A Biomechanical Analysis of the Effect Wear Patterns of Running Shoes Have on Kinematic Variables of the Lower Extremities

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A BIOMECHANICAL ANALYSIS OF THE EFFECT WEAR PATTERNS OF RUNNING SHOES
HAVE ON KINEMATIC VARIABLES OF THE LOWER EXTREMITIES

by

Audrey E. Randall

A Thesis
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A BIOMECHANICAL ANALYSIS OF THE EFFECT WEAR PATTERNS OF RUNNING SHOES HAVE ON KINEMATIC VARIABLES OF THE LOWER EXTREMITIES

Audrey E. Randall, M.A.
Western Michigan University, 1988

The purpose of the study was to investigate the relationship between wear patterns of running shoes and selected kinematic variables of the lower extremities. Statistical analyses were completed by using a case study design for two male subjects. Subjects were filmed for ten strides on six different sessions over a three-month period. A two-way ANOVA design, with repeated measures, evaluated the dependent variables: (a) footstrike, (b) midstance and (c) toeoff phases. The degree of change was determined by digitizing ten points on the body. A University of California, Los Angeles, BMDP2V statistical package was used to determine differences between means. A Tukey Significant Difference Test identified differences between times and conditions.

Results of the ANOVA revealed that Subjects One and Two exhibited significant changes in pronation/supination and Q-angle with respect to times. Further investigation showed an interaction effect between pronation/supination and Q-angle of the right foot between the footstrike and midstance phases for Subject One.
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Audrey E. Randall
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A biomechanical analysis of the effect wear patterns of running shoes have on kinematic variables of the lower extremities

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CHAPTER I

INTRODUCTION

Society has turned towards jogging as a means of offsetting the health hazards encountered by a largely inactive population. The widespread use of jogging as a means to achieve weight reduction and cardiorespiratory health has created an increase in running related injuries.

In examining the factors relating to running injuries it is evident that the runner can dramatically reduce his/her potential for injury. The literature indicated that the increase in running related injuries could be due to one or more of the following: high mileage, biomechanical abnormalities, impact forces, lack of flexibility and strength, improper running surfaces and shoes (Cavanagh, Valiant, and Misevich, 1984; Higdon, 1978; McKenzie, Clement, and Taunton, 1985; Nigg, 1985). Little can be done to alter the anatomical structure of the runner's body. However, the anatomy of a running shoe can be altered to effect a change in the occurrence of running injuries.

Since the introduction of the first pair of running shoes in 1865, great technological advances have been made. The most important has been the design and material properties of the running shoe. Leading the field is the development of ethylene vinyl acetate (EVA) which functions as an energy absorber in the midsole region and
the construction of heel flare and counters for rearfoot control.

It is extremely difficult to test the effect material and design of running shoes have on the runner's body. However, test procedures have been developed which purport to measure such variables. Among the most common procedures are: force plate studies, artificial athletes, Shore A and D Hardness tests, electrodynogram (EDG), the use of digitizing procedures of high speed film, and in vitro experiments utilizing a prosthetic foot.

While researchers have identified properties of the shoe which affect the degree of injury, little research has been conducted to measure the effect wear patterns of shoes have on running related injuries.

There exists a need to document the effect wear patterns of running shoes have on the mechanics of the foot during running. Further research is needed to determine the effect these imbalances have on the kinetics of the lower extremities during running.

Statement of the Problem

The problem of this study was to investigate the relationship between wear patterns of running shoes and selected kinematic variables of the lower extremities. The investigation involved a biomechanical analysis of the following subproblems.

1. The effect wear patterns of running shoes have on pronation/supination of the right and left legs.
2. The effect wear patterns of running shoes have on Q-angles of the right and left legs.

3. The effect wear patterns of running shoes have on leg angles of the right and left legs.

Purpose of the Study

The purpose of this investigation was to provide scientific information concerning the effect wear patterns of running shoes had on Q-angles, leg angles and pronation/supination of the runners' lower extremities. The findings of this investigation may have implications for (a) the length of time a given pair of shoes is worn for serious running, and (b) the construction of various parts of the shoe (e.g., material and design of the heel counter).

Need for the Study

A review of the literature indicated few, if any, studies measuring the effect of wear patterns on running mechanics. The literature did indicate that shoe companies have done extensive studies evaluating certain shoe properties which affect a runner's lower extremities. However, these studies have used mechanical devices which simulate running stress on shoes. The results of a study using human subjects could lead to the evolution of new designs to decrease stress on the lower limbs. Therefore, there exists a need to analyze the effect wear patterns have on selected kinematic variables of the lower extremities using human subjects.
Delimitations

The study was delimited to: (a) two male runners, aged 21 and 35 years; (b) a two dimensional cinematographical analysis; (c) two models of track shoes; (d) treadmill running; and (e) a case study data analysis design.

Limitations

The study was limited by the following: (a) shoe wear patterns were not consistent across the sample of subjects, (b) running speed was not controlled by the investigator, and (c) mileage varied for each subject during the filming session.

Assumptions

Assumptions for the study were: (a) subjects were injury free at the time of data collection, and (b) subjects kept accurate logs of their mileage between each filming session.

Hypotheses

The following is a list of hypotheses that were tested in this study.

1. As the wear patterns of running shoes increased, Q-angles of runners were affected.

2. As the wear patterns of running shoes increased, pronation/supination at the subtalar joint during the heel strike and midstance phase were affected.
3. As the wear patterns of running shoes increased, leg angles of runners were affected.

Definition of Terms

The following terms are pertinent to the understanding of this investigation.

1. **Critical Limit**: The stress limit beyond which the material will be permanently damaged (Nigg, Denoth, Kerr, Lueth, Smith and Stacoff, 1984).

2. **Heel Counter**: That part of the shoe which cradles the heel to prevent rotation and slippage (McKenzie, Clement, and Taunton, 1985).

3. **Footstrike**: The initial contact between the foot and ground (MacLellan, 1984).

4. **Load**: The external forces which act upon an object (Nigg, Denoth, Kerr, Lueth, Smith, and Stacoff, 1984).

5. **Midstance**: That phase of running which occurs when the center of gravity passes over the weight bearing foot (Cavanagh, Valiant, and Misevich, 1984).

6. **Pronation**: The rotation of the foot and leg inward (James, Bates, and Ostering, 1978).

7. **Q-Angle**: The angle formed between the inferior poles of the patella and the attachment of the patella tendon (Subotnick, 1979).

8. **Rearfoot Control**: The relative ability of a shoe to limit the amount or rate of subtalar joint pronation immediately following footstrike (McKenzie et al., 1985).
9. **Supination**: The rotation of the foot and leg outward (James et al., 1978).

10. **Valgus**: The degree a segment bends outward from the midline of the body (Olmstead, Wevers, Bryant, and Gouw, 1986).

11. **Varus**: The degree a segment turns inward toward the midline of the body (Olmstead et al., 1986).
CHAPTER II

REVIEW OF LITERATURE

The twentieth century is experiencing a new zest for physical activity. Studies which reveal the health benefits attained from aerobic exercise have prompted millions of people to dig up their old running shoes and "hit the road." Running has become the most visible form of aerobic activity. Cook, Kester, and Brunet (1985) estimated that "between 25 and 40 million Americans participate in some form of running" (p. 248). A study conducted by Nigg (1985) showed that "the number of joggers in the U.S. has reached 30 million which is more than 10 percent of the total population" (p. 367). Sadly, along with the increased popularity of jogging is an increase in running related injuries.

The literature revealed numerous studies which stated that 50%-70% of the 25-40 million runners experience some form of running related injury annually (Clarke, Frederick and Hamill, 1983; Nigg, 1985; Pagliano, 1978). The majority of injuries occur in the lower extremities, particularly at the knee joint. Nigg (1985) determined that the "most common injuries are reported to be knee injuries (25%), achillis tendonitis (18%), and shin splints (15%)" (p. 368). The literature suggested that injuries are the result of mechanical abnormalities and repetitive stress absorbed by the lower extremities during running. Further investigations have concluded that additional abnormalities may occur as the wear patterns of running
shoes increase. Pagliano (1978) reported that "the running shoe, has been the greatest boom to runners in preventing foot and leg injuries" (p. 64).

In 1967, 16 pairs of running shoes existed on the market. It is estimated that there are now several hundred pairs of different running shoes. Runners World (1984) identified the first shoe specifically designed for running to be the "Spencer shoe, which was low cut, all leather and had 4 spikes" (p. 83). The Spencer shoe was first sold in 1865. The first marathon shoe ever designed was introduced by Spalding and named "The Marathon Shoe." Since that time running shoe companies have recognized the need for a greater understanding of the effect material and design of running shoes have on the occurrence of running related injuries. Runners World (1984) lists the changes born out of this understanding as "revolutionary materials, enhanced stability and shock absorption" (p. 85). Currently running shoes are designed to provide stability and motion control through the use of varying last designs, heel counters, lacing systems, fiberglass midsole plates, and the use of varying density in the midsole of the shoe. The primary responsibility of the shoe is to protect the body from injury.

