Quest Journals
Journal of Research in Mechanical Engineering
Volume 10 ~ Issue 5 (2024) pp: 21-31
ISSN(Online):2321-8185
www.questjournals.org

Research Paper

An in-Depth Study of the Concepts of Kinematics and Dynamic Son Enhancing the Potential of Sportspersons.

Nakin Singla

ABSTRACT:
Physics and sports are closely related; they are two sides of the same coin. Understanding kinematics has helped immensely in increasing the ability of sportspersons, the equipment they use as well as the areas that they play on. In recent times, the close relationship between the two has been studied and researched in great detail resulting in the enhancement and success of sportspersons in nearly every field that they participate in. In depth examples were studied in the case of Tennis and Football.

RESEARCH QUESTION:
How important are kinematics and dynamics on increasing the speed and capability of various sportspersons?Does this differ amongst various sports that exist? If so, what are the areas that need to be developed or enhanced depending on the sport that an individual takes? What are the different laws of physics that specifically work for sportspeople? How close is the relationship between these two fields? These and other such questions would be attempted to be addressed during the course of the paper.

KEYWORDS:
1. Kinematics
2. Dynamics
3. Newton's Laws
4. Potential Energy
5. Kinetic Energy
6. Projectile Motion
7. Mechanical Power
8. Motion
9. Athlete Performance
10. Physics of Sports

***R**eceived 07 Oct., 2024; **R**evised 16 Oct., 2024; **A**ccepted 18 Oct., 2024 © The author(s) 2024.*
P**ublished with open access at **www.questjournas.org

I. INTRODUCTION

Sports are a practical application of science and physics in particular. A study of the above concepts can help athletes develop new techniques that increase their chances of winning and outperforming their rivals. One of the earliest laws of physics which is the Newton's laws also commonly referred to as the Laws of Inertia, acceleration and reaction go a long way in the manner in which athletes control their movements, improve their speed and thus they gain performance.

The principals of physics describe certain phenomena and influence various facets of sports right from helping athletes to move faster, hit harder, train more efficiently, prevent injuries, strengthen their mindset, designing aero dynamic clothing and devices.

Physics and sports are intimately connected. The main reason being that every sport discipline depends on the ability of an athlete to exercise a force and force as everyone knows is the domain of the laws of motion as stated by Newton.

Sports involve fitness, competition, endurance, exercise and recreation, the synergy between physics and sports is extremely important as science demonstrates scientific usage in skill strength and techniques that are required by sportspeople. Besides just the understanding of this by the sportsperson there are additional factors that the athletes need to keep in mind with respect to the equipment and the clothing that they use and wear. with respect to this, to scientific knowledge and application are an extremely important factor.

II. DEFINITION

The concept of work and energy plays a pivotal role in sports. In physics, work is explained as the result of a force moving an object to a definite distance. Force and work are directly proportional to each other. Similarly, work and energy are also closely related. Within this sphere mechanical power is a metric that is used by sports scientists, athletes and coaches forresearch and training purpose. It provides a valuable insight in the capability of athletes to generate power as well as using it effectively for enhanced performance. The term "mechanical power and sport" are concerned with strength characteristic and performance measures. To determine the amount of work that is done on an object it is essential to know the following:

1. Average force exerted on the object
2. Direction of this force
3. Displacement of the object along the line of action of force during the time the force acts on the object.

