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A Review of applications and Developments of Biomechanics in Sports

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A Review of applications and Developments of Biomechanics in Sports

Koustav Kanjilal [α] & Sudipto Shekhor Mondol [σ]

Abstract- Sports biomechanics is an analysis of sports' activities and professional athletes in general. It can plainly be called the Physics of Sports. In this sub division of biomechanics, the principles of mechanics are incorporated to gain a better insight of athletic performance via computer simulation, mathematical modelling and measurement. This paper briefly describes about the various methods in which biomechanics has enabled the athletes to perform better while being safe.

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I. Introduction

Biomechanics can be defined as the study of the structure and function of biological entities by application of biological principles coupled with the principles of mechanics. Basically it serves to unify two vastly different disciplines – biology and mechanics. It also utilizes the concepts of physics, aerodynamics and material sciences among other subjects. In biomechanics, the human body is analogously treated as a mechanical system i.e. the concept of links, degrees of freedoms, equilibrium of forces, etc. can be applied to a living body as it can be applied to any inanimate object. For example, the human body has 244 degrees of freedom. There are 230 joints in the body, most of which have 1 degree of freedom (exception – hips and shoulders that have 3 degrees of freedom), so in totality, there are 244 degrees of freedom controlled by 630 muscles. These concepts are very pivotal in the making of prosthetics, orthotics and building humanoids.

II. Major Subdivisions

a) Soft Body Mechanics

Soft Body Mechanics deals with the motion and properties of deformable objects.

b) Kinesiology

It is the combination of kinetics and physiology. It governs the physiological, mechanical and psychological mechanisms of living bodies. Application areas include strength and conditioning of athletes and refinement of sport exercises.

c) Allometry

This subject deals with the relationship of body size to shape or in scientific terms it deals with the statistical shape analysis. Study of insect species is conducted by utilizing its principles.

d) Orthotics and Prosthetics

Orthotics are externally applied systems that support a deformity or deficiency of a subject. They are used to restrict movement in a particular direction or assist movement in a particular direction. Prosthetics are artificial limbs that help a subject to perform normal human functions which would otherwise not have been possible due to its absence.

e) Ergonomics

It deals with the reduction of injuries in the workplace, thereby creating an environment of maximum comfort and ease which in turn optimizes their workplace efficiency. For example, the ideal distance between a person's sight and the computer screen on which they work should be 26 inches. There should provisions on the chairs so that the person can rest their arms, the computer screen should me moveable so as not to strain the person's neck.

III. Applications in Sports

a) Improvement of movement techniques involved in athletic performances

The fundamental aspect of any sport is movement and through effective gait analysis optimization of musculoskeletal functions is highly possible. It not only improves the performances of the athletes but also helps in their career longevity and reduction of injuries. In this case, I have proceeded to show how the high jump technique has evolved over the years leading to a gradual increase in the world record heights.

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Figure 1: Scissors Technique

(Courtesy of The 1908 London Olympics Gallery By Stan Greenberg)

Figure 2: Eastern Cut-Off

(Courtesy of German Federal Archive)

Figure 3: Straddle Technique

(http://m.eb.com/assembly/87963)

Figure 4: Fosbury Flop

(http://thinklink.in/richard-douglas-fosbury)

In the above four figures the gradual evolution of the high jump technique is shown. Figure 1 denotes the earliest technique, known as the scissors technique. The main advantage of the scissors technique was that parts of both legs are well below the level of the bar at the peak of the jump. This increases the height of the pelvis and consequently the height of the bar that can be cleared. The world record was set at 1.97 m. Figure 2 shows the next technique that came about, known as the eastern cut-off. In this technique the body is in the horizontal position at the peak and thus the pelvis is lifted higher than in the scissors technique. But the main disadvantage of this technique is that it requires tremendous flexibility. The world record was set at a rather modest 2.01 m. Figure 3 shows the straddle technique in which the athlete cleared the bar face down. Parts of leg and pelvis is higher and effective bar clearance is more. The athlete cleared the bar by virtue of the angular momentum generated due to movement of hip and lower back. The world record increased from 2.01 m to 2.13 m and finally to 2.28m. The technique's main drawback was that it depended very much on the strength of the athlete and caused a burnout. Figure 4 shows the current technique that has completely dominated the sport since its inception. The Fosbury Flop has now emerged as the most successful of the 4 techniques. The athlete arches back in this case, thus the bending lifts the belly higher than all the previous techniques. For this reason the present world record has shot up to 2.45m.

Explanation: The sport of high jump is based on two simple principles:

a) To lift the C.M. of the human body as high as possible.

b) To keep the C.G.of the human body as low as possible.

