IDENTIFYING THE RUNNING MECHANICS DUE TO THE SYSTEMATIC VARIATION IN RUNNING STYLE

ABSTRACT

THESIS
SUBMITTED FOR THE AWARD OF THE DEGREE OF
Doctor of Philosophy
IN
PHYSICAL EDUCATION

BY
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ALIGARH MUSLIM UNIVERSITY
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2006
ABSTRACT

Track and field originated in Greece with the ancient Olympic games whose earliest origin dates back to the 13th century B.C. Since then it is increasingly becoming an essential part of social life and consequently stimulated greater interest in the technique of body mechanics.

Track and field is the basic sport for all and so it has assumed greater importance in recent years. The physical educationists, coaches and sports scientists of today are becoming more aware of the scientific informations and potential proficiency in athletics. Research in Nutrition, Psychology, Biochemistry and Physics have contributed much to the improvement of performance level of athletes in various competitive arenas today. In recent years, the sports scientists have taken interest in the analysis of human movement in various sports activities. The value of this kind of explanation to the problem varies from event to event. The mechanics of running are extraordinarily complex, yet most good sprinters and long distance runners develop an efficient style without giving the matter much thought, whereas sprinters, hurdlers
and field event athletes need a more technical, analytical approach to the mastery over skill.

The successful physical educator must be proficient in the qualitative analysis of motion. The researcher on the other hand attempts to make accurate quantitative evaluation of human performance. A systematic and theoretically sound approach similar to that used in classical mechanics can be adopted for the investigation of biomechanical problems. It should be recognized, however, that human body is foremost a complicated system than most encountered in the field of biomechanics. Therefore, although the major emphasis is placed upon the mechanical principles, appropriate modification must be incorporated to address the nature of man.

Biomechanics of human movement, broadly defined, as the science involving the internal and external forces acting on a human body and description of motion, including the pattern and speed of movement of body segments, is one of the required courses for students majoring in kinesiology, exercise science and physical education.
The role of biomechanics in attaining high performances cannot be overlooked, since it is the only scientific method which helps to identify the faults in performing technique very precisely.

The biomechanical analysis of different events can help to understand the critical points of the technical performance, thus helping coaches and athletes in their preparation. One area of major concentration over the past few years is that of biomechanical analysis. Human motion analysis is frequently used today for both clinical and research application.

Coaches and athletes have traditionally used video cameras and videocassette recorders (VCR) to scrutinize and improve their performances. Today, computers and high-tech devices are available to retrieve, analyze, replay, edit and print the desired performance into a two-dimensional (2D) and three-dimensional (3D) stick figure image that is analyzed from different angles without the need of VCR. An endless number of athletic movements can be digitally assessed in the indoor, outdoor or underwater environment. This PC-based program and display gives the coaching staff another way to examine objectively stroke patterns, center of mass, reaction/response time, change of direction, stance, symmetry of gait, optimal angles and velocity of movement from module systems.
consisting of multiple cameras. Beside enhancing sports performance, these computer-generated figures can be used to analyze how athletes can run faster with minimum effort.

To justify a movement as an economic one, it is very essential to analyse the movement first. Some time, it is very difficult for a naked eye to analyse all the movements of various body segments and joints at the same time, so various instruments like still camera, video camera etc. are used to analyse various movements.

There is little information on how one feature of an individual's running mechanics affects the running style. There have been relatively few attempts to monitor changes in motor performance during continuous activity in motor task as basic as running.

The purpose of this study is to identify the running mechanics due to the systematic variation in running style, so that this study can be useful to the coaches, administrators and athletes. They can improve their performance and also reduce the total time of athletes participating in competition and also during training programs without getting fatigued. Coaches routinely make changes in running style in order to improve running performance but an
induced change could also cause other changes in mechanics that would have adverse side effects. That would be of interest to understand how a particular change in running mechanics will influence other aspects of running style. Information such as this will help us understand why an individual runs in a particular pattern and perhaps it can be used to predict the consequences of changing features of an athlete’s running style.

In order to achieve this purpose, fifty All India level male athletes (long distance runners and short distance runners) were selected as subjects of the All India Athletic Meet held at JRD Tata Complex Jamshedpur, Feb 28 to March 1, 2004.

The subject’s anthropometric measurements like body weight, height, leg length, thigh length, lower leg length and shoulder width were recorded. These measurements were recorded by using the standard anthropometric kit, available in the department of Physical Health and Sports Education, AMU, Aligarh. The different variations of running as short distance (sprints) and long distance were considered. The ground contact by heel of the running foot and take off was selected as the beginning and ending of the running sequence respectively. The sequence of the running motion was divided into two phases (a) take off phase and (b) landing phase.
To evaluate the running mechanics of long distance runners and short distance runners, the subject’s running motion were recorded using two Synchronised Panasonic F15 S-VHS video cameras in a field setting. The videotapes were used TDK E180 Extra Grade videotapes, Panasonic zooming lenses and two video cameras rigid tripod stands etc. The sampling rates of the video cameras were 50 fields per second (25 frames per second). The shutter of the cameras was fixed with a high speed (1/1000th of a second) in order to eliminate the blurring effect while video recording.

The first camera was positioned at 18-metres on the field from the center of first lane and 45-metres from the starting line of the 100metre sprint. This camera was perpendicular to the sagittal plane and parallel to the mediolateral axis. Camera optical axes were perpendicular to the sagittal plane for measuring the stride length, shoulder, knee, hip angle and ankle angle. Once the camera was thus positioned, the zoom on the camera was adjusted in order to see that the four selected short distance runner’s stride and long distance runners stride respectively of the whole running motion were recorded into video tape.
The second camera was positioned 2 meter behind from starting line of the 100metre sprint. The camera optical axes were perpendicular on the frontal plane for measuring the rear foot motion.

The running mechanics of both short distance and long distance were recorded from same video cameras point (i.e. no change in cameras position). For long distance, video of the running motion was recorded during final lap of 5000m race (at 4950m).

Throughout the day at the All India Athletic Meet, the video recording of the running motions was conducted. The video-cassette was converted in to compact disc (CD) through video capture card, which was used to convert movies of VHS & DV cam. to CD & DVD into computer system, loaded into personal computer(PC), then the full-scale CD data were processed for editing so as to acquire only the required motion. It was played with the help of computer Chinese software (SthSDVD) to make a number of slides. Slides shows on computer monitor screen with the help of mosaic roll up. Final positions of each selected subject’s slides were obtained on the screen by trail and retrail method. Editing and saving all selected slides of the final position of each runner (the selected subject) from the mosaic roll up were transferred (copy
paste) and pasted into a new frame of Photo Studio software with appropriate dimensions.

The following softwares were used to analyse running mechanics from the recorded data: (a) Chinas Software (SthSDVD), (b) Photo Studio, (c) Corel-5, (d) Corel-9, (e) Link MPEG Player and (f) SPSS Software and office Excel was used for the statistical analysis.

**Statistical Analysis**

To determine the running mechanics on both long distance running and short distance running, Analysis of Variance (ANOVA) was used. Critical Difference (C.D) was applied to find out whether the differences of the paired means of running mechanics were significant in both long distance running and short distance running. For comparing means of running mechanics for both events (i.e. long distance running and short distance running), we applied student's t-test. The level of confidence was set at .05.
Conclusion

From the result of the study, the following conclusions have been drawn.

That the Knee Extension, Knee angle at Landing, Knee Flexion, Hip Extension, Hip Flexion, Ankle angle at Take Off, Ankle angle at Landing, Shoulder Rotation, Shoulder Extension, Shoulder Flexion, Heel angle at Take Off and Heel angle Landing play significant role in long distance running.

That the running mechanics Leg angle at Landing, Leg angle at Take Off and Rear Foot angle do not have any significant role in long distance running.

That the Knee Extension, Knee Flexion, Knee angle at Landing, Hip Extension, Hip Flexion, Ankle angle at Take Off, Ankle angle at Landing, Shoulder Rotation, Shoulder Extension, Heel angle at Take Off and Heel angle Landing, Leg angle at Landing and Leg angle at Take Off are significant and thus play significant role in short distance running.

That the running mechanics Shoulder Flexion and Rear Foot angle are insignificant, do not play any significant role in short distance running.
That the joint effect of Stride Length and Stride Width play a significant role in short distance running mechanics.

That the joint effect of Stride Length and Stride Width does not play any significant role in long distance running mechanics.

That the comparison of means of Leg angle at Landing, Hip Extension, Ankle angle at Landing, Shoulder Extension and Shoulder Flexion were significant in long distance running and short distance running.

That the comparison of means of Knee Extension, Knee Flexion, Knee angle at Landing, Hip Flexion, Ankle angle at Take Off, Shoulder Rotation, Heel angle at Take Off, Heel angle Landing, Rear foot angle and Leg angle at Take Off were insignificant in long distance running and short distance running.
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ALIGARH MUSLIM UNIVERSITY
ALIGARH (INDIA)
2006
DEDICATED
TO
MY
PARENTS
This is to certify that Mr. Naushad Waheed Ansari has completed his research assignment entitled "Identifying the running mechanics due to the systematic variation in running style" under my supervision and guidance. The work is being submitted for the award of the degree of Doctor of Philosophy of the Aligarh Muslim University, Aligarh in Physical Education.

I further certify that the work is original and has not been submitted in any University or Institution for the award of any other Degree or Diploma.

(Dr. Ikram Hussain)
Supervisor
CERTIFICATE

This is to certify that Mr. Naushad Waheed Ansari has carried out this investigation on the "Identifying the running mechanics due to the systematic variation in running style" under my Co-Supervision for the award of the degree of doctor of philosophy of the Aligarh Muslim University, Aligarh. The work is an original contribution to the existing knowledge of the subject.

He is allowed to submit the work for the Ph.D. degree of the Aligarh Muslim university, Aligarh.

Mr. Arfan R. Faridi
Co-Supervisor
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(Naushad Waheed Ansari)
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CHAPTER-1

INTRODUCTION
CHAPTER I

INTRODUCTION

Track and field originated in Greece with the ancient Olympic games whose earliest origin dates back to the 13th century B.C. This sport has assumed growing importance in social life and increased standards of track and field performance, which have stimulated greater interest in the technique of body mechanics.

The elevation of track and field is a recognition that it is the sport of supreme endeavor, the sport where man pits himself not only against other men, but also against the limitations which nature has imposed upon him; the sport where frontiers of human endurance are attained and surpassed. (Rossum, 1987)

Track and field is the basic sport for all and so it has assumed greater importance in recent years. The physical educationists, coaches and sports scientists of today are becoming more aware of the scientific informations related to the athletes and potential proficiency in sports. Research in Nutrition, Psychology, Biochemistry and Physics have contributed much to the improvement of performance level of athletes in various competitive
sports today. In recent years, the sports scientists have taken interest in the analysis of human movement in various sports activities making use of the laws of physics. "Man as a moving, living body obeys the scientific law of the universe, with adequate knowledge of scientific truths and application of them to his efforts, man can move more efficiently". (Baverly and Methew, 1972)

An important feature in the development of track and field coaching has been to spread the knowledge of the mechanical principles essential to its skills. For human motion, with its boundless variability, obeys the law of motion and athletic skill at the highest level and always applies these same principles to its advantage. The scientifically minded youth of today is ready to accept the truths of mechanics and certainly the subject as applied to sports is of considerable interest to young people. In the teaching of the skill on the sports ground, in the gymnasium or in the swimming pool, mechanical explanation should be used with discretion, for athletes differ widely in intelligence, education and interest; while some will be intellectually stimulated and athletically improved by it, others will be confused. (Dyson, 1978)
Athletes learn their skills through their kinesthetic sensations, translating what they see or what they are told in terms of what it feels like to do, more descriptive (if mechanically inaccurate) language is often preferable to the jargon of mechanics. Herein lies the art, as opposed to the science, of coaching athletes.

The value of this kind of explanation to the problem varies from event to event. The mechanics of running are extraordinarily complex, yet most good sprinters and middle distance runners develop an efficient style without giving the matter much thought. On the other hand, sprinters, hurdlers and field event athletes need a more technical, analytical approach to the mastery over skill.

There are mechanical principles that govern all movements and determine what the body can and cannot do. These principles are the same, regardless of the type of activity. The human mechanism is endorsed with certain reflexes upon which effective pattern of movement can be built. This human mechanism is based upon those on which the mechanical principles are applied.

All movements of material bodies, both of man and animal are subject, without execution, to the law of mechanics as every movement involves mechanical movement and the locomotion of
parts of mass in space and time. It is the task of science to recognize that it is necessary to make this qualification, because movement is not only locomotion, but also a change in quality in the field above the purely mechanical. (Gerland, 1994)

The primary objective of a course of study in physical education is to understand the nature and function of human movement in sports, dance, physical recreation and adapted movement activities. The competent professional should be well versed in the body of knowledge or subject matter of this specialized field, which demands an understanding of numerous subdisciplines. (Kreighbaum, 1985)

The successful physical educator must be proficient in the qualitative analysis of motion, the biomechanics and the researcher’s attempt is to make accurate quantitative evaluation of human performance. A systematic and theoretically sound approach similar to that used in classical mechanics can be adopted for the investigation of biomechanical problems. It should be recognized, however, that human body is foremost a complicated system than most encountered in the field of biomechanics. Therefore, although the major emphasis is placed upon the mechanical principles,
appropriate modification must be incorporated to account for the nature of man. (Doris, 1976)

Hay (1993) defined the term biomechanics as follows:

"Biomechanics is the science concerned with the internal and external forces acting on human body and the effects produced by these forces".

Biomechanics of human movement, broadly defined, as the science involving the internal and external forces acting on a human body and description of motion, including the pattern and speed of movement of body segments, is one of the required courses for students majoring in kinesiology, exercise science and physical education. In this course, students are required to learn basic mechanical concepts, methods and analysis techniques for human motion from course lectures and laboratory activities. (Chow and Carlton, 1998)

Biomechanics is an applied form of mechanics and consequently the methods used to investigate it must be derived from those of mechanics. However, biomechanics have not
developed in the wake of mechanist but as a bordering science in other scientific discipline such as anatomy, physiology and technique of sports.

Biomechanics aims to explain the mechanics of life and living from molecules to organism, everything must obey the law of mechanics. Biomechanics helps us to appreciate life. It sensitizes us to observe nature. It is a tool for design and invention of devices to improve the quality of life. It is a useful, valuable and unavoidable tool. It is a necessary part of biology and engineering. (Fung, 1998)

The role sports biomechanics plays, is becoming more widely understood in the sports community, and the demand for the service increasing. Researchers in sports biomechanics will have to consider carefully how much time they can devote to the provision of scientific services without impairing their performance as researchers. To avoid the problems inherent in this situation, it may be necessary to develop programme of the study for the training of technicians in sports biomechanics; a technician who can provide the kind of services sought by sporting kind. (Gerland, 1984)

The role of biomechanics in attaining high performances cannot be overlooked, since it is the only scientific method which
helps to identify the faults in performing technique very precisely. There are basically two methods by which motor skill can be analyzed. They are qualitative and quantitative method. High-speed movie film for exactness has been used extensively to examine in great details the movements of the body, which occur too fast for the human eye to detect. In many of the elite sport training and research institution around the world, the analysis test have done much to improve understanding of movement and the performance of the elite athletes. The analysis tasks faced by the coach are predominantly qualitative in nature. (Moria, 1990)

BIOMECHANICAL ANALYSIS

The biomechanical analysis of different events can help to understand the critical points of the technical performance, thus helping coaches and athletes in their preparation. One area of major concentration over the past few years is that of biomechanical analysis. Human motion analysis is frequently used today for both clinical and research application. The art and science of motion analysis has expanded beyond basic descriptions of ambulatory
patterns to include front line clinical roles in Rehabilitation, Surgery, Prosthetics, Orthotics, Ergonomics and Athletics.

Human motion has been observed since ancient times. In ancient Rome, Galen created a classification of movement in which exercises were described according to the part of the body used, activity, duration and frequency. Interest in the role of movement and exercise in health continued over the centuries, but a new era began in 1836 with work by the W. Weber and E. Weber brothers that introduced the scientific investigation of the mechanics of human gait. They measured and reported on stance and swing phase, trunk movements, step duration and step length. In 1881, V. Vierordt contributed to the development of kinematics by studying foot print patterns with colored fluid projections. This allowed analysis of body part movement in space during gait.

In 1880, E. Marey introduced the use of photographic techniques using light stripes attached to body parts. At about the same time, E. Muybridge began to use cameras triggered sequentially to record motion during gait. In 1895, W. Braune and O. Fischer added mathematical techniques to allow calculation of velocities, acceleration and force during gait. Electrogoniometers is
used to measure two-dimensional (2D) or three-dimensional (3D) joint motion.

In the past decade, automated tracking systems for motion analysis have demonstrated increasing clinical acceptance. Passive reflective and active illuminated markers are automatically tracked with the multi-camera system. Body segment motion combined with force data gathered from a force plate of force dynomometer has been used to calculate the internal joint moments causing motion.

Coaches and athletes have traditionally used video cameras and videocassette recorders (VCR) to scrutinize and improve their performances. Today, computers and high-tech devices are available to retrieve, analyze, replay, edit and print the desired performance into a three-dimensional (3D) stick figure image that is analyzed from different angles without the need for a VCR. An endless number of athletic movements can be digitally assessed in the indoor, outdoor, or underwater environment. This PC-based program and display gives the coaching staff another way to examine objectively stroke patterns, center of mass, reaction/response time, change of direction, stance, symmetry of gait and optimal angles and velocity of movement from module systems consisting of
multiple cameras, synchronized force platforms and electromyography (EMG) analysis. Beside enhancing sports performance, these computer-generated figures can be used to analyze how athletes can run faster with minimum effort.

To justify a movement as an economic one, it is very essential to analyse the movement first. Some time, it is very difficult for a human eye to analyse all the movements of various body segments and joints at the same time, so various instruments like still camera, video camera etc. are used to analyse various movements.

The best method to analyse or evaluate various movements is called cinematography. This is a quantitative method which is very accurate but at the same time costly and time consuming. The role of cinematography in biomechanical research involves form of recording motion to a sophisticated means of computer analysis of better efficiency. Over the years, new techniques in filming and timing have been perfected to aid the research in achieving accurate time measurements of both simple and complex locomoting patterns. (Newton and Arnoncher, 1996)

The key is the ability to merge both the experience of the coach with the objective of the analyzed sport movement to create a
plan for athletic enhancement. There are numerous sport skills that have been successfully analysed. These include the soccer kick, softball hitting and baseball pitching, the football pass, the golf swing etc. With the recent advent of smaller digital cameras, a more accurate evaluation through biomechanical analysis has allowed injury prevention to come to the forefront. Not only will the athlete have the advantage of immediate analysis through computerized re-enactment, but he will also have printed hard copies that will enhance the diagnostic and prescriptive value of filming for more efficient training. (Meyers, 1998)

Human motion is composed of the angular relevant joint. The angular momentum of each human body segment is important for understanding the kinematic characteristics of the angular motion, specially the angular motion of the body segments during walking reflects the summed action of the arms and the legs about the center of the mass of the whole body, and the proper head and trunk orientation needed for keeping movement forward while maintaining equilibrium. The magnitude of the angular momentum also reflects the requirements of the angular impulses for walking. (Wang, 1998)
There is little information on how one feature of an individual’s running mechanics affects the running style. There have been relatively few attempts to monitor changes in motor performance during continuous activity in motor task as basic as running. In the studies that have been conducted, researchers generally have to allow the subject to freely choose running velocity. Results have shown that as a runner fatigues, velocity decreases stride length shorten and range of motion exhibited at joints of the lower extremity is reduced. (Adrian and Kreighbaum, 1973); Although many descriptive studies have been done on the biomechanics of running, there is relatively little information documenting the changes that occur to various aspects of running mechanics when one feature of an individual’s running style is altered. The absence of speed control in the above mentioned studies present a confounding factor in that all of the changes in running pattern cited have also been seen with decreasing running speeds in the absence of fatigue. Consequently by not forcing the runners to maintain a constant running velocity, these studies did not attempt to differentiate between behavioral changes occurring with the development of fatigue and those associated with a reduced
running speed. The fact that the few studies that have controlled running speed. (Cavanagh et al., 1985) have shown a number of kinematics changes over the course of hard, prolonged run (e.g.; increased stride length, altered rear foot mechanics and modified joint angles at key point in the running cycle) suggests that fatigue causes a performance to make a number of compensatory adaptation to maintain faster runners who may be more successful because they have developed a subconscious ability to adopt a running pattern when compared with a group of slower runners exercising at the same relative intensity. Very few studies (Buckalew et al., 1985) have attempted to compare fast and slower distance runners in terms of the changes that occurs in running pattern with the onset of fatigue. The studies that did consider this equation did not control running speed, introducing the confounding factors discussed previously. In other words, it appears there is no previous research comparing the type and relative timing of compensation in running style made by fast and slower runners forced to maintain a speed.

The proposed aim of this research is to study the changes in running mechanics due to the systematic variation in running style,
so that this study can be useful to the coaches, administration and for the athletes. They can improve their performance and also reduce the total time of athletes participating in competition and also during training programs without getting fatigued. Long distance runners are able to maintain their speed through treadmill run due to which they suffer volitional exhausted. Runners differ in 10 km performance time display differences in the relative timing of any compensation in running pattern as they approach volitional exhaustion. These compensation include increased stride length, range of motion at the joint of the lower extremity, head-neck-trunk segment (HNT) angle at time of maximum extension and average internal mechanical power output. Coaches routinely make changes in running style in order to improve running performance but an induced change could also cause other changes in mechanics that would have adverse side effects. That would be of interest to understand how a particular change in running mechanics will influence other aspects of running style. Information such as this will help us understand why an individual runs in a particular pattern and perhaps it can be used to predict the consequences of changing features of an athlete's running style.
There is no conclusive evidence available at the present time. It would appear that the knowledge of biomechanical principles involved might well enhance the performance of a skilled athlete. The mechanics of athlete is a comparatively undeveloped field in which, because of a multiplicity of unknown or only partially known factors, precise calculation is often impossible. Moreover, principles applicable to rigid bodies are being applied to bodies that are far from rigid.