Cook, Kester, Brunet and Haddad (1985) studied the forces exerted on the body during running and determined that "the running shoe protects the body from injury by absorbing and distributing a significant amount of forces" (p. 620). Further studies completed by Nigg (1985) determined that the construction of the running shoe is a possible factor influencing the amount of force experienced by the
runner's body. The positive changes brought by continuous research have been the use of revolutionary materials, enhanced stability and increased shock absorbing capabilities of the running shoe. However, running related injuries are still increasing. A full understanding of why must begin with the breakdown of running mechanics.

Running Mechanics

James and Brubaker (1972) described running as a "form of locomotion consisting of alternate support and airborne phases" (p. 1014). Running requires coordinated action between the extremities and the trunk. The function of the lower extremities during running is to support the lower body while providing a force to overcome inertia and accelerate the center of gravity against internal and external resistance. Cavanagh (1980) defined a running cycle as "the body goes between two contacts of the same foot" (p. 80). Each running stride consists of a footstrike, midstance and toe off phase. Heelstrike is referred to by MacLellan (1984) as "the first instant of contact between the heel and floor" (p. 76). Cavanagh, Valiant and Misevich (1984) dispelled the heelstrike myth by using center of pressure measurements in determining which portion of the shoe made contact with the ground first. Using center of pressure data Cavanagh et al. (1984) determined that "footstrike may occur in the rearfoot, midfoot or forefoot area" (p. 24). Studies completed by James, Bates and Ostering (1978) determined that "footstrike is generally on the lateral side of the heel" (p. 43).
Cavanagh and Lafortune (1980) also examined runners and concluded that "in the late stages of the swing phase the feet of most runners are in a supinated position and the hip in adduction, hence initial ground contact is made in almost every case with the lateral border of the shoe" (p. 404). At footstrike the foot is in a supinated position. The tibia experiences external rotation and as the body moves closer to the midstance phase the tibia begins to rotate internally while the subtalar joint is experiencing eversion. The foot reaches maximum pronation at 40 percent of the midstance phase and continues on through 70 percent of this phase. Cavanagh et al. (1984) determined that "maximum pronation occurs within 25 milliseconds from footstrike" (p. 28). At this time the center of gravity passes over the weight bearing foot, moving the body into the midstance phase. Forward propulsion occurs as the muscles of the support leg contract to provide extension at the hip and knee joint. Clarke, Frederick and Hamill (1983) examined the function of pronation and supination at the subtalar joint during running and determined that these motions "act to decrease peak forces experienced by the leg immediately after foot strike by increasing the time over which the foot becomes stationary on the ground" (p. 167).

Running injury free, requires that the articulation and connection of 26 bones, in addition to joints, ligaments and muscles be balanced throughout the running cycle. The complex structure of the human body has been referred to as a kinetic chain. The literature suggested that running imbalances begin at the foot and
extend up the lower extremities to the lower back. Higdon (1978) contends that, "more than four degrees deformity can set forces in motion as the bones and muscles struggle to achieve a state of balance during the act of running which can cause any one of a dozen injuries to the ankles, calves, knees, thigh, hips or even the back" (p. 42). It is difficult to determine if the increased injury rate is due to mileage logged specifically or to biomechanical abnormalities of the running body. The literature overwhelmingly stated that it is the mechanical abnormalities compounded by high mileage that is the precursor to injury. Higdon (1978) stated that "some biomechanical difficulty (malfunction in the running mechanism) has to be added to long mileage and high speed to cause disease" (p. 42). Excessive pronation is the most frequently occurring biomechanical abnormality. Bateman and Trott (1979) determined that "hyper pronation was a significant factor in 50% of foot and 76% of knee injuries" (p. 156). Additional factors identified by D'Ambrosia and Drez (1982) are "pronation, supination, varus, valgus and excessive Q-angle" (p. 1011).

Running Injury

Several investigations analyzed the dynamic functions which occur in the lower extremities during running. These investigations concluded that most injuries occur as a result of a biomechanical abnormality intensified by repetitive impact loading. In an investigation of running shoes and injuries (McKenzie, Clement and
Taunton, 1985) showed that "the body experiences 1000 to 1500 foot strikes per mile and a vertical ground reaction force of close to 3 times the body weight" (p. 345). Further investigations completed by D'ambrosia and Drez (1982) determined that "the stress absorbed by a 150 pound person running one mile at 1,175 steps per mile with an impact of 250 percent body weight is 220 tons of weight per mile" (p. 10). The majority of the weight is absorbed by the foot through pronation with most of the remainder absorbed through flexion at the knee and hip joint. Soft muscle tissue, tendons, ligaments and the heel pad also play a significant role in absorbing the mechanical shock experienced by the body during running.

Numerous studies indicated a correlation between increased mileage and the occurrence of injuries. Lutter (1985) stated, "of runners going approximately thirty miles a week, more than 60% are injured in a given year" (p. 155). Powell, Kohl, Caspersen and Blair (1986) cited a survey which analyzed 2,500 runners and found that "the annual incidence of injury was 37% and it increased significantly with weekly mileage" (p. 107). Recent research submitted by Cook, Kester, Brunet and Haddad (1985) estimated that "running between 50 and 70 miles per week results in approximately a 50 percent chance of knee injury" (p. 624). The risk of injury is in part due to the repetitive loading of the joint. However, recent studies indicate that the injury rate is also greatly affected by the shock absorbing capacity of the running shoe.

The body experiences maximum impact forces approximately 15-35 milliseconds following footstrike. A runner can expect these forces
to equal 2 to 4 times his body weight. The ability of the shoe and body to absorb these forces is of primary concern to sports physicians.

Pronation/Supination

Motion at the subtalar joint acts to decrease peak forces experienced by the body during running. Two motions occur at this joint, pronation and supination. Research completed by D’Ambrosia and Drez (1982) stated that “normal pronation is 10 degrees and normal supination is 30 degrees” (p. 18). Pronation is a complex triplane movement which involves simultaneous foot abduction, dorsiflexion and eversion in the transverse, sagittal and frontal planes. Supination includes the movements of inversion, adduction and planter flexion (see Figure 1). Supination allows for lateral border contact at footstrike and causes the foot to become a stiff rigid lever during the take off phase. Pronation functions as a shock absorber at footstrike and throughout the midstance phase. Research conducted by Clarke, Frederick and Hamill (1983) stated that “the normal amount of pronation provides a means of decreasing peak forces experienced by the leg immediately following foot strike” (p. 376). Taunton, Clement, Smart, Wiley and McNicol (1985) determined that “maximum pronation and maximum knee flexion must occur simultaneously to avoid conflicting rotatory forces through the tibia” (p.114). Such forces would create an antagonistic relationship between ankle and knee joint predisposing the runner to
Figure 1. Diagram Illustrating Neutral, Supination and Pronation of Right Foot.
injury. The literature suggested that excessive pronation is cited as the cause of various injuries of the hip, knee, achilles tendon and foot. Excessive supination appears to be less of a tyrant than its counterpart, pronation. However, supination is correlated with achilles tendon pain and injury to the tibialis anterior.

Varus/Valgus

Varus and valgus are deviations of the leg-heel alignment which may affect pronation/supination. Two to three degrees of varus are considered normal. Cavanagh (1980) identified “varus as turning toward the midline of the body” (p. 82) (refer to Figure 2). Factors which affect varus are pelvic width and crossing over the midline of the body at the time of footstrike. Both conditions serve to increase pronation. Valgus is defined as “turning away from the midline of the body” (p. 73). Valgus results in increased supination as well as excessive stress on the knee and hip joint (refer to Figure 3).

Q-angle

Knee pain is the most frequently occurring syndrome among runners. McKenzie et al. (1985) cited “an 18% to 50% rise in the incidence of knee pain in runners during the past 13 years” (p. 334). The relationship between Q-angle and pronation has been cited as the most likely reason for the increase. Grana and Kriegshauser (1985) showed that the Q-angle “depicts the degree of real or relative lateral insertion of the patella tendon” (p. 249).
Figure 2. Illustration of Femoral, Tibial and Rearfoot Varus as Seen from an Anatomical Position.
Functionally excessive pronation causes internal rotation of the tibia. The knee cap becomes unstable as the thigh bone resists the internal rotation. As the quadricep mechanism contracts, it pulls the knee cap to the outside causing abnormal tracking of the patella. Subotnick (1979) defined Q-angle as "the angle which forms between the inferior pole of the patella and the attachment of the patella tendon" (p. 43). Grana and Kriegshauzer (1985) determined that "normal Q-angle averages 10-12 degrees in the male and 15-18 degrees in the female" (p. 249) (see Figure 4). Studies have demonstrated a 50 percent reduction in patella stress when the Q-angle was reduced from 15 to 5 degrees.

Shoe Design

The compensatory motions of the human body are not always enough to deter injury. Consequently, there is a great need for shoe designers to develop shoes which absorb forces and protect against mechanical abnormalities. If prevention of running related injuries is to occur, manufacturing companies must understand the effect the construction and design of the running shoe has on the kinematics of the lower extremities during running.