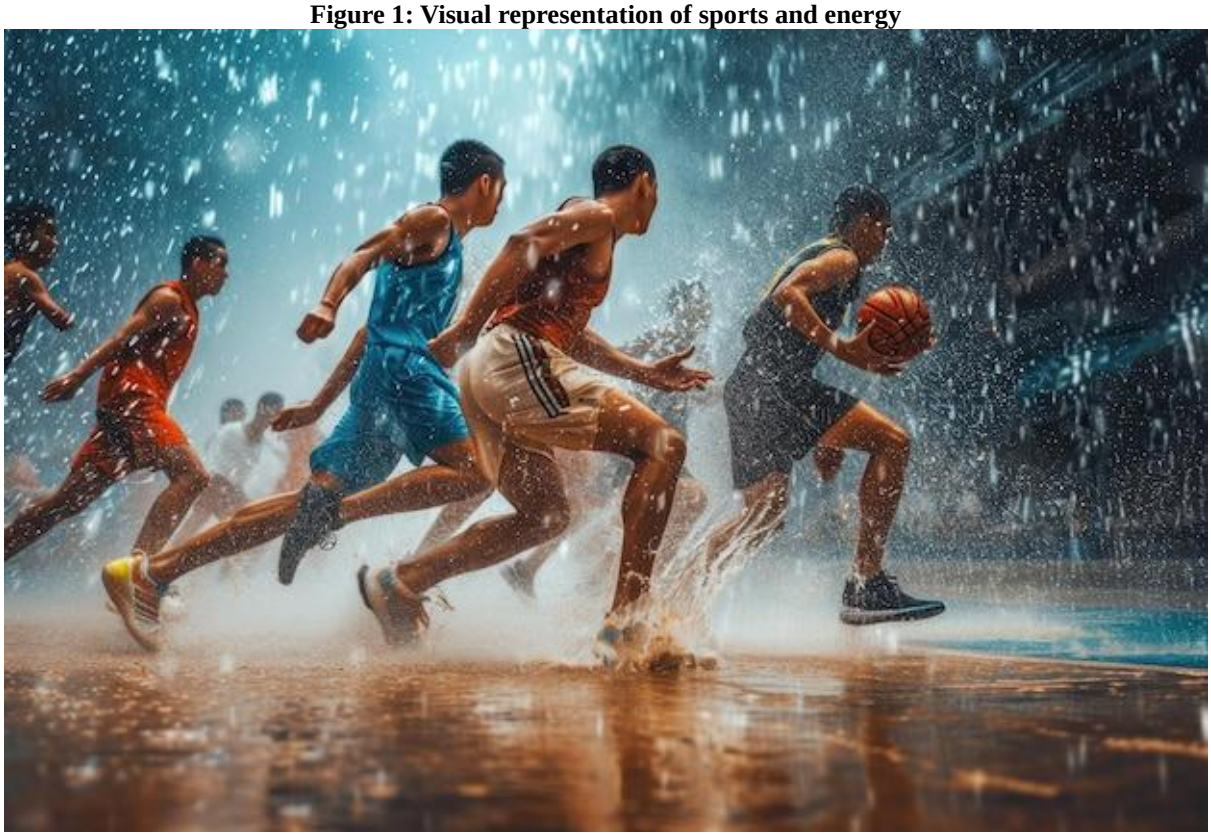
All isotonic movements of sports for example benchpress, pullups etc all use the above principle.

Power is defined as the rate of doing work. It is the ability to perform large amount of work as fast as possible. The capacity to do work is called energy and in sports there are 2 types of energy that are used:

1. Kinetic Energy: it is the energy due to motion.
2. Potential Energy: it is the energy due to position.

Work and energy are the 2 most important concepts of physics that play an important role in sports. Work transfers energy from one place to another or one form to another. Forexample : athletes transform chemical energy into kinetic energy of their body when they are running. Part of this kinetic energy becomes elastic potential energy(observed by the deformation of the pole): the rest of the energy becomes gravitational potential energy, which is again transformed into kinetic energy when athletes fall away from the bar in the example given above.

Figure 1: Visual representation of sports and energy



Source: https://www.google.com

2.1 KINEMATICS

This is the branch of mechanics that is concerned with the motion of objects or motion of points or objects and systems of groups of objects without reference to the forces that are causing the motion. It involves the study of motion of mechanical points, bodies and systems without consideration of their associated physical properties and the forces acting on them. It is also referred to as "geometry of motion".

To study this sphere, it is essential to connect the material physics with contextual phenomena as everything in nature can be connected to physics. For example, kinematics and dynamics of motion of sloping and flat trajectories need physics quantities like position, distance, displacement, speed, velocity, kinematics and dynamics of motion on circular path, which involve angular position, angular velocity, angular acceleration, centripetal acceleration, centripetal force and speed.

This part of science studies the natural phenomena of matter or matter in the sphere of space and time that can be explained through quantitative calculations.

2.2 DYNAMICS

Dynamics is a branch of physical science and a sub division of mechanics that is concerned with the motion of material objects in relation to the physical factors that affect them: force, mass, momentum and energy. In the late 1600s, Isaac Newton hypothesized that motion does not require a cause rather changes in motion.

Dynamics is distinguished from kinematics, which describes motion without regard to its causes in terms of position, velocity and acceleration and kinetics which is basically concerned with the effect of forces and torques on the motion of bodies having mass. The foundation of dynamics was laid at the end of 16th century by Galileo who by experimenting with a smooth ball rolling down an inclined plane derived the law of motion for falling bodies. He also recognised that force is the cause of changes in the velocity of a body. This was incorporated by Isaac Newton in the 17th century in his 2nd law of motion.