Running is a fundamental natural human movement, which is essential to successful performance in many sports and games. It is the primary activity in a sport. Considerable interest in distance running can be found throughout the world as indicated by the number of runners participating in national and international competitions. The increased enthusiasm for running has been accompanied by expanded interest on the part of the scientists concerned with various aspects of the sport, resulting in better training methods.

Running mechanics vary from person to person and they also vary in the same person running at different speeds. Generally, the running mechanics changes with speed in the three ways (a) Amount
and type of foot contact with the surface, (b) Amount of joint flexion and extension of internal amplitude and (c) Amount of body inclination or angle of inclination. Running speed is determined by two factors, the length of stride and frequency of stride. For increasing the running speed, one or both of these factors must be increased. Length of stride is dependent primarily upon leg length and the power of the stride. Leg speed (frequency) is mostly dependent upon speed and strength of muscle contraction as well as neuro-muscular coordinator (skill) in running. (Shaw, 1998)

Running is a cyclic behavior in which the legs swing fore and aft and provide support for the body in alternation. Because the legs perform different functions during the phases of the locomotion cycle, the muscles are used for different control actions at different times in the cycle. When the foot of the simulated runner is on the ground, the ankle, knee and hip provide support and balance. During the flight phase, a leg is swung forward in preparation for the next touchdown. These distinct phases and corresponding changes in control actions make a state machine a natural tool for selecting the control actions that should be activated at a particular time. The
state machine and transition events are used for the simulation of Running. (Wooten, 1995)

Hay (1993) described that in running events the primary objective of an athlete is to cover a set distance in the least possible time. Running speed depends on stride length and stride rate/frequency.

The running speed increases when stride length remains constant and stride rate increases. Similarly, if stride rate remains constant then stride length increases resulting increase in speed (Enoka, 1994). The stride length is again related with the range of motion about a joint (quantity) and the pattern of displacement (quality). As the runner goes from a walk to a run the angular displacement around about the knee joint increases. Likewise, the range of motion around both shoulder and elbow joints also increases as a person goes from walk to a sprint (Vaughan, 1984).

All running movements consist of a series of bounding actions in which both feet are off the ground at the same time at certain stages of the movement. Nevertheless, there are many distinctive styles of running and in competitive athletics, efforts have been made to cultivate specialized actions which lead to higher standards
of efficiency for various distances. In sprinting, middle distance running and in cross-country running vigorous thrusting action of the feet and powerful arm action play an important part in the movements. While in longer distances, particularly in marathon running, those actions are reduced to a minimum. This distinction is due to the fact that in the shorter distances, speed is essential and this requires the more powerful thrusting efforts of the feet and arms. Strong foot thrusts and vigorous arm actions are common to cross-country running and sprinting. The shorter leg action with bent knees which is essential in cross-country running is detrimental to good sprint. The key positions, most effective for detailed analysis of running movements are the same stages as are employed for walking movements. (Anderson, 2003)

Running not only is an athletic event but is also a very important part of other sports. Short distance and middle distance races are similar except that the actions are greatly accentuated in running. The basic sprinting action is of considerable importance not only in track and field but in many other sports as well. Although success in sprinting obviously depends on athlete’s ability to combine the actions of the legs, arms, trunk and so on into
a smoothly coordinated whole, for the purpose of analysis that follows, the position and movements of each body part are considered separately. The action of the legs in running is cyclic. Each foot in turn lands on the ground, passes beneath and behind the body and then leaves the ground to move forward again ready for the next landing. This cycle can be conveniently subdivided into the following.

**Supporting phase:** Begins when the foot lands and ends when the athlete’s center of gravity passes forward.

**Driving phase:** Begins as the supporting phase ends and ends as the foot leaves the ground.

**Recovery phase:** During which the foot is off the ground and is being brought forward preparatory to the next landing.

As the length of the race increases beyond 400m normally regarded as the longest sprint event. The athlete’s stride length and stride frequency are both substantially reduced; so too are the range and vigor of most of athlete’s actions. The forcefulness of the extension of the hip, knee and ankle joints during the driving phase
is reduced. The extent to which the foot rises toward the buttocks and the height of the knee raised in front during the recovery phase are both reduced. The arms swing through a lesser range than they would if the athlete were sprinting, and part of their function of balancing the leg action may be assumed by the shoulders rotating in opposition to the hip. Finally, with reduction in both air resistance and horizontal ground reaction, the forward inclination of the trunk when running at a constant speed is generally less than it would be if the athlete were sprinting. (Hay, 1993)

Proper running form (i.e. biomechanics) in important to minimize wasted energy expenditure. With good running biomechanics, athletes will generate the most speed with the least amount of physical effort. Sport scientists and coaches, along with most of the athletic federations in the world have recognized the importance for scientific support in the improvement of athlete's performance. The athletes of today, whether recreational or elite, run and swim faster, throw farther and jump higher than their competitors from the past. A greater understanding of biomechanics of sport movement is important for better training techniques,
advances in psychological support and improvements in coaching education. (Bill and Corcoran, 1999)

Several researchers have dedicated their time to study the complex running motion of track and events by examining the relevant biomechanical variables. These include kinematics studies concerning the joint movements at the lower extremities for changing direction for walking (Chow, Rosengren and Carlton, 1997), the biomechanics of lower extremity action in distance running (Cavanagh PR, 1987), three-dimensional measurement of rear foot motion during running (Areblad Nigg, 1990), moment and power of lower limb joints in running (Belli, Kyrolainen and Komi, 2002), leg stiffness in running humans: effects of body size (Carruthers and Farley, 1998), the effects of dorsiflexor fatigue on kinetic measures during running (Christina, White and McCrory, 1998).

Only a few studies have been conducted to examine changes in running motion due to some type of experimental manipulation or running mechanics. Although Bates et al. (1978) reported no change in rearfoot variables at 3.3 to 3.5 m/s range of running speeds, Nigg
et al. (1985) showed an increased initial angular velocity and total pronation with increases in speed between 3 and 6 m/s.

All the above mentioned researches that were based on human motion have been done in restricted conditions to the selected subjects/participants in biomechanical laboratory with some given instructions. But athletes can not run with restricted conditional approach during a competition. Therefore in this study the researcher has calculated kinematics variables of athletes during sprint and long distance running in natural condition (during All India Athletic Meet) where all athletes are free from any restrictions of their running styles, except the rules of All India Athletic Association Committee.

The purpose of this study is to examine how several kinematic measure changes when stride length, stride width and shoulder motion are manipulated during running. These were chosen for manipulation because they often show marked differences between individual and are relatively easy to control in an experimental understanding of how these variable change when one of the others is manipulated may further or understanding of whether the three variables are tightly linked within same overall movement pattern or
are essentially independent of each other. Rearfoot measures are also likely to be linked with these features of running mechanics since motion following foot contact is associated with the position of the lower leg during support.

**STATEMENT OF THE PROBLEM**

The purpose of this study is to identify the running mechanics due to the systematic variation in running style.

**DELIMITATION**

1. This study was confined to fifty males of All India level athletes of different Universities.
2. The data for this study were collected in standard synthetic track only.
3. This study is delimited to the following selected running mechanics:
   - Rearfoot motion
   - Heel Angle
   - Leg Angle
   - Rear foot Angle
- Knee Angle
- Hip Angle
- Ankle Angle
- Shoulder Angle
- Shoulder Rotation
- Stride Length
- Stride width

**LIMITATION**

Following were the limitations of the study:

1. The changes in climatic conditions such as air, temperature, atmospheric pressure and relative humidity during the testing period could not be controlled and their possible influence on the results of this study was recognized as a limitation.

2. Proper care has been taken to use the available standard equipments. The instruments errors may also be a limitation for this study but consistent calibration has been attempted.

3. The accuracy of the sophisticated softwares ability to digitise the kinematic data.
4. The competition pressure on athletes and injuries of athletes during All India Athletic Competition could not be controlled.

5. Certain factors like daily routine, life style and food habits, which would have an effect on the performance of the athletes, could not be controlled.

**HYPOTHESES**

The following null hypotheses were tested at the .05 level of significance.

1. There is no significant effect of Heel angle at landing on long distance and short distance running.

2. There is no significant effect of Heel angle at take off on long distance and short distance running.

3. There is no significant effect of Leg angle at landing on long distance and short distance running.

4. There is no significant effect of Leg angle at take off on long distance and short distance running.

5. There is no significant effect of Rear foot angle on long distance and short distance running.
6. There is no significant effect of Knee extension on long distance and short distance running.

7. There is no significant effect of Knee flexion on long distance and short distance running.

8. There is no significant effect of Knee angle at landing on long distance and short distance running.

9. There is no significant effect of Hip extension on long distance and short distance running.

10. There is no significant effect of Hip flexion on long distance and short distance running.

11. There is no significant effect of Ankle angle at landing on long distance and short distance running.

12. There is no significant effect of Ankle angle at take off on long distance and short distance running.

13. There is no significant effect of Shoulder extension on long distance and short distance running.

14. There is no significant effect of Shoulder flexion on long distance and short distance running.

15. There is no significant effect of Shoulder rotation on long distance and short distance running.
16. There is no significant joint effect of Stride length on long distance and short distance running.

17. There is no significant joint effect of Stride width on long distance and short distance running.

DEFINITION AND EXPLANATION OF TERM

Rearfoot Motion

The total movement of the back foot from the contact to push off phase. It include three angles (a) Heel angle, (b) Leg angle and (c) Rear foot angle.

(a) Heel Angle

Defined by markers at the top of the heel counter in the center of the heel and just above the midsole attachment point with a vertical plumb line used to align the markers.

(b) Leg Angle

Defined by a line between the center of the rear knee and the center of the Achilles tendon just above its attachment to the calcaneus.
(c) **Rear foot Angle**

Defined by the angle between the rearfoot bisection and the direction of the Achilles tendon.

**Knee Angle**

Defined as by anatomical lines of a femur and tibia.

**Hip Angle**

Defined as by anatomical lines of a femur and drawing line between shoulder joint to hip joint.

**Ankle Angle**

Defined as by anatomical lines between the tibia and foot at ankle joint.

**Shoulder Angle**

Defined as the included angle between anatomical lines drawn from the greater trochanter to the estimated center of the shoulder joint, and a line from this point along the central axis of the arm to the elbow joint.
Shoulder Rotation

Shoulder rotation is the total angle at shoulder joint from arm position of landing phase to the arm position of just before the take off.

Stride Length

Defined as the horizontal distance between successive foot strikers.

Stride Width

Defined as the average perpendicular distance from a midline in the direction of running to the center of the ankle joint.

ABBREVIATIONS AND SYMBOLS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAL</td>
<td>Heel angle at landing</td>
</tr>
<tr>
<td>HATO</td>
<td>Heel angle at take off</td>
</tr>
<tr>
<td>LAL</td>
<td>Leg angle at landing</td>
</tr>
<tr>
<td>LATO</td>
<td>Leg angle at take off</td>
</tr>
<tr>
<td>RFA</td>
<td>Rear foot angle</td>
</tr>
<tr>
<td>KE</td>
<td>Knee extension</td>
</tr>
<tr>
<td>KF</td>
<td>Knee flexion</td>
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<tr>
<td>KAL</td>
<td>Knee angle at landing</td>
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SIGNIFICANCE OF THE STUDY

1. This study will attempt to understand the effect of running mechanics.

2. This study will provide a mechanical area of skill movement and technique of sportspersons.

3. This study will generalize the mechanical aspects of sprinters and distance runners.

4. This study will provide the base to those athletes who are participating in running events.
5. This study will analyze the perfect movements, segmental positions and angle of the lower limbs and to understand the intricacies involved in coming up with best performance in running. An athlete who has slow running time shall be benefited to increase his running timing.

6. This study will provide the mechanical advantages of segmental movements in running.

7. This study will equip athletes, trainers, physical educators and coaches to get the maximum advantages of mechanical aspect in running.

8. This study will provide appropriate information to athletes, trainers, physical educators and coaches etc. about the best take of mechanical systematic variation in running.

9. This study may throw new light in the field of running sports and give direction to further researches.

10. The finding of present study may be of help to athlete to know the technique of correct running

11. The finding of present study may be of help the coaches and trainers to correct techniques of running of their athletes.
CHAPTER-II
REVIEW OF
RELATED
LITERATURE
Sicco (1999) has studied biomechanical characteristics of running in elderly men. Thirteen young and sixteen elderly, healthy and well trained, male runners participated in the study. An infrared video based 4-camera Precision Motion Analysis System (100 Hz) was used to obtain three dimensional joint angular displacements of the right lower extremity and the vertical impact speed at heel strike. Simultaneously, the vertical and fore-aft ground reaction force was determined with the use of a Kistler force plate. Running speed, stride length and step frequency were also determined. Subjects were tested at two different running speeds: a preferred and a controlled running speed of 3.3 m/s. Subjects, wearing a standard running shoe, were instructed to run along a 17m long runway. t-tests compared total group means on statistical significance (p<0.02) with Bonferroni adjustment. And in the result it was found that elderly subjects showed a significantly lower running speed (3.34 vs. 3.77 m/s), shorter stride length (2.41 vs.
2.91 m) and higher step frequency (1.30 vs. 1.38 Hz) than the young subjects. At the controlled running speed, the elderly subjects still showed a significantly smaller stride length (2.43 vs. 2.61) and higher step frequency (1.38 vs. 1.28 Hz).

Kersting and Neumann (1999) have studied the effect of controlled variations in running style on rear foot movement and ground reaction forces. Ten recreational runners participated in this study, all of them were rearfoot strikers, injury free and experienced in treadmill running. A standard running shoe (Asics Gel 121) was used. Subjects had to run under five different running conditions: NN-preferred style, normal step width and length; NL-normal step width, step length 10 % greater than NN; NS-normal width, 10 % shorter steps; WN-5 cm wider than NN, normal step length; XON-crossing the midline with normal length. During the experiment subjects were required to run on a motor driven treadmill at a velocity of 3.5m/s. A strain gauge based force plate built into the treadmill was used to collect ground reaction force data, while an in shoe goniometer recorded rearfoot motion. The subjects were videotaped in a sagittal view with a 50 Hz video camera (Sony CCD, S-VHS video system) and ankle and knee kinematics were
analysed by commercially available software (PEAK Motus). Data collection systems were synchronised using a synchronisation unit (PEAK). Each subject performed one trial for each testing condition of which 10 consecutive steps were selected for further analysis. And in the result it was found that differences in pronatory movement do not simply and directly change the magnitude of impact shock at touch-down in heel toe running.

Hardin, Hamill, and Bogert (1999) have studied adaptation of running kinematics to surface and footwear. Twelve male subjects ran at a speed of 3.4m/s on a treadmill with adjustable surface compliance. Six different combinations of surface and shoe stiffness were created and sagittal plane kinematic data were collected at 200 Hz with reflective markers placed on the humeral head, greater trochanter, femoral condyle, lateral malleolus, calcaneus and fifth metatarsal. Marker paths were digitally filtered at 12 Hz and hip, knee and ankle joint angles were calculated. Mean values were calculated from ten randomly selected stance periods for joint angle at contact, maximum joint angle and peak joint velocity. A two-way repeated-measures ANOVA was used to test for surface and midsole differences ($p<0.05$). A two-segment model was used to establish
theoretical force-length relationships of the lower extremity. Experimental results were that as the surface stiffness increased, knee flexion at touchdown decreased ($p<0.05$), peak knee angle remained the same ($p>0.05$) and peak joint velocity of the hip, knee and ankle increased ($p<0.05$). Effects of midsole hardness were smaller. Increased knee flexion" has been proposed as a mechanism for adaptation to running on hard surfaces. And in the result it was found that for range of surface stiffness, runners had on impact with more extended knee on a harder surface while the peak flexion angle did not change.

Williams, McClay, and Laughton (1999) have studied a comparison of between day reliability of different types of lower extremity kinematic variables in runners. Twenty recreational runners volunteered for this study. The right leg was tested in all individuals and subjects had no lower extremity injuries at the time of testing. Four retroreflective markers were affixed to a velcro-backed polyform shell and attached to the thigh via a neoprene wrap. In addition, four markers were attached to the shank via neoprene wrap and three markers were attached to the heel counter of the shoe. Data were sampled at 120 Hz with a 6 camera VICON
(Oxford Metrics, UK) motion analysis system. Ground Reaction Forces were collected with a Bertec (BERTEC Corp, OH) forceplate being sampled at 480 Hz. Three-dimensional joint kinematics were calculated using MOVE3D software (NIH Biomechanics Laboratory). The variables of interest were three-dimensional angular peaks, excursions and velocities at the hip, knee and ankle. Additionally, ground reaction forces were evaluated. Intraclass correlation coefficients \( \{ICC(2,k)\} \) were used for the chosen variables to compare reliability between days. And in the result it was found that the lower ICCs for the peak rearfoot values suggest more attention should be paid to the placement of the foot markers. And ground reaction force ICCs. between day variability may be due to true mechanical differences. Velocities and excursions are more reliable from day to day and these values may be more useful than peaks in interpreting changes.

Kivi and Alexander (1998) have studied a kinematic comparison of the running A and B drills with sprinting, a group of four males university level sprinters were recruited. A seven meter filming grid was located on a straight 400m mondo track. Through this grid the subjects completed four repetitions of both the running
A and B drills, followed by two runs of 60 metres at maximum velocity. Two genlocked cameras filmed in the sagittal and frontal views at a speed of 60 Hz, with a shutter speed of 1/2000. A three dimensional model of the performance was reconstructed via DLT using the Peak Performance technologies motion analysis system. Twenty-three kinematic variables describing performance were analyzed. Three consecutive steps from one trial were analyzed, beginning with contact of the right foot. The peak values for each of the three steps were averaged to give one representative value used for analysis. A one-way analysis of variance was used to determine. And in the result it was found that shoulder range of motion was found to be significantly greater for sprinting, as was shoulder flexion angular velocity. No significant differences in shoulder extension angular velocity were seen among the three skills. Elbow range of motion and elbow extension angular velocity was similar for all three skills but elbow extension angular velocity was found to be significantly slower in the B drill. At the hip, maximum hip flexion was greater for the A and B drills than for sprinting. There were no differences in knee range of motion.
Seyfarth, Geyer, Gunther and Blickhan (2002) have studied a movement criterion for running. The adjustment of the leg during running was addressed using a spring-mass model with a fixed landing angle of attack. The objective was to obtain periodic movement patterns. Spring-like running was monitored by a one-dimensional stride-to-stride mapping of the apex height to identify mechanically stable fixed points. And in the result it was found that for certain angles of attack, the system becomes self-stabilized if the leg stiffness was properly adjusted and a minimum running speed was exceeded. At a given speed, running techniques fulfilling a stable movement pattern are characterized by an almost constant maximum leg force. With increasing speed, the leg adjustment becomes less critical. Mechanically self-stabilized running requires a spring-like leg operation, a minimum running speed and a proper adjustment of leg stiffness and angle of attack.

Milani, and Hennig (2000) have studied measurements of rearfoot motion during running. Excessive rearfoot motion is an important factor that has been linked to the development of injuries in running. Therefore, extensive research has been performed to investigate the movement of the foot and factors that influence the
degree of rearfoot motion. Several methodological procedures are available which indirectly determine the degree of rearfoot movement. High-speed film, high-speed video and opto-electric techniques have been used to analyse the posterior aspect of the heel counter of the shoe in the frontal plane to determine rearfoot motion at ground contact on a treadmill or during overground running. Recent studies used invasive pin methods to determine rearfoot motion during running under different conditions. Using a non-invasive approach, electrogoniometers have been used to quantify rearfoot motion. The purpose of this study was to explore the use of an in-shoe electrogoniometric method to investigate rearfoot motion during running in different running shoes. And in the result it was found that rearfoot motion variables were lower using the in-shoe goniometer compared to a heel counter method. This confirms previous bone pin studies where significant lower eversion and eversion velocity values were revealed by the bone pins compared to the shoe counter markers. Thus, external measurements seem to overestimate rearfoot motion significantly. On the other hand, the in-shoe measurements revealed slightly lower ground reaction force related values. As with any other shoe insert,
an in-shoe device elevates the foot slightly and thus may influence the mechanical behaviour of the shoe.

McClay and Williams (1998) have studied lower extremity mechanics in a converted forefoot strike pattern in runners. Eighteen recreational runners in which nine-forefoot striker and nine rearfoot striker volunteered for this study. The dominant leg was tested, and this foot exhibited excessive eversion (≥ 15 deg) as determined during an initial treadmill screening. Four retroreflective markers were affixed to two velcro-backed polyform shells and attached to the thigh and shank via a neoprene wrap. In addition, three markers were attached to the heel counter of the shoe. Additional markers were placed over various body landmarks to establish the anatomical coordinate systems in which the motion would be described. Subjects then ran along a 75 feet. Runway at a speed of 3.35 m/s (±10%). The rearfoot striker first ran with their normal strike pattern. They were comfortable running within the speed range striking the forceplate with a forefoot strike pattern. The forefoot striker ran with their normal strike pattern. Five trials were collected for each footstrike pattern. Data were sampled at 120 hz with a 5 camera VICON motion analysis system. Ground reaction
forces were collected with a Bertec; forceplate being sampled at 480 Hz. Three-dimensional joint kinematics and kinetics were calculated using MOVE3D software. Independent t-tests (adjusted p<0.025) were run for the chosen variables comparing the converted forefoot strike pattern and forefoot striker data. Rearfoot striker data are presented for comparison. And in the result it was found that discrete variables, kinematic and kinetic patterns of motion were visually similar between groups.