The primary function of the running shoe is to reduce the load to the body. Nigg et al. (1984) defined load as the "external forces that act upon the body" (p. 2). Critical limit is defined as "the limit beyond which the material will be damaged" (p. 2). The literature showed that the running shoe is a main factor in reducing the load on the running body. Typically, impact forces and pronation
Figure 4. Illustration of the Q-angle of the Right Leg.
are the two variables which are most controlled by the construction of a running shoe. Dickinson, Cook and Leinhardt (1985) studied the effect running shoes have on impact forces at foot strike. They showed that for shoes to have a significant effect on dampening the forces experienced by the body during running they should have maximum shock absorbing capacity in the heel and maximum cushioning ability in the forefoot.

The sole of the running shoe is responsible for shock absorption. It is composed of an outsole, midsole and wedge. The outsole is responsible for traction and the initial absorption of shock. The primary shock absorption takes place in the midsole area which comes in varying densities and is primarily composed of ethylene vinyl acetate (EVA). Clarke, Frederick and Hamill (1983) used a Shore A hardness scale to rate the density of EVA foams. The foams were rated in the following order: "soft (25 durometer), medium (35 durometer) and hard (45 durometer)" (p. 377).

Most running shoes have a softer EVA foam on the lateral border and increasing hardness moving laterally to medially. Varying degrees of EVA provides allowance of maximum shock absorption on the lateral border and motion control of rearfoot movement on the medial border.

Clarke, Frederick and Hamill (1983) defined rearfoot control as "the relative ability of a shoe to limit the amount and/or rate of foot pronation immediately following footstrike" (p. 376). Three rearfoot parameters were determined by Clarke, Frederick and Hamill
(1983): "maximum pronation (MVP), total rearfoot movement (TRM) and the time to maximum velocity (TMVP)" (p. 378). The results suggested that pronation can be minimized by adjusting heel flare and midsole hardness. McKenzie et al. (1985) showed that the "optimum combination of rearfoot control and cushioning occurs in thickly soled shoes with a 35 durometer midsole/wedge flared to 15 degrees" (p. 339).

The literature suggested that additional energy absorbing materials, mainly sorbothone heel inserts and the combination of akton and zekon, increased the recovery rate of stress fractures and decreased the incidence of achilles tendonitis. With this information it is recommended that all individuals over the age of 20 years wear some form of inserts in their running shoes as well as in their everyday shoes.

Misevich and Cavanagh (1984) completed investigations into construction and design of the running shoe. The studies analyzed the forces at footstrike created during body to ground and heel to shoe contact. The investigations showed the importance of considering all forces created between body, shoe and ground as a single system; namely, the conformity of the outsole, midsole and insole to the characteristics of the calcaneous and subcalcaneal layer. Misevich and Cavanagh (1984) determined that "the crucial pressure to both the body and the shoe is right under the calcaneous" (p. 71).

The design and construction of running shoes have certainly come a long way since the "Spencer shoe" in 1865. The changes have been
dramatic and great technological advances made. However, the incidence of running related injuries has steadily increased. Many of the current changes in running shoes are the result of data collected by Runners World. Since 1975, Runners World has been conducting surveys to gather data on runners' satisfaction with the quality of their running shoes. These surveys were probably the first test procedures seriously evaluated by shoe companies. The interest generated by the annual survey is instrumental in the development and utilization of additional testing procedures. In today's running circles a shoe is evaluated by its shock absorbing capacity, rearfoot control, durability, looks, weightedness, last design and numerous other criteria.

Test Procedures

The test procedures can be divided into areas of measurement. The primary areas are the shock absorbing nature and ability to control rearfoot movement. The forceplate is used to analyze the ground reaction forces at footstrike. In his publication, Denoth (1986) described the Drop test created by Berlin and Stuttgart as "a means of measuring impact forces" (p. 97). The Shore A and D hardness test evaluated material hardness by "measuring the resistance of a material against the penetration of a defined object under a defined pressure" (p. 96). In 1977 researchers at Pennsylvania State University evaluated the impact properties of running shoes. Funding by Etonic allowed researchers to simulate

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force plate readings by dropping an 8.5 Kg mass (18.7 lbs.) from a height of 5 cm. The electrodynogram (EDG) was used to determine the protection a shoe afforded the runner. Runners World (1984) stated, "The EDG system identifies the amount of force traveling through the foot and determines how long a given force is present at a given location" (p. 95).

Researchers have found that digitizing high speed film is the most efficient way to monitor the position of the foot at contact and throughout the running cycle. Anatomical markings on the lower extremities allow for readings on pronation and supination at the subtalar joint. Cook, Kester, Brunet and Haddad (1985) conducted a study evaluating the long term shock absorption properties of running shoes. Their study utilized a prosthetic foot with a cushioned heel component mounted on a test fixture. Numerous runners completed the same mileage providing the researchers a comparison for obtained results. Cook, Kester, Brunet and Haddad (1985) showed that, "between 250 and 500 miles, shoes retained approximately 55 percent of their shock absorbing capacity" (p. 623).

Conclusion

These and other test procedures are the catalyst for change. Yet the changes have not prevented running related injuries. Sufficient information exists in the literature pertaining to running mechanics, biomechanical abnormalities, shoe design and materials and their effect on the runner's body. The research has led the way to a running shoe which provides shock absorption, stability and motion
control. It has been determined that it is the shoe manufacturer's responsibility to protect the runner from injury. The scientific changes evident in today's running shoes reflect the serious and competitive attitude running shoe manufacturers are taking.

Today a new need is being created. The damaging effect, the logging of high mileage has on the runner's body, has created the need to analyze the effect wear patterns of running shoes have on the runner. The absence of human data makes it difficult for test standards to exist. Intuitively, we know that the shock absorbing properties of running shoes deteriorate with mileage. Little is known concerning the rate of deterioration. The proposed study attempts to analyze the effect wear patterns have on the running body.
CHAPTER III

PROCEDURES

The problem of the study was to investigate the effect wear patterns of running shoes had on the kinematics of the lower extremities during running. The headings used to organize this chapter were as follows: (a) subjects, (b) cinematographical procedures, (c) procedures for collecting data, (d) data analysis procedures, and (e) statistical analysis.

Subjects

Two subjects were selected for this investigation. The subjects were male runners, aged 21 and 35 years. Both runners were recreational runners and ran a minimum of 25 miles per week. See Table 1 for characteristics of subjects.

Table 1

Characteristics of Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>21</td>
<td>6'</td>
<td>170</td>
</tr>
<tr>
<td>II</td>
<td>35</td>
<td>6'1&quot;</td>
<td>165</td>
</tr>
</tbody>
</table>
Cinematographical Procedures

Subjects were filmed at the Biomechanics Laboratory at Western Michigan University in Kalamazoo, Michigan. Filming took place bi-monthly for three months or approximately 600 miles per pair of shoes. One Photo Sonic 1-PL Camera was placed perpendicular to the frontal plane and posterior to the subjects as they ran on a Quinton treadmill. The camera was fitted with Eastman Ektachrome Video News Film, High Speed 7250 Tungsten, with ISO/ASA 400. A light emitting diode set at .01 second was used to calibrate camera speed, which was set at 100 frames per second.

Two Color Tran Mini Brute light banks (each containing three banks) were placed at a 45 degree angle approximately 10 feet away from and facing the treadmill. The camera was placed 25 feet straight back from the center of the treadmill. The height of the camera was 4 feet from the floor. Details of the filming site are illustrated in Figure 5.

Data Analysis Procedures

The film analysis took place in the Biomechanics Lab at Western Michigan University in Kalamazoo, Michigan. The degree of pronation/supination, Q-angle and leg angle was determined by digitizing ten points on the body: (a) right heel, (b) left heel, (c) right calcaneous, (d) left calcaneous, (e) right achilles, (f) left achilles, (g) right center of knee, (h) left center of knee, (i) right hip, and (j) left hip. The points marked on the posterior
Figure 5. Illustration of Data Collection Site.
portion of the lower leg and foot allowed the investigator to see the position of the subtalar joint in relation to the calcaneus during footstrike, midstance and toe off. Digitizing procedures allowed the investigator to analyze the degree of pronation/supination during subsequent phases and trials. Diagram of points digitized for calculation of pronation/supination are illustrated in Figure 6. Figure 7 illustrates the points digitized to determine Q-angle and leg angle. Q-angle was determined by calculating the vector formed by a straight line extending from the center of the knee to the hip and a second line extending vertically through the patella tendon (refer to Figure 7). Calculations for the leg angles were determined by the angle formed between a straight line extending from the calcaneus to the hip and one extending vertically through the calcaneus.

Ten strides from each filming session were analyzed for three conditions: footstrike, midstance, and toeoff phases. For each stride and each phase five consecutive angles were calculated for pronation, supination, Q-angle, and leg angle. For each condition, a special computer program (see Appendix) automatically eliminated the high and low angle and computed the mean of the three remaining angles. These means were then used to determine degree of change in wear patterns for pronation/supination, Q-angle and leg angle.