Figure 2: Picturization of dynamics in sports

Source:https://www.google.com

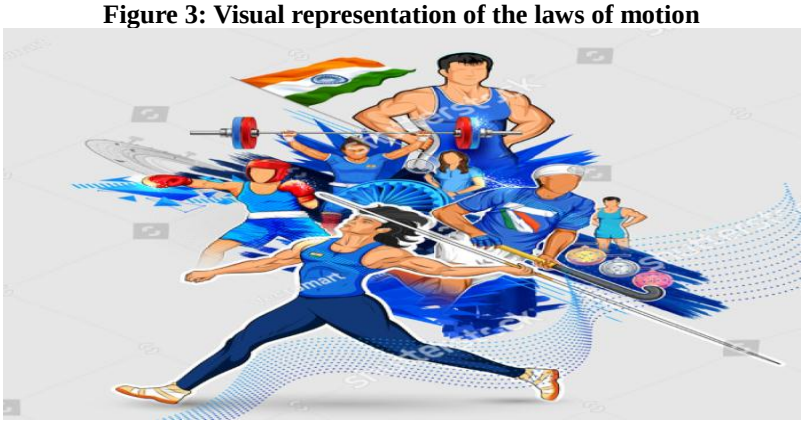
This concept is concerned with describing motion and explaining its causes. The field of dynamics consists of two major areas; kinematics and kinetics. Each of these areas can be further divided to describe and explain linear, angular or general motion of bodies. The fundamental concept in dynamics is space (relative position or displacement), time, mass, and force. Other important concepts include velocity, acceleration, torque, moment, work, energy, power, impulse and momentum.

2.3 POTENTIAL OF SPORTSPERSONS

One of the major factors is that people tend to express themselves through sports. Participating in games of athleticism as a means of discovering who they are as well as reaching their potential. Flourishing is the pinnacle of human potential also known as self -actualization excellence and well-being. It is also described as an 'optimal human functioning'. This means that an individual is one with his environment thus functioning more efficiently and effectively.

Sports from a philosophical perspective carry people from their current sense of self so that they can break apart from it then rebuild in a stronger manner. This means replacing one's old self with an evolved version through physical effort. During sports, people burn off their old self through sweat and hard work replacing it with a stronger body and mind as they adapt to a stimulus. Sports are a catalyst for action. They are a means by which people voluntarily create, problem solve and act within a boundary of agreed upon rules receiving feedback as a result of their action. Sports activates one's entire spectrum of emotion. As athletes develop their skills and participate at a level of competition appropriate for their current abilities, they see progress and the rise of positive emotions when one sees improvement in their sport.

Figure 3: Visual representation of the laws of motion

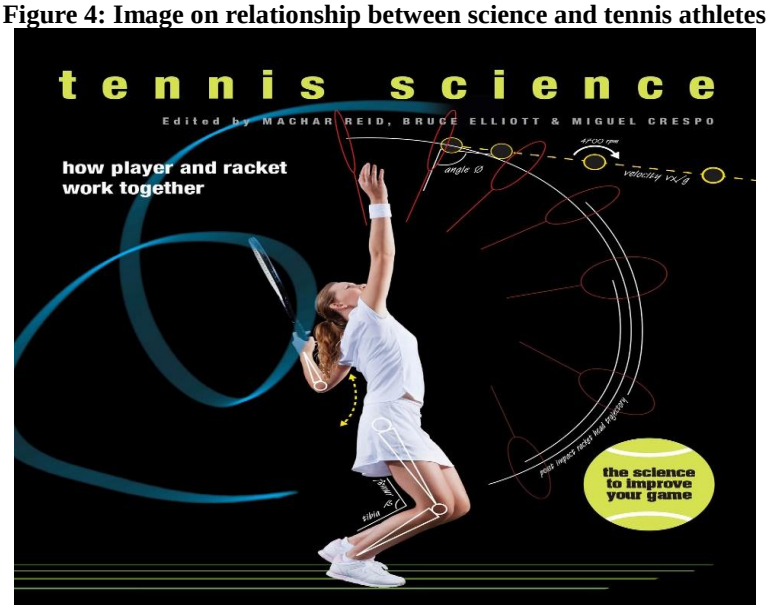


Source: www.shutterstock.com

III. EXTENT OF THE PHYSICS OF SPORTS

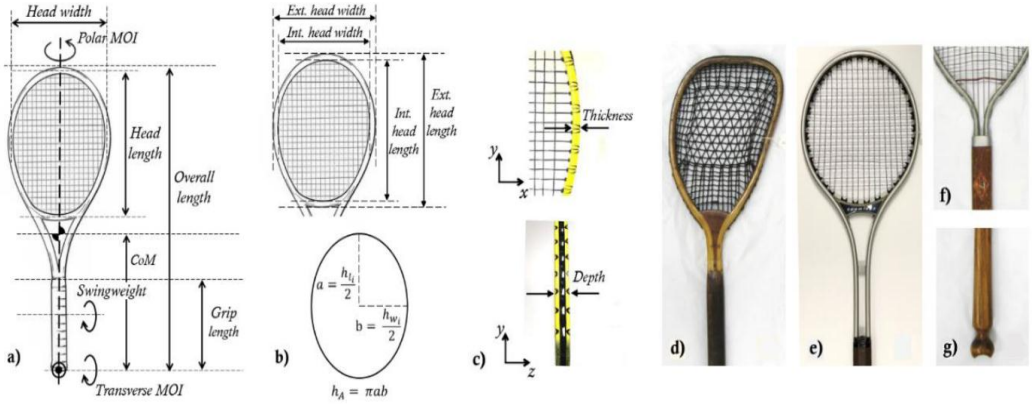
The concept of physics and sports is intertwined. Modern sports are not only demonstration of skills, strength and techniques but it is also a scientific performance. Every aspect of sports right from the bicycle to tennis rackets, from high jump to long jump involve science. It is science that helps athletes to run at such high speeds. The application of the principles of physics is known as biomechanics. The word 'bio' indicates a living or a biological system and the word 'mechanics indicates the analysis of forces and its effects. Herbert Hatze in 1974 said that "biomechanics is the study of the structure and function of biological systems by means of the methods of mechanics. The goals of both these aspects namely sports and science is to improve performance, improve techniques, improve equipment, prevent injury and rehabilitation