Schache, Blanch, Rath, Wrigley, Starr and Bennell (2001) have studied a comparison of overground and treadmill running for measuring the three-dimensional kinematics of the lumbo-pelvic-hip complex. Ten subjects ran overground and on a treadmill at a self-selected speed. The treadmill speed was matched to each subject's respective average overground speed. The time-distance and the three-dimensional angular kinematic data were captured using a passive marker based motion analysis system. A set of angular and temporal kinematic parameters were extracted from the data and subjected to statistical analyses. And in the result it was found that significant differences were found between overground and treadmill running for all time-distance parameters. Despite this, the
kinematics of the lumbar spine and pelvis were similar between the two running conditions, with only three parameters being significantly different. These were lumbar extension at initial contact, anterior pelvic tilt at initial contact and the first maximum anterior pelvic tilt. Hip flexion-extension parameters were also found to display only subtle differences. Of the seventeen hip parameters analyzed, only hip flexion at initial contact, maximum hip flexion at loading response, hip extension at toe off, maximum hip extension and hip flexion-extension range of motion were found to be significantly different.

Hennig, Möring and Milani (1998) have studied measurement of rearfoot motion during running with an in-shoe goniometer device. Seventeen male runners participated in this study. They ran in 5 different pairs of commercially available shoes at a speed of 3.3 m/s across a Kistler force platform. Two electro-goniometric methods of rearfoot motion measurements were employed. In each of the ten experimental conditions (5 shoes / 2 measuring methods) eight repetitive trials were performed by each subject. A conductive plastic potentiometer (Megatron MP10) was used to determine the achilles tendon angle to estimate rearfoot motions during running.
The movable part of the goniometer was fixed at the lower leg in parallel to the achilles tendon orientation. Rearfoot angle could be determined by the electro-goniometer. Several models of the heel cup device were built until the subjects reported that there was no more difference in their running style as compared to running without the device. Using a pretrigger mode, the ground reaction forces and rearfoot motion were collected at a rate of 1 KHz per channel with a resolution of 12 bit. The range of angular motion from rearfoot supination at contact to maximum pronation during stance was determined and the maximum pronation velocity was calculated. Ground reaction forces were also recorded. The averaged parameter means of the 8 repetitive trials were used for statistical evaluation. And in the result it was found that in-shoe measurements show less variability within a series of repetitive trials. Although in-shoe goniometric measurements provide more reliable information about subtalar joint pronation, they will influence the mechanical behavior of the shoe slightly. As with any other shoe insert, an in-shoe device elevates the foot and may cause different heel cushioning characteristics of the shoe.
Tillman, Chow, Gutierrez and Hass (2004) have studied biomechanical comparison of lower extremity exercise machines used for knee injury rehabilitation. Fourteen healthy individuals with no history of lower extremity injury participated. Subjects were video-taped with two cameras as they performed moderate exercise on a stepper and a cycle. Four seat positions were utilized resulting in minimum knee flexion angles of 0°, 15°, 30°, and 45°. Video (60Hz) and force data (900Hz) were synchronized and used to perform an inverse dynamics analysis of the lower extremity. To assess the myoelectric activity of selected lower extremity muscles, six pairs of surface electrodes were attached to the right side of the body over the following muscles: vastus lateralis, vastus medialis, rectus femoris, biceps femoris, medial gastrocnemius and soleus. And in the result it was found that the proximal/distal forces were significantly decreased for the stepper compared to the cycle while medial/lateral forces increased. Reduced muscle activity was detected for the vastus lateralis and vastus medialis while using the stepper. Increased muscle activity occurred with increasing knee angle for the vastus medialis. A similar trend was observed for the
vastus lateralis. No differences were detected between subject groups.

Jean, Janice and Cavanagh (1997) have studied ground reaction forces in overground and simulated zero-gravity running. Sixteen subjects participated in this study. Subjects ran at 2.68 ms\(^{-1}\). One Kistler force plate recorded normal force data as subjects ran across the laboratory floor and another, mounted within the treadmill belt, measured normal ground reaction forces of subjects in the Penn state zero gravity simulator. Two Penn state zero gravity simulator subject load configurations were assessed: a "shoulder only" design, in which four springs were attached to shoulder pads worn by the subject, and "waist and shoulder" design, and four to a waist harness. Load cells measured tension in the springs. Data were collected at 500 Hz. And in the result it was found that the maximum active force was significantly greater in the over ground condition, although the timing of this event was the same in all conditions. The magnitude of the passive peak was similar in all conditions, but this peak occurred earlier in the Penn state zero gravity simulator conditions, resulting in a significantly
greater loading rate. The impulse was greater in over ground condition.

Scholten, Stergiou, Houser and Blanke (1999) have studied footstrike patterns during running over obstacles of different heights. Ten heelstrike subjects ran at a self-selected pace under seven conditions: unperturbed running (no obstacle present) and over obstacles of six different heights. The obstacle was placed directly before a Kistler force platform so that the subject had to clear the obstacle with the right leg and land on the platform. Ground markers ensured that stride length was kept the same for all conditions. Ground reaction force data from ten trials per condition were sampled at 900Hz. Parameters analyzed were the heel impact peak from the vertical ground reaction force, times for braking and propulsion periods, minimum braking and maximum propulsion peaks from the anterior posterior ground reaction force and an index of the anterior posterior position of the center of pressure. One-way repeated measures ANOVAs were performed on the subject means for all parameters. A Tukey test was performed for comparative study. And in the result it was found that the group analysis results are significant differences for all parameters. Times for braking had
an inverse linear relationship with obstacle height and 12 out of 21 possible post-hoc comparisons were significant, while TP was less affected (1/21). However, opposite to times for braking, TP increased, which was expected since the speed, was kept constant between conditions. Maximum propulsion revealed a direct linear relationship with obstacle height (20/21), while maximum propulsion showed less changes (2/21).

Williams and Cavanagh (1987) have studied biomechanical studies of elite female distance runners. Their ground reaction forces showed peaks of 3.3 times body weight in the vertical component, 0.8 times body weight in the braking phase and 0.3 times body weight in the mediolateral direction. The asymmetry in their ground reaction forces was expressed mainly in the mediolateral component. Only minor differences were found between ground reaction forces in racing and training shoes. More abduction during foot placement was associated with greater rearfoot motion and with greater change in mediolateral component of velocity. Among the numerous moderate to high correlations of interest were those between vertical oscillation and peak vertical force, crossover and change in mediolateral velocity, and between
movements of the swing leg and mediolateral force values. There were very few correlations between running economy and biomechanical variables and stride length correlated poorly with stature. The elite runners were shorter in stature, lighter, had shorter legs and considerably less iliac crest fat than a typical non-athletic female population. The runners also had narrower pelvic than a student population of similar age. They were reasonably homogeneous and symmetrical in anthropometric dimensions. Compared with a group of elite male runners at the same running velocity, the elite women exhibited more hip flexion, greater angular velocities in hip flexion and extension, and longer stride lengths relative to leg length during running. Their vertical oscillation (expressed relative to leg length) was less than their male counterparts. And in the result it was found that on the issue of relative pelvic width, the women had greater relative bitrochanteric and bi-iliac crest widths but similar bispinous widths compared to the elite male runners.

McClay and Manal (1998) have studied the influence of foot abduction on differences between two-dimensional and three-dimensional rearfoot motion. Eighteen recreational runners
participated in this study. This study was to examine differences in
typical rearfoot variables obtained using a two-dimensional analysis
compared with a three-dimensional approach. In addition, the
influence of foot placement angle on these differences was assessed.
Two-dimensional and three-dimensional rearfoot kinematics were
collected from recreational runners. And in the result it was found
that two-dimensional values for eversion at toe-off and time to peak
eversion were found to be significantly different from the three-
dimensional motion. Differences between two-dimensional and
three-dimensional variables were magnified with increased toe-out.
Differences between eversion values were found to be minimal
when the foot was abducted between 7 and 10 degrees. The premise
that excessive pronators have more pronounced toe-out was not
supported by this study, and the caution should be exercised when
assessing two-dimensional rearfoot motion in subjects with
excessive toe-out.

have studied the effect of fatigue of the quadriceps and hamstrings
during running. Five male experienced runners completed two tests,
and these tests were completed between forty eight hours and one
week. Each test day consisted of a three minutes non-fatigued run followed by a "fatigue protocol", designed to fatigue a specific muscle group bilaterally (either quadriceps or hamstrings). Using an isokinetic dynamometer, five consecutive maximal repetitions of the test muscle were completed. All testing/exercise was done with the subject seated and angular speed set at 30 deg./s. The peak torque value out of the five repetitions was recorded. The criteria for the number of repetitions to be completed within a set was 80% of this value. The fatigue protocol consisted of eight sets of maximal contractions, with forty five seconds rest between sets. Within a set, repetitions were continued until the peak torque of three consecutive repetitions fell below eighty pounds. The test of the muscle was tested at random and only one muscle was fatigued per test day. And in the result it was found that no differences in maximum knee flexion between fatigue (Quadriceps Fatigued or Hamstring Fatigued) and non-fatigued run conditions during support or swing (p>0.05). There were no significant differences in stride rate between non-fatigued run and hamstring fatigued running across any blocks.
McClay and Manal (1998) have studied a comparison of three-dimensional lower extremity kinematics during running between excessive pronators and normals. Eighteen subjects (nine excessive pronators -- PRs; nine normals -- NLs) were studied during treadmill running at 3.35 m/s. Retroreflective markers were placed on the foot, shank and thigh segments and recorded with four 200 Hz video cameras. Three-dimensional kinematics were computed. And in the result it was found that a downward shift of the eversion curve was seen in the PR group resulting in an everted position of the rearfoot at both footstrike and toe-off compared with an inverted posture seen in the NL group. The amount of toe-out was not significantly different between the two groups. At the knee, the PR group demonstrated significantly less adduction and significantly greater flexion than the NL. Mean peak velocities of the PR group were greater in all angular measures except knee adduction. However, only foot dorsiflexion and eversion and knee flexion velocities were significantly different.

Nigg, Boer and Fisher (1995) have studied a kinematic comparison of overground and treadmill running. Twenty-two
subjects ran on four different surfaces: overground and three treadmills that differed in size and power. The kinematics of the right leg and foot were studied using two high-speed Locam cameras (lateral and posterior view). The subjects ran in two different shoes at four different speeds (3.0-6.0 m.s\(^{-1}\)). The differences in the kinematics between treadmill and overground running could be divided into systematic and subject dependent components. Subjects systematically planted their feet in a flatter position on the treadmill than overground. And in the result it was found that the most of the lower extremity kinematic variables inconsistent trends for individual subjects, depending on the individual subject's running style, running speed, and shoe/treadmill situation. The differences were substantial. Individual assessment of running kinematics on a treadmill for shoe or shoe orthotic assessment may possibly lead to inadequate conclusions about overground running.

McClay and Manal (1999) have studied three-dimensional kinetic analysis of running: significance of secondary planes of motion. Twenty recreational runners participated in this study. Angular kinetic data provides important information regarding
muscle function and may lend insight into the etiology of overuse injuries common to runners. These injuries are often due to deviations in the secondary planes of motion. However, little is known about the angular kinetics in these planes leaving no reference for comparison. Therefore, three-dimensional kinematic and ground reaction force data were collected on twenty recreational runners with normal rearfoot mechanics. And in the result it was found that the sagittal plane kinetic data were similar to the two-dimensional. Sagittal plane data were least variable (CV: 9.3-11.0%) and comprised the largest percentage of positive or negative work done (80.2-88.8%) at both the rearfoot and knee joints. Transverse plane kinetics were most variable (CV: 68.5-151.9%) and constituted the smallest percentage of work done at both joints (0.7-7.4%)

Soutas, Beavis, Verstraete and Markus (1987) have studied analysis of foot motion during running using a joint co-ordinate system. The amount and rate of pronation and supination have been the subject of interest to runners for some time. Exact determination of the motions has been hampered by their complexities and use of a two-dimensional data collection protocol. Rearfoot motion,
measured by determining the projection of the angle between a line on the posterior of the shank and a line on the heel, has been a common approach. This projection measures a rotation about a laboratory axis and not a body segment axis and has a potential of error due to projection onto a plane. The angle measured in rearfoot motion is not the true angle between these lines in space and has projection distortion errors which are compounded during plantar and dorsiflexion and medial and lateral foot rotations. The rearfoot motion angle, however, does approximate foot inversion-eversion during much of stance phase. And in the result it was found that the change in research protocol allows analysis of the three-dimensional position data of targets to construct a "joint coordinate system" which gives more accurate data on inversion-eversion and data on plantar-dorsiflexion and medial-lateral rotation of the foot.

Areblad, Nigg, Ekstrand, Olsson and Ekstrom (1990) have studied three-dimensional measurement of rearfoot motion during running. This study is to present a three-dimensional model for calculation of angles between lower leg and foot, lower leg and ground, and foot and ground, and to compare results from treadmill running derived from this model with results derived from a two-
dimensional model for different alignment angles between foot axis and camera axis. A two camera Selspot system was used to obtain three-dimensional information on motion of the studied segments. And in the result it was found that the several two-dimensional variables measured from a posterior view are very sensitive to the alignment angle between the foot and the camera axis. Some variables change as much as 1 degrees for every 2 degrees of change of the alignment angle. The large influence of rotations other than the measured one in two-dimensional measurements makes advisable the use of a three-dimensional model when studying motion between foot and lower leg during running.

Kernozek and Ricard (1990) have studied foot placement angle and arch type: effect on rearfoot motion. Twenty women were filmed in the frontal plane at 100 fps. Subjects displaying a variety of foot placement angles were chosen. Before data collection, arch indices were calculated. Each subject ran five trials at a pace of 3.5 m/sec. All subjects wore the same type of shoe. All trials were digitized to determine rearfoot angles throughout foot contact. The following mean values were obtained: total rearfoot was 10.09 degrees, maximum pronation was -9.63 degrees, foot placement
angle was 7.58 degrees and arch index was 0.23 cm². Non-linear regression was used to predict the relationship between maximum pronation and total rearfoot motion using foot placement angle and arch index. Foot placement angle was the best single predictor of total rearfoot motion. When using both foot placement angle and arch type as predictors of total rearfoot motion. Less abduction was associated with more total rearfoot motion. Arch type exhibited a quadratic relationship with total rearfoot motion. Normal-arched individuals exhibited less total rearfoot motion than high-arched and flat-arched individuals. And in the result it was found that for maximum pronation, foot placement angle was the only significant predictor. Greater foot placement angles (more abduction) were associated with less maximum pronation.

Heiderscheit, Hamill and Caldwell (2000) have studied influence of Q-angle on lower-extremity running kinematics. Thirty-two nonimpaired subjects (men: n = 16, mean age = 22 +/- 3 years; women: n = 16, mean age = 23 +/- 3 years) ran over ground, and 3-dimensional kinematic data were collected from the right lower extremity. Subjects with a Q-angle of 15 degrees or less comprised the low-Q-angle group, whereas those with Q-angles of more than
15 degrees comprised the high Q-angle group. Segment and joint maximum angles and the times when the maxima occurred during stance were measured. And in the result it was found that the Q-angle magnitude did not increase the maximum segment or joint angles during running. The groups displayed similar maximum angles for rearfoot eversion (low Q-angle, -15.5 +/- 5.0 degrees; high Q-angle, -15.6 +/- 6.6 degrees) and tibial internal rotation (low Q-angle, -8.8 +/- 4.8 degrees; high Q-angle, -6.8 +/- 5.1 degrees). The high Q-angle group (39.5 +/- 16.3%) achieved maximum tibial internal rotation later in the stance phase than the low-Q-angle group (28.8 +/- 10.7%).

Salo, Paul and Jukka (1997) have studied reliability of variables in the kinematic analysis of sprint hurdles. Seven British national level athletes in sprint hurdles were videotaped and all eight trials of each athlete were digitized from two camera views to produce three-dimensional coordinates. The reliability of twenty eight kinematic variables across eight trials ranged from 0.54 to 1.00 for females and from 0.00 to 0.99 for males. The number of trials needed to reach a certain reliability level was evaluated using Spearman-Brown prophecy formula, and in the worst case
(horizontal velocity lost for males) 78 trials would be needed to reach 0.90 reliability. And in the result it was found that the reasonably high reliability and the values for the female trials were generally higher than the male trials. The relative height of the hurdles enforces a more demanding clearance for males that can lead to increased variation within the subjects and thus lowered reliability.

Gottschall and Palmer (2001) have studied the acute effects of prior cycling cadence on running performance and kinematics. Thirteen male athletes of the University of Colorado triathlon team volunteered. Each participant completed three sessions of testing. During the control condition, each participant completed a 30minutes cycling bout immediately followed by a 3200m running bout. Heart rate was recorded every two minutes so the participants could monitor and maintain similar intensities during the second and third sessions. During the fast condition and the slow condition, each participant completed a 30-minute, high intensity cycling bout at a cadence 20% faster or 20% slower than the control condition. The cycling bout was immediately followed by a 3200m run at the same heart rate intensity as during the control
run. And in the result it was found that the faster cadence cycling substantially increased the subsequent average running speed of the 3200ms race effort. During the fast condition, participants ran almost a minute faster than during the slow condition.

Stackhouse, Davis and Hamill (2004) have studied orthotic intervention in forefoot and rearfoot strike running patterns. Fifteen subjects ran with both a forefoot and a rearfoot strike pattern with and without orthoses. Lower extremity kinematic and kinetic variables were compared between strike pattern and orthotic conditions. Five trials were collected for each condition. Peak rearfoot eversion, eversion excursion, eversion velocity, peak inversion moment, and inversion work were compared between conditions. Kinematic variables in the sagittal plane of the rearfoot and in the frontal and sagittal plane of the knee were also determined. And in the result it was found that the increased rearfoot excursions and velocities and decreased peak eversion were noted in the forefoot strike pattern compared to the rearfoot strike pattern. Orthotic intervention, however, did not significantly change rearfoot motion in either strike pattern. Reductions in internal
rotation and abduction of the knee were noted with orthotic intervention.

Williams, Mclay, Scholz, Buchaman and Hamill (2001) have studied lower extremity stiffness in runners with different foot types. The study included twenty high arch and twenty low arch with no lower extremity injury at the time of the experiment. The arch ratio was defined as the height to the dorsum of the foot from the floor at 50% of the foot length divided by the individual's truncated foot length. Arch ratio values fell at or outside 1.5 standard deviations of the mean DORS/TFL ratio measurement based on a sample of 102 feet. Retroreflective markers were placed unilaterally on the segments of the rearfoot, shank, thigh and pelvis. The subjects ran along a 25m. runway at a speed of 3.35 m/s +/- 5%. Kinematic data were collected at 120Hz using 6 camera VICON motion analysis system were recorded at 960 Hz. Ten footstrikes were collected and averaged for each subject. The kinematic and force data were combined to calculate joint moments through inverse dynamics. Comparison between high arch and low arch subjects were made using a one-tailed student's t-test to determine whether differences in stiffness existed between these groups. And
in the result it was found that the significant relationship between loading rate and peak knee flexion angle and lower extremity stiffness \( R=0.558, p=0.000 \). Vertical loading rates and peak knee flexion angle explained 27.8% of the variance present in lower extremity stiffness \( R=0.563, p=0.001 \).

Pearsall and Costigan (1996) have studied the effect of segment parameter error on gait analysis. From a sample of fifteen young, healthy males varying in body mass indices (18.8 to 27.3 cm/ kg²). Segment parameter estimates of the leg and thigh were calculated. Segment parameter was varied to examine the effect of changing segment parameters on the kinetic output. Each SP was varied in steps over nine levels by a defined percentage (-40% to +40%) of the original segment parameter baseline value. Walking kinematic and kinetic data were collected for each subject. The three-dimensional motion of the right lower limb was recorded at 50 Hz using the WATSMART motion tracking system (Northern Digital, Waterloo). Inverse dynamic analysis was performed iteratively to compute hip forces and moments while simultaneously varying SP values over nine intervals within ± 40% of a baseline value. The output data were the forces and moments about the hip
joint expressed in the thigh fixed-body coordinate system. And in the result it was found that the significant differences were found for measures of mass, center of mass and moment of inertia of body segments parameters for both the leg and thigh.

Heiderscheit, Hamill and Emmerik (1998) have studied the importance of intersegmental coordination variability during running. All subjects signed an informed consent in accordance with University policy. Three-dimensional kinematics were collected on each subject during ten trials of running. After digitizing and filtering the data, a direct linear transformation was employed to reconstruct the three-dimensional image. Segment angles and respective velocities were calculated throughout the stance phase. Normalized phase plots of angular position and velocity were constructed leading to the calculation of phase angles. Continuous relative phase angles were defined between three segment couplings (thigh flexion/extension with leg rotation, thigh adduction/abduction with leg rotation, and leg rotation with foot eversion/inversion) by subtracting the phase angle of the proximal segment from the distal.
For further comparison, means of continuous relative phase variability were calculated across various stride phase intervals.

Representative data of individual subjects from two different studies was presented. Study 1 investigated differences between asymptomatic subjects with varying lower extremity alignment as determined by the Q-angle. Study two addressed differences between asymptomatic subjects and those with patellofemoral pain. Over-ground running kinematics were collected for study one while the second study involved a treadmill. The result in Study 1, revealed no significant differences in continuous relative phase variability for any couplings, and the anatomical alignments do not affect the coordination variability during running. Study 2 demonstrated a distinct loss of continuous relative phase variability in the patellofemoral pain group relative to the asymptomatic. Further analysis across the stance intervals revealed the patellofemoral pain individuals to have less variability during terminal stance and prior to heel-strike.