Procedures for Collecting Data

Subjects were filmed bi-monthly over three months in which they ran approximately 400 miles per pair of shoes. All subjects were
Figure 6. Illustration of the Anatomical Sites Used to Calculate the Degree of Pronation/Supination.
Figure 7. Illustration of the Anatomical Sites Used to Calculate the Q-angle and the Leg Angle.
filmed while running on a Quinton Model 643, programmed exercise treadmill. The treadmill was adjusted to allow a comfortable running pace for each runner. Ten complete strides were analyzed during each filming session. A stride consisted of right foot contact to right foot contact. Six frames from each stride were digitized: (a) footstrike right foot, (b) footstrike left foot, (c) midstance right foot, (d) midstance left foot, (e) toeoff right foot, and (f) toeoff left foot. Footstrike was determined when the first portion of the foot made contact with the treadmill. Midstance was determined as that point when the hip of the support leg was directly over the support foot. Toeoff was determined to be the last contact the foot had with the treadmill. Data obtained throughout the digitizing process provided information concerning Q-angle, pronation/supination and leg angle of the right and left legs.

To isolate the neutral position for determining degree of pronation/supination the following marks were drawn on the subjects' legs. (1) A horizontal line passing through the center of the medial malleolus. (2) A second horizontal line was drawn five centimeters vertically above the first transverse line. (3) A line drawn vertically, five centimeters in length, extending up the tibial crest connected the transverse lines. Shoes were marked on the heel at the point where the heel counter began extending vertically to the termination of the heel. Details of markings on the legs are illustrated in Figure 8.
Figure 8. Illustration of Skin Marks Placed on the Posterior Side of Subject's Legs in Preparation for filming.
Statistical Analysis

Statistical analysis was completed by using a case study for two subjects. A two-way ANOVA with repeated measures was used for three dependent variables. The dependent variables were: (a) degree of pronation at footstrike, midstance and toeoff; (b) Q-angle at foot strike, midstance and toeoff; and (c) leg angle at footstrike, midstance and toeoff. The independent variables for each of the three dependent variables were: (a) six bi-monthly times, (b) phases (footstrike, midstance and toeoff), and (c) ten strides.

The computer program utilized was the BMDP2V statistical package from the University of California, Los Angeles. Differences were considered significant when the probability was 0.05 or less. A Tukey Honestly Significant Difference (HSD) test was used to test for differences between levels of each of the independent variables.
CHAPTER IV

RESULTS

The purpose of this study was to analyze the effect wear patterns of running shoes had on pronation/supination, Q-angle and leg angle of a runner's lower extremities during specific phases of running. The headings used to organize this chapter were as follows: (a) characteristics of subjects, (b) sole wear, (c) pronation/supination, (d) leg angle, and (e) Q-angle.

Characteristics of Subjects

Data relevant to this study were provided by two male subjects. Differences between the subjects were not examined, as a case study was utilized for research purposes. Subject One was 21 years of age, 6 feet tall and weighed 170 pounds. Subject Two was 35 years of age, 6 feet, 1 inches tall and weighed 165 pounds.

Total mileage run between filming sessions was documented by the runners' completion of a training log. Subject One ran a total of 409 miles and Subject Two totaled 507 miles. Subject One averaged 68 miles per filming session and Subject Two averaged 84 miles per filming session.

Sole Wear

The rate of physical wear on the outsole was determined by use of a depth gauge used for calculating the amount of remaining tread
on tires. Data were obtained during each filming session from readings at the medial, lateral and ball of the foot of the right and left shoe. These locations were chosen as they represented the contact points during the footstrike, midstance and toeoff phases of running. Mileage between measurements and depth of tread measured in millimeters for each case study is presented in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time</th>
<th>Mileage</th>
<th>Medial (mm)</th>
<th>Lateral (mm)</th>
<th>Ball of the Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>One</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>One</td>
<td>2</td>
<td>60</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>One</td>
<td>3</td>
<td>106</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>One</td>
<td>4</td>
<td>76</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>One</td>
<td>5</td>
<td>72</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>One</td>
<td>6</td>
<td>95</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Average Mileage per Session</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference between 1 &amp; 6</td>
<td>409</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Two</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Two</td>
<td>2</td>
<td>92</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Two</td>
<td>3</td>
<td>81</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Two</td>
<td>4</td>
<td>92</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Two</td>
<td>5</td>
<td>115</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 2—Continued

<table>
<thead>
<tr>
<th>Subject</th>
<th>Time</th>
<th>Mileage</th>
<th>Medial (mm)</th>
<th>Lateral (mm)</th>
<th>Ball of the Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
<td>Left</td>
</tr>
<tr>
<td>Two</td>
<td>6</td>
<td>127</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Average Mileage per Session</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference between 1 &amp; 6</td>
<td>507</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Pronation/Supination

The hypothesis to investigate the degree of pronation/supination stated: As the wear patterns of running shoes increases, pronation/supination at the subtalar joint during the heel strike, midstance, and toeoff phases will be affected. The hypothesis was tested by the use of an analysis of variance. The independent variables were: (a) six times, bi-monthly; (b) ten strides; and (c) three phases, footstrike, midstance and toeoff. The dependent variable was pronation/supination.

Subject One

Right Foot

The results of the ANOVA (refer to Table 3) indicated a significant difference, $F(5,153) = 5.15$, $p < .05$ between times.
Table 3
ANOVA Summary Table for Pronation/Supination
Right Foot, Subject One

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>1473.19</td>
<td>9</td>
<td>163.69</td>
<td>1.12</td>
</tr>
<tr>
<td>Time</td>
<td>3761.70</td>
<td>5</td>
<td>752.34</td>
<td>5.15*</td>
</tr>
<tr>
<td>Phase</td>
<td>11743.02</td>
<td>2</td>
<td>5871.51</td>
<td>40.19*</td>
</tr>
<tr>
<td>TXP</td>
<td>5491.38</td>
<td>10</td>
<td>549.14</td>
<td>3.76*</td>
</tr>
<tr>
<td>Residual</td>
<td>22353.72</td>
<td>153</td>
<td>146.10</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

The Tukey Honestly Significant Difference (HSD) test for differences between timed comparisons was computed to determine between which times significant differences occurred. All comparisons for the mean differences between times are shown in Table 4. The critical value, HSD .95 q (5,153) = 8.89, was exceeded by the obtained difference of 10.30, 11.91, 9.06, 10.95 and 10.64 between the means of bi-monthly times 1 and 5, 2 and 5, 2 and 6, 3 and 5, and 4 and 5, respectively. Therefore, the research hypothesis that the amount of pronation/supination occurring at the subtalar joint was significantly (p < .05) greater as the wear patterns of running shoes increased, was supported.
Table 4

Difference Between Means for Bi-monthly Times for Subject One Right Foot, Pronation/Supination

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.40</td>
<td>0</td>
<td>1.61</td>
<td>.50</td>
<td>.34</td>
<td>10.30*</td>
<td>7.45</td>
</tr>
<tr>
<td>2</td>
<td>7.79</td>
<td>0</td>
<td>1.11</td>
<td>1.27</td>
<td>11.91*</td>
<td>9.06*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8.90</td>
<td>0</td>
<td>.16</td>
<td>10.95*</td>
<td>7.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>9.06</td>
<td>0</td>
<td>10.64*</td>
<td>7.79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>19.70</td>
<td>0</td>
<td>2.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>16.85</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

Note: The obtained difference between means are presented.

HSD .95 a (5,153) = 8.89

The ANOVA also indicated a significant difference, F (2,153) = 40.19, (p < .05) between phases. Because a difference between the grouping variable, phases, was an expected result, the Tukey Honestly Significant Difference test was not administered.

The results of the ANOVA indicated a significant difference F (10,153) = 3.76, (p < .05) between the interaction between time and phase. Figure 9 shows the interaction effect between time and phase during heelstrike, midstance and toeoff phase.
Figure 9. Illustration of the Interaction of Feet Between Time and Phases for Pronation/Supination for Subject One, Right Foot.
**Left Foot**

The results of the analysis of variance indicated a significant difference $F(5,153) = 6.23, (p \leq .05)$, between times. Table 5 illustrates the ANOVA results.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>5689.37</td>
<td>9</td>
<td>632.15</td>
<td>1.55</td>
</tr>
<tr>
<td>Time</td>
<td>12710.43</td>
<td>5</td>
<td>2542.09</td>
<td>6.23*</td>
</tr>
<tr>
<td>Phase</td>
<td>12775.99</td>
<td>2</td>
<td>6388.00</td>
<td>15.65*</td>
</tr>
<tr>
<td>T X P</td>
<td>6179.39</td>
<td>10</td>
<td>617.94</td>
<td>1.51</td>
</tr>
<tr>
<td>Residual</td>
<td>62406.69</td>
<td>153</td>
<td>407.89</td>
<td></td>
</tr>
</tbody>
</table>

$p < .05$

The Tukey Honestly Significant Difference (HSD) test for differences between bi-monthly comparisons was computed to determine between which times significant differences occurred. All comparisons for the mean differences between times are shown in Table 6. The critical value, $HSD .95 q (5,153) = 14.86 (p < .05)$ was exceeded by the obtained difference of 21.29, 20.42, 23.52 and 23.62 respectively between the times of means 1 and 5, 2 and 5, 3 and 5, and 4 and 5. Therefore, the hypothesis, that as the wear patterns of running shoes increased pronation/supination at the subtalar joint
during heel strike and midstance phase will be affected, was supported.

