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Physics perspectives and analytics in sports

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Abstract- *Fitness, competition, endurance, exercise, and pleasure often spring to mind when we think of sports. Physical education and sports are also quite scientific. It has deep scientific roots. In contemporary sports, performance is demonstrated through science as well as skill, strength, and technique. It is an equally compelling scientific illustration. Sport is influenced in every way by gravity, friction, velocity, and projectile. It encompasses basic laws of Physics in everything from bicycles to tennis rackets, and from high jump to long jump. Understanding the Physics of motion can help athletes move quicker, prevent injuries, plan more effective training sessions, and design aerodynamic equipment and clothes, among other things. Sports and Physics are strongly linked. This is because every sport's discipline is based on an athlete's capacity to exert force, and force is one of the fundamental notions in Newton's laws of motion and other fundamental physics concepts. In this paper the concepts of work, energy, angular momentum, friction, aerodynamics and applications of laws of Physics in various sports activities like tennis, basketball, swimming, skating, surface sports etc. are discussed.*

Key words**:** Gravity, Friction, Velocity, Projectile, Tennis, Basketball, Newton's laws.

Introduction:

A sport is a skillful, organised, competitive, and enjoyable physical exercise that requires dedication, strategy, and fair play. Physics is a natural science that studies matter and how it moves through space and time, as well as all associated notions such as energy and force. It is evident from this that both physics and sports are closely linked. Athletes must apply Physics concepts to the sports in which they participate in order to be successful. When people think about sports and athletics, Physics isn't typically the first thing that comes to mind. However, Physics has an impact on every facet of the activity. Physics can be as simple as a ball bouncing or as complicated as a roller coaster. A considerable deal of Physics goes into every single movement in a sport. Every sport makes use of a number of Physics ideas. There is no sport that can be played without Physics. On a variety of levels, Physics and sports can be related. Players won't realise how much Physics is involved when they play sports and lift weights. Because all sports contain motion, mass, energy, and gravity. The athlete should have a strong understanding of Physics (Hatze H., 1974).

Physics behind the tennis:

The path of the ball in tennis is the most evident example of Newton's first law. When the ball is hit with the racket, it travels in a specific direction. The ball would continue in that path more or less eternally if the game were played in the vacuum of intergalactic space, light years from any gravity-producing body, because no external forces would be acting on it. However, on Earth, two significant factors are at work: air resistance slows the ball's speed and gravity pulls it toward the ground (Cross RC.,1999).When that tennis ball was thwacked with a racket, it put a force on it, whether in space or on Earth. How much force is required? The second law of Newton comes into play here: Mass multiplied by acceleration equals force. The mass is expressed in kilogrammes, and the acceleration in ms^{-2}. Acceleration is not the same as speed; it refers to the pace at which something accelerates.

When the ball is served, opponent returns the serve, and player proceed to volley. Push off with the player's foot planted on the ground. The body moves in the opposite direction, at an angle away from the ground, as the foot pushes into the ground at an angle. The force with which the body was driven forward was the force with which it was pressed into the earth. That is the concept of action and reaction which is Newton's third law of motion.

A tennis racket can be roughly described as an item hanging from a fixed point on the grip and moving freely around that point. The tennis ball strikes the racket at an angle along its length, causing a dynamic interaction between the racket and the ball. This will be treated as a two-dimensional problem.

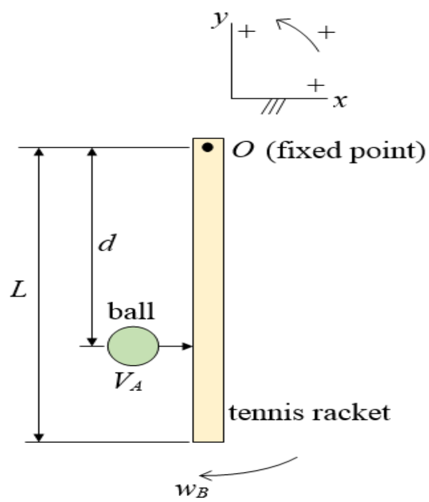


Figure 1: Schematic representation of the tennis racket with sign convention

Where, L is the length of the racket, d is the distance, V_A is the velocity of the ball before impacts, w_B is the angular velocity of the racket before impact