Bachman, Heise and Bressel (1999) have studied the symmetry of the human leg spring coefficients between right and left legs during running. Eight healthy women and thirteen healthy men
volunteered as subjects. None of the subjects exhibited any obvious leg length asymmetry. Each subject attended one test session. After a 10-min warm-up, during which subjects practiced striking the force plate, each subject to run at a preferred "slow" or "fast" pace. A 25m runway with a force plate flush mounted in the middle was used. Forward running speed was calculated from a video record of the sagittal plane movement. Standing leg length was measured from the greater trochanter of the femur to the floor. Time of contact, peak vertical ground reaction force and peak vertical center of mass displacement were obtained from force records. Stiffness measures between right and left legs for the two running speed conditions were tested with repeated measures ANOVA. And in the result it was found that the no significant differences were found for leg spring stiffness or effective vertical stiffness between right and left legs within the two speed conditions. Significantly higher values of effective vertical stiffness were found between running conditions.

Borstad and Ludewig (2002) have studied comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. Twenty-six symptomatic and twenty six healthy
subjects performed five repetitions of humeral scapular plane abduction. An electromagnetic tracking device described three-dimensional scapular kinematics during arm elevation and lowering. Angular values for scapular anterior/posterior tipping in the sagittal plane, upward/downward rotation in the scapular plane, and internal/external rotation in the transverse plane were calculated. Scapular orientation relative to the thorax at humeral angles of 40 degree, 60 degree, 80 degree, 100 degree, and 120 degree were statistically tested for effects of phase and trial, or for interactions of phase with group or humeral angle. And in the result it was found that the internal rotation was significantly increased in the eccentric phase for both groups at the 100 degrees angle (P<0.05) and for the symptomatic group only at the 120 degree angle (P<0.05). Scapular anterior tipping was significantly decreased during the eccentric phase in both groups at the 80 degree (P<0.001), 100 degrees (P<0.0001), and 120 degree (P<0.0001) angles.

Williams, Devis and Baitch (2003) have studied effect of inverted orthoses on lower-extremity mechanics in runners. The purpose of this study was to compare the three-dimensional kinematics and kinetics of the rearfoot and knee during running
while varying orthotic intervention. Eleven subjects were initially fitted with standard foot orthoses and then with inverted orthoses. Three-dimensional kinematic and kinetic data were collected for conditions of no orthoses, standard orthoses, and inverted orthoses. And in the result it was found that no differences between conditions in peak rearfoot eversion or rearfoot eversion excursion. Peak rearfoot inversion moment and work were significantly reduced (P = 0.045 and P < 0.001, respectively) in the inverted orthotic condition suggesting a decreased demand on the soft tissue structures that control eversion. Significant differences were seen in tibial rotation (P = 0.043) knee adduction (P = 0.035), and knee abduction moment (P < 0.001) in the inverted orthotic condition.

Stacoff, Reinschmidt, Nigg, Bogert, Lundberg, Denoth, and Stussi (2000) have studied effects of foot orthoses on skeletal motion during running. Intracortical Hofman pins with reflective marker triads were inserted under standard local anesthetic into the calcaneus and tibia of five healthy male subjects. The three-dimensional tibiocalcaneal rotations were determined using a joint coordinate system approach. Eversion (skeletal and shoe) and tibial rotation were calculated to study the foot orthoses effects. And in
the result it was found that the orthotic effects on eversion and tibial rotations were small and unsystematic over all subjects. Differences between the subjects were significantly larger than between the orthotic conditions. Significant orthotic effects across subjects were found only for total internal tibial rotation; p<0.05).

Freychat, Belli, Carret and Lacour (1996) have studied relationship between rearfoot and forefoot orientation and ground reaction forces during running. Footprint and ground reaction forces were simultaneously recorded from thirty two male subjects running barefoot. Angle between the rearfoot and the forefoot in static (alpha S) and in running (alpha R) conditions, and orientations of both, rearfoot and forefoot with the direction of running, were measured and correlated to selected ground reaction force parameters. The dynamic rearfoot/forefoot angle was correlated, positively with arch deformation (r = 0.58, P < 0.001), vertical loading peak (r = 0.60, P < 0.001), mediolateral, and anteroposterior force rates (r = 0.47 and 0.48, P < 0.01), and negatively with stance time (r = -0.41, P < 0.05) and total course of the force application point path (r = -0.71, P < 0.001). Both a medial and a lateral rotation were observed on footprint between the rearfoot and the
forefoot in the horizontal plane. And in the result it was found that the medially rotated forefoot ("closed foot") was associated to a rigid and inverted foot, whereas a laterally rotated forefoot ("open foot") was associated to a flexible and everted foot.

DeVita and Stribling (1991) have studied lower extremity joint kinetics and energetics during backward running. Ten trials of high speed (100 Hz) sagittal plane film records and ground reaction force data (1000 Hz) describing backward running were obtained from each of five male runners. Fifteen trials of forward running data were obtained from one of these subjects. Inverse dynamics were performed on these data to obtain the joint moments and powers, which were normalized to body mass to make between-subject comparisons. Backward running hip moment and power patterns were similar in magnitude and opposite in direction to forward running curves and produced more positive work in stance. Functional roles of knee and ankle muscles were interchanged between backward and forward running. Knee extensors were the primary source of propulsion in backward running owing to greater moment and power output (peak moment = 3.60 N.m.kg⁻¹; peak power = 12.40 W.kg⁻¹) compared with the ankle (peak moment =
1.92 N.m.kg⁻¹; peak power = 7.05 W.kg⁻¹). The ankle plantarflexors were the primary shock absorbers, producing the greatest negative power (peak = -6.77 W.kg⁻¹) during early stance. Forward running had greater ankle moment and power output for propulsion and greater knee negative power for impact attenuation. And in the result it was found that the large knee moment in backward running training leads to increased knee extensor torque capabilities.

Swanson and Caldwell (2000) have studied an integrated biomechanical analysis of high speed incline and level treadmill running. Sagittal plane video (200 Hz) and electromyography (EMG) from eight lower extremity muscles were recorded during each of three locomotion conditions that are incline running at 4.5 m x s⁻¹ and 30% grade (INC), level running at 4.5 m x s⁻¹, and level running at the same stride frequency as INC (LSSF). A rigid body model was used to estimate net muscle power and work values at the hip, knee, and ankle during swing. Timing and amplitude of EMG signals for each muscle relative to footstrike were compared between conditions. And in the result it was found that the Stride frequency and percentage of stride spent in stance were
significantly higher during INC (1.78 Hz; 32.8%) than in the LSS (1.39 Hz; 28.8%) condition. Stride frequency played an important role, as most measures were more similar between INC and LSSF. Extensor range of motion of all joints during push-off was higher for INC. During INC, average EMG amplitude of the gastrocnemius, soleus, rectus femoris, vastus lateralis, and gluteus maximus were higher during stance, whereas the hamstrings activity amplitudes were lower. Average power and energy generated during hip flexion and extension in the swing phase were greatest during INC.

Viale, Dalleau, Freychat, Lacour and Belli (1998) have studied leg stiffness and foot orientations during running. This study was done to determine whether leg stiffness during running was related to rearfoot-to-forefoot angle in standing (RFAst) and running (RFARun). Footprints obtained from thirty two subjects were used to calculate RFAst and RFARun, defined as positive when forefoot axis was abducted from rearfoot axis. A spring-mass model was used to calculate leg stiffness in running from ground reaction forces, measured by a force platform. The leg stiffness of runners was negatively correlated with RFAst and RFARun. When runners were divided into opened foot (RFARun > 0; N = 19) and closed foot
(RFArun < 0; N = 12) groups, the leg stiffness of opened foot runners was less than that of the closed runners. And in the result it was found that the foot structure is a factor responsible for the differences in leg stiffness observed in runners.

Nigg, Cole and Nachbauer (1993) have studied effects of arch height of the foot on angular motion of the lower extremities in running. The three-dimensional kinematics of the lower extremities were measured during running for thirty subjects using high-speed video cameras. A joint coordinate system was used to calculate the three-dimensional orientation of the ankle joint complex for a single stance phase. And in the result it was found that the arch height does not influence either maximal eversion movement or maximal internal leg rotation during running stance. However, assuming that knee pain in running can result from the transfer of foot eversion to internal rotation of the tibia, a functional relationship between arch height and injury may exist in that the transfer of foot eversion to internal leg rotation was found to increase significantly with increasing arch height. A substantial (27%), yet incomplete, amount of the variation in the transfer of movement between subjects was explained by arch height, indicating that there must be factors other
than arch height that influence the kinematic coupling at the ankle joint complex. Additionally, the transfer of movement is only one factor of many associated with the etiology of knee pain in running.

McPoil and Cornwall (1996) have studied relationship between three static angles of the rearfoot and the pattern of rearfoot motion during walking. The pattern of rearfoot motion was assessed using two-dimensional video recordings for each lower extremity of thirty one healthy young adult subjects with a mean age of 25.2 years. The mean path of rearfoot motion during walking crossed relaxed standing foot posture but did not cross single leg standing or subtalar neutral position. And in the result it was found that the mean path of rearfoot motion during the first 60% of the walking cycle occurs between the static angles of relaxed standing foot posture and single leg standing. In addition, the static angle of the rearfoot in single leg standing may serve as a clinical indicator of the degree of maximum rearfoot eversion occurring during the walking cycle.

Joseph, Marshall, and McNair (2005) have studied relationships between ground reaction force impulse and kinematics
of sprint running acceleration. Thirty-six athletes performed maximal-effort sprints from which video and ground reaction force data were collected at the 16-m mark. Associations between ground reaction forces impulse (expressed relative to body mass) and various kinematic measures were explored with simple and multiple linear regressions and paired $t$-tests. The regression results showed that relative propulsive impulse accounted for 57% of variance in sprint velocity. Relative braking impulse accounted for only 7% of variance in sprint velocity. In addition, the faster athletes tended to produce only moderate magnitudes of relative vertical impulse. Paired $t$-tests revealed that lower magnitudes of relative braking impulse were associated with a smaller touchdown distance ($p < 0.01$) and a more active touchdown ($p < 0.001$). Also, greater magnitudes of relative propulsive impulse were associated with a high mean hip extension velocity of the stance limb ($p < .05$). And in the result it was found that the high magnitudes of propulsion are required to achieve high acceleration. Although there was a weak trend for faster athletes to produce lower magnitudes of braking, the possibility of braking having some advantages could not be ruled out.
Ratanaprasert, Smith, Sullivan and Gillear (1999) have studied three-dimensional kinematics of the forefoot, rearfoot and leg without the function of tibialis posterior in comparison with normals during stance phase of walking. Subjects with 10, 12 mm retro reflective markers placed on their right leg, rearfoot and forefoot, performed five trials of walking at self-selected speed on a 10 m walkway. A four-camera three-dimensional motion analysis system and a synchronized force platform were used to record three-dimensional motions of the segments and force variables during stance phase of walking. And in the result it was found that the patterns and range of motion of the rearfoot relative to the leg, and the forefoot relative to the rearfoot demonstrated some differences between the tibialis posterior dysfunction case and normals. Most of the major differences occurred from just prior to heel-off through to toe-off, the period when a stable arch would be required.

Mundermann, Nigg, Humble and Stefanyshyn (2003) have studied foot orthotics affect lower extremity kinematics and kinetics during running. Twenty one volunteers participated in this study. Kinematic and kinetic variables obtained during overground running for medial posting, custom-molding, and the combination of medial
posting and custom-molding of foot orthotics were compared to a control condition. Repeated measures ANOVA and student t-tests were used to detect significant differences (alpha=0.05). And in the result it was found that the posting of foot orthotics reduced maximum foot eversion and ankle inversion moment, and increased vertical loading rate and maximum knee external rotation moment (P<0.05).

Kernozek and Greer (1993) have studied quadriceps angle and rearfoot motion: relationships in walking. Twenty women were videotaped with two cameras, one located behind the subject and one located in front providing both front and rear views of the frontal plane. Each subject was required to walk at a 1.5 mph pace on a treadmill while five consecutive right footfalls were videotaped. Leg length and hip width were measured. Arch index was measured to determine arch type of the subject. All trials were digitized and analyzed using the Peak Performance Motion Measurement System. Q-angles and rearfoot angles were calculated and averaged over the five trials. The following group means were obtained: maximum pronation was -7.88 degrees, total rearfoot motion was 8.20 degrees, static rearfoot angle in a chosen stance
was -3.45 degrees, static rearfoot angle in a calibrated stance was -2.40 degrees, dynamic q-angle at heel strike was 16.13 degrees, dynamic q-angle at midstance was 16.00 degrees, static q-angle in a chosen stance was 18.32 degrees, static q-angle in a calibrated stance was 17.42 degrees, hip width was 25.66cm, leg length was 85.76cm and arch index was 0.23cm. Pearson product moment correlations were used to calculated between each of the variables. And in the result it was found that the all of the q-angle variables, both static and dynamic, correlated poorly with rearfoot motion variables.

McPoil and Cornwall (1996) have studied the relationship between static lower extremity measurements and rearfoot motion during walking. Rearfoot motion of each lower extremity was measured from videotape in twenty seven healthy young adult subjects participated in this study. In addition, seventeen static measurements were measured and recorded bilaterally for each subject. And the result found that the the only variable that was able to predict maximum rearfoot pronation was the "difference in navicular height". None of the seventeen measurements were found to predict time to maximum pronation. And in the result it was
found that static measurements of the lower extremity and foot are poor predictors of dynamic rearfoot motion as measured by maximum pronation or time to maximum pronation in healthy individuals without severe foot deformities.

Hunt, Smith, Torode and Keenan (2001) have studied the inter-segment foot motion and ground reaction forces over the stance phase of walking. Motion data were obtained from surface markers, and force data from a force plate, from the right limb of participants while walking at a self-selected pace. And in the result it was found that the stance phase range of motion across sagittal, frontal and transverse planes was 12 degree, 4 degree and 10 degree for the forefoot, compared to 22 degree, 8 degree and 10 degree for the rearfoot. Most motion occurred at the beginning and end of stance phase when support was via only the rearfoot or forefoot, and when forces were maximal. Arch height decreased from heel contact and increased after heel rise to its maximum at toe-off.

Eng and Pierrynowski (1994) have studied the effect of soft foot orthotics on three-dimensional lower-limb kinematics during walking and running. Thirty strides of walking and running
on a treadmill were recorded for each of the orthotic and nonorthotic conditions for each subject using an optoelectronic recording technique. Analyses of variance for repeated measures were performed on the range of motion of the talocrural/subtalar joint and knee joint for each plane of motion. The main factors of each analysis were the effect of the orthotic (orthotic condition versus nonorthotic condition), mode of ambulation (walking and running), and phase of the stance period (contact, mid-stance, and propulsion). And in the result it was found that no differences were found in sagittal-plane movements. Reductions of 1 to 3 degrees occurred with orthotic use for the talocrural/subtalar joint during walking and running in the frontal and transverse planes. The orthotics reduced knee motion in the frontal plane during the contact and mid-stance phases of walking, but increased the motion during the contact and mid-stance phases of running.

Nawoczenski, Saltzman and Cook (1998) have studied the effect of foot structure on the three-dimensional kinematic coupling behavior of the leg and rear foot. Ten recreational runners were assigned to a low rear-foot group and another ten recreational runners were assigned to a high rear-foot group. Three-dimensional
kinematic data were collected during treadmill running. Individual axis rotations and the "coupled" relationship between the leg and rear-foot segments were defined using a Cardan angle system of three ordered rotations. And in the result it was found that the combined subtalar and talocalcaneal joint axis to favor calcaneal eversion and inversion for the low rear-foot group and tibial medial and lateral rotation for the high rear-foot group. Group differences were also found for the coupling ratio, which described the proportion of calcaneal eversion and inversion transferred or coupled to tibial axial rotation.

McCulloch, Brunt and Vander Linden (1993) have studied the effect of foot orthotics and gait velocity on lower limb kinematics and temporal events of stance. Ten subjects demonstrating a minimum of 3 degrees of calcaneal eversion in relaxed standing participated in the project. All subjects were routinely functional orthotics that used during testing in conjunction with personal athletic shoes. Individuals were tested with and without the orthotics while walking on a treadmill at 2 and 3 mph. A four-camera motion analysis system was used to capture three-dimensional motion at 60 frames per second. Angle plots illustrated
changes in joint motion at the knee, ankle and rearfoot. Temporal
data for heel strike, heel rise and toe off of the foot during the
stance were calculated. A two-factor repeated analysis of variance
was used to determine the main and interactive effects of the
orthotic and speed on the dependent variables. And in the result it
was found that the significant reduction in the degree of pronation
throughout stance as well as an increase in the duration of stance
time as measured from heel strike to heel rise. The orthotic did not
significantly reduce the velocity of pronation during the first 20%
of stance. There was a speed effect for peak dorsiflexion and knee
flexion.

Carruthers and Farley (1998) have studied leg stiffness in
running humans: effects of body size. Twenty one healthy adult
subjects ran at 4.0 +/- 0.2 ms\(^{-1}\) over a force platform while being
videotaped at 200 Hz in sagittal view. Leg stiffness for each subject
calculated by dividing the peak ground reaction force by the change
in the length of the leg spring (leg compression) during the ground
contact phase. The vertical displacement of the COM was calculated
by double integration of the vertical acceleration of the COM. Half
the angle swept by the leg spring was calculated from the ground
contact time, forward velocity and leg length. And in the result it was found that the peak ground reaction force was greater in larger, leg compression increased slightly with body mass, leg stiffness increased dramatically with body.

Reinschmidt, Bogert, Nigg, Lundberg and Murphy (1997) have studied effect of skin movement on the analysis of skeletal knee joint motion during running. In addition to skin markers attached to the shank and thigh, triads of reflective markers were attached to bone pins inserted into the tibia and femur. Three-dimensional kinematics of the stance phase of five running trials were recorded for three subjects using high-speed cine cameras (200 Hz). The knee motion was expressed in terms of Cardan angles calculated from both the external and skeletal markers. Good agreement was present between the skin and bone marker based knee flexion/extension. For abduction/adduction and internal/external knee rotation, the difference between skeletal and external motion was large compared to the amplitude of these motions. Average errors relative to the range of motion during running stance were 21% for flexion/extension, 63% for internal/external rotation, and 70% for abduction/adduction. The errors were highly subject dependent
preventing the realization of a successful correction algorithm. And in the result it was found that the knee rotations other than flexion/extension, affected with substantial errors when using skin markers.

Morley, Stergiou, Dierks, Blanke and French (2000) have studied an examination of ground reaction forces in runners with various degrees of pronation. Thirty subjects (17 males and 13 females) ran at a self-selected pace with and without their normal athletic shoes. Frontal kinematic (Peak Performance video system; 60 Hz) and kinetic (Kistler force platform; 960 Hz) data were collected for 10 trials per condition. Following data analysis, the subjects were divided into three equal groups based upon their peak eversion values: the underpronation (U; 3-8.9 deg), the normal-pronation (N; 9-12.9 deg), and the overpronation (O; 13-18 deg) groups. The kinematic parameters analyzed were the maximum eversion, and the time to maximum eversion. A one-way ANOVA was performed on group means for average speed of running trials to confirm that groups performed similarly under testing conditions. And in the result it was found that the speeds were not significantly
different among groups. The barefoot condition resulted in decreased eversion values across all groups.

Hreljac, Stergiou and Scholten (2001) have studied lower extremity joint power when running over obstacles. Ten subjects (4 males, 6 females) ran at their preferred speed down a 25 m runway over a balsa wood obstacle, landing with their right foot on a floor mounted force platform. Seven obstacle height conditions (level, and heights ranging from 10% to 22.5% of standing height in 2.5% increments) were tested. Sagittal plane kinematics (180 Hz) of relevant markers were recorded and synchronized with ground reaction force data (900 Hz). After smoothing, using a fourth order, zero lag Butterworth filter, ankle and knee joint angular velocities, moments, and powers were calculated. The height at which no initial plantarflexion occurred was defined as the transition height (TH). Joint powers were normalized by dividing body mass before comparing peak power absorption and generation values at the ankle and knee between level running (H0), the height prior to TH (H1), and TH using a repeated measures MANOVA (p = 0.05). And in the result it was found that no significant differences noted between height conditions in peak power generation at the ankle, and peak
power absorption at the knee. The relative contribution of the ankle joint to power absorption increased significantly at the transition height at which time the landing strategy changed from a heel strike pattern to a forefoot strike pattern.

Gwyneth, Weyand and Biewener (2001) have studied changes in muscle mechanical advantage of human runners during sprint acceleration. Nine runners (5 male & 4 female) sprinted from a four-point start (with > 90% of body weight supported over the primary propulsive limb) beginning on a Kistler 9203 force platform and preceding the platform at specific distances to record the fore-aft and vertical ground reaction forces for steps 1,2,3,4 & 5, and steady speed of maximal sprints over the force platform. A MacReflex (Qualysis) infrared camera was used to record joint positions of the lower limb and trunk at 60 Hz. Joint coordinate data were smoothed using a four-order Digital Butter Worth Filter (17Hz 3db cut-off) and referenced to the platform and the location of ground reaction force application in order to calculate the external moments acting at the hip, knee and ankle joints. All signal processing and computations were performed in Matlab. By focusing on how muscle forces are influenced by limb posture and
ground reaction force, EMA ignores inertial and gravitational moments, which are likely important at the hip and knee. And in the result it was found that the significant decline in EMA were observed at the hip for step 1 \((p<0.001)\) and step 3 \((p<0.005)\) compared with step 5 and steady speed.

