High Jump Analysis

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Abstract

This project mathematically analyzes the track and field event, high jump. The factors of motion, velocity, force, time, gravity, mass, and position are all analyzed to determine how the high jump works. The first and second stages of high jump make up the approach, consisting of linear motion and angular motion of the running approach. The third stage is the high jumper's flight through the air over the bar; this is called projectile motion. The mass (the athlete's weight) is also taken into consideration. This project investigates how all of these factor's are all interconnected on a mathematical basis.

Problem Statement

According to Plunkett Research, 422 billion dollars were spent on the sports industry in the United States in the year 2011. This statistic shows just how large a part sports play in our lives. High jump is one of the sports making up this industry. Whether an individual is a spectator or a competitor, individuals want a good performance. This project aims to explain the high jump in mathematical terms in order to better understand the process which can thereby improve performance. The high jump can be divided chronologically into three parts: 1) linear motion, 2) angular motion, and 3) projectile motion.

Mathematical Approach

Linear Motion: V=m/s
Angular Motion: Centrifugal force = velocity^2 / radius
Centrifugal force also plays a part in why the high jump bar is approached on a curve. The velocity generated generated by the curve forces the jumper into the high jump mat area. Figure 2 demonstrates this horizontal motion.
Force and Mass: F = m × a

- The acceleration due to gravity is multiplied by the high jumper's weight to determine the downward force. The acceleration of gravity is constant at -9.8 m/s^2, so the value is substituted into the formula. The negative value of gravity indicates its downward direction.

- **Projectile Motion:** $x = x_0 + V_i t + (a t^2) / 2$
  - Take off Angle: $\tan\theta = V_v / V_h$
  - Determining Initial Velocity: The horizontal velocity generated by the curve and vertical velocity generated by the jump can also be used to determine the initial velocity of the jump by applying Pythagorean's Theorem.
    - $V_h^2 + V_v^2 = V_i^2$

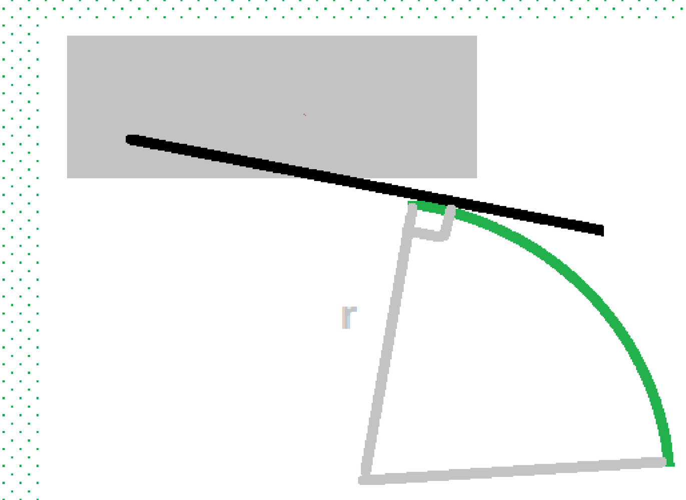
Discussion

The results show how variables effect the high jump. The speed of linear motion is more focused on consistency of strides and building up a controllable speed before proceeding into the second stage of high jump, which is the curve.
It can then be deduced from angular motion that a tighter curve with a smaller radius generates more force into the mat horizontally. A tighter curve creates more force; whereas, a wider curve generates less force. Therefore, it makes sense that a jumper would not want a curve that is too wide as they would not gather enough horizontal motion to propel them over the bar. However, too much horizontal motion is also bad.
In order to attain the optimal height in high jump, vertical velocity must remain larger than horizontal velocity. As shown in the formula for projectile motion, the greater the initial velocity, the greater the height attained will be. The jump height being cleared by the hips is considered the position.
Because the hips are the center of gravity, the initial position, x_0, is equal to the height of a person's hips. This is why taller individuals have an advantage in the high jump. They are starting from a great initial position than a shorter person.
The downward force acting on the high jumper is also an important result. The force working against the high jumper is greater with greater mass values.

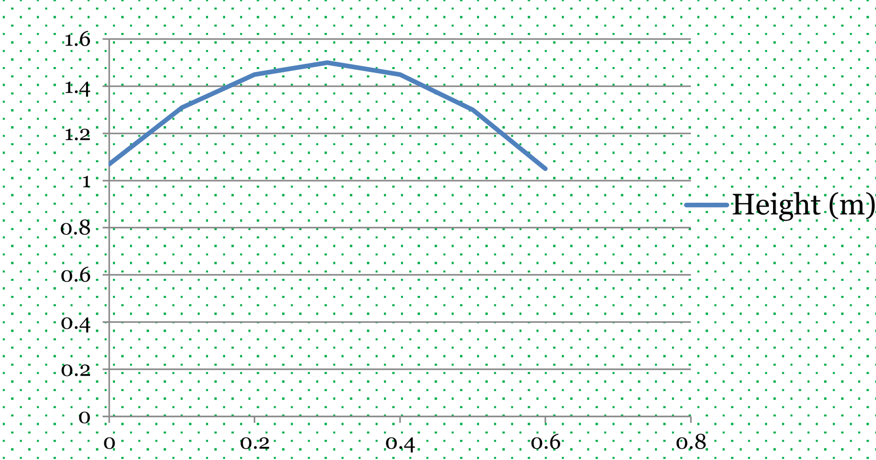
Conclusions

The results provide multiple conclusions. One, the first stage of the high jump (linear motion) is best to not be at full velocity. The jumper should strive to simply build up a controllable amount of momentum before the second stage. The second stage is a continuation of the first stage's velocity. The athlete begins to pick up speed with the last steps running along the curve. A high velocity of the run is good as long is it is controllable and paired with an even greater velocity generated by the vertical jump. Another important recommendation for high jumpers is to kick their feet up after the time at which the maximum height has been reached. Conclusions can also be made that it is favorable for a high jumper to be tall, muscular, and low in body fat.

Centrifugal Force



Position Time Graph



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