In this case the angular momentum before the impact between ball and racket is equal to that of after collision. This satisfies law of conservation of angular momentum. Hence we have

$$V_A m_A d - I_B w_B = I_B w_B' + V_A' m_A d \text{----------- (1)}$$

Where, m_A is the mass of the ball, I_B is the moment of inertia of the racket, V_A' is the velocity of the ball after impact, w_B' is the angular velocity of the racket before impacts

The energy loss during inelastic impact between ball and racket is given by

$$V_A' - V_B' = e\,(V_B - V_A) \text{ --------------- } (2)$$

Where, e is the coefficient of restitution, V_B is the velocity of the racket just before impact, V_B' is the velocity of the racket just after impact

From kinematics, we can write $V_B' = w_B' \, d$ and $V_B = -w_B \, d$

Equation (2) can be rewritten as

$$V_A' - w_B' \, d = e(-w_B d - V_A) \text{ ----------- } (3)$$

From equation 1 & 3, the final velocity of the ball after the impact with the racket is given by

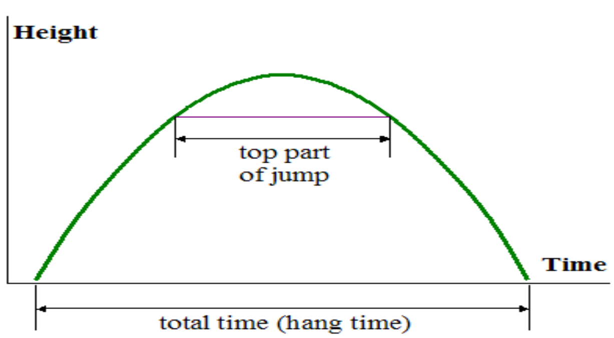
$$\boldsymbol{V_A' = \frac{(V_A m_A d - I_B w_B)d - e(w_B d + V_A)\, I_B}{I_B + m_A d^2}} - - - - - - - - (\mathbf{4})$$

On Sept. 24, 1984, Vicki Nelson and Jean Hepner, who were ranked No. 93 and No. 172 in the world, engaged in a 29-minute, 643-shot rally that remains the longest point played in a professional tennis match. The capacity to enhance tennis game can be greatly increased by having a solid understanding of Physics. Understanding how activities affect the body is really helpful because it will help to change how to play tennis to reach full potential. Through the study of air movement and friction, the secrets of spin can be easily comprehended. Similar to this, can start to make shots that are more powerful by understanding how power is created in the first place. Even fora spectator, understanding the Physics of tennis can help decipher the seemingly superhuman accomplishments of the pros and give a deeper appreciation for the sport.

Physics behind the Basketball:

If a basketball player shoots, there appears to be nothing in the way of the ball. However, the ball is subjected to a number of external influences. The ball would continue to fly in its current direction if it weren't for these factors. To begin, gravity pulls the ball down to the ground. To locate the appropriate line of trajectory so the ball arcs into the basket, the athlete must judge the force of gravity by the weight of the ball. Force of friction is another way that air resists the ball. Wind can be a huge effect during outdoor sports, even if it isn't evident indoors. This explains the law of inertia.

Figure 2: Trajectory a basketball player might travel as makes a jump



(Source: https://www.real-world-physics-problems.com/physics-of-basketball.html)

The time spent in the top of the jump is calculated using the equation of linear motion with constant acceleration as follows.

$$d = V_1 t - \frac{1}{2} g t^2 \text{ ------------ (5)}$$

Where, d is the vertical jump distance, V_1 is the vertical component of jump velocity at take-off, t is time, g is the acceleration due to gravity, which is 9.8 m/s^2

Maximum jump height is reached at $t = \frac{V_1}{g}$

Using the above formula for d, the maximum height reached is

$$d_{max} = \frac{V_1^2}{2g} \text{------------ (6)}$$

Now, set $t = \frac{V_1}{2g}$ this is half the time it takes to reach maximum height called ast_{half}. Using the above formula for d, the height reached during t_{half} is

$$d_{half} = \frac{3V_1^2}{8g} \text{---------- (7)}$$

Therefore from equation 6 and 7, $\frac{d_{half}}{d_{max}} = \mathbf{0.75}$**------- (8)**

This explains that the half the jump time is spent in the highest 25% of the jump (the top part of the arc). Hence a basketball player appears to "hang" during the jump.