Farley and Morgenroth (1998) have studied mechanisms for leg stiffness adjustment during locomotion. Five healthy subjects performed two-legged hopping at 2.2 Hz on a force platform while being videotaped (200 Hz) in sagittal view. In half of the trials, subjects were simply instructed to follow the beat of the metronome ("preferred height hopping"). In the other half of the trials, subjects were instructed to hop as high as possible while following the beat of the metronome. Calculated leg stiffness from the ratio of the peak ground reaction force to the leg compression during the contact phase. Leg compression was equal to the vertical displacement of the center of mass, calculated by double integration of the vertical acceleration with respect to time. They calculated the average stiffness of each joint from the ratio of the change in net muscle moment to the joint angular displacement between the beginning and middle of the contact phase. Both leg stiffness and joint
stiffness values represent the sum of the two limbs in contact with the ground. The sensitivity of leg stiffness to the stiffness of each joint using a model consisting of four segments (foot, shank, thigh & head-arms-trunk) interconnected by three constant stiffness torsional springs (ankle, knee & hip). Systematically altered the stiffness of each joint and measured the effect on leg stiffness. And in the result it was found that the leg stiffness approximately doubled between preferred height and maximum height hopping. Average ankle stiffness increased by 1.9-fold from 401 (± 25) to 766 (± 102) Nm/rad while average knee stiffness increased by 1.7-fold from 368 (± 80) to 631 (± 85) Nm/rad. Hip stiffness was unchanged.

Mercer, Black, Branks and Hreljac (2001) have studied stride length effects on ground reaction forces during running. Subjects were ten physically active college students practiced running across a force plate flush with the floor in the middle of a 20m runway. Running velocity was calculated by placing timing light sensors on both sides of the force plate. Ground reaction forces data were recorded (1000 Hz) for each subject at a range of velocities during three conditions that were preferred stride length (PSL), SL set to
2.5m (SL2.5), and SL set to 3.0m (SL3.0). During SL2.5 and SL3.0 conditions, markers were placed on the floor 2.5m and 3.0m apart, respectively. Resultant ground reaction force was calculated from vertical and anterior posterior force data, normalized to body weight and impact peak (IP) identified and recorded. The angle (θIP) between IP and the horizontal was calculated and recorded. The relationship between IP and running velocity was quantified by generating a scatterplot of IP vs running velocity data for each subject condition combination. Slopes for IP vs running velocity and θIP vs running velocity were analyzed using repeated measures ANOVA. Simple effect contrasts were used to compare PSL to SL2.5 and SL3.0. And in the result it was found that the relationship between IP and velocity was different between conditions p<0.05), with IP vs velocity slope during PSL greater than SL3.0 (p<0.05) but not different that SL2.5 (p>0.05). The slope of the θIP vs running velocity relationship was greater positive during PSL than both SL2.5 and SL3.0.

Gutierrez, Chow, Tillman, Castellano, McCoy and white (2004) have studied effects of resistance training on gait kinematics of individuals with multiple sclerosis. Multiple sclerosis subjects (7
female, 1 male) with expanded disability status scores were tested for temporal and spatial parameters of gait prior to and after an eight-week resistance training program. The strength training consisted of twice weekly training sessions where two sets of 15-20 repetitions of each of the following exercises were performed: leg extension, leg flexion, ankle plantarflexion, trunk extension, and trunk flexion. Pre- and post-training data were compared using Wilcoxon matched-pairs signed-ranks tests (alpha = 0.05). And in the result it was found that the significant decrease in stance time (from 67.4 to 66.4% of stride time, p=0.036) and an increase in swing time (32.6 to 33.6%, p=0.036) were found in the more affected limb. For the less affected limb, significant increases in the step length (0.53 to 0.56 m, p=0.025) and foot angle (10.7° to 18.1°, p=0.036) and decrease in toe clearance (0.17 to 0.14 m, p=0.021) were observed. Among different stride parameters, a significant increase was found in stride length (1.06 to 1.14 m, p=0.017). Although not statistically significant gait velocity increased from 0.908 to 0.976 m/s (p=0.116).
Van Don (1997) has studied errors in hamstring muscle fiber length estimates during sprinting using two-dimensional versus three-dimensional analysis. Computer simulation of the leg motion of an individual (1.70m, 70 kg) during sprinting was developed. The hip angle versus time and the knee angle versus time relationships for a skilled sprinter were used to determine the hip, knee and ankle joint centers during one sprint cycle for the 2D condition. And in the result it was found that the maximum percentage errors were determined with the use of the percentage error versus percentage sprint cycle relationships of each muscle for all the simulated conditions. The errors obtained in the estimates of the muscle fiber lengths of the bi-articular muscles of the hamstring group using a 2D rather than a 3D analysis are very small. Therefore, a 2D analysis of sprinting is sufficient to obtain estimates of hamstring muscle fiber lengths.

Hughes, Kaufman, Cherng and Shaughnessy (1999) have studied center of mass (COM) parameters in children walking at different velocities. Nine healthy normal children (7 females and 2 males) were recruited for this study. The protocol involved level walking at three velocity conditions: 1) Natural self-selected, 2) fast
and 3) slow. A set of 27 reflective markers was placed on body landmarks of the subject. An eight-camera Real Time System (Motion Analysis Corp.) was used to collect 3-D marker trajectories at 60 Hz during gait. Kinetics were calculated from three force plates, EVa software (Motion Analysis Corp.) was used to track the trials and create virtual marker trajectories which were used to define joints. Finally, OT4 (Motion Analysis Corp.) was used to calculate the following temporal distance parameters that are velocity, stride length, right and left step length, right and left single support time, step width and cadence. ANOVA was used for statistical analysis. And in the result it was found that the significant difference (p<0.05) between the fast and slow walking velocities. When analyzing the displacement of the whole body COM in the three orthogonal directions. There was a significant difference between all conditions for the maximum anterior/posterior velocity, but no significant differences between any of the conditions for the maximum medial/lateral velocity. Stride length and right and left step lengths exhibited significant differences between only fast and slow walking conditions.
Erdemir and Piazza (1999) have studied foot placement specifies the resistance arm of the ground reaction force during push-off in gait initiation. Kinematic data, ground reaction force and center of pressure location were measured during the walking initiations of ten healthy, barefoot subjects using a six camera motion analysis system and a force plate (Kistler Inst. Corp.). Reflective marker clusters were placed on the left foot and shank to record motions of these segments during the push-off period, the left foot of each subject was placed such that an axis determined by the second toe and the posterior aspect of the heel was aligned with markings on the force plate. The right foot was placed in neutral position, then walked several steps forward, leading with the right foot. Each subject completed ten trials with each of two foot placements with 20° internally rotated and 30° externally rotated. The resistance arm of the ground reaction force was determined by calculating the distance from the talocrural joint axis to the line of action of the ground reaction force. A two way repeated-measures ANOVA followed by pair wise comparisons were used to test the effects of foot placement internally and externally rotated and time. And in the result it was found that the significant resistance arm
differences were found between foot placement conditions only from 76%-100% of push-off (p-values <= 0.038). And that this study demonstrates that internal rotation of the foot reduces the resistance arm of the ground reaction force during push-off in gait initiation.

Chang, Kelly and Rodger (2001) have studied running speed on curved paths is limited by the inside leg. Five recreationally fit men gave informed consent to serve as subjects. They sprinted along a straight track and along circular tracks of 1m, 2m, 3m, 4m, and 6 m radii. Curve sprinting was performed normally and with a tether. The tether attached a harness worn about the waist to a vertical pole at the center of each track. Speeds were determined from high-speed video analysis. Ground reaction forces were recorded from a force platform mounted flush with the running surface. Tether forces were recorded from an in-line force transducer. And in the result it was found that the Sprint velocity decreased with radius, but less so with the tether. At the 3m radius, velocity decreased by 42% for normal curve sprinting, but only 33% with the tether. The outside leg produced significantly more force than the inside leg during normal curve sprinting.
Thomas and Tilman (1997) have studied a kinematic analysis of obstacle clearance strategies in normal gait. Eighteen healthy individuals (2 females, 16 males) participated in the obstacle clearance study. To assess obstacle clearance quantitatively, a reflective marker was placed on the lateral side of the right shoe, at the location of the 5th toe. An RCA video camera was used for data collection. The video data were collected at 30 Hz and were analyzed using the PEAK Video Illustrator. The obstacles were color contrasted to the floor and therefore were easily seen. A video camera was placed perpendicular to the line of motion and parallel to the line of the obstacle providing a sagittal view of the movement. The camera and lamp were 7.3m from the line of motion. The obstacles were placed in the middle of a flat level 5.5m runways. The PEAK Video Illustrator was used to determine obstacle clearance height and the angle of ascent during clearance. To measure angle of right foot ascent, the path of the 5th toe was traced from right foot contact before clearance to right foot contact after clearance. The path was divided into 16 distinct points and the slope was measured at the steepest part of the ascending portion of
the curve. And in the result it was found that no significant difference ($p>0.05$) between the 8cm and 2cm clearance heights.

Darren and Smith (1999) have studied changes in vertical ground reaction force during endurance running to exhaustion on a treadmill. Six male trained endurance runners performed a test run to exhaustion, at a speed approximately 80% of VO$_2$ peak ($4.21 \pm 0.35$ m/s), on a treadmill instrumented to measure vertical ground reaction forces. Determination of exhaustion was subjective and left to the discretion of the runner. The average duration of the exhaustive run was 56 minutes (range: 38-78 min). Ground reaction force data were sampled for 15 seconds at 1000 Hz every five minutes; individual heel strike and toe-off points were identified from the force data. Between 38 and 40 steps were identified for each sampling period. Characteristics measured from the force data include that is peak impact force, loading rate, peak active force, foot contact time and step time. A within-subject ANOVA was used to determine variable changes, and Fisher's PLSD test was used for follow-up tests. A coefficient of variation was determined for each variable and averaged across the six subjects at each time point. And in the result it was found that the magnitudes of the active and
impact peak varied between individuals, and the changes with exhaustion were inconsistent. Increases, decreases, and no change were observed with exhaustion in different runners.

Chow, Rosengren and Carlton (1997) have studied joint moments at the lower extremities for changing direction during walking. Six males and two females university students participated in this study. They all had no history of injury at the lower extremities. The subjects walk on force platforms while walking straight forward and while changing direction. They were turning to the right at 450m and 900m. It was assumed that the result of turning to the right direction was the same as the turning to the left direction. The natural walking speed (1.35 (0.15 m/sec) was evaluated. Both the right foot and left foot were used as the pivot foot for changing direction respectively. Each subject performed 18 trials for these different walking directions and pivot feet. The testing conditions were conducted in random order. Two AMTI force platforms (200Hz sampling rate) and two Peak Performance video cameras (60Hz) were used to collect the kinetic and kinematic data respectively. The Peak Synchronization Events was employed for synchronizing the force platform and video camera systems. The
three-dimensional coordinate data were computed with the DLT technique. The moments of force at the lower extremity joints were computed in terms of the anatomic joint axes. The data, which were used for analysis of the joint moments of force, were normalized by dividing the body mass. And in the result it was found that the changes of moments at the sagittal plane for altering direction appeared at the ankle joint during the heel strike before propelling forward.

Gard and Childress (1997) have studied the effect of stance-phase knee flexion on the vertical displacement of the trunk during normal walking. Kinematic measurements of three male subjects were made using a Vicon six-camera system using a standard clinical marker arrangement, and the data was subsequently process with Vicon Clinical Manager software. The subjects walked at five speeds (approximately 0.8 m/sec, 1.0 m/sec, 1.4 m/sec, 1.7 m/sec, 2.0 m/sec). Kinematic gait data was acquired for three walking trials per speed for each subject.

The vertical displacement of the trunk was measured from a virtual anterior marker lying at the midpoint between the two anterior superior iliac spine markers. The knee flexion angle was measured
over a single gait cycle in each of the data trials. The vertical displacement of the trunk due to the stance-phase knee flexion wave was determined by finding the vertical distance between the measured position of the hip joint center and the calculated position. They assumed that stance-phase knee flexion would have the same vertical effect on the ipsilateral hip joint center as it would on the trunk. And in the result it was found that the stance-phase knee flexion does not significantly reduce the vertical excursion of the trunk.

Knutzen and Price (1994) have studied lower extremity static and dynamic relationships with rearfoot motion in gait. Twenty nonsymptomatic subjects were assessed while walking at a photoelectronically monitored place (2 +/- 0.1 m.s\(^{-1}\)) using high speed cinematography (200 Hz) to record the rearfoot motion in the frontal plane, and electrogoniometry (100 Hz) to measure joint kinematics in the lower extremity. The foot type of the subjects was determined statically by using a podiascope and digitization techniques. And in the result it was found that no foot type variables contributed significantly to the variance in either rearfoot angle at foot strike or maximum rearfoot angle.
Aron, Robert and Aaron (2003) have studied kinematic determinants of early acceleration in field sport athletes. The aim of this study was to investigate the kinematic differences between individuals with fast and slow acceleration. Twenty field sport athletes were tested for sprint ability over the first three steps of a 15m sprint. Subjects were filmed at high speed to determine a range of lower body kinematic measures. For data analysis, subjects were then divided into relatively fast (n = 10) and slow (n = 10) groups based on their horizontal velocity. Groups were then compared across kinematic measures, including stride length and frequency, to determine whether they accounted for observed differences in sprint velocity. And in the result it was found that the fast group had significantly lower (~11-13%) left and right foot contact times (p < .05) and an increased stride frequency (~9%) as compared to the slow group. Knee extension was also significantly different between groups (p < .05). There was no difference found in stride length.
Dierks, Stergiou, Buzzi, Keenan and Heidel (2001) have studied the effect of speed on performer variability during locomotion. Twenty subjects attended five test sessions on five different days. On the first day, the subjects walked on a treadmill to establish a comfortable self-selected pace. This pace was used as the baseline speed for subsequent testing. Following this procedure, the subjects were required to walk for five minutes at five different speeds. Baseline, 10% and 20% faster, and 10% and 20% slower. The same procedure was used for running. The time series from the accelerometer data sampled (180 Hz) were analyzed using the Chaos Data Analyzer software. The Lyapunov Exponents (LE) and the Correlation Dimensions (COD) were calculated. LE is a measure of the stability of a dynamical system and its dependence on initial conditions. COD describes the geometric dimension of a dynamical system. All calculations were performed using five embedded dimensions. Mean group values for LE and COD were analyzed statistically using one-way repeated measures ANOVAs (p<0.05). And in the result it was found that the both LE and COD significantly decreased with increases in running speed. This may indicate a change in variability, which can be interpreted as an
increase in periodicity and less control with larger speeds. No significant differences were observed for LE during walking. The COD values were significant and actually, the 20% slower speed had the larger COD value.

DeVita (1994) has studied the selection of a standard convention for analyzing gait data based on the analysis of relevant biomechanical factors. Net joint torques and electromyographic (EMG) data from selected muscles in the lower extremity were obtained from four subjects while walking and running. Data were collected for consecutive swing, stance and swing phases to compare the variables at the swing-to-stance and stance-to-swing transitions. Larger joint torques were observed at the swing-to-stance transition at the hip and knee for both gaits compared to the other transition. EMG results showed greater activation levels for five of the six muscles at the swing-to-stance transition. And in the result it was found that the subjects needed to prepare for the initiation of stance and the application of relatively large external forces and moments. Further, the transition from stance to swing did not seem to be as critical a point in the gait cycle since the movements and EMG were relatively low. This being the case, the
stance-to-swing transition should be used as the beginning and ending of the gait cycle (toe-off initiating the cycle) and the more meaningful transition of swing-to-stance phases should occur in the middle of the analysis.

Grenier and Robertson (1998) have studied comparison of mechanical and physiological energy costs of walking. Eight subjects were recruited to perform three types of gait: normal, splinted knee and splinted ankle. Five normal trials and one trial of each splinted gait were recorded. The splinted trials were individually compared to the normal gait trials for each subject. Each trial was filmed by three video cameras to provide a 3D image. Markers were attached to the upper and lower extremities, bilaterally. Force platform data (2 AMTI at 600 Hz) were combined with video data (60 Hz) for inverse dynamics analysis. Each subject's oxygen consumption while walking was measured with a TEEM 100. The standing value was subtracted from the walking value to approximate the actual physiological cost of locomotion. And in the result it was found that no significant differences in the mechanical work done for the three walking conditions. Repeated measures ANOVA revealed no significant differences among the
work measures for the different methods due to the large between subject variability, as might be expected.

Riley and Kerrigan (1999) have studied linear power flow in voluntary toe-walking. The heel-toe and toe-walking gait of ten healthy young adults was evaluated. Gait laboratory kinematic and kinetic data were obtained for the subjects walking at their chosen speed (and toe-walking at nearly the same speed. Individual models of each subject’s right lower extremity were developed using SIMM/Dynamic Pipeline. Inverse dynamic analysis was then performed using SD/Fast. The net joint moments were calculated and the instantaneous velocity and contact force at the hip joint were determined. Each net joint moment was then applied individually and the resulting joint velocity and contact force were determined. This permitted to determine the total hip joint linear power throughout the gait cycle and each joint torque’s contribution to the total power. Three trials of each form of gait were analyzed for each subject And in the result it was found that the throughout the gait cycle the net linear power at the hip joint in toe-walking was similar to that in heel-toe walking. The ankle moment contribution to the total power showed two positive peaks in stance.
The first peak occurred in early stance and the ankle moment makes no significant contribution in swing.

Wang (1998) has studied lower extremity contributions to altering direction during walking analysis of angular momentum. Eight normal young adults (six males and two females) participated in this study. None had a history of lower extremity injury. Gait was examined while subjects were walking straight forward or while changing direction. They were turning to the right at 45° and 90° respectively. Both natural walking speed (1.35 m/sec ± 0.15) and fast walking speed (1.85 m/sec. ± 0.15) were evaluated. The right foot and the left foot were used as the pivot foot for changing direction at 45° and 90°, respectively. The performance for each condition was induced in random order. Two Peak Performance video cameras were used to collect kinetic and kinematic data. The data were collected for one stride at 60 Hz.

The angular momentum was normalized by dividing body mass and the square of the subject's standing height. And in the result it was found that the unit of the normalized angular momentum becomes $10^{-3}$ s$^{-1}$ (kg m$^2$ s$^{-1}$ /kg/m$^2$ x 103). The examination of changing direction during walking is based upon comparison of the
angular momentum under the three independent variables: pivot foot, altering angle, and walking speed.

Julianne and Michael (2004) have studied peak ground reaction forces and braking forces while walking downhill with and without the use of trekking poles. Ten subjects were recruited on a volunteer basis, from a healthy, active adult population (5 men and 5 women). Participants were screened for any conflicting medical issues and signed informed consents. Procedures included a practice session which involved walking down a wooden ramp at all gradients to become familiar with each appropriate protocol, until participants felt natural in their gait patterns, and with pole use. The data collection consisted of ten successful trials per condition. A predetermined counterbalanced order of conditions was used, due to the change-over time in adjusting the slope of the ramp. Force data was collected on a Bertec force plate at 500 Hz, mounted flush with the wooden ramp. Means and standard deviation were calculated for the multiple trials of each condition. And in the result it was found that the breaking forces were similar to ground reaction forces data, in that gradient and gender differences were noted overall, but with pole use, breaking forces were not statistically different. Kinetic
parameters of peak ground reaction force and breaking force (N/kg) were examined for differences between gradient, gender and pole use. Significant differences between conditions were determined using a 3-way ANOVA. Statistically significant differences (p<.05) were noted for changes in ground reaction forces between gradients, and for gender, but not for pole use.
CHAPTER-III

PROCEDURES
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PROCEDURES

Description of the experimental equipments and procedures used during the investigation are contained in this chapter. This chapter is divided into the following sections: (i) General procedure, (ii) Selection and Description of Instrumentation, (iii) Analytical Software, (iv) Data Reduction and Analysis, (v) Analysis of Running Mechanics (vi) Statistical procedures.

GENERAL PROCEDURES

The general procedures that were followed during this investigation are presented in this section. The section is divided into five subsections: (a) Subject approval, (b) Preliminary investigation, (c) Selection of subjects, (d) Filming procedure and (e) Selection of trials and frames for analysis.

Subject Approval

In order to ensure the subject’s involvement in the investigation, an approval from the All India Athletic Organisation Committee, Ranchi University, Jharkhand, India was obtained.
Preliminary Investigation

The preliminary investigation helped to reduce problems that could have occurred during the actual data collection. So prior to the actual data collection, a preliminary investigation was conducted in order to tackle the possible hindrances concerning the video-graphic set-up. Applying a different camera positions and focus setting, a single male runner was filmed while performing the 100metre (m) and 5000metre (m) long distance runners on the synthetic track (JRD, TATA Complex Athletic Stadium Jamshedpur, Jharkhand). The areas of investigation included (a) determination of optimal locations for two cameras, (b) determination of the correct aperture and focal setting for each lens, (c) determination of the correct film speed and field of view, (d) determination of appropriate lighting, (e) approach angle and trial identification location and (f) familiarisation of the investigator and research assistants with the experimental equipment.

As a result of the preliminary investigation, the investigator and their assistants became familiar with the equipment used for
this study. The correct lighting, aperture and focus settings ensured appropriately exposed film to aid in the digitising process.

Both the researcher and the assistants were trained in the collection of data pertaining to the selected subject’s anthropometrical measurements.

Selection of Subjects

The researcher was permitted to collect his research data from the Organizing Committee of All India Athletic Meet, Ranchi University, Jharkhand for only first lane runner on synthetic track. So only first lane sprinters and 5000m long distance runners were selected randomly (including Heats) from All India Athletic Meet held at JRD Tata Complex Jamshedpur, from Feb 28 to March 1, 2004.

The subjects had no lower extremity injuries at the time of video recording. Their ages ranged from 18 to 25 years, (According to the All India Intervarsity eligibility rule). The height was from 156 to 185 centimetre and the body weight ranged from 49 to 75 kg. All of them were regularly trained athletes. All the above informations have been provided by the Universities eligibility
forms, which have been collected from the office of Organizing Committee prior to the competition.

In order to maintain homogeneity, only left-foot of runners were selected for the study.