Figure 4: Image on relationship between science and tennis athletes



Source:https://press.uchicago.edu

Figure 5: Image of relationship between science and tennis equipment



Source:https://www.mdpi.com

Not only is science related to the way a tennis athlete handles the game or the way equipment has been developed, science has also helped in measuring the way the player performsand interacts with his equipment. This was earlier shared by analysis made by the coach. Nowadays, the devices are available in the form of KITRIS-KIT, the play racket, and the Play Sight smart court. Players now had access to the sophisticated coaching information at low cost even if they have no coach. This has had a major impact on the sport. The information obtained from these devices is real time information and extremely more detailed than that was previously available.

A noticeable scientific recent advance has been the introduction of an electronic live calling system in tennis called 'Hawkeye'. This device accurately records the ball impact area. The information is provided to players, spectators and match umpires and is accepted as a definitive answer to the question 'in or out'. This has reduced pressure on officials as well and rapid closure for the players involved in contested points and decisions.

A number of studies have also investigated the thermo-regulatory response of tennis players to heat stress. It shows that core body temperature should be maintained at a safe level across a wide range of environmental conditions and is determined by the intensity of the exercise and the resulting metabolic rate.

Biomechanics plays an integral role in the stroke production of a tennis player. All strokes have a fundamental mechanical structure and normally sports injuries have a mechanical cause. Biomechanics theory provides coaches players and sports science support staff with a general framework for the development of stroke production.

*Muscle pre-tension (*elastic energy*)*

Figure 6: Image on elastic energy

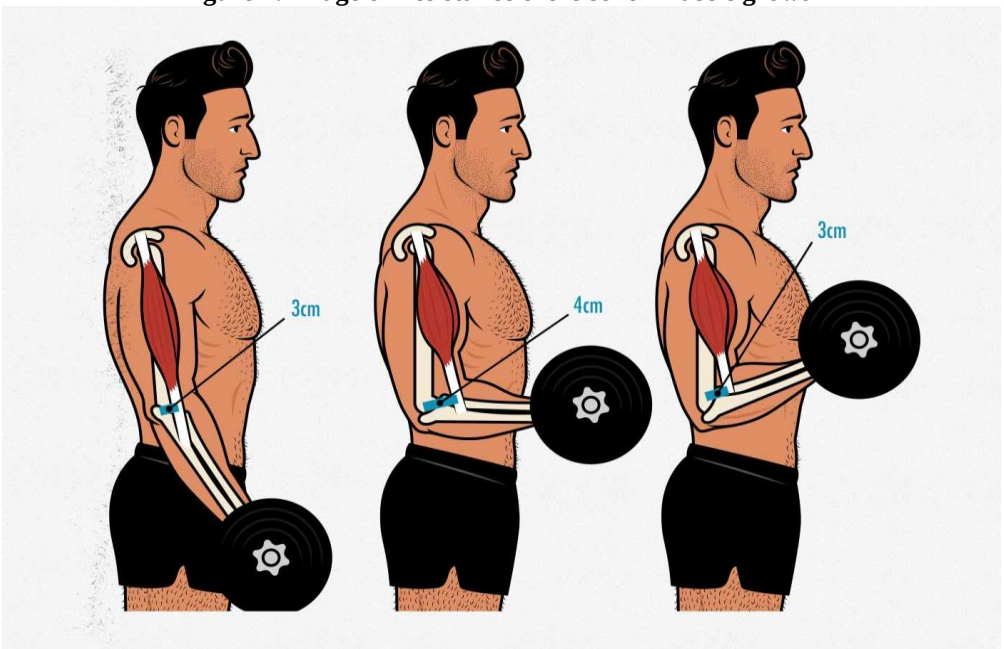
Source:https://physioclinics.co.uk

In sports pre tensed and conventional starts that exert large and small forces against the starting block. The starts were videotaped and the horizontal forces on feet and hands were obtained from separate force plates. In the pre tensed start the legs received larger forward impulses early in the acceleration and the hands received larger backward impulses. This concept of a sprint start has emerged int the last two decades which involve advance technologies high precision methods for sprinters to achieve high performance levels. Several technical (kinematic) and dynamic (kinetic) aspects are currently identified as factors for starting lock face and the initial sprint acceleration.