In Figs. 1, 2, 3 and 3 the C.M. of the athlete is over the bar. The height of C.M. in descending order in the four figures are as follows–Figure 4 >Figure3 >Figure2 >Figure 1. Due to arching backwards in case of Fosbury Flop the pelvis is lifted higher than all the 3 other techniques. The effectiveness if the Fosbury Flop technique in lifting the pelvis over the bar causes the effective bar clearance to increase. In case of C.G., in Figures 1, 2 and 3 the C.G.s of the athletes are over the bar but in Figure 4 the C.G. is well below the bar because of the 140 degree arched configuration of the body. If the C.G. is lower the energy required to generate the jump will also be lower leading to performance of successive jumps effectively.

The effect of C.G. can be seen from the equation,

$$1/2\ mv2 = mgh$$

1/2 mv2 is the kinetic energy generated before take-off. mgh = the potential energy of the athlete at the peak position where velocity is zero;

i.e. at the peak height kinetic energy is converted into potential energy. Here, h is the height of the C.G. of the athlete. So evidently, lower value of h will require a lower value of kinetic energy.

b) Improvement of interface between the athlete and environment

With the application of biomechanics the interface between the athlete and his environment can be made significantly congenial for him. The improvement of ice skates used for ice skating is testament of this fact.

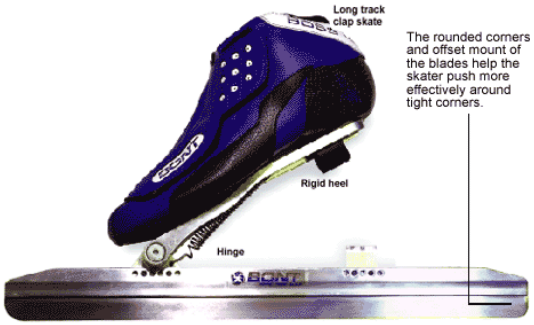

Figure 5: Clap Skates

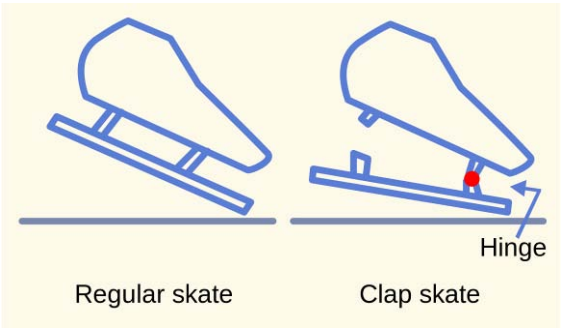

Figure 6: Regular Skate vs Clap Skate

(Drawn by Branko, vectorized by Mysid)

Figure 6 shows the regular skates that were prevalent in the ice skating circuit before clap skates (Figure 5) were introduced in 1998. Clap skates proved highly beneficial and completely dominated the ice skating circuit since.

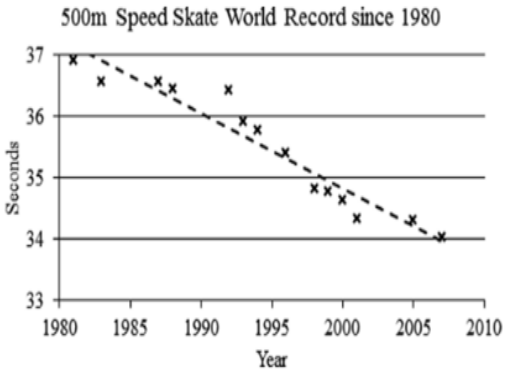

Figure 7

(http://researchgate.net/)

The graph above shows the influence of clap skates since its introduction in 1998. The dotted line represents an average or mean graph of the time vs year. After 1998, the cluster of 'x' marks are well below

the dotted line, indicating that as the years have progressed the time required in 500m speed skating has decreased considerably, which proves the effectiveness of the clap skates.

Explanation: The regular skates used to amplify plantar flexion of the feet by which the toe would strike the ground in an inclined position while the heel remained raised. Ankle flexion causes forces of the order of 1000 KPa to act on the ground thereby causing the skates to dig into the ground and cause accidents or loss of time/momentum. The regular skates being hinged at both ends the leg would come off the ice long before the back leg was fully extended, thereby maximum utilization of the elastic potential energy generated at the knee was not possible. It also caused muscular fatigue. The clap skates being unhinged allows longer strides and greater ground clearance because the back leg can come off the ice yet the skates can remain fully in contact with the ice. The spring provided at the front suppresses plantar flexion of the foot by recoiling it, thereby the forces generated due to plantar flexion are minimized.

Figure 8: Hinge of a clap skate
(Picture taken by Cassi Saari)

The edges of the blades are also rounded off so to decrease stress concentration and effectively manoeuvre around tight corners. It has been found that 5% more power is utilized by clap skates than the regular skates.

c) *Development of sport specific equipments*

Various sports are played on grass turfs (or plastic pitches) like football, rugby union, rugby league, etc. Yet in spite of the similarities of conditions the demands and dynamics of the sports vary from one to the other. Here comes the need for development of sport specific equipments.