**Filming Procedure**

The film recording was conducted on a sunny and clear weather in the Athletic Stadium of the JRD Tata Complex Jamshedpur, Jharkhand. All the sessions of the competition were conducted in three consecutive days to complete the video recording. The average wind velocity and the weather temperature during the filming session were 0.75 m/s and 21.37° Celsius respectively. These informations have been collected by the researcher from technical assistants of the long jump event, equiped with the instruments Anemometer, used for measuring wind velocity and Ideal Gas Thermometer on the field, used for measuring weather temperature for the meet records.

As the data were collected in the competition, the subjects wore complete competitive sport kit in order to perform successful
running/sprint. No instructions were given to the subject with regard to running technique to be used during filming etc.

**Selection of Trials and Frames for Analysis**

During the film analyses, specific video fields were selected. The ground contact by heel of the running foot and take off was selected as the beginning and ending of the running sequence respectively. The sequence of the running motion was divided into two phases (a) take off phase (i.e. the center of gravity is forward of the toe of the take off foot at the instant the latter leaves the ground) and (b) landing phase (i.e. the toe of the leading foot is forward of the center of gravity at the instant the runner lands). Single video to take off and single following the heel contact were included in the video digitilising process.

**SELECTIONS AND DESCRIPTION OF INSTRUMENTS**

The selection and description of instrumentation used during this investigation involved two sections. These were as follows: (a) Anthropometric Measurements and Instruments and (b) Videography Technique and Equipments.
Anthropometric Measurements and Instruments

Subject's body Height, Weight, Leg length, Thigh length, Lower leg length and Shoulder width were recorded as outlined in giving below table.

Table-I

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>Ht</td>
<td>Distance measured from the sole of the feet up to the vertex. Vertex is the highest point on the head.</td>
</tr>
<tr>
<td>Weight</td>
<td>Wt</td>
<td>Total body weight with competitive sport kit.</td>
</tr>
<tr>
<td>Leg Length</td>
<td>LL</td>
<td>Greater trochanter of femur to the sole.</td>
</tr>
<tr>
<td>Thigh Length</td>
<td>THL</td>
<td>Distance between greater trochanter and lateral epicondyle of femur</td>
</tr>
<tr>
<td>Lower Leg Length</td>
<td>LLL</td>
<td>Distance between lateral condyle and lateral malleolus.</td>
</tr>
<tr>
<td>Shoulder Width</td>
<td>SW</td>
<td>Distance between left acromion processes to right acromion process of shoulder.</td>
</tr>
</tbody>
</table>
The measurements were recorded by using the standard anthropometric kit, available in the Department of Physical Health Education, Aligarh Muslim University, Aligarh.

The body weight was recorded in kilogram (kg) by using weighing machine (included athlete's kit which was wore during the competition). Height was recorded in centimetre (cm) by using stadiometer. Leg Length, Thigh Length, Lower Leg Length and Shoulder Width of each subjects were recorded in centimetre (cm) by using steel measuring tape.

**Videography Techniques and Equipments**

The videographic technique is further organised into three sections. These are (a) Videographic Equipment and Location, (b) Camera Speed and Synchronisation, (c) Subject and Trial Identification.

(a) **Videographic Equipments and Location**

The subject's running motion was recorded using two Synchronised Panasonic F15 S-VHS video cameras in a field setting. The videotapes used were TDK E180 Extra Grade
videotapes. Panasonic zooming lenses and two video cameras rigid tripod stands etc.

One camera was set-up on a first rigid tripod and secured to the floor in the appropriate location, the second camera set up on second rigid tripod. In order to obtain maximum accuracy in the reconstruction of the two-dimensional co-ordinates, the location of the cameras were chosen such that the optical axes of the cameras intersected perpendicular on both planes namely Sagittal plane and Frontal plane. The first camera were operated by Mr. Balvinder Sigh, (Lecturer, Department of Mass Communication, Karim City College, Jamshedpur), Second camera was operated by his assistant Mr. Biswanath Paul.

First camera position was on field area which was perpendicular to the sagittal plane and parallel to the mediolateral axis (camera optical axes perpendicular on the sagittal plane). For measuring the Stride length, Rear foot motion, Shoulder angles (shoulder extension and shoulder flexion), Shoulder rotation, Knee Angle (knee flexion, knee extension and knee angle at landing), Hip Angle (hip flexion and hip extension) and Ankle Angle (at take off and landing). Once the camera was installed in its player position,
the zoom on the camera was adjusted in order to see that the four selected sprinters stride and long distance runner's stride respectively of the whole motion during the 100meter sprint and 5000meter distance running were recorded into video tape. This camera position was 18m side from center of first lane of the track and 45m from the starting line of the 100m sprint. And the second camera was positioned two metre behind from starting line of the 100m sprint. The camera optical axes perpendicular on the frontal plane for measuring the Rear foot motion (heel angle at take off and landing, rear foot angle and leg angle) and Stride width. Both cameras were started on the electronic gun shot signal. Zooming focus were video recorded time at on same point (i.e. 50m for 100m sprinter and 4950m for 5000m long distance runners from 100m starting line). For both running, the two cameras positions were the same. But in a long distance event, the video recording is done during the last lap (i.e. 50m before the finishing line) of the subject run.
(b) Camera Speed and Synchronisation

The sampling rates of the video cameras were 50 fields per second (25 frames per second). The shutter of the cameras was fixed with a high speed (1/1000th of a second) in order to eliminate the effect of blurring while video recording. Single Charge Couple Device (Single CCD), and Camera zooming capacity was 12X but video camera man used 7X zoom focus in this video film as per the film adjustment.

(c) Subject and Trial Identifications

For identification purposes, a tag number that was awarded by All India Athletic Meet Committee to the subject was used. These numbers represented the subject.

ANALYTICAL SOFTWARE

After the video recording session was over, the following softwares were used to analyse the recorded data: (a) Chinese Software (SthSDVD) was used to find the frame rate and data was digitised for each video field using Chinese software program. Frames were digitised sequentially one frame at a time for each
trial. (b) Photo Studio was used for the colours available for axis marking. (c) Corel-5 was used for selection of final position frame of the subject with the help of mosaic roll up (a tool of the Corel-5 software's). (d) Corel-9 was used to set the distance between grid lines, to measure angles of different body segments with the help of freehand tools of the same software and also used for draw elgon (stick figure), (e) Link MPEG Player used for calculating the time of the runner's stride length and (f) SPSS Software and Office Excel used for the statistical purposes.

DATA REDUCTION AND ANALYSIS

The data were collected into all the sessions of the competition were conducted in two days of the three days of the competition. On the first day, the data was collected for 100m sprinters and on the second day, the data was collected for 5000m long distance runners. Subjects were selected only on first lane of the track because All India Athletic Organisation Committee (AIOC) permitted researcher only first lane for capturing the runner's video. On the basis of that restrictional condition, one video camera was placed on the left side of the runner (i.e. on field
area) and a second camera was placed 2-metre behind the 100metre starting line.

After video recording, the videocassette was converted into compact disc (CD) through video capture card which used to convert movies of VHS and DV cam. to VCD and DVD into computer system, loaded into Personal computer (PC) and it was played with the help of computer Chinese software (SthSDVD) to make a number of slides. Slides shows on computer monitor screen with the help of mosaic roll up. Final position of each selected subject's slides were obtained on the screen by trial and retrial method. The selected slide of the final position of each runner (selected subject) from the mosaic roll up was taken and pasted into new frame of Photo Studio software with appropriate dimension (351x288 pixel, width 4.458cm, height 3.658cm and resolution 200 dpi).

The various joint axis were marked on the selected final position slide as a reference point associated with each segment through pen tool (a tool of the Photo Studio software) with appropriate distinguishing color. Colors were chosen by the researcher separately for separate selected subjects to avoid the
identification hindrances among subjects during analysis of running mechanics. Further, the “Elgon” or stick figure of each phase, that is the movement of landing phase and take off phase during the running were constructed by the joint-point method for all selected subjects with the help of dimension tool of the Corel-9 software.

ANLYSES OF RUNNING MECHANICS

REAR FOOT MOTION

Rear foot motion consist (a) Heel angle, (b) Leg angle and (c) Rear foot angle.

(a) Heel angle was measured by mark point at the top of the heel counter in the center of the heel and just above the mid sole attachment point with a vertical plumb line used to align the mark point (figure-1). After completion of videography and data, the final slide was taken of selected subject for measuring the heel angle from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. For measuring the heel angle, one mark point was placed on the top of the heel counter in the centre of the heel just above mid sole of shoe. The second mark
point was placed on the attachment of the Achillis tendon just above its attachment to the calcaneus.

After completion of this process marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corel-9. By dimensional tool of the corel-9 software, a line was drawn from the second mark point to the floor passing over the first mark point. Heel angle was measured between calcaneus line to the drawing line.

(b) Leg angle was measured by a line between the centre of the rear knee and the centre of the Achilles tendon just above its attachment to the calcaneous (figure-1). After completion of videography and data, the final slide of selected subject was taken for measuring the leg angle from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. For measuring the leg angle, one mark point was placed between the centre of the rear knee and second mark point was placed on the Achilles tendon just above its attachment to the calcaneus.

After completion of this process marked slide of the selected subject was taken from photo studio and pasted onto a new graphic
frame of the corel-9. By dimensional tool of the corel-9 software, a line was drawn from the first mark point to the second mark point. A perpendicular line at the centre of the rear knee was also drawn. Leg angle was measured between the drawing line and the constructed perpendicular line.

(c) Rear foot angle was measured by the angle between the rear foot bisection and the direction of the Achilles tendon (figure-1). After completion of videography and data, the final slide of selected subject was taken for measuring rear foot angle from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. For measuring the rear foot angle, one mark was placed on the tip of calcaneus, just below the attachment of the Achillis tendon and second mark was placed on the attachment of the Achillis tendon just above its attachment to the calcaneus.

After completion of this process, marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corel-9. By dimensional tool of the corel-9 software, a line was drawn from attachment of Achillis tendon to the floor
passing over the calcaneus mark. Rear foot angle was measured between this line to the straight line that was drawn from centre of rear knee to the floor passing over the attachment of Achillis tendon.

**KNEE ANGLE**

Knee angle was measured between anatomical lines of the femur and tibia (figure-2). Knee joint consist only two movements, knee extension and knee flexion. Full extension of the knee joint was defined as straight angle (180 degree) and angular positions less then straight angle indicated knee flexion. Just before the take-off of the running athlete's shoe toe, rear leg knee joint become fully extended while front leg knee joint during same phase of running in flexion positioned.

After completion of videography and data, the final slides of selected subject were taken for measuring knee angle from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. For measuring knee angle, first mark point was placed on the knee joint over lateral condyle of tibia. Second mark point was placed on the hip joint over the greater trochanter
and third mark point was placed on the ankle joint over the lateral malleolus.

After completion of this process, marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corel-9. By dimensional tool of the corel-9 software, joined second mark point to first mark point and third mark point to the first mark point by drawing line. Knee extension and knee flexion was measured between these two lines.

**HIP ANGLE**

Hip angle was measured between anatomical line of femur and drawing line between shoulder joint to hip joint. Hip joint consists of two movements hip extension (figure-3) and hip flexion (figure-2). Full extension of the hip joint was defined as straight angle (180 degree) and angular positions less then straight angle indicated hip flexion. After full landing of athlete’s foot during running, hip joint becomes fully extended while front leg hip joint during same phase of running in flexion positioned.

After completion of videography and data, the final slides of selected subject were taken for measuring hip joint angle from
corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. For measuring hip angle, first mark point was placed on the hip joint over the greater trochanter of femur. Second mark point was placed on the knee joint over lateral condyle of tibia. Third mark point was placed on the estimated centre of the shoulder joint over the head of humerus.

After completion of this process marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corel-9. By dimensional tool of the corel-9 software, joined first mark point to second mark point and third mark point to the first mark point by drawing line. Hip extension and hip flexion was measured between these two lines.

ANKLE ANGLE

Ankle angle was measured between the tibia and foot at ankle joint (figure-2). After completion of videography and data, the final slides of selected subject were taken for measuring ankle angle from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. For measuring the ankle angle, first mark point was placed on the ankle joint over the lateral malleolus
of fibula. Second mark point was placed on the toe of athlete’s shoe and third mark point was placed on the knee joint over the lateral condyle of the femur.

After completion of this process, marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corel-9. By dimensional tool of the corel-9 software, two lines are drawn, first line was drawn form first mark point to the second mark point and second line was drawn from first mark point to the third mark point. Ankle angle was measured between these two lines.

**SHOULDER ANGLE**

Shoulder angle was measured between a line drawn from the greater trochanter of femur to the estimated centre of the shoulder joint and a line from this point along the central axis of the arm to the elbow joint (figure-2). After completion of videography and data, the final slides of selected subject were taken for measuring shoulder angle from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. For measuring shoulder angle, first mark point was placed on the
estimated centre of the shoulder joint over the acromion process. Second mark point was placed on the hip joint over the greater trochanter of femur and third mark point was placed on the elbow joint over the lateral epicondyle of humerus.

After completion of this process marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corl-9. By dimensional tool of the corel-9 software, two lines were drawn, first line from second mark point to first mark point and second line was drawn third mark point to the first mark point. Shoulder angle was measured between these two lines.

**SHOULDER ROTATION**

Shoulder rotation is the total angle at shoulder joint from arm position of landing phase to the arm position of just before the take off (figure-4). After completion of videography and data, the two final slides, one of landing phase and one of just before the take off phase of selected subject were taken for measuring shoulder rotation from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking on slide was one by one. For measuring shoulder rotation, first mark point was placed on the
estimated centre of the shoulder joint over the acromion process. Second mark point was placed on the elbow joint over the lateral epicondyle of humerus. These above mentioned mark points have already been mentioned on both phases slides.

After completion of this process, landing phase marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corel-9. By dimensional tool of the corel-9 software, a line was drawn from first mark point to second mark point, and the landing phase picture was removed from over the new graphic frame of corel-9 software. The take off phase (i.e. just before the take off phase) slide of the selected subject was taken from photo studio and pasted on first slide into the coral-9 new graphic frame in such a way that shoulder joints of both phases over lapped to each other. By dimensional tool of the corel-9 software, a second line was drawn from first mark point to second mark point of take off phase slide and the take off phase picture was removed from over the new graphic frame of corel-9 software. Shoulder rotation was measured between these two lines.
Figure 1
Rear Foot Motion
Figure-2
Take Off Phase
Figure-3
Landing Phase
Figure-4
Take Off Phase
(Shoulder Rotation)
STRIPE LENGTH

Stride length was measured as the horizontal distance between successive foot strikers (from left tip of toe to right tip of toe), (figure-5). After Video recording and reduction of the data, the selected toe marking slides were taken from the corel-5 photo paint software and pasted onto a new graphic frame of the corel-9 software, and a perpendicular line was drawn on both the toes marking points with the help of dimensional tool of the corel-9 software.

The distances were measured in centimeter between the perpendiculars by horizontal dimensional tool of corel-9 software. After that, distance measurement was converted into real value (metre) on the basis of reduction percentage of the zooming lens which was used during the capture of the selected subject motion. For actual measurement, the researcher held up a metre stick in the field of view for ten seconds. The metre stick was used as a reference for determining actual measurements of the distance between the toes.
STRIDE WIDTH

Stride width was measured as the average perpendicular distance from a midline in the direction of running to the centre of the ankle joint (figure-6). An estimated stride width was obtained from rear view films. Rear view film was recorded by an additional camera at running 50 films per sec (50f/s) that was placed 52 metre behind from the camera focus point (i.e.2 metre from the 100 metre sprint starting line). The camera was perpendicular to the frontal plane and parallel to the anterioposterior axis or sagittal plane. For 100m sprinters, films were recorded at the 50metre where as for long distance (i.e.5000 m) runner’s film was recorded at 4950m of last lap of 5000m on 400-metre standard synthetic track.

After completion of this videography and reduction of stride data, the final slides of selected subjects were taken for measuring stride width from corel-5 photo paint and pasted onto a new frame of photo studio for body segment axis marking. Marking should be on middle of the heel of the shoe. After completion of this process, marked slide of the selected subject was taken from photo studio and pasted onto a new graphic frame of the corel-9. By dimensional tool of the coral-9 software, construct a perpendicular line between
the feet. Stride width were recorded the sum of both distances from right mid heel of shoe to perpendicular line and left mid heel of shoe to perpendicular line. The stride width values were averaged over four cycles of running for both the left and right foot. These values converted into original values on the basis of reduction percentage of the Panasonic video zooming lances that was used during video recording of the stride width.
Figure-6
Stride Width
STATISTICAL ANALYSIS

Running mechanics investigated throughout the two phases of running motion were represented through various tables by using the SPSS and Excel computer software programs.

The effect of different running mechanics were determined significant by using Analysis of Variance (ANOVA) technique on both long distance running and short distance running. Further, Critical Difference (C.D) was applied to find-out which of the differences of the paired means of running mechanics were significant on both long distance running and short distance running.

\[ CD = \sqrt{\frac{2s_e^2}{r}} \times t_a \text{ for error d.f.} \]

Where

\( C.D \) = Critical Difference

\( S_E \) = Sum of square of error

\( t_a \) = Table value of \( t \) at \( \alpha \) level of significant

\( r \) = Number of participated subjects
Through goodness of fit test it is known that subjects are normally distributed and the subjects samples are small (less than 30). Therefore comparing means of running mechanics for both events (i.e. Long distance running and Short distance running), we applied student's t-test, which is as below.

\[ H_0, \mu_1 = \mu \quad \text{(there is no significant difference between means of short distance running and long distance running)} \]

\[ \text{Vs } H_1 : \mu_1 \neq \mu_2 \quad \text{(the result is significant)} \]

Then under \( H_0 \), test statistics is

\[
t = \frac{\bar{x} - \bar{y}}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \sim t_{n_1+n_2-2}
\]

\[
s_p = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1 + n_2 - 2}}
\]

\[
s_1^2 = \frac{1}{(n_1-1)} \sum_{i=1}^{n_1} (x_i - \bar{x})^2
\]

\[
s_2^2 = \frac{1}{(n_2-1)} \sum_{i=1}^{n_2} (y_i - \bar{y})^2
\]
Where

\[ \bar{x} = \text{Mean of the short distance runners} \]
\[ \bar{y} = \text{Mean of the long distance runners} \]
\[ n_1 = \text{Number of subjects in short distance running} \]
\[ n_2 = \text{Number of subjects in long distance running} \]
\[ s_1^2 = \text{Mean sum of square of short distance runners} \]
\[ s_2^2 = \text{Mean sum of square of long distance runners} \]
\[ \alpha = 5\% \text{ (Level of significant)} \]

To test the joint effect of Stride Length and Stride Width on short distance running and long distance running on performance timings of the subjects, the F-test has been applied. The F-test is as below.

\[ H_0 : \tau_{1,23} = 0 \quad \text{(That is no effect S.L and S.W on short distance running)} \]
\[ V s \quad H_1 : \tau_{1,23} > 0 \quad \text{(there is some effect)} \]

\[ F = \frac{\left( r_{1,23}^2 \right)/\left( p - 1 \right)}{\left( 1 - r_{1,23}^2 \right)/\left( n - p \right)} \]
\[ \alpha = 5\% \]
\[ F_{0.05, 2, 20} = 3.49 \]
Where

\[ p = \text{Number of dependent variables} \]

\[ n = \text{Number of subjects} \]

\[ r_1 = \text{Performance timing of the subject (sec.),} \]

\[ r_2 = \text{Stride length (m)} \]

\[ r_3 = \text{Stride width (m)} \]
CHAPTER-IV

RESULTS
CHAPTER-IV

RESULTS

The purpose of this investigation was to analyse the selected running mechanics on short distance running and long distance running. The results of the present investigation have been categorised under the following headings:

(a) Description of the subject

(b) Kinematic description of long distance running motion

(c) Kinematic description of short distance running motion

(d) Description of kinematic variables of running

(e) Description of Stride length and Stride width

(a) DESCRIPTION OF THE SUBJECT

Fifty male athletes (runners) of All India Athletic Meet Competition, held at Tata Stadium Jamshedpur Jharkhand, India, acted as subjects for the study. Table-2 presents the demographic data of all the subjects who participated in the investigation.
Table - 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Range (Min - Max)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>50</td>
<td>7.00 (18.00-25.00)</td>
<td>21.58</td>
<td>2.64</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>50</td>
<td>26.00 (49.00-75.00)</td>
<td>60.98</td>
<td>6.24</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>50</td>
<td>29.00 (156.00-185.00)</td>
<td>171.66</td>
<td>6.26</td>
</tr>
</tbody>
</table>

Demographic Profile of the Subjects

Table-2 demonstrates that a relatively homogeneous group participated in the study, as evidenced by the small standard deviations. Demographic profiles, particularly height and body weight, presented in earlier studies {Kivi, and Alexander (1998); Mercer and Kindling, (1998)} can be compared to the present study.
Basic anthropometric measurements of the subjects presented in Table-3 also show that the subjects were relatively homogeneous with low standard deviation for these variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range (Min - Max)</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg Length (cm)</td>
<td>14.47 (83.82-98.29)</td>
<td>89.87</td>
<td>3.78</td>
</tr>
<tr>
<td>Thigh Length (cm)</td>
<td>10.16 (36.83-46.99)</td>
<td>42.00</td>
<td>2.59</td>
</tr>
<tr>
<td>Lower Leg Length (cm)</td>
<td>6.86 (39.37-46.23)</td>
<td>42.64</td>
<td>1.76</td>
</tr>
<tr>
<td>Shoulder Width (cm)</td>
<td>12.45 (32.00-44.45)</td>
<td>38.74</td>
<td>2.39</td>
</tr>
</tbody>
</table>

Anthropometric Data of the Subjects
(b) **KINEMATIC DESCRIPTION OF LONG DISTANCE RUNNING MOTION**