Swimmers can grasp the front edge of the starting platform whereas on the other hand runners can merely place their hands on the ground. But the runner's hand can hardly exert horizontal force but the swimmer can exert forces not only vertically upwards but also horizontally backwards. For runners, at the sprint start they are required to become motionless at the 'set command'.

Thus, muscle time under tension during resistance exercise stimulates differential muscle protein, sub fractional synthetic responses in sportspersons. This result is used in the case of weight training that is a result of resistance exercise that makes the muscles grow bigger also known as 'hypotrophy'. Results have indicated that the time the muscle is under tension during an exercise is important in optimising muscle growth.

Figure 7: Image on resistance exercise for muscle growth



Source:https://bonytobeastly.com

Effective stretching is an important pre-requisite for a range of motion (ROM) which is extremely important for athletes. Muscles in the body are unlike any material that is used in engineering. They are a highly dynamic tissue with cellular composition and architecture that supports and provides mobility. During isometric

contraction, they bulk up to increase the volume of the muscle tissue increasing their stiffness and yet they do not change the length while doing so. Muscle generates its own internal forces. It consumes energy through static and dynamic adjustments by changing the force it generates internally and through changing its length. Muscle is the only part of the human body that responds immediately to demand. It is also activated predictively to the load that it is expected to encounter.

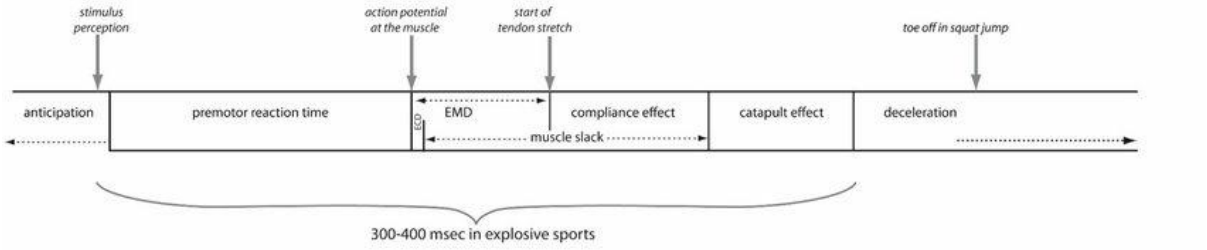
In most sports, the time to develop force is limited. Most players are performing under time pressure. In sprinting, javelin throw and short put the time period in which force is developed is only about 300 milliseconds and possibly shorter. In linear top speed sprinting, the ground contact time is only about 100 milliseconds while it can take about 900 milliseconds to develop maximum force. Thus, it is extremely important in sports to rapidly develop force which is critical for maximizing sport performance.

As the development of maximum force is important for sportspersons, it is necessary to define mechanisms and their influence. The first is a relevant stimulus. This contains perception or is processed into perception. Then the central nervous system sends a signal to activate the muscles. This leads to shortening of the contractile element (CE) of the muscle. The contraction of the CE leads to the muscle tended unit (MTU). They might be an electro mechanical delay (EMD).Reducing the time to move through the above stated steps will benefit high intensity sport performance.

IV. EXAMPLES INDICATING THE APPLICABILITY OF THE LAWS OF PHYSICS IN SPORTS

A large number of sports motions and actions can be explained by the science of physics and laws that come under it. The image below is that of a squat jump:

Figure 8:Image on schematic representation of the time course of different processes during a squat jump



Source:https://www.researchgate.net

When a cricket or football swings, it deviates but the deviation is in the air. This deviation is explained by the Bernoulli's principle. According to this principle, air exerts less sidewards pressure when it is moving faster.
Sports are, infact, a practical application of science and physics can help athletes develop new techniques that increase their chances of outperforming their rival.
Newton's three laws that of:

1. Law of Inertia
2. Law of Acceleration
3. Law of reaction

The three laws explain how athletes control their movement and improve their speed and gain performance. The principles of physics describe certain phenomena and influence various facets of sports right from helping athletes to move faster, hit harder to training more efficiently to preventing injuries to strengthening their mindset to designing aero dynamic clothing and design.

