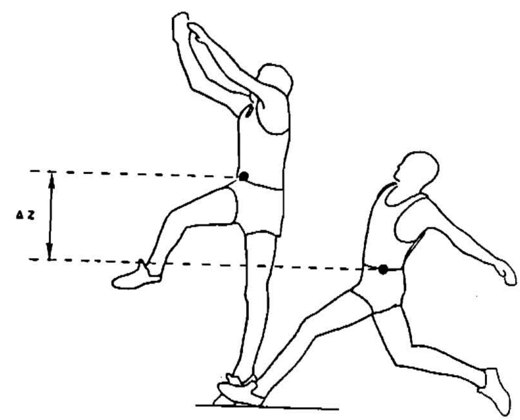

Figure 3

A fast horizontal velocity at the end of the run-up may lead to a larger vertical force during the takeoff phase. This may happen in the following way: At the start of the takeoff phase the takeoff leg is planted well ahead of the body (Fig. 2). The momentum of the body makes the leg bend at the knee. The jumper tries to resist this bending, but the leg will still flex, stretching the knee extensors. The elastic component of the muscles and a stretch reflex mechanism may then act (in a way still not clearly understood) to produce a very strong contraction of the extensor muscles of the takeoff leg, exerting a large vertical force on the ground and straightening the takeoff leg again.

The time during which vertical force is applied can be increased through an increase in the vertical range of motion (ΔZ) covered by the c.m. during the takeoff phase (Fig. 3). For this, the c.m. has to be low at the start of the takeoff phase and high at the end of it. Most jumpers are fairly high by the end of the takeoff phase, but it is difficult to be low at the start of the takeoff phase, as it requires a fair amount of strength in the non-takeoff leg during the penultimate stride (stars in Fig. 4) and the learning of a rather unnatural pattern of movements during the last strides of the approach run. Consequently, a fast and low approach run can be achieved, but it requires quite a bit of effort and training.

If an athlete learns how to run fast and low, there may be a new problem: he may 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 other words, the takeoff leg may buckle under the stress, resulting in a very bad jump. There probably is an optimum combination of run-up speed and height, and this optimum may be different for different athletes.

APPLICATION

A plot of c.m. height at the end of the approach run (h_{TD}) versus final speed of the approach run (V_{H1}) is shown in Fig. 5. Each dot represents one jump by one athlete. To facilitate comparison among jumpers the c.m. height is expressed as a percent of the standing height of each athlete.

Let us see what should be expected to happen if an athlete changed his position on this graph. A change toward the upper left quadrant from his present position (Fig. 6) would imply slower velocity and higher c.m. The athlete has probably tried such combinations before, because most young high jumpers start jumping using slow and high approach runs: it is the easiest thing to do. Therefore, the athlete has probably tried before points in the upper left quadrant from his present position on the graph, but he is now at the lower right corner of it. This probably indicates that he jumps better in his present position: his takeoff leg is

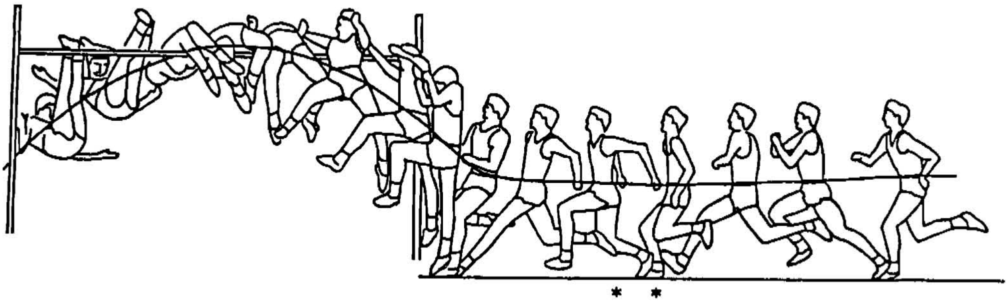

Figure 4

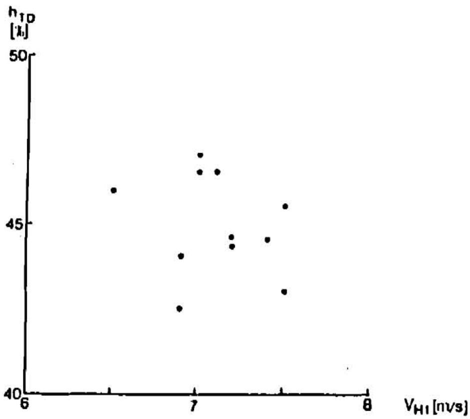

Figure 5

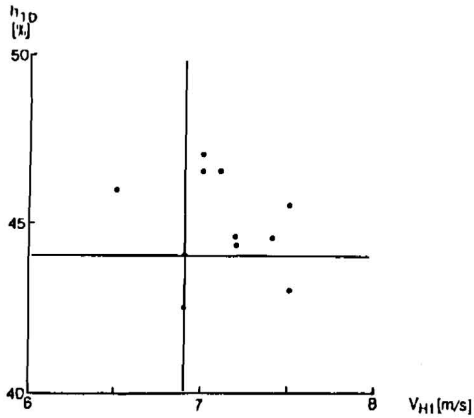

Figure 6

probably not buckling at that point. Consequently, it seems reasonable to assume that a change toward the upper left quadrant would be likely to result in a deterioration of performance.

If the athlete changed his position toward the upper right quadrant, the desirable increase in velocity would be accompanied by an unwanted increase in c.m. height; if he changed his position toward the lower left quadrant, the desirable decrease in c.m. height would be accompanied by an unwanted decrease in velocity. In these two cases it is not possible to say whether there would be an improvement or a deterioration of performance, but it seems reasonable to expect rather small changes in performance given the combination of desirable and undesirable factors.

The lower right quadrant implies faster speed and lower c.m. This should result in better jumps, unless the athlete is too fast and too low, in which case the takeoff leg will begin to buckle. If the athlete had experimented with jumps in this last quadrant and still decided to stay in its upper left corner, this would be a strong suggestion that the athlete already is at his optimum combination of speed and c.m. height, and that faster and lower approach runs would make his leg buckle. But this lower right quadrant requires a fast and low approach run, and it was indicated before that this is difficult to achieve, as it requires quite a bit of effort and training before it can be done correctly. Consequently, many athletes have never experimented with this lower right quadrant. Therefore, it is assumed that the optimum combination of speed and c.m. height is, most likely, either at the present position of the athlete on the graph or somewhere in the lower right quadrant from it.

Jumpers are encouraged to learn a faster and lower approach run, and then to experiment jumping with that run-up. If the athlete is able to jump higher than before, he should retain the new run-up; if the takeoff leg buckles, he should go back to his old technique. Most of the efforts for change are concentrated on the athletes in the upper left section of the graph (Fig. 5), because they are thought the most likely to benefit from faster and lower run-ups. The jumpers in the lower right section of the graph are more likely to be near their limits for buckling and, consequently, faster and lower run-ups are not stressed for them.

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