Table 6
Difference Between Means for Bi-monthly Times for Subject One, Left Foot, Pronation/Supination

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.85</td>
<td>0</td>
<td>.87</td>
<td>2.23</td>
<td>2.33</td>
<td>21.29*</td>
<td>8.58</td>
</tr>
<tr>
<td>2</td>
<td>16.72</td>
<td>0</td>
<td>3.1</td>
<td>3.2</td>
<td>20.42*</td>
<td>7.71</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13.62</td>
<td>0</td>
<td>0.1</td>
<td>23.52*</td>
<td>10.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>13.52</td>
<td>0</td>
<td>0</td>
<td>23.62*</td>
<td>10.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>37.14</td>
<td>0</td>
<td>12.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>24.43</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

Note: The obtained difference between means are presented.

HSD .95 g (5,153) = 14.86

The results of the ANOVA indicated a significant effect between phases, *F* (2,153) = 15.65, (p < .05). A significant difference between phases was an expected result. Therefore, the HSD test was not administered. The results of the ANOVA are presented in Table 5.

Subject Two

Right Foot

The analysis of variance table showed no significance differences *F* (5,153) = 1.96, p < .05 between times in reference to
changes in pronation/supination of the right leg. Therefore, the research hypothesis, that there is a difference in pronation/supination as wear patterns increase, was not supported. Table 7 shows the ANOVA results.

Table 7

ANOVA Summary Table for Pronation/Supination
Subject Two, Right Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>1404.80</td>
<td>9</td>
<td>156.09</td>
<td>.48</td>
</tr>
<tr>
<td>Time</td>
<td>3204.17</td>
<td>5</td>
<td>640.83</td>
<td>1.96</td>
</tr>
<tr>
<td>Phase</td>
<td>7894.85</td>
<td>2</td>
<td>3947.43</td>
<td>12.06*</td>
</tr>
<tr>
<td>TXP</td>
<td>2217.59</td>
<td>10</td>
<td>221.76</td>
<td>.68</td>
</tr>
<tr>
<td>Residual</td>
<td>50096.85</td>
<td>153</td>
<td>327.43</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

The ANOVA also indicated a significant difference $F(2,153) = 12.06$ ($p < .05$) between phases. Because a difference between the grouping variable, phases, was an expected result the Tukey Honestly Significant Difference test was not administered.

Left Foot

The results of the analysis of variance indicated a significant difference $F(5,153) = 8.05$ ($p < .05$) between times. Table 8 shows the ANOVA results.
Table 8
ANOVA Summary Table for Pronation/Supination
Subject Two, Left Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>4684.85</td>
<td>9</td>
<td>540.54</td>
<td>2.16</td>
</tr>
<tr>
<td>Time</td>
<td>10095.79</td>
<td>5</td>
<td>2019.16</td>
<td>8.05*</td>
</tr>
<tr>
<td>Phase</td>
<td>4760.74</td>
<td>2</td>
<td>2380.37</td>
<td>9.49*</td>
</tr>
<tr>
<td>TXP</td>
<td>1013.22</td>
<td>10</td>
<td>101.32</td>
<td>.40</td>
</tr>
<tr>
<td>Residual</td>
<td>38373.24</td>
<td>153</td>
<td>250.81</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

The Tukey Honestly Significant Difference (HSD) test for differences between times was computed to determine between which times were significant. All comparisons, for the mean differences between times are shown in Table 9. The critical value, HSD .95 q (5,153) = 11.65 was exceeded by the obtained difference of 19.76, 16.5, 18.71, 15.45, 15.52 and 12.26 between the means of times 1 and 5, 1 and 6, 2 and 5, 2 and 6, 3 and 5 and 3 and 6, respectively. Therefore, the hypothesis that as the wear patterns of running shoes increased, pronation/supination at the subtalar joint during heelstrike, midstance and toeoff phases will be affected, was supported.
Table 9

Difference Between Means for Bi-monthly Times for
Subject Two, Left Foot

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.23</td>
<td>0</td>
<td>1.05</td>
<td>4.24</td>
<td>8.7</td>
<td>19.76*</td>
<td>16.5*</td>
</tr>
<tr>
<td>2</td>
<td>17.28</td>
<td>0</td>
<td>3.19</td>
<td>7.65</td>
<td>18.71*</td>
<td>15.45*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>20.47</td>
<td>0</td>
<td>4.46</td>
<td>15.52*</td>
<td>12.26*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>24.93</td>
<td>0</td>
<td>11.06</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>35.99</td>
<td>0</td>
<td>3.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>32.73</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The obtained difference between means are presented.

HSD .95 q (5,153) = 11.65

*p < .05

The ANOVA also indicated a significant difference $F(2,153) = 9.49$ ($p < .05$) between phases. Because a difference between the grouping variable, phases, was an expected result the Tukey Honestly Significant Difference test was not administered.

Leg Angle

The hypothesis to investigate the degree of leg angle stated, as the wear patterns of running shoes increased, leg angles of runners will be affected. The hypothesis was tested by the use of an
analysis of variance. The independent variables were: (a) six times, (b) bi-monthly, and (c) three phases, footstrike, midstance and toeoff phase. The dependent variable was leg angle.

Subject One

The analysis of variance showed no significant differences, $F(5,153) = .43 (p<.05)$, and $F(5,153) = .85 (p<.05)$ between times in reference to change in leg-angle for the right and left legs respectively. Therefore, the hypothesis that as the wear patterns of running shoes increases, leg angles of runners will be affected was not supported. Table 10 shows the results for Subject One's right foot. Table 11 shows the ANOVA results for Subject One's left foot.

Table 10

ANOVA Summary Table for Leg Angle
Subject One, Right Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>93.69</td>
<td>9</td>
<td>10.41</td>
<td>1.23</td>
</tr>
<tr>
<td>Time</td>
<td>18.34</td>
<td>5</td>
<td>3.67</td>
<td>.43</td>
</tr>
<tr>
<td>Phase</td>
<td>406.87</td>
<td>2</td>
<td>203.43</td>
<td>23.98*</td>
</tr>
<tr>
<td>T X P</td>
<td>73.44</td>
<td>10</td>
<td>7.34</td>
<td>.87</td>
</tr>
<tr>
<td>Residual</td>
<td>1298.12</td>
<td>153</td>
<td>8.48</td>
<td></td>
</tr>
</tbody>
</table>

*p<.05
Table 11
ANOVA Summary Table for Leg Angle
Subject One, Left Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>638.23</td>
<td>9</td>
<td>70.91</td>
<td>1.11</td>
</tr>
<tr>
<td>Time</td>
<td>273.22</td>
<td>5</td>
<td>54.64</td>
<td>.85</td>
</tr>
<tr>
<td>Phase</td>
<td>391.51</td>
<td>2</td>
<td>195.75</td>
<td>3.06*</td>
</tr>
<tr>
<td>T X P</td>
<td>1177.53</td>
<td>10</td>
<td>117.75</td>
<td>1.84</td>
</tr>
<tr>
<td>Residual</td>
<td>9796.20</td>
<td>153</td>
<td>64.03</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05

The ANOVA for the right and left leg also indicated a significant difference $F(2,153) = 23.98 (p < .05)$, and $F(2,153) = 3.06 (p < .05)$ between phases. Because a difference between the grouping variable was an expected result the Tukey Honestly Significant Difference test was not administered.

Subject Two

The analysis of variance table showed no significant differences, $F(5,153) = .85 (p < .05)$, and $F(5,153) = 1.99 (p < .05)$, between times for leg angles for the right or left legs respectively. Therefore, the hypothesis that as the wear patterns of running shoes increase, leg angles of runners will be affected was not supported. Table 12 and 13 show the ANOVA results.
Table 12
ANOVA Summary Table for Leg Angle
Subject Two, Right Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>46.75</td>
<td>9</td>
<td>5.19</td>
<td>.57</td>
</tr>
<tr>
<td>Time</td>
<td>90.80</td>
<td>5</td>
<td>18.16</td>
<td>1.99</td>
</tr>
<tr>
<td>Phase</td>
<td>9.15</td>
<td>2</td>
<td>4.57</td>
<td>.50</td>
</tr>
<tr>
<td>T X P</td>
<td>148.77</td>
<td>10</td>
<td>14.88</td>
<td>1.63</td>
</tr>
<tr>
<td>Residual</td>
<td>1398.24</td>
<td>153</td>
<td>9.14</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

Table 13
ANOVA Summary Table for Leg Angle
Subject Two, Left Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>284.47</td>
<td>9</td>
<td>31.61</td>
<td>1.80</td>
</tr>
<tr>
<td>Time</td>
<td>27.78</td>
<td>5</td>
<td>5.56</td>
<td>.32</td>
</tr>
<tr>
<td>Phase</td>
<td>467.18</td>
<td>2</td>
<td>233.59</td>
<td>13.27</td>
</tr>
<tr>
<td>T X P</td>
<td>260.48</td>
<td>10</td>
<td>26.05</td>
<td>1.48</td>
</tr>
<tr>
<td>Residual</td>
<td>1692.59</td>
<td>153</td>
<td>17.60</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

The ANOVA also indicated a significant difference $F(2,153) = 13.27$ (p < .05) between phases for Subject Two Left Foot. Because a difference between the grouping variable, phases, was an expected
result the Tukey Honestly Significant Difference Test was not administered.