4.1 Laws of physics with respect to tennis

Tennis as a sport involves both simple and advanced physics concept. These are:

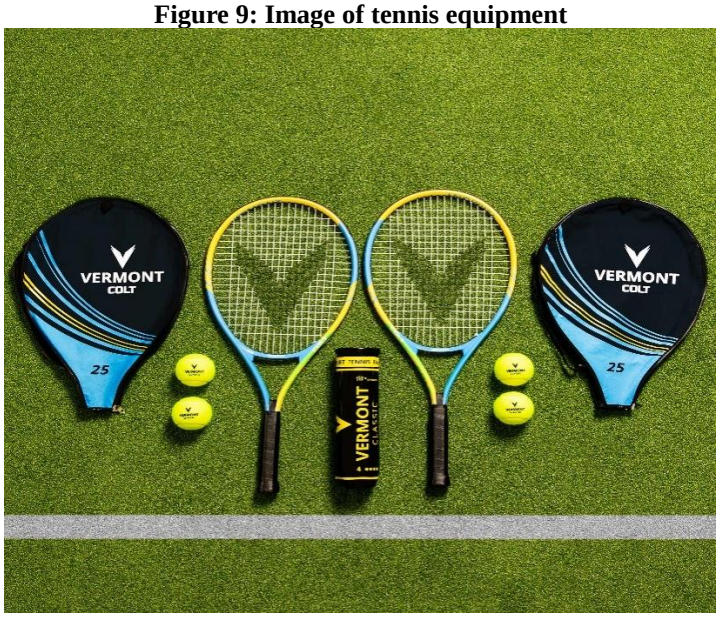
1. Moments of inertia
2. Elastic impacts
3. Momentum

While the tennis player is training, the focus is on concepts such as:

1. Point of impact
2. Balance
3. Inertia
4. Mass

The concept of physics is also used in the equipment that is used for the game

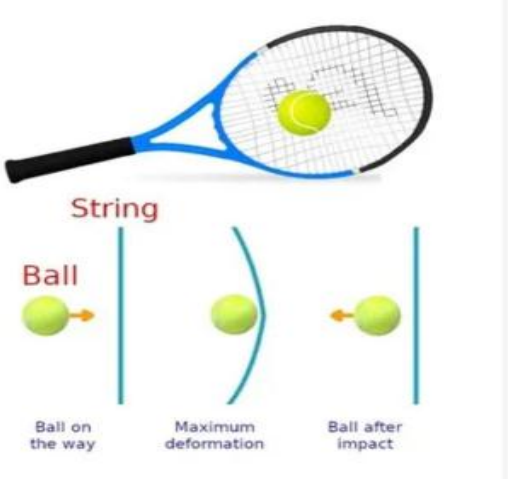
Figure 9: Image of tennis equipment



Source: https://www.networldsports.in

The racket as indicated above is usually six times heavier than the ball and around one sixth the weight of the player's arm. In sports, where a tool is used to hit a ball. The tennis ball is 57 grams in weight, and an adult's arm weighs around 2 kilograms, thus the ideal weight of the racket should be 340 grams. The significance of this numerical co-relation is that when the weight of the tool surpasses this ratio, the weight of the racket tends to slow down the arm's speed. The speed with which the racket strikes the ball is also determined by its weight. A ball struck with a heavier instrument will go quicker at the same speed.

Figure 10: Image of tennis racket striking a ball in motion



Source: https://www.eetimes.eu/

When the racket and the ball meet, they generate a force that causes them to change their state of motion. The force required to change a body's state of motion that is either acceleration or decelerating is proportional to its mass.

$$F = m \times a$$

where, F = force

m = mass

a = acceleration

when two moving bodies collide, a certain quantity of kinetic energy is released. This is determined by their mass and speed.

$$K.E. = \frac{1}{2}(mv^2)$$

As the ball and the string are elastic, they are able to save a certain amount of kinetic energy when they collide changing it into elastic energy that may then be returned to the bodies. Due to friction, a portion of the collected elastic potential energy is inevitably lost and turned into vibrations and heat, when the ball hits the strings of the racket, 45% of the energy is dissipated. To improve their performance, players work with their trainers in performing kinematic and dynamic analysis to study the relationship between the forces acting on a body and its motion.

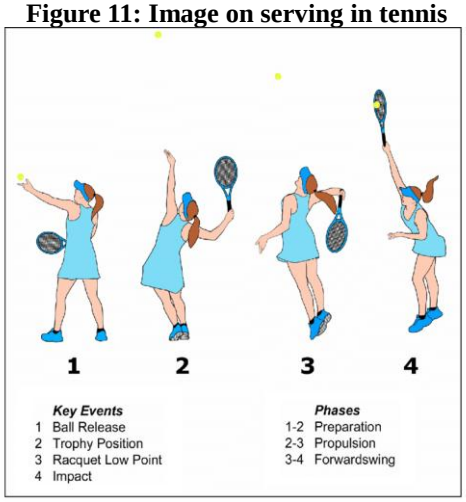
4.2 SERVING IN TENNIS

The use of anthropometric factors and whole-body kinematics is important for ball speed as well as for training strategies to improve the quality of tennis serves. The tennis serve is divided into four phases:

1. Back swing phase
2. Lead leg drive phase
3. Forward swing phase
4. Follow through phase

It was studied that the number of 'aces' increased as serve speed increases. Especially for ball speeds over 161 kilometres per hour. The serve is the only stroke in which the player has full control over the ball trajectory. It is difficult to master the serve as it involves complex coordination of the trunk, upper and lower limbs in a kinetic chain movement. Kinematic and kinetic studies have indicated that contribution to racket speed comes sequentially from shoulder abduction, elbow extension, ulnar deviation rotation at the wrist, axial rotation of the upper trunk relative to the lower trunk and wrist flexion. Maximum resultant linear velocities of these joints produced maximum angular velocity of the racket. It is important that the whole-body kinematics that include analysis of ankle and hip segment should be studies simultaneously to obtain the best results and understanding of the serve kinematic chain motion.

Figure 11: Image on serving in tennis



Source:https://www.researchgate.net

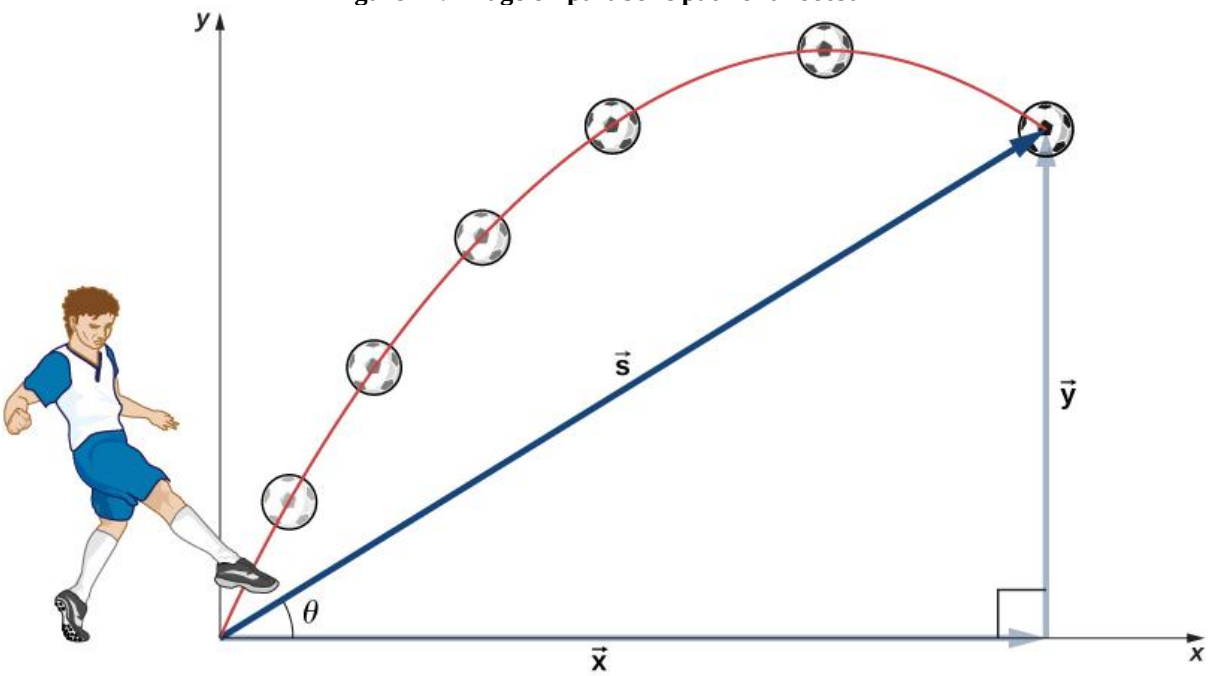
V. PHYSICS OF MOTION IN FOOTBALL

When players run and kick the ball, the combination of mass and velocity is transferred to the ball's momentum. The greater the momentum, the faster the ball moves. When a ball is being received, the momentum is reduced when the goalkeeper transfers the excess to his body.