Table – 4

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1305289</td>
<td>14</td>
<td>93234.92</td>
<td>1220.251</td>
</tr>
<tr>
<td>Within Groups</td>
<td>30944.58</td>
<td>405</td>
<td>76.40637</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1336233</td>
<td>419</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test for Long distance running mechanics from ANOVA Single Factor

Result of the ANOVA (Table-4) revealed that calculated value of F=1220.251 is highly significant. Hence it can be concluded that several running mechanics in long distance running differ significantly. Since these running mechanics differ significantly, we proceed further to find out which of the running mechanics means in long distance running differ significantly. The “Critical Difference” (C.D.) has been calculated to find the significant difference between means of different kinematic variables considered in long distance running mechanics, i.e., the least difference between any two running mechanic's means in long distance running to be significant. The value of C.D=4.58
### Table - 5

<table>
<thead>
<tr>
<th>Abbreviation of kinematic variable</th>
<th>Average</th>
<th>Abbreviation of kinematic variable</th>
<th>Average Difference</th>
<th>Abbreviation of kinematic variable</th>
<th>Average Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>KE</td>
<td>158.9</td>
<td>KE &amp; KAL</td>
<td>5.5986*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KAL</td>
<td>153.3</td>
<td>KAL &amp; HE</td>
<td>2.9277</td>
<td>KAL &amp; HF</td>
<td>34.2651*</td>
</tr>
<tr>
<td>HE</td>
<td>150.37</td>
<td>HE &amp; HF</td>
<td>31.337*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>119.04</td>
<td>HF &amp; KF</td>
<td>27.472*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KF</td>
<td>91.565</td>
<td>KF &amp; AATO</td>
<td>10.087*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AATO</td>
<td>81.478</td>
<td>AATO &amp; SR</td>
<td>7.5746*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>73.903</td>
<td>SR &amp; SE</td>
<td>14.018*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>59.886</td>
<td>SE &amp; AAL</td>
<td>27.596*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAL</td>
<td>32.29</td>
<td>AAL &amp; HATO</td>
<td>13.279*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HATO</td>
<td>19.01</td>
<td>HATO &amp; SF</td>
<td>4.9929*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>14.018</td>
<td>SF &amp; HAL</td>
<td>2.0062</td>
<td>SF &amp; LAL</td>
<td>5.0584*</td>
</tr>
<tr>
<td>HAL</td>
<td>12.011</td>
<td>HAL &amp; LAL</td>
<td>3.0522</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAL</td>
<td>8.9591</td>
<td>LAL &amp; LATO</td>
<td>1.8144</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LATO</td>
<td>7.1446</td>
<td>LATO &amp; RFA</td>
<td>2.4853</td>
<td>HAL &amp; LATO</td>
<td>4.8666*</td>
</tr>
<tr>
<td>RFA</td>
<td>4.6594</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates significant

Critical Difference
The averages of data were arranged in descending order so that the average differences among the consecutive data averages could be determined. Comparison of these average differences with the C.D. were computed and presented in table-5. The table reveals that running mechanics KE, HE, HF, KF, AATO, SR, SE, AAL, and HATO play a significant role in long distance running while running mechanics KAL, SF, HAL, LAL, LATO and RFA have no significant effects in long distance running. While KAL has greater average than the HE but C.D. analysis reveals that HE is significant. So KAL will also play a significant role in long distance running. For this, we find the average difference of KAL with the next significant variable in average descending order (i.e., HE). But when we compared running mechanics KAL with running mechanics HF we find that the running mechanics KAL differ significantly from running mechanics HF. Similarly when we compared running mechanics SF with running mechanics LAL, we find that the running mechanics SF differ significantly from running mechanics LAL. Also we find that by comparing running mechanics HAL with running mechanics LATO. The running mechanics HAL differ significantly from running mechanics LATO.
Table-5 revealed that the KE, KAL, HE, HF, KF, AATO, SR, SE, AAL, HATO, SF and HAL, play significant role in long distance running while running mechanics LAL, LATO and RFA have no significant effects in long distance running mechanics.
(c) KINEMATIC DESCRIPTION OF SHORT DISTANCE RUNNING MOTION

Table – 6

ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1107054</td>
<td>14</td>
<td>79075.26447</td>
<td>922.167</td>
</tr>
<tr>
<td>Within Groups</td>
<td>28297.29</td>
<td>330</td>
<td>85.7493709</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1135351</td>
<td>344</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test for short distance running mechanics from ANOVA Single Factor

Result of the ANOVA (Table-6) revealed that calculated value of $F=922.167$ is highly significant. Hence it can be concluded that several running mechanics in short distance running differ significantly. Since these running mechanics differ significantly, we proceed further to find out which of the running mechanics means in short distance running differ significantly. The "Critical Difference" (C.D.) has been calculated to find the significant difference between means of different kinematic variables considered in short distance running mechanics, i.e., the least difference between any two running mechanic’s means in short distance running to be significant. The value of C.D=5.35
Table 7

<table>
<thead>
<tr>
<th>Abbreviation of kinematic variable</th>
<th>Average</th>
<th>Abbreviation of kinematic variable</th>
<th>Average Difference</th>
<th>Abbreviation of kinematic variable</th>
<th>Average Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>KE</td>
<td>158.70</td>
<td>KE &amp; HE</td>
<td>2.52</td>
<td>KE &amp; HF</td>
<td>34.89*</td>
</tr>
<tr>
<td>HE</td>
<td>156.18</td>
<td>HE &amp; KAL</td>
<td>1.21</td>
<td>HE &amp; HF</td>
<td>32.37*</td>
</tr>
<tr>
<td>KAL</td>
<td>154.97</td>
<td>KAL &amp; HF</td>
<td>31.16*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HF</td>
<td>123.81</td>
<td>HF &amp; AAL</td>
<td>31.56*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAL</td>
<td>92.25</td>
<td>AAL &amp; KF</td>
<td>6.36*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KF</td>
<td>85.89</td>
<td>KF &amp; AATO</td>
<td>3.04</td>
<td>KF &amp; SR</td>
<td>13.21*</td>
</tr>
<tr>
<td>AATO</td>
<td>82.85</td>
<td>AATO &amp; SR</td>
<td>10.17*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>72.68</td>
<td>SR &amp; SE</td>
<td>5.36*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>67.32</td>
<td>SE &amp; HATO</td>
<td>48.09*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HATO</td>
<td>19.23</td>
<td>HATO &amp; HAL</td>
<td>7.85*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAL</td>
<td>11.38</td>
<td>HAL &amp; LAL</td>
<td>0.42</td>
<td>HAL &amp; SF</td>
<td>6.03*</td>
</tr>
<tr>
<td>LAL</td>
<td>10.96</td>
<td>LAL &amp; LATO</td>
<td>1.77</td>
<td>LAL &amp; SF</td>
<td>5.61*</td>
</tr>
<tr>
<td>LATO</td>
<td>9.19</td>
<td>LATO &amp; SF</td>
<td>3.84</td>
<td>LATO &amp; RFA</td>
<td>5.69*</td>
</tr>
<tr>
<td>SF</td>
<td>5.35</td>
<td>SF &amp; RFA</td>
<td>1.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFA</td>
<td>3.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* indicates significant

Critical Difference
The averages of data were arranged in descending order and the average differences among the consecutive data averages could be determined. Comparison of these average differences with the C.D. were computed and presented in table-7. The table reveals that running mechanics KAL, HF, AAL, AATO, SR, SE and HATO play a significant role in short distance running while running mechanics KE, HE, KF,HAL, LAL, LATO, SF and RFA do not have any significant effect in short distance running. While KE and HE have greater average than the KAL but C.D. analysis reveals that KAL is significant. So KE and SE will also play a significant role in short distance running mechanics. For this, we find the average differences of KE and HE with the next significant variable in average descending order (i.e., KAL). But when we compared running mechanics KE with running mechanics HF, we find that the running mechanics KE differ significantly from running mechanics HF. And the comparison of running mechanics HE with running mechanics HF, we find that the running mechanics HE differ significantly from running mechanics HF. Similarly, we find that by comparing running mechanics KAF with running mechanics SR, the running mechanics KAF differ significantly from running mechanics
SR. And in the comparison of running mechanics HAL with running mechanics SF, we find that the running mechanics HAL differ significantly from running mechanics SF. And the comparison of running mechanics LAL with running mechanics SF, we find that the running mechanics LAL differ significantly from running mechanics SF. And the comparison of running mechanics LATO with running mechanics RFA, we find that the running mechanics LATO differ significantly from running mechanics RFA.

Table-7 revealed that the KE, HE, KAL, HF, AAL, KF, AATO, SR, SE, HATO, HAL, LAL and LATO are significant and thus play a significant role in short distance running while running mechanics SF and RFA are insignificant and have no significant effects in short distance running mechanics.
(d) DESCRIPTION OF KINEMATIC VARIABLES OF RUNNING

The focus of the study in the kinematic variables obtained through analytical software and was mainly projected in the running motion of the athlete’s limb (e.g. hip, knee, heel and ankle) and shoulder of the body. These data of kinematic variables of athletes were taken during competition and not in lab setting, and were calculated at the important events of athlete’s long distance and short distance running Take off phase and Landing Phase. Apart from this human body kinematics, the stride length and stride width of the athlete during the competition long distance and short distance running events were also analyzed in the one cycle Phase. For clarity and better understanding of the results discovered in this area, it has been subdivided into the following headings:

i. Heel angle at landing (HAL)
ii. Heel angle at take off (HATO)
iii. Leg angle at landing (LAL)
iv. Leg angle at take off (LATO)
v. Rear foot angle (RFA)
vi. Knee Extension (KE)

vii. Knee Flexion (KF)

viii. Knee angle at landing (KAL)

ix. Hip Extension (HE)

x. Hip Flexion (HF)

xi. Ankle angle at landing (AAL)

xii. Ankle angle at take off (AATO)

xiii. Shoulder Extension (SE)

xiv. Shoulder Flexion (SF)

xv. Shoulder rotation (SR)

For comparison of the means of running mechanics for both running (i.e., short distance and long distance), we applied normal test and used level of significant 0.05. The results are as follows:
<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>11.38</td>
<td>8.57</td>
</tr>
<tr>
<td>Long Distance</td>
<td>12.01</td>
<td>18.09</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Heel Angle at Landing

|t|cal|= 0.61

t₀.₀₅₄₉=1.96 at 5%.

Since |t|cal is less than t₀.₀₅₄₉ therefore this shows that the means do not differ significantly at 5% level.

Table-8 reveals that the comparison of means of heel angle at landing of long distance and short distance running mechanics has shown |t|cal. Value (0.61) is less than the t₀.₀₅₄₉ value (1.96) at 5% level. This statistical finding exhibits that the heel angle of long distance and short distance running mechanics at landing is not significant and hence does not influence long distance and short distance running mechanics.
Table-9

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square ($s^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>19.23</td>
<td>72.78</td>
</tr>
<tr>
<td>Long Distance</td>
<td>19.01</td>
<td>47.78</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Heel Angle at Take off

$|t|_{cal} = 0.10$

$t_{05.49} = 1.96$ at 5%.

Since $|t|_{cal}$ is less than $t_{05.49}$ therefore this shows that the means do not differ significantly at 5% level.

Table-9 reveals that the comparison of means of heel angle of long distance and short distance running mechanics at take off has shown $|t|_{cal}$ value (0.10) is less than the $t_{05.49}$ value (1.96) at 5 % level. This statistical finding exhibits that the heel angle at take off is not significant and hence does not influence long distance and short distance running mechanics.
<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>10.96</td>
<td>20.08</td>
</tr>
<tr>
<td>Long Distance</td>
<td>8.96</td>
<td>5.81</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Leg Angle at Landing

$|t|_{cal} = 2.04$

$t_{0.05,49} = 1.96$ at 5%.

Since $|t|_{cal}$ is greater than $t_{0.05,49}$, therefore this shows that the means exist differ significantly at 5% level.

Table-10 reveals that the comparison of means of leg angle at landing of long distance and short distance running mechanics has shown $|t|_{cal}$ value (2.04) is greater than the $t_{0.05,49}$ value (1.96) at 5% level. This statistical finding exhibits that the leg angle of long distance and short distance running mechanics at landing differ significantly and hence influences long distance and short distance running mechanics.
Table-11

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>9.19</td>
<td>24.39</td>
</tr>
<tr>
<td>Long Distance</td>
<td>7.14</td>
<td>5.81</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Leg Angle at Take off

\[|t|_{cal} = 1.89\]

\[t_{0.05,49} = 1.96\] at 5%.

Since \(|t|_{cal}\) is less than \(t_{0.05,49}\), therefore this shows that the means do not differ significantly at 5% level.

Table-11 reveals that the comparison of means of leg angle at take off of long distance and short distance running mechanics has shown \(|t|_{cal}\) value (1.89) is less than the \(t_{0.05,49}\) value (1.96) at 5% level. This statistical finding exhibits that the leg angle of long distance and short distance running mechanics at take off is not significant and hence does not influence long distance and short distance running mechanics.
Table-12

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>3.50</td>
<td>6.62</td>
</tr>
<tr>
<td>Long Distance</td>
<td>4.66</td>
<td>3.99</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Rear Foot Angle

|t|cal|= 1.81

t.05,49 =1.96 at 5%.

Since |t|cal is less than t.05,49, therefore this shows that the means do not differ significantly at 5% level.

Table-12 reveals that the comparison of means of rear foot angle of long distance and short distance running mechanics has shown |t|cal value (1.81) is less than the t.05,49 value (1.96) at 5% level. This statistical finding exhibits that the rear foot angle of long distance and short distance running mechanics is not significant and hence does not influence long distance and short distance running mechanics.
Table-13

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>158.69</td>
<td>37.99</td>
</tr>
<tr>
<td>Long Distance</td>
<td>158.89</td>
<td>25.89</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Knee Extension

|t|cal = 0.13
t.05,49 = 1.96 at 5%.

Since |t|cal is less than t.05,49, therefore this shows that the means do not differ significantly at 5% level.

Table-13 reveals that the comparison of means of knee extension of long distance and short distance running mechanics has shown |t|cal value (0.13) is less than the t.05,49 value (1.96) at 5% level. This statistical finding exhibits that the knee extension of long distance and short distance running mechanics is not significant and hence does not influence long distance and short distance running mechanics.
Table-14

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>85.89</td>
<td>281.19</td>
</tr>
<tr>
<td>Long Distance</td>
<td>91.56</td>
<td>338.95</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Knee Flexion

|t|cal| = 1.14

\( t_{0.05,49} = 1.96 \) at 5%.

Since \(|t|_{\text{cal}}\) is less than \( t_{0.05,49} \), therefore this shows that the means do not differ significantly at 5% level.

Table-14 reveals that the comparison of means of knee flexion of long distance and short distance running mechanics has shown \(|t|_{\text{cal}}\) value (1.14) is less than the \( t_{0.05,49} \) value (1.96) at 5% level. This statistical finding exhibits that the knee flexion of long distance and short distance running mechanics is not significant and hence does not influence long distance and short distance running mechanics.
Table-15

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>154.97</td>
<td>55.00</td>
</tr>
<tr>
<td>Long Distance</td>
<td>153.30</td>
<td>81.22</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Knee Angle at Landing

\[ |t|_{cal} = 0.71 \]

\[ t_{0.05,49} = 1.96 \text{ at } 5\%. \]

Since \[ |t|_{cal} \] is less than \[ t_{0.05,49} \], therefore this shows that the means do not differ significantly at 5% level.

Table-15 reveals that the comparison of means of knee angle at landing of long distance and short distance running mechanics has shown \[ |t|_{cal} \] value (0.71) is less than the \[ t_{0.05,49} \] value (1.96) at 5% level. This statistical finding exhibits that the knee angle of long distance and short distance running mechanics at landing is not significant and does not influence long distance and short distance running mechanics.
Table-16

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square ( $s^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>156.18</td>
<td>152.90</td>
</tr>
<tr>
<td>Long Distance</td>
<td>150.37</td>
<td>124.59</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Hip Extension

$|t|_{cal} = 2.15$

$t_{0.05,49} = 1.96$ at 5%.

Since $|t|_{cal}$ is greater than $t_{0.05,49}$, therefore this shows that the means exist differ significantly at 5% level.

Table-16 reveals that the comparison of means of hip extension of long distance and short distance running mechanics has shown $|t|_{cal}$ value (2.15) is greater than the $t_{0.05,49}$ value (1.96) at 5% level. This statistical finding exhibits that the hip extension differ significantly and influences long distance and short distance running mechanics.
Table-17

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square ($s^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>123.81</td>
<td>103.71</td>
</tr>
<tr>
<td>Long Distance</td>
<td>119.04</td>
<td>141.70</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Hip Flexion

$|t|_{cal} = 1.52$

$t_{0.05,49} = 1.96$ at 5%.

Since $|t|_{cal}$ is less than $t_{0.05,49}$, therefore this shows that the means do not differ significantly at 5% level.

Table-17 reveals that the comparison of means of hip flexion of long distance and short distance running mechanics has shown $|t|_{cal}$. value (1.52) is less than the $t_{0.05,49}$ value (1.96) at 5% level. This statistical finding exhibits that the hip flexion of long distance and short distance running mechanics is not significant and hence does not influence long distance and short distance running mechanics.
Table-18

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>92.24</td>
<td>43.78</td>
</tr>
<tr>
<td>Long Distance</td>
<td>32.29</td>
<td>77.71</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Ankle Angle at Landing

$|t|_{cal} = 26.97$

$t_{0.05,49} = 1.96$ at 5%.

Since $|t|_{cal}$ is greater than $t_{0.05,49}$, therefore this shows that the means exist differ significantly at 5% level.

Table-18 reveals that the comparison of means of ankle angle at landing of long distance and short distance running mechanics has shown $|t|_{cal}$ value (26.97) is greater than the $t_{0.05,49}$ value (1.96) at 5% level. This statistical finding exhibits that the ankle angle of long distance and short distance running mechanics at landing differ significantly and influence long distance and short distance running mechanics.
Table-19

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square ( $s^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>82.85</td>
<td>108.38</td>
</tr>
<tr>
<td>Long Distance</td>
<td>81.45</td>
<td>111.44</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Ankle Angle at Take off

$|t|_{cal} = .46$

$t_{0.05,49} = 1.96$ at 5%.

Since $|t|_{cal}$ is less than $t_{0.05,49}$, therefore this shows that the means do not differ significantly at 5% level.

Table-19 reveals that the comparison of means of ankle angle at take off of long distance and short distance running mechanics has shown $|t|_{cal}$ value (.46) is less than the $t_{0.05,49}$ value (1.96) at 5% level. This statistical finding exhibits that ankle angle at take off of long distance and short distance running mechanics is not significant and hence does not influence long distance and short distance running mechanics.
Table-20

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square ( s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>67.32</td>
<td>202.49</td>
</tr>
<tr>
<td>Long Distance</td>
<td>59.89</td>
<td>98.59</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Shoulder Extension

\[ |t|_{cal} = 2.20 \]

\[ t_{.05,49} = 1.96 \text{ at } 5\%. \]

Since \(|t|_{cal}\) is greater than \(t_{.05,49}\), therefore this shows that the means exist differ significantly at 5% level.

Table-20 reveals that the comparison of means of shoulder extension of long distance and short distance running mechanics has shown \(|t|_{cal}\) value = (2.20) is greater than the \(t_{.05,49}\) value (1.96) at 5% level. This statistical finding exhibits that shoulder extension of long distance and short distance running mechanics differ significantly and influences long distance and short distance running mechanics.
Table-21

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>5.35</td>
<td>2.48</td>
</tr>
<tr>
<td>Long Distance</td>
<td>14.02</td>
<td>28.49</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Shoulder Flexion

\[|t|_{\text{cal}} = 7.52\]
\[t_{05.49} = 1.96\text{ at }5\%.

Since \(|t|_{\text{cal}}\) is greater than \(t_{05.49}\), therefore this shows that the means exist differ significantly at 5% level.

Table-21 reveals that the comparison of means of shoulder flexion of long distance and short distance running mechanics has shown \(|t|_{\text{cal}}\) value = (7.52) is greater than the \(t_{05.49}\) value (1.96) at 5% level. This statistical finding exhibits that shoulder flexion of long distance and short distance running mechanics differ significantly and influences long distance and short distance running mechanics.
Table-22

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean</th>
<th>Sum of square (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short distance</td>
<td>72.68</td>
<td>169.48</td>
</tr>
<tr>
<td>Long Distance</td>
<td>73.90</td>
<td>2608.28</td>
</tr>
</tbody>
</table>

Descriptive Statistics of Shoulder Rotation

\[ |t_{cal}| = 0.11 \]

\[ t_{0.05,49} = 1.96 \text{ at 5\%}. \]

Since \(|t_{cal}| < t_{0.05,49}\), therefore this shows that the means do not differ significantly at 5\% level.

Table-22 reveals that the comparison of means of shoulder rotation of long distance and short distance running mechanics has shown \(|t_{cal}| = 0.11\), value \(|t_{cal}| = 0.11\) is less than the \(t_{0.05,49} = 1.96\) value at 5\% level. This statistical finding exhibits that shoulder rotation of long distance and short distance running mechanics is not significant and hence does not influence long distance and short distance running mechanics.
(e) DESCRIPTION OF STRIDE LENGTH
AND STRIDE WIDTH

To test the joint effect of stride length and stride width on short distance running and long distance running on performance timings of the subjects, the F-test has been applied. For applying F-test we assume \( r_1 = \) performance timing of the subject (sec.), \( r_2 = \) stride length (m) and \( r_3 = \) stride width (m). The F-test has revealed joint effect of stride length and stride width have significant effect on short distance running while joint effect of stride length and stride width have no significant effect on long distance running at 5%. The detailed results of the F-test are as below.