**Q-angle**

The hypothesis to investigate the degree of Q-angle stated: As the wear patterns of running shoes increased, Q-angles of runners will be affected. The hypothesis was tested by the use of an analysis of variance. The independent variables were: (a) six times bi-monthly, (b) ten strides and (c) three phases, footstrike, midstance and toeoff. The dependent variable was Q-angle.

**Subject One**

**Right Foot**

The analysis of variance for Subject One right foot showed a significant difference, $F(5,153) = 29.51 \ (p < .05)$, between times. Table 14 shows the ANOVA results.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>8.74</td>
<td>9</td>
<td>0.97</td>
<td>1.76</td>
</tr>
<tr>
<td>Time</td>
<td>81.48</td>
<td>5</td>
<td>16.29</td>
<td>29.51*</td>
</tr>
<tr>
<td>Phase</td>
<td>1049.35</td>
<td>2</td>
<td>524.67</td>
<td>950.44*</td>
</tr>
<tr>
<td>T X P</td>
<td>13.95</td>
<td>10</td>
<td>1.40</td>
<td>2.53*</td>
</tr>
<tr>
<td>Residual</td>
<td>84.46</td>
<td>153</td>
<td>.55</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05
The Tukey Honestly Significant Difference (HSD) test for differences between bi-monthly comparisons was computed to determine between which times significant differences occurred. All comparisons for the mean differences between times are shown in Table 15. The critical value, HSD .95 q (5,153) = .55 was exceeded by the obtained difference of .62, .88, .71, .49, .94, 1.33, 1.11, 1.56, 1.59, 1.37 and 1.82 between the means of times 1 and 2, 1 and 3, 1 and 4, 1 and 5, 1 and 6, 2 and 4, and 2 and 5, 2 and 6, 3 and 4, 3 and 5 and 3 and 6, respectively. Therefore, the hypothesis that as the wear patterns of running shoes increased, Q-angles of runners will be affected was supported.

Table 15

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.20</td>
<td>0</td>
<td>.62*</td>
<td>.88*</td>
<td>.71*</td>
<td>.49*</td>
<td>.94*</td>
</tr>
<tr>
<td>2</td>
<td>5.82</td>
<td>0</td>
<td>.26</td>
<td>1.33*</td>
<td>1.11*</td>
<td>1.56*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6.08</td>
<td>0</td>
<td>1.59*</td>
<td>1.37*</td>
<td>1.82*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4.49</td>
<td>0</td>
<td>.22</td>
<td>.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.71</td>
<td>0</td>
<td>.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4.26</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The obtained difference between means are presented. HSD .95 q (5,153) = .55
*p < .05
The results of the ANOVA indicated a significant difference $F(10,153) = 2.53 \ (p < .05)$ between times and phase. Figure 10 shows the interaction effect between time and phase during heel strike midstance and toe-off phase.

**Left Foot**

The results of the analysis of variance indicated a significant difference for time $F(5,153) = 3.99 \ (p < .05)$. The results of the ANOVA are presented in Table 16.

<table>
<thead>
<tr>
<th>Table 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA Summary Table for Q-angle Subject One, Left Foot</td>
</tr>
<tr>
<td>Source of Variance</td>
</tr>
<tr>
<td>Stride</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Phase</td>
</tr>
<tr>
<td>TXP</td>
</tr>
<tr>
<td>Residual</td>
</tr>
</tbody>
</table>

*p < .05

The Tukey Honestly Significant Difference (HSD) test for differences between time comparisons was computed to determine between which times significant differences occurred. All comparisons for the mean differences between times are shown in
Figure 10. Illustration of the Interaction Effect Between Time and Phases for Q-Angle for Subject One, Right Leg.
Table 17. The critical value, $HSD .95 \approx (5,153) = .81$, was exceeded by the obtained difference of $0.87$ and $1.19$ found between the times of 1 and 4 and 1 and 6. Therefore, the hypothesis that as the wear patterns of runners increase the Q-angles will be affected was supported.

Table 17

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.77</td>
<td>.54</td>
<td>.51</td>
<td>.87*</td>
<td>.73</td>
<td>1.19*</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4.31</td>
<td>0</td>
<td>.03</td>
<td>.33</td>
<td>.19</td>
<td>.65</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.28</td>
<td>0</td>
<td>.36</td>
<td>.22</td>
<td>0</td>
<td>.68</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4.64</td>
<td>0</td>
<td>.14</td>
<td>.32</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.50</td>
<td>0</td>
<td></td>
<td>.46</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4.96</td>
<td>0</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The obtained difference between means are presented.

$HSD .95 \approx (5,153) = .81$

*p < .05

The ANOVA indicated a significant difference $F (2,153) = 156.84$ ($p < .05$) between phases. Because a difference between the grouping variable, phases, was an expected result the Tukey Honestly Significant test was not administered. The results of the ANOVA are presented in Table 18.
Subject Two

Right Foot

The analysis of variance showed no significant differences, $F(5,153) = 1.08 \ (p < .05)$, between times in reference to Q-angle of the right leg. Therefore, the research hypotheses that as the wear patterns of running shoes increased, Q-angles of runners will be affected was not supported. Table 18 shows the results.

Table 18

ANOVA Summary Table for Q-angle
Subject Two, Right Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>252.99</td>
<td>9</td>
<td>28.11</td>
<td>1.34</td>
</tr>
<tr>
<td>Time</td>
<td>112.89</td>
<td>5</td>
<td>22.58</td>
<td>1.08</td>
</tr>
<tr>
<td>Phases</td>
<td>111.33</td>
<td>2</td>
<td>55.66</td>
<td>2.65</td>
</tr>
<tr>
<td>T X P</td>
<td>149.75</td>
<td>10</td>
<td>14.97</td>
<td>.71</td>
</tr>
<tr>
<td>Residual</td>
<td>3210.01</td>
<td>153</td>
<td>20.98</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

Left Foot

The results of the analysis of variance indicated a significant difference, $F(5,153) = 5.82 \ (p < .05)$, between times. Table 19 shows the ANOVA results.
Table 19
ANOVA Summary Table for Q-angle
Subject Two, Left Foot

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride</td>
<td>72.82</td>
<td>9</td>
<td>8.09</td>
<td>2.34</td>
</tr>
<tr>
<td>Time</td>
<td>100.42</td>
<td>5</td>
<td>20.08</td>
<td>5.82*</td>
</tr>
<tr>
<td>Phase</td>
<td>56.25</td>
<td>2</td>
<td>28.13</td>
<td>8.15*</td>
</tr>
<tr>
<td>T X P</td>
<td>17.29</td>
<td>10</td>
<td>1.73</td>
<td>.50</td>
</tr>
<tr>
<td>Residual</td>
<td>528.00</td>
<td>153</td>
<td>3.45</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05

The Tukey Honestly Significant Difference (HSD) test for differences between bi-monthly times was computed to determine between which times significant differences occurred. All comparisons for the mean differences between trials are shown in Table 20. The critical value $q(5,153) = 1.37$, was exceeded by the obtained difference of 1.64, 1.46, 1.48, 2.02, 1.84 between the means of times 2 and 5, 2 and 6, 3 and 5, 4 and 5 and 4 and 6 respectively. Therefore, the hypothesis that as the wear patterns of running shoes increased, Q-angles of runners will be affected was supported.
Table 20

Difference Between Means for Bi-monthly Times for Subject Two, Left Foot

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.61</td>
<td>0</td>
<td>.42</td>
<td>.26</td>
<td>.8</td>
<td>1.22</td>
<td>1.04</td>
</tr>
<tr>
<td>2</td>
<td>3.19</td>
<td>0</td>
<td>.16</td>
<td>.38</td>
<td>1.64*</td>
<td>1.46*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.35</td>
<td>0</td>
<td>.54</td>
<td>1.48*</td>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.81</td>
<td>0</td>
<td>2.02*</td>
<td>1.84*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.83</td>
<td>0</td>
<td>.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4.65</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: the obtained differences between means are presented.

HSD .95 q (5,153) = 1.37
*p < .05

The ANOVA also indicated a significant difference, F (2,153) = 8.15 (p < .05), between phases. Because a difference between the grouping variable was an expected result the Tukey Honestly Significant Difference test was not administered.