When the football travels through the air, it follows a curved or a parabolic path as it is influenced by the force of gravity. When a player hits the ball, he/shecan control:

1. The velocity at which the ball leaves the foot
2. The angle of the kick
3. The rotation of the ball

Figure 12: Image on parabolic path of a football

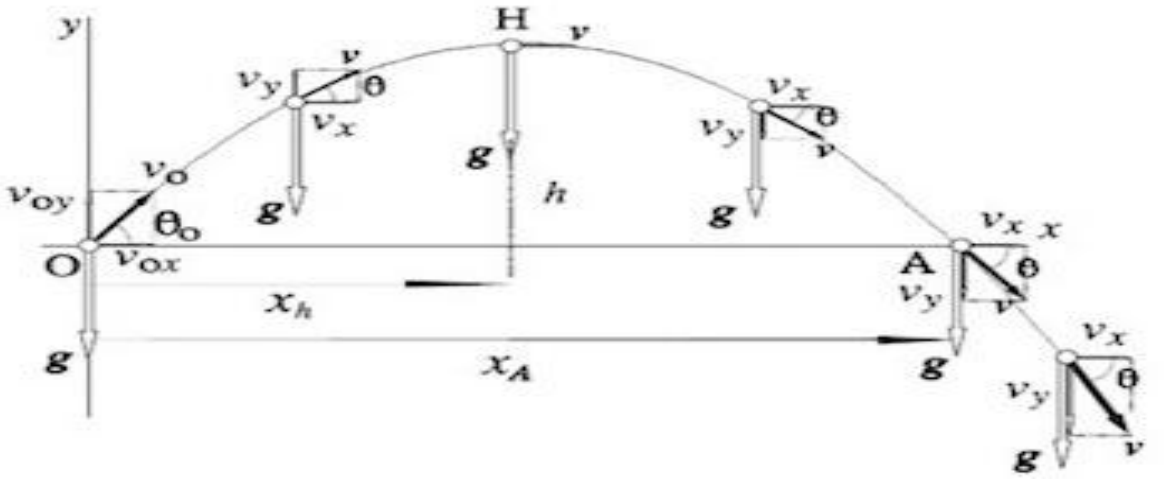


Source: https://courses.lumenlearning.com

For this game, the following factors are extremely important namely:

1. Acceleration
2. Force
3. Velocity
4. Speed

Figure 13: Image on equations representing projectile motion



Source: https://study.com

Where, 'y' is the height

'V_y' is the vertical component of the football's initial velocity

'g' is the acceleration due to earth's gravity is 9.8 m/s^2

'x' is the horizontal distance of the ball at any time 't'

'V_x' is the horizontal component of the football's initial velocity

With respect to positions in a football game, the position of the 'backs' allows them room and time to 'accelerate' from a state of rest to reach a high speed. When a player plants his foot, he applies force to the turf. This force accomplishes two things:

1. Stop his motion to the right; the coefficient of friction between the turf and the player is reduced, this reduces the frictional force making it harder for him to stop his motion and may result in the runner falling.

2. Friction between his foot and the turf.
3. The applied force and the frictional force together must stop the motion to the right
4. To accelerate up-field, Newton's third law of motion is in place 'for every action there is an equal and opposite reaction'. The player pushes against the turf and the turf applies an equal and opposite force on him, propelling him up-field.

When the player is running in an open field, the player reaches the maximum momentum. Momentum, $p = m \times v$

Tackling and blocking players rely on three important principles of physics namely:

1. Impulse
2. Conservation of momentum
3. Rotational motion

$$F = \text{Impulse}/t$$

Coaches tell football players to tackle a runner low. The reason being that the runner's feet will rotate in the air in the direction of the tackle

Figure 13: Picturization of a 'tackle' in football

Source: https://www.shutterstock.com

The reason being that this brings their centre of mass closer to the ground so an opposing player's point of contact is near the centre of mass making it difficult for the opposing player to move the other player.

VI. CONCLUSION

It is evident that all sports whether in the form of player's techniques or motions or equipment or clothes are all based on physics. The role of physics is so encompassing that coaches practice with the players on how to tackle, serve, kick and move one's body weight such that the maximum force can be applied. A lot of new technologies like the GPS and simulation techniques are used to explain, understand and imbibe the optimal manner in which a player can achieve the desired results. Besides the player it is also the equipment and the clothes that they wear that helps them achieve a faster pace without injuring themselves.

These scientific techniques and the understanding of the concept of physics behind them helps in achieving higher accolades for the sportsperson.

BIBLIOGRAPHY

[1]. Arasa, C. (2016). Connect The physics of sports 25 July 2016 | By Carina Arasa Cid, PhD. Elsevier.
[2]. Asai, T., Akatsuka, T., & Haake, S. (1998). The physics of football. Physics World, 11(6), 25–28.
[3]. Brancazio, P. J. (1985). The physics of kicking a football. The Physics Teacher, 23(7), 403–407.
[4]. Brody, H. (1979). Physics of the tennis racket. American Journal of Physics, 47(6), 482–487.
[5]. Cross, R. (1999). The bounce of a ball. American Journal of Physics, 67(3), 222–227.
[6]. Daum, M. M., Rauch, J., & Wilkening, F. (2008). Intuitive physics: naïve concepts about the ball's momentum among professional football players. In Cambridge Scholars Publishing eBooks (pp. 39–60).
[7]. Lees, A. (2019). The evolution of racket sport science—a personal reflection. German Journal of Exercise and Sport Research.