For long distance running

\[
\begin{align*}
r_{12} &= -0.20 \\
r_{23} &= -0.09 \\
r_{13} &= -0.05 \\
R^2_{123} &= \frac{r_{12}^2 + r_{13}^2 - 2r_{12}r_{13}r_{23}}{1 - r_{23}^2} \\
H_0 : \nu_{123} &= 0 \quad \text{(there is no significant)} \\
H_1 : \nu_{123} &> 0 \quad \text{(there is significant)}
\end{align*}
\]
Result of Long distance running

\[ F = 0.52 \]
\[ F_{0.05,2,25} = 3.38 \]

Since the calculated \( F \) is less than tabulated \( F \),
Therefore the result is not significant at 0.05 level of significant.

The F-test result reveals that the joint effect of stride length and stride width does not play a significant role in long distance running mechanics.

For Short distance running

\[ r_{12} = -0.86 \]
\[ r_{23} = 0.67 \]
\[ r_{13} = -0.63 \]

\[ R^2_{1, 23} = \frac{r^2_{12} + r^2_{13} - 2r_{12}r_{13}r_{23}}{1 - r^2_{23}} \]

\( H_0 : t_{1,23} = 0 \) (there is no significant)
\( Vs \ H_1 : t_{1,23} > 0 \) (there is significant)
Result of Short distance running

\[ F = 45.55 \]

\[ F_{0.05;2,20} = 3.49 \]

Since the calculated F is greater than tabulated F,

Therefore the result is significant at 0.05 level of significant.

The F-test result reveals that the joint effect of stride length and stride width play a significant role in short distance running mechanics.
CHAPTER-V
DISCUSSION

The general objective of the study was to identify running mechanics due to the systematic variation in running style. Specifically, this study examined the effects of running mechanics on major angles of the running segments and also joint effect of stride length and stride width on long distance and short distance. The present study also sought to identify which running mechanic(s) contribute most significantly to the long distance and short distance running during the All India Athletic Competition.

In the present study the sequence of the running motion has been studied on two phases of running (i.e., landing phase and take off phase).

The limitation of this study was two dimensional (2D). However, various investigators have studied running motion in both two dimension (2D) as well as three dimension (3D). For example in sprinting, the kinematics and kinetics are also well documented but are usually obtained with a 2D analysis, with the exception of
Novacheck's (1995) study in which a 3D approach was used. The appropriateness of 2D instead of a 3D analysis for the sprinting motion has not been studied and is of importance for future research in sprinting.

The result of the study indicated that there were some significant differences in the running mechanics. Heel angle at landing and take off phase (two phases) of running in both short distance and long distance running was significant. The more supinated the foot is at footstrike, the greater the angle of the heel with the vertical, the greater the movement that must occur for the foot to go flat. Cavanagh and Lafortune (1980) suggested that 90% of the population use a heel-to-toe landing pattern. However during sprinting many of these runners will change to a toe only (forefoot) strike.

Hamill et al. (2000) has also reported that the energy absorption and shock attenuation have been shown to be superior in a forefoot landing compared to a heel strike landing in both running. Gollhoher et al. (1987) found peak force and rate of force development to decrease and contact time to increase over 100 cycles. During running to fatigue. Verbitsky et al. (1998) found
shank accelerations to increase during the run. Increased shank accelerations may be indicative of increased leg stiffness during heel strike and associated with increased impact forces.

The result of the study indicated that Leg angle of two phases in short distance running plays a significant role while it does not play a significant role in long distance running. In shorter distance running, vigorous thrusting action of the feet and powerful arm swing play an important role in the movements. But these actions are reduced in long distance running. This distinction is due to the fact that in short distances, speed is essential and needs powerful thrusting of arm and legs whereas in long distance running, movements are to be maintained for longer periods and muscular effort has to be reduced as far as possible. Williams and Ziff (1991) have mentioned since maximal pronation is related to leg angle during support, this might put pronation into unacceptable ranges and cause the runner to effect some type of change to return leg position to more acceptable positions.

The result of the study indicated that knee flexion, knee extension, hip flexion and hip extension at two phases of running and knee angle at landing in both short and long distance running
were significant. In running, marching action performed at a running pace, where the legs alternate from a position of support to a position of hip and knee flexion. In support, the hip and knee should be fully extended with the ankle plantarflexed. Following support, there is a simultaneous and rapid flexion of the hip and knee, where the thigh is brought to horizontal and the foot is brought up to the buttocks with the ankle dorsiflexed. Next, the hip and knee rapidly extend, and the ankle plantarflexes for ground contact. The mechanics of the upper body should resemble those of sprinting with a slight forward body lean and a vigorous arm action with the elbows flexed. There were significant differences of knee extension and knee flexion, hip extension and hip flexion for short distance running and long distance running. Williams and McClay (1998) reported that high arch runners exhibited shorter contact times and less vertical displacement of the center of mass, which would account for the increased stiffness.

The actions of knee and ankle joints compensates for the flexion-extension motion of the hip. At extreme flexion of the hip (at heel-strike and toe-off) the knee is extended, while during knee flexion and ankle dorsiflexion help to reduce the effective height of
the body. Bohn and Attermeyer (1998) reported that the main differences between the varied velocities and acceleration of athletes became evident in the velocities and the accelerations of the hip and the knee-angles. Particularly variable forces in the direction of movement (retarding stroke) came forward between the different athletes. Gladys and Scott (1970) have also reported that in the running, the knee is flexed so that the heel is near the thigh; this means a shortened lever arm, which permits greater speed.

The effect of muscular fatigue on stride rate was observed only during the first minute of running following quadriceps fatigue. There was no effect of muscular fatigue (either quadriceps or hamstrings) on maximal knee flexion during the support or swing phase of running.

Although decreases in joint excursions of hip flexion, knee flexion and ankle dorsiflexion could account for a decreased center of mass excursion, only knee flexion excursion was significantly lower (p=0.007) in the high arc group by 4.2 degrees when compared to the low arch group. The decrease in contact times in the high arch group may be due to smaller center of mass and knee joint excursion resulting in a more efficient stretch-shortening cycle
and a quicker return of energy (McMahon and Greene, 1979). The increase in hip flexor moment reflects the large horizontal component of ground reaction force and large amount of positive mechanical work (Cavagna et al. 1971) that occurs as a runner accelerates early in a sprint. The large hip extensor force contributes to increased mechanical power developed at the hip, which is likely to be transmitted to more distal limb joints in a temporally coordinated manner (Jacobs et al., 1992), in order to facilitate more rapid acceleration of a sprinter.

A computer simulation of the leg motion of an individual during sprinting was developed. The hip angle versus time and the knee angle versus time relationships were reported by Mann et al. (1986). Skilled sprinters were used to determine the hip, knee and ankle joint centers during one sprint cycle for the 2D condition. The ranges of hip adduction / abduction and internal and external was superimposed on the 2D motion to obtain a 3D sprinting motion.

The result of the study indicated that shoulder rotation and shoulder extension were significant in short distance and long distance running but shoulder flexion in short distance was insignificant while in long distance running, shoulder flexion was
significant. In long distance running, the body weight should be
smoothly transmitted from one foot to the other-gliding action, in
contrast to the bounding action of the sprinter. In this style of
running, foot thrust should be more or less eliminated, so that the
need for side checking action of the arms is considerably reduced.
To maintain the steady forward glide of the efficient long distance
runner, arm movements must take place in the shoulder joints, with
practically no movement of the shoulder blades. Speed walkers
must avoid the bounding action of the runner by landing with the
heel of one foot before the toes of the other foot leave the ground.
In adhering to this rule, speed walkers more or less eliminate the
tendency towards the side of the body, which necessitates the
checking cross-swing of a running arm action. For this reason, the
forearm is fully flexed and the amount of movement in the shoulder
joint is less than in speed running. Shoulder range of motion was
found to be significantly greater for sprinting, as was shoulder
flexion angular velocity.

Bohn and Attermeyer (1998) also reported that very different
rotary actions of the shoulders to balance the hip action were
observed. Williams and Ziff (1991) has investigated that if shoulder
rotation must remain in its increased state, then other alteration could be made to change to movements of the lower leg.

The result of the study indicated that the rear foot angle in both short distance and long distance running was insignificant. Changes to the angle of the lower leg at contact as a result of the stride width conditions did not cause the runner to change the relationship between the leg and heel at foot strike, as indicated by the lack of significant differences in rear foot angle at foot strike.

Williams and Ziff (1991) have investigated changes in muscles activation in the hip-trunk region. Thus variables, such as step width and rearfoot motion, could show no changes as a result of increasing shoulder rotation. The changes in rearfoot motion caused by the step width alterations may have been too extreme to allow acceptable rear foot angle to be maintained. No effective way was found to prevent leg angles from changing markedly, and the only way to reduce pronation in such a case would exert much greater than normal force from the muscles that affect inversion and eversion of the foot. Because these muscles are relatively weak, this was probably not a feasible alternative and the runners had to endure the changes in rearfoot motion.
The result of this study indicated that the joint effect of the stride length and stride width was significant in short distance running while the joint effect of the stride length and stride width was not significant in long distance running. Increased speed is the characteristic of running and achieved by increased horizontal force when it is impossible to swing the leg forward before the other finishes its drive, the body is pushed hard in its forward and upward direction. The length of the stride is longer as a result of progress during non-support and of the greater angle of the driving leg. The greater angle of backward gives an increased forward component. The body weight rides lower so supporting knee bends more as the body passes over it.

Monica and Kokubun (1998) observed that the stride length was sufficient to compensate the decreases in stride rate, thus maintaining the velocity, only when fatigue was not severe.

Derrick and Hamill (1996) reported that the energy absorbed by the hip, knee and ankle during non-fatigued running was dependent on stride rate. Subjects ran at a constant speed, and changed stride rate to higher or lower rates compared to the preferred stride rate. Derrick, et al., 1996 was reported that the
level of impact was lower and the energy absorbed by the lower extremity was lower during the higher stride rates. The energy absorbed by each joint was dependent on stride rate relative to the preferred stride rate. At stride rates greater than preferred, most of the energy was absorbed by the knee and ankle. At stride rates lower than the preferred, most of the energy was absorbed by the knee.

Hay (1993) described that in running events, the primary objective of an athlete is to cover a set distance in the least possible time. Running speed depends on stride length and stride rate/frequency. Vaughan, (1984); Hay, (1993), The running speed increases when stride length remains constant and stride rate increases. Similarly, if stride rate remains constant then stride length increases resulting in increase in speed. Enoka, (1994), the stride length is again related with the range of motion about a joint (quantity) and the pattern of displacement (quality). As the runner goes from a walk to a run the angular displacement about the knee joint increases. Vaughan, (1984) stance phase of gait includes both flexion and extension during walking and running but only extension in sprint. Likewise, the range of motion about both
shoulder and elbow joints also increases as a person goes from walk to a sprint.

The result of this study indicated that the ankle angle in two phases of running on both short and long distance was significant. Landing with the foot plantarflexed functionally lengthens the lower extremity. Increasing knee flexion at foot strike is one way in which to functionally shorten the limb to compensate for the plantarflexed ankle. In addition, inversion is mechanically linked with planterflexion of the ankle and therefore greater in a forefoot strike pattern.

Observations of Gollhofer et al. (1987) is that for the upper-extremity, runners with increased foot contact time tended to have decreased peak active forces. The same runners also increase step time. These changes may be associated with the generation of vertical impulse during foot contact. With reduced force production, contact time must be increased to provide a similar vertical impulse.

The relative contribution of the ankle joint to energy absorption was found to be greater in a forefoot jump landing compared to a heel strike landing (Kovács et al., 1999). During the propulsive phase of running, it has been suggested (Hamill et al.,
that the ankle is a better energy generator following a forefoot landing than following a heel strike landing.

A possible direction to vary rearfoot motion is the specific variation of running style as described by Williams and Ziff (1991). Though significant effects on pronation were achieved by varying step width ground reaction forces and acceleration of the shank. Analytical approaches suggest (Denoth, 1986) a direct relationship between impact forces and rearfoot pronation. To ascertain if variations in running style that alter the pronatory movement of the foot lead to expected changes in passive forces or tibial acceleration, kinematic and kinetic parameters were sampled synchronously.

In running the angle of the body is more forward in sprint running than in long distance running but, as in long distance running, the forward lean should be from the ankles so that the trunk is kept almost in line with driving leg. This forward angle reduces the pressure against the body and puts the center of gravity more ahead of the driving foot enlarging the forward component of the propulsive force. Also, the forward angle combined with additional bending of the supporting knee as the body passes over
it, reduces the up and down bobbing of the body which would occur with the greater propulsive force if the angle of the body were more upright.
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Track and field is the basic sport for all and so it has assumed greater importance in recent years. The physical educationists, coaches and sports scientists of today are becoming more aware of the scientific informations related to the athletes and potential proficiency in sports. Research in Nutrition, Psychology, Biochemistry and Physics have contributed much to the improvement of performance level of athletes in various competitive sports today.

Several researches have been conducted on the human motion in restricted conditions to the selected subjects/participants in biomechanical laboratory with some given instructions. But athletes cannot run with restricted conditional approach during the competition. Therefore, to be more practical-oriented, the researcher has taken the running mechanics of athletes during short distance (sprints) and long distance running in competitive conditions (during All India Athletic Meet), where all athletes were free from any restriction in their running styles.

The purpose of this study was to identify the running mechanics due to the systematic variation in running style.
In order to achieve this purpose, fifty All India level male athletes (long distance runners and short distance runners) were selected as subjects from first lane on synthetic track of the All India Athletic Meet held at JRD Tata Complex Jamshedpur, Feb 28 to March 1, 2004.

The subject's anthropometric measurements like body weight, height, leg length, thigh length, lower leg length and shoulder width were recorded. These measurements were recorded by using the standard anthropometric kit, available in the department of Physical Health and Sports Education AMU, Aligarh. The different variations of running as short distance (sprints) and long distance were considered, and it has been inversely proved that the running style differs in short distance and long distance.

The ground contact by heel of the running foot and take off was selected as the beginning and ending of the running sequence respectively. The sequence of the running motion was divided into two phases (a) take off phase and (b) landing phase.

To evaluate the running mechanics of long distance runners and short distance runners, the subject's running motion were
recorded using two Synchronised Panasonic F15 S-VHS video cameras in a field setting. The videotapes were used TDK E180 Extra Grade videotapes, Panasonic zooming lenses and two video cameras rigid tripod stands etc. The sampling rates of the video cameras were 50 fields per second (25 frames per second). The shutter of the cameras was fixed with a high speed (1/1000th of a second) in order to eliminate the blurring effect while video recording.

First camera position was on field area of track and field, which was perpendicular to the sagittal plane and parallel to the mediolateral axis. Camera optical axes perpendicular to the sagittal plane for measuring the stride length, shoulder angles (shoulder flexion and shoulder extension and shoulder rotation), knee angles (knee flexion, knee extension and knee angle at landing), hip angle (hip flexion, hip extension) and ankle angle (ankle angle at landing and ankle at take off).

The first camera was positioned at 18-metres on the field from the center of first lane and 45-metres from the starting line of the 100metre sprint. Once the camera was thus positioned, the zoom on the camera was adjusted in order to see that the four selected short
distance runner’s stride and long distance runners stride respectively of the whole running motion were recorded into video tape.

The second camera was positioned 2 meter behind from starting line of the 100metre sprint. The camera optical axes was perpendicular on the frontal plane for measuring the rear foot motion (rear foot angle, heel angle at landing and heel angle at take off), leg angles (leg angle at landing and leg angle at take off) and stride width.

The running mechanics of both short distance and long distance were recorded from same video cameras point (i.e. no change in cameras position). For long distance, video of the running motion was recorded during final lap of 5000m race (at 4950m).

Throughout the day at the All India Athletic Meet, the video recording of the running motions was conducted. The video-cassette was converted into compact disc (CD) through video capture card, which was used to convert movies of VHS & DV cam. to CD & DVD into computer system, loaded into personal computer (PC), then the full-scale CD data were processed for editing so as to acquire only the required videography. It was played with the help
of computer Chinese software (SthSDVD) to make a number of slides. Slides show on computer monitor screen with the help of mosaic roll up. Final positions of each selected subject's slides were obtained on the screen by trail and retrail method. Editing and saving all selected slides of the final position of each runner (the selected subject) from the mosaic roll up were transferred (copy paste) and pasted into a new frame of Photo Studio software with appropriate dimensions.

The various joint axis were marked on the finally selected position slide as a reference point associated with each segment though pen tool with appropriate distinguishing colour. Colours were chosen by the researcher separately for separate selected subject to avoid the identification hindrances among subjects during analysis of running mechanics. Further the "Elgon" or stick figure of each phase, that is the movement of landing phase and take off phase during the running were constructed by the joint-point method for all selected subjects with the help of dimension tool of the Corel-9 software.

The following softwares were used to analyse running mechanics from the recorded data: (a) Chinas Software (SthSDVD)
was used to find the frame rate and data was manually digitised for each video field using Chines software program. Frames were digitised sequentially one frame at a time for each trial, (b) Photo Studio was used for the colours available for axis marking, (c) Corel-5 was used for selection of final position frame of the subject with the help of mosaic roll up, (d) Corel-9 was used to set the distance between grid lines, to measure angles of different body segments with the help of freehand tools of the same software and also used to draw elgon (stick figure), (e) Link MPEG Player was used to calculate the time of the runner’s stride length and (f) SPSS Software and office Excel was used for the statistical analysis.

Thereafter to determine the running mechanics on both Long distance running and short distance running, Analysis of Variance (ANOVA) was used. Critical Difference (C.D) was applied to find out whether the differences of the paired means of running mechanics were significant in both long distance running and short distance running. For comparing means of running mechanics for both events (i.e. long distance running and short distance running.), we applied student’s t-test. The level of confidence was set at .05.
The result of this study indicated that the Knee Extension, Knee Angle at Landing, Hip Extension, Hip Flexion, Knee Flexion, Ankle Angle at Take Off, Shoulder Rotation, Shoulder Extension, Ankle Angle at Landing, Heel Angle at Take Off, Shoulder Flexion and Heel Angle at Landing play significant role in both long distance and short distance running mechanics while running mechanics Rear Foot Angle do not play significant role in both long distance and short distance running mechanics. And the Shoulder Flexion plays a significant role in short distance running mechanics. But it does not play any significant role in long distance running mechanics. Leg Angle at Landing and Leg Angle at Take Off are significant, and thus play significant role in short distance running but they do not play any significant role in long distance mechanics.

The joint effect of Stride Length and Stride Width play a significant role in short distance running but they do not play any significant role in long distance running.

The comparison of means of Leg angle at Landing, Hip Extension, Ankle angle at Landing, Shoulder Extension and Shoulder Flexion were significant in long distance running and short distance running. But comparison of means of Knee Extension,
Knee Flexion, Knee angle at Landing, Hip Flexion, Ankle angle at Take Off, Shoulder Rotation, Heel angle at Take Off, Heel angle at Landing, Rear foot angle and Leg angle at Take Off were insignificant in long distance running and short distance running.

CONCLUSION

From the result of the study, the following conclusions have been drawn.

That the Knee Extension, Knee angle at Landing, Knee Flexion, Hip Extension, Hip Flexion, Ankle angle at Take Off, Ankle angle at Landing, Shoulder Rotation, Shoulder Extension, Shoulder Flexion, Heel angle at Take Off and Heel angle Landing play significant role in long distance running.

That the running mechanics Leg angle at Landing, Leg angle at Take Off and Rear Foot angle do not have any significant role in long distance running.

That the Knee Extension, Knee Flexion, Knee angle at Landing, Hip Extension, Hip Flexion, Ankle angle at Take Off,
Ankle angle at Landing, Shoulder Rotation, Shoulder Extension, Heel angle at Take Off and Heel angle Landing, Leg angle at Landing and Leg angle at Take Off are significant and thus play significant role in short distance running.

That the running mechanics Shoulder Flexion and Rear Foot angle are insignificant, do not play any significant role in short distance running.

That the joint effect of Stride Length and Stride Width play a significant role in short distance running mechanics.

That the joint effect of Stride Length and Stride Width does not play any significant role in long distance running mechanics.

That the comparison of means of Leg angle at Landing, Hip Extension, Ankle angle at Landing, Shoulder Extension and Shoulder Flexion were significant in long distance running and short distance running.

That the comparison of means of Knee Extension, Knee Flexion, Knee angle at Landing, Hip Flexion, Ankle angle at Take Off, Shoulder Rotation, Heel angle at Take Off, Heel angle Landing, Rear foot angle
and Leg angle at Take Off were insignificant in long distance running
and short distance running.

**RECOMMENDATIONS FOR FUTURE RESEARCH**

Based on the findings of study, the following recommendations
can be made:

1. Similar study can be undertaken for District, State and National
   level men and women athletes.

2. Investigation can be done for a similar study with different
   populations with sex and age groups at different skill levels as
   major considerations. This would provide invariant parameters for
   the study.

3. A similar study may be conducted in biomechanical laboratories
   set-up.

4. A similar study may be conducted in three dimensions (3D)
   instead of two dimension (2D).

5. A similar study may be conducted in curve running on cinder and
   synthetic tracks.
6. Similar study with sophisticated equipments and subjects of higher level, taking bigger sample and with greater number of variables may be conducted.

7. A similar study may be under-taken to analyse other events in running like Hurdle races, Relay races and Walk etc. and other games and sports.

8. A comparative study may be under-taken considering the short, middle and long distance.

9. A similar study may be conducted considering both kinematic and kinetic.

10. A similar study may be conducted to investigate separately the upper body kinematics and lower body kinematics during running on track.

11. Investigation can be done in the same study with different age group populations (i.e. comparison of old people with young people).
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APPENDIX
### Appendix A

**Kinematic Variables Raw Data's of Short Distance Runners**

<table>
<thead>
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<th>Subject</th>
<th>HAL</th>
<th>HATO</th>
<th>LAL</th>
<th>LATO</th>
<th>RFA</th>
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<th>KF</th>
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## Appendix A (Continue)

### Kinematic Variables Raw Data's of Short Distance Runners

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