Discussion

In the past, runners were individuals who possessed a specific body type conducive to efficient running. Today, the popularity of running has enticed individuals who are biomechanically ill-suited for running. Increased involvement coupled with increased mileage
has significantly increased the injury rate of runners. Research attributes the increased injury rate to biomechanical problems and increased stresses experienced by the body.

The importance of the running shoe in absorbing and distributing forces created at footstrike has been well established. Additional knowledge pertaining to the effective protective life of a running shoe is needed.

The current study examined data relative to the protective life of a running shoe. Two subjects were filmed bi-monthly for three months. Ten strides were digitized for each subject. For each trial calculations were performed for each phase on each of ten consecutive strides. The high and low were discarded and the remaining eight strides were averaged to account for variability between strides. The values obtained provided information on the effect wear patterns of running shoes had on a runner's pronation/supination, Q-angle, and leg angle while running for each phase, leg, time and stride.

Little information exists in the literature regarding actual biomechanical changes occurring with increased wear patterns. Cook, Kester and Brunet (1985), have conducted some excellent research concerning the rate of deterioration in the shock absorbing qualities of shoes with the mileage run. Present data provide additional information regarding the rate of deterioration and the subsequent effect on the kinematics of a runner's lower extremities while running.

The present data support the hypothesis that as wear patterns of running shoes increased pronation/supination at the subtalar joint
during the heelstrike and midstance phase are affected. Significant differences were found in Subject One with respect to the right and left foot. The greatest difference occurred between times 2 and 5 for the right foot, and between 2 and 5, 3 and 5, and 4 and 5 for the left foot. It was expected that the greatest change would exist between times 1 and 6. Digitizing errors, or a change in running mechanics, could have prevented this. The existing outcome, however, indicated that as the actual mileage increased, the running shoe experienced structural breakdown.

An expected difference between phases occurred. Because of the obvious differences between footstrike, midstance and toeoff, the significance of these differences will not be discussed.

Data collected on Subject One showed an interaction effect between time and phase for the right foot with regard to pronation/supination (Refer to Figure 9). To understand the significance of this effect, points were graphed for each time and phase. The graph shows different patterns in pronation/supination at footstrike and at midstance. Research showed that the subtalar joint is typically in a supinated position at footstrike and quickly moves into pronation throughout the midstance phase. The present data supported the research pertaining to subtalar joint position during the footstrike and midstance phases. This investigation provided information on the relationship of pronation/supination between phases. The difference between times 5 and 6 best illustrates this point. The average rate of change between times 1
through 5 at midstance was .98 degrees. Subject One experienced a 7.61 degree of change between times 5 and 6.

Similarly, the average rate of change in pronation/supination between times, at footstrike, was 1.82 degrees. Subject One experienced an 8.78 degree difference between times 5 and 6 at heelstrike. The deviation from the average, between times 5 and 6, may be due to Subject One unconsciously adjusting his running pattern. Research conducted by Dickinson, Cook and Leinhardt (1985) indicated that fatigue may also have been a factor.

An interaction effect also existed with respect to the toeoff phase. Cinematography provided two-dimensional insight into lower limb motion, neglecting movement which occurs in the transverse plane. At the toeoff phase the foot is placed outside the sagittal plane of motion. As supported by research, toeoff is not a reliable measurement and therefore will not be discussed.

It was expected that pronation/supination would change with respect to wear patterns between times. Subject Two experienced no significant difference with respect to the right foot.

An expected difference between phases for the right and left foot occurred. Because of the obvious differences between footstrike, midstance, and toeoff the significance of these differences will not be discussed.

Subject Two experienced a significant difference between times with respect to the left foot. Research indicated that the greatest difference should occur between times 1 and 6. Subject One exhibited the greatest difference between times 1 and 5. Factors such as
weather, perspiration, fatigue or running style could have affected the outcome. The possibility of digitizing error existed. Significant difference between phases was anticipated.

It was expected that a significant difference in leg angles between times would occur. No significant differences were noted in Subject One or Two with respect to the right and left foot.

The hypothesis that as wear patterns of running shoes increase, leg angles of runners will be affected was not supported for either subject. Research providing insight as to why the hypothesis was not supported is limited. Possibly leg angle is not easily altered with respect to wear patterns. Secondly, different procedures may be needed to more accurately calculate leg angle and subsequent changes.

Previous research indicated that running over 50 miles per week increases the potential for knee injury by 50% (Cook, Kester, Brunet and Haddad, 1985). Changes in Q-angle are closely associated with this increase.

Present data indicates that increased mileage resulted in a gradual breakdown in the structured components of the running shoe. The greatest difference in Subject One, right foot, occurred between times 3 and 6. Data collected on the left foot showed the difference between times 1 and 6 to be greatest.

The relationship between pronation/supination and Q-angle as indicated by the research was supported. Data collected revealed a second interaction effect for Subject One, right foot, with respect to Q-angle (refer to Figure 9). To further understand the
significance of this effect, points were graphed for each time and phase. Similarities existed between the footstrike and midstance phase. Cinematography provided a two-dimensional insight into lower limb motion, neglecting movement which occurs in the transverse plane. At the toeoff phase the foot is placed outside the plane of motion. Therefore, toeoff is not a reliable measurement and will not be discussed.

The calculated baseline angles were 4.34 and 8.59 degrees for footstrike and midstance, respectively. Both phases experienced an increase in Q-angle up to time period three. Each subsequent time showed a gradual decrease in Q-angle. Research conducted by Grana and Kriegshauser (1985) indicated that a normal Q-angle for males was 10 to 12 degrees. Data collected indicated that Subject One experienced a 1.26 degree change in Q-angle at footstrike or approximately a 15% reduction from the baseline. A .25 degree reduction from the baseline or approximately 6 percent was found at the midstance phase. This demonstrated that footstrike and midstance are related and changes made at footstrike have an effect on the Q-angle at the midstance phase.

The hypothesis, that as wear patterns of running shoes increased Q-angles of runners will be affected, was not supported by subject two's right foot. However, a significant difference between times with respect to the left foot did exist. The greatest difference occurred between times 4 and 5. The reason for this is unknown.

McKenzie, Clement and Taunton (1985) determined that "the sole should always be examined for wear patterns as it can provide
valuable information concerning running mechanics” (p.339). Research conducted by Cavanagh and Lafortune (1980) suggested that two visual patterns of wear can be observed on the running shoe. Visible patterns are seen on the posterior two-thirds of the shoe and directly under the ball of the foot. Data collected using a treadguage were consistent with the literature. Differences of 3 millimeters were found in subject one on the lateral portion of the right and left shoe between times 1 and 6. Differences of 2 millimeters were found at the ball of the foot and at the medial measuring site.

Subject Two experienced less of a wear pattern indicating a difference in running style or perhaps shoe properties. However, a 2 millimeter difference did occur between times 1 and 6 with respect to the right foot at the lateral portion and the area directly under the ball of the foot. The breakdown of the shock absorption qualities was not measurable, but might affect the patterns.

Cook, Kester, Brunet and Haddad (1985) determined that shoes experienced a loss of 25% shock absorbency qualities after 50 miles. A gradual and consistent loss continued with a 33% loss at 100-150 miles and a loss greater than 40% at 250-500 miles. This investigation similar losses with respect to wear patterns and mileage logged. At 60 miles Subject One experienced a 1 millimeter loss in tread at the ball of the foot. Subject Two experienced similar results at 92 miles. An initial 2 millimeter loss in tread at the lateral heel was found for Subject One at 60 miles. Research
indicated that mechanical properties of shoes are temporarily changed while running in the rain. The fact that Subject One gained one millimeter in tread the following session indicated that this may have happened. The next significant decrease in tread was found after approximately 210 miles had been attained. Losses in tread seem to correspond with the changes in pronation/supination and Q-angles.

Subject Two experienced similar wear patterns with respect to the ball of the foot. However, a significant change in wear patterns did not occur on the lateral heel until approximately 409 miles had been attained. Subject Two appeared to be a stronger and more experienced runner. The patterns of wear may be due to the fact that he appeared to be a midfoot striker. Center of pressure data are not available to determine the accuracy of this statement. However, research conducted by Cavanagh (1980) would support this contention.

An examination of the data revealed similarities between pronation/supination and Q-angle for Subject One and Two. Powell, Kohl, Caspersen and Blair (1986) reported that "changes in the loading of the feet or motion of the leg can affect the knees, hips, and possibly the back, neck or head" (p. 110). Pronation/supination is the result of movement at the subtalar joint. Q-angle is defined by Subotnick (1979) as the angle formed between the inferior poles of the patella and the attachment of the patella tendon. Measurement is limited to the knee. Present data suggest that actions at the subtalar joint had a significant effect on the angles created at the knee joint.
The data were examined with respect to differences between subjects' right and left legs. Subjects did not appear to be consistent between legs. These data are consistent with data provided by Taunton, Clement, Smart, Wiley and McNicol (1985). The study indicated that "the left and right feet display significant variability of certain temporal events and associated kinematic parameters in runners who display compensatory overpronation" (p. 114).