Work – Energy concept in pole vault:

In athletics, the principles of work and energy are important and they are interconnected (Schade, F et al., 2012). As a result, work is the process of transferring energy from one location to another or from one form to another. Athletes must use a variety of energies while performing a pole vault. First, while running, the athletes convert chemical energy into kinetic energy. Pole vaulters must move as quickly as they can and then use proper vaulting technique to convert their kinetic energy into maximum height. The faster the vaulter runs, the greater their kinetic energy, and the higher they can vault. At this point the kinetic energy is equal to potential energy at that point (Dillman, C.J, et al., 1968).

$$\frac{1}{2} mv^2 = m\, g\, (\Delta h) \text{ ----------- (9)}$$

Where, *'m'* is the mass of the pole vaulter, 'v' is the velocity of the pole vaulter just before the vault, g is the gravitational constant,Δh is the change in height of the pole vaulter's

Therefore the maximum height that vaulter can reach is $\Delta h = \frac{1}{2}\frac{v^2}{g}$ ----------- (10)

Elasticity is a feature of fibreglass poles like carbon fibre. Due to the fibre glass's elastic nature, when the athlete applies force to the pole, it will bend and store some elastic energy. The fibre glass's elastic energy will be transferred to the athlete when they pass the bar. As a result, when the athlete passes the bar, they will have more energy. Because of this, when the wooden pole was replaced with a fibre glass pole, pole vaulting underwent a significant change.

Sergei Bubka was a world record holder in Pole Vault for six long years. His coach VitalyPetrov guided him meticulously taking into account his weight, strength, metabolism and other related parameters, and it is more important that Bubka could take his physical capability in conformity with the directions given by his coach.

Bubka had outstanding agility, speed, and strength. Bubka grabbed the pole more firmly than most vaulters did in order to gain an advantage, albeit he downplayed the significance of grip alone.

It is also believed that his development and mastery of the Petrov/Bubka technical model was crucial to his success. (A technical model is a series of stresses and locations that characterise the pole vaulting technique and form.) Because it enables the vaulter to constantly exert force into the pole as they rise towards the bar, the Petrov/Bubka model is regarded as being superior to many others today. The majority of traditional models emphasise putting the pole firmly in the pole vault box to bend it as much as possible before it leaves the ground. The Petrov/Bubka model emulates Kjell Isaksson's method, which emphasises high running speed and forcing the pole up rather than bending it while planting it on the landing pad. The Petrov/Bubka model may take use of the pole's recoil and apply more force on it during the swinging movement than the older models, which relied on the pole's recoil by bending it.

Frictional force in skating and swimming:

Friction is defined as the force that prevents sliding of one over another. The heat generated by friction melts the fluid barrier between the ice and the skate, allowing skating to occur (Berre Le et al., 2015 and Koning De et al., 1992). The angle of lean in the ice skating is given by

$$\theta = tan^{-1}\left(\frac{R\,g}{v^2}\right) \text{ -------- (11)}$$

Where, θ is the lean angle which is angle between the horizontal plane and center of mass, R is radius of the turn, v is velocity.

The swimmers are slowed by gravity and viscous friction. Resistance can be reduced by decreasing the surface area, which acts as a counterweight to the swimmer's efforts, similar to air resistance outside the water. Hence streamline motion is beneficial (Minetti et al., 2009).

Drag force is the another factor which reduces the speed of the swimmer. It depends on shape and size of the swimmer with speed relative to the water. The velocity is given by

$$v = \sqrt[3]{\left(\frac{2P}{\rho\,A\,C}\right)} \text{ -------- (12)}$$

Where, P is the power, ρ is density of water, A is area of cross section and C is drag coefficient.

Conclusion:

To summarise, sports are inextricably linked to Physics. Without Physics, no sport can be successfully played. With today's Physics and technologies, world records will be broken on a regular basis. New sports will be invented, and Physics will be useful at that time. The literature reveals that physics concepts play an important effect in sports performance. Athletes in today's sports should be biomechanically powerful. The application of physics concepts increases sports performance while also lowering the risk of injury.

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