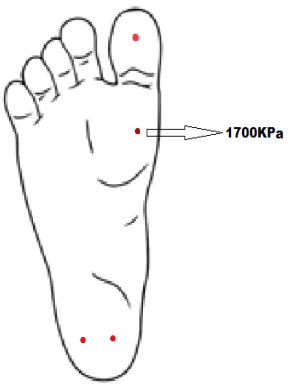

Figure 9: Stress Concentration on a footballer's foot

The above figure shows the stresses that are developed on the foot of a professional footballer. Highest stresses are recorded in the ball of the foot as shown (1700 KPa). These soaring stresses are tremendously detrimental for the health and career longevity of the footballer. Therefore in case of football boots polyfoam urethane is provided in that section to minimize the build-up of such high stresses. But at the same time one may argue that for a game like rugby union which involves a lot of running like football, normal football boots would suffice for the rugby players. But in reality it is not so.

Figure 10: Direction of force on a rugby player's foot
(https://www.flickr.com/photos/phillygryphons/771273148/sizes/l/)

In the above figure if this particular position in rugby union is concerned where the arrows indicate the maximum stresses being developed at the ankle of the player. So rugby players have a cushioning and ankle protection provided in their boots and not on the ball of the toe.

d) Development of prosthetics

The area of prosthetic development has improved manifold by the application of biomechanical principles. People who are differentially abled can now rub shoulders with the best able-bodied athletes because of the advancements and availability of a wide variety of prosthetics.

Figure 11: Pistorius' running blades
(Shaun Botterill, Getty Images)

Figure 11 above shows the running blades by Oscar Pistorius. They are known as Flex Foot Cheetahs and are now developed by an Icelandic Company called Ossur. These blades act as a spring and a shock absorber. As the unit is compressed on impact, the energy is stored and the stress is absorbed within it, which eventually propels the athlete forward. They are made of layers of carbon-fibre – mainly 30-90 layers depending upon the athlete's weight and the impact levels to which he will subject them to. The apex of the J-curve is fitted with more layers of carbon-fibre to resist high stress and those in need of greater flexibility are fitted with less. Vertical forces generated at the heel contact are stored and translated into linear motion. It benefits more natural gait and reduced walking effort. Deflection of carbon-fibre heel and forefoot components are proportional to the user's weight and impact levels. It optimizes walking efficiency.

However, the Cheetah returns only 80% of the energy stored during compression which is a far cry from the 249% a normal able bodied runner's foot and ankle system delivers. Oscar Pistorius has to generate twice the amount of power from his hips and gluteal muscles than a normal sprinter.

IV. Developments

There has been a lot of activity in the field of biomechanics particularly in the last 20-30 years. A brief illustration of some of them have been described below:

a) Improvement of scrimmaging

The International Rugby Board have funded a research programme for the improvement of scrummaging in the sport. The research is being conducted at the University of Bath, England where researchers are trying to minimize the forces on the necks and spinal cords of players in the game. Peak engagement forces have been recorded at 16.5 kN (men's elite international level) to 8.7 kN (women's elite international level). The new research has refined the technique of scrummaging whereby they have decreased the forces by 25% in elite level competitions. Yet, this has not been declared as the finished product and continuous research is still going on.

b) Swimgear improvement

SPEEDO's Aqualab in Nottingham, England has developed a new set of swimsuit and swimgear. The latest swimsuits compresses the swimmer's body into a streamline tube, traps air to add buoyancy. It has vertically stitched or ultrasonically welded seams to reduce drag.

c) Artificial Muscles

University of Texas is in the process of making artificial muscles from carbon nanomaterials. These artificial muscles can contract about 30000% per second while an ordinary muscle contracts about 20-40% per second.

d) Reactive padding

University of Delaware are developing a new kind of reactive padding that seeks to significantly reduce the impact stresses and harmful injuries like concussion. In the initial stages of research Kevlar was used because of its lightness and durability.

Besides these there have been many more developments like the developments of various softwares like SIMM, Quintic Biomechanics V26, etc.

V. Conclusion

The future of Biomechanics looks even brighter than it was a couple of decades back. The 18th World Congress on Biomechanics is to be held at Dublin in 2018. The University of Omaha in Nebraska has developed a $6 million stand-alone facility specifically for Biomechanical research which is also the first of its kind research facility in the world. These examples and many more bear witness to the fact that this subject will only flourish in the future. This in turn will cause tremendous advancements in the field of sports biomechanics, development of sports equipment and injury management and might someday lead to the development of the perfect athlete.

VI. Acknowledgment

We, Koustav Kanjilal and Sudipto Shekhor Mondol, are indebted to a number of people, who helped and motivated us to bring out this project. I would like to thank all the faculty members of the department of mechanical engineering of Heritage Institute of Technology specially Dr. Siddhartha Ray who constantly motivated and guided us.

NOMENCLATURE

C.G.	Centre of Gravity
C.M.	Centre of Mass
m	Mass
v	Velocity
g	Acceleration due to gravity
h	Height
KPa	Kilo pascal
KN	Kilo Newton
SIMM	Software for Interactive Musculoskeletal Modeling

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