Similar patterns of leg angles were found in both subjects. Subject One exhibited no significant difference in the right or left legs. Subject Two exhibited no significant difference in the right leg but differences were found with respect to the left leg.
CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Summary

Today, an individual who is not informed about the current health cost caused by our inactive society is indeed a rarity. Such knowledge combined with zealous ambition has resulted in a fitness and health craze. Currently, well over 40 million Americans are utilizing some form of running or jogging to meet their fitness needs. The cardiovascular and health benefits attained have been tremendous. Sadly, likened to a car's response to increased mileage, the structural body of 50-70% of these runners is experiencing breakdown (Clark, Frederick and Hamill, 1983). Researchers attribute the increased injury rate to high mileage, biomechanical abnormalities, impact forces and improper running surfaces and shoes. The goal of this study was to provide data which will lead to a better understanding of the causes of running injuries.

This study investigated the relationship between wear patterns of running shoes and selected kinematic variables of the lower extremities. Two male subjects, aged 21 and 35 years were used. A case study design was utilized for each subject. Dependent variables measured were: (a) degree of pronation at footstrike, midstance and toeoff; (b) degree of Q-angle at footstrike, midstance and toeoff; and (c) degree of leg angle at footstrike, midstance and toeoff. The
independent variables were: (a) six bi-monthly times, (b) phases (footstrike, midstance and toeoff), and (c) ten strides.

Findings

Subject One

The findings of this study were:

1. Wear patterns of running shoes significantly affected pronation/supination of subject one with respect to times and phases.

2. Pronation/supination at footstrike had a significant interaction effect between the footstrike at the midstance phases with respect to right foot.

3. No changes occurred with respect to leg angles and wear patterns.

4. Q-angle at footstrike had a significant interaction effect with the midstance phase with respect to Subject One, right foot.

5. Subject One showed similar results between the dependent variables pronation/supination and Q-angle.

6. No significant difference was found in leg angles with respect to time.

Subject Two

The findings of this study were:

1. Pronation/supination did not differ with respect to time for the right foot.

2. Significant differences were found with respect to
pronation/supination between times with the left foot.

3. No significant differences were found with respect to leg angles.

4. No significant differences were found in Q-angle with respect to the right leg.

5. A significant difference was found in Q-angle with respect to the left leg.

6. Similar results were found between the dependent variables pronation/supination and Q-angle.

Conclusions

The conclusions of this study were:

1. Increased wear patterns of running shoes have a significant effect on pronation/supination at the subtalar joint.

2. Increased wear patterns of running shoes have a significant effect on runners' Q-angles.

3. Right and left legs differ with respect to wear patterns of running shoes.

4. A reduction in tread was associated with pronation/supination and Q-angle of the lower extremities while running.

Recommendations

Recommendations for this study are:

1. Further research needs to be conducted concerning the effect wear patterns have on the lower extremities while running. More
information is needed concerning the wear patterns and a runner's potential for injury. Standards need to be estimated concerning the length of time a given pair of shoes should be worn by serious runners. Further studies are needed to determine midsole properties and the long term protection the midsole provides. Additional research into the loss of shock absorption qualities in shoes and the resulting kinematic changes which occur in the lower extremities while running needs to be completed.

2. Longer time periods and larger samples of runners should be studied. Female subjects need to be studied and compared with male subjects to determine if gender differences exist. A protocol needs to be established for use in measuring tread wear of running shoes.
APPENDIX

PRINT CHR$ (9) "8CN"

LIST

10 DIM X(5), Y(5), ANG(5), F(3), A$ (20), Q(5), L(5), Q1(3), L1(3)
20 INPUT "INPUT SUBJECT'S NAME. "; N$
21 INPUT "INPUT SUBJECT'S ID. "; i$
22 INPUT "INPUT STRIDE NUMBER. "; N
23 INPUT "INPUT FOOT (RIGHT, LEFT). "; R$
30 FOR G = 1 TO 3
40 READ S$
50 READ DATA FOR S$
60 FOR A = 1 TO 5
70 PRINT "INPUT POINTS FOR THE "; R$; " LEG — TRIAL "; A
80 PRINT "INPUT HEEL. ": GOSUB 1000
85 X(1) = X: Y(1) = Y
90 PRINT "INPUT CALCANEUS. ": GOSUB 1000
95 X(2) = X: Y(2) = Y
100 PRINT "INPUT ACHILLES TENDON. ": GOSUB 1000
105 X(3) = X: Y(3) = Y
106 PRINT "INPUT KNEE. ": GOSUB 1000
107 X(4) = X: Y(4) = Y
108 PRINT "INPUT HIP. ": GOSUB 1000
109 X(5) = X: Y(5) = Y
110 B = ABS ( ATN ((X(4) - X(3)) / (Y(4) - Y(3))) * 57.3)
115 C = ABS ( ATN ((X(2) - X(1)) / (Y(2) - Y(1))) * 57.3)
120 M2 = (X(2) - X(1)) / (Y(2) - Y(1)): M1 = (X(4) - X(3)) / (Y(4) - Y(3))
122 IF M1 = M2 THEN ANG(A) = 0: GOTO 145
125 IF R$ = "RIGHT" AND M2 < 0 THEN SC = -1: GOTO 140
130 IF R$ = "LEFT" AND M2 > 0 THEN SC = -1: GOTO 140
135 SC = 1
140 ANG(A) = SC * (B + C)
145 IF R$ = "LEFT" GOTO 160
150 Q(A) = ATN ((X(5) - X(4)) / (Y(5) - Y(4))) * 57.3
155 L(A) = ATN ((X(5) - X(2)) / (Y(5) - Y(2))) * 57.3: GOTO 170
160 Q(A) = ATN ((X(4) - X(5)) / (Y(4) - Y(5))) * 57.3
165 L(A) = ATN ((X(2) - X(5)) / (Y(5) - Y(2))) * 57.3
170 NEXT A
180 S = ANG(1); B = ANG(2): S1 = Q(1); B1 = Q(1): S2 = L(1); B2 = L(1)
190 FOR A = 2 TO 5
200 IF S > ANG(A) THEN S = ANG(A)
210 IF S1 > Q(A) THEN S1 = Q(A)
211 IF B1 < Q(A) THEN B1 = Q(A)
212 IF S2 > L(A) THEN S2 = L(A)

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IF B2 < L(A) THEN B2 = L(A)
NEXT A
F(G) = (ANG(1) + ANG(2) + ANG(3) + ANG(4) + ANG(5) - S - B) / 3.0
Q1(G) = (Q(1) + Q(2) + Q(3) = Q(4) + Q(5) - S1 - B1) / 3.0
L1(G) = (L(1) + L(2) + L(3) + L(4) + L(5) - S2 - B2) / 3.0
IF G <> 1 GOTO 265
PRINT "DATA FOR ";I$;
PRINT "ID# ";I $: PRINT 
PRINT : PRINT "DATA FOR ";I$I$ 
PRINT TAB(10);"PRONATION"; TAB(25); "Q-ANGLE"; TAB(40);""; 
TAB(1);"LEG-ANGLE" 
FOR H = 1 TO 5 
PRINT TAB(10);ANG(H); TAB(25);Q(H); TAB(40);""; TAB(1);L(H): NEXT H: PRINT 
PRINT TAB(1);"MEAN = "; TAB(10);F(G); TAB(25);Q1(G); TAB 
(40);""; TAB(1);L1(G) 
PRINT 
PRINT TAB(8);"DEGREES OF PRONATION" 
PRINT TAB(10);"BIW HS & MS ";P1 
PRINT TAB(10);"BIW MS & TO ";P2 
PRINT TAB(10);"BIW HS & TO ";P3
PRINT : PRINT : PRINT 
PRINT 0: RESTORE
INPUT " DO YOU WANT TO MAKE ANOTHER CALCULATION (Y,N) ? ";Z$ 
IF Z$ = "Y" GO TO 20 
IF Z$ = "N" THEN END 
GOTO 370 
DATA "HEEL STRIKE", "MIDSTANCE", "TOE OFF" 
IN# 4 
B$ = "";A$ = "";X$ = "";Y$ = "" 
FOR M = 1 TO 19 
GET A$(M)
B$ = B$ + A$(M)
IF A$(M) = CHR$(13) THEN GOTO 1070 
NEXT M 
IN# 0 
FOR M = 1 TO 19 
Xi$ = " 
UDDU Xi$ = MID$(B$,M,1) 
IF M < 3 GOTO 1130 
IF Xi$ = (32) THEN GOTO 1150 
X$ = X$ + Xi$ 
NEXT M 
FOR L = M TO 19 
YL$ = " " 

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1170  Y1$ = MID$(B$, L, 1)
1180  IF Y1$ = CHR$(13) THEN GOTO 1210
1190  Y$ = Y$ + Y1$
1200  NEXT L
1210  X = VAL(X$); Y = VAL(Y$)
1220  RETURN
1230  NEXT G
1240  END
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