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An Investigation of the Effects of Different Running Shoes on the Gait Pattern of Runners

Linda S. Leeds
Western Michigan University

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AN INVESTIGATION
OF THE EFFECTS OF DIFFERENT RUNNING SHOES
ON THE GAIT PATTERN OF RUNNERS

by

Linda S. Leeds

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
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and Recreation

Western Michigan University
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AN INVESTIGATION
OF THE EFFECTS OF DIFFERENT RUNNING SHOES
ON THE GAIT PATTERN OF RUNNERS

Linda S. Leeds, M.A.
Western Michigan University, 1984

The objective of the study was to investigate the effects of different models of running shoes on the gait pattern of runners. A biomechanical analysis was employed using one high speed camera, digitizing equipment, and a computer. Statistical analysis was performed to determine differences in pronation, Q-angle and leg angle at foot strike and midstance. The analysis of variance indicated no difference between the shoes in pronation at foot strike or midstance. Furthermore, no difference existed in either Q-angle or leg angle during foot strike and midstance.

Apparently, shoes had no effect on running gait during foot strike and midstance. More research is needed on running shoes with a human element maintained in the research design.
ACKNOWLEDGMENTS

I would like to acknowledge Dr. Mary Dawson, my thesis adviser, for her immeasurable aid, guidance, and patience to the completion of this investigation. I would also like to thank Dr. Roger Zabik for his assistance in the collection of data and for serving on my advisory committee. Thank you also goes to Dr. Harold Ray for his contribution as a member of my advisory committee.

Appreciation is extended to the Athlete's Shop for their time in fitting the subjects and providing the running shoes. Special thanks go to the subjects who volunteered for the study.

Linda S. Leeds
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CHAPTER I
INTRODUCTION

During the past ten years the number of runners has increased considerably. With the increase in running there has been an increase in some running-related injuries while others have decreased. The decrease in injuries is purported to be related to the testing and research efforts of various shoe companies. From these tests and related research studies many improvements in shoes have been introduced since 1971. (Cavanagh, 1980) One such improvement led to a decrease in achilles tendonitis. This was accomplished by increasing the heel height one-half inch higher than the forefoot. Another shoe modification was an improvement in the cushion material in the forefoot that helped to decrease the number of metatarsal stress fractures. Decreases in other running related injuries have been attributed to improvement in rearfoot control and to a better understanding of running technique.

Though shoes have improved considerably since 1971, shoe manufacturers have continued to perform tests concerning both durability and changes that might decrease jogging injuries. Running injuries that are still very common include leg fractures, heel spur syndrom, shin splints
and knee injuries. (Cavanagh, 1980) It is believed that the increase in diagnosed leg fractures is partly due to the improved diagnostic tests performed today. Before bone scanning was used, stress fractures were often labeled as shin splints or other broadly defined injuries. Today, radionuclide bone scanning is used to diagnose stress fractures in their early stages, thus preventing major problems. (D'Ambrosia & Drez, 1982)

The largest increase, ten percent, in injuries in the past ten years has been knee related. (Cavanagh, 1980) Cavanagh believes that the increase in distance and intensity of training is part of the reason for the increase in knee injuries. He also believes that excessive pronation at the subtalar joint is a leading cause for knee strain. Pronation is a normal function at the subtalar joint except when excessive pronation occurs, i.e. the fibula and tibia rotate inward which then applies greater stress on the knee.

The cause of excessive pronation is still being researched, but there is evidence that suggests that structural abnormalities, tibia vara (bow legs), tight achilles tendons, tight gastrocnemius, and heel and forefoot varus may be associated with excessive pronation. (Brody, 1980) Within the last five years shoe companies have developed their own solutions for controlling pronation of the subtalar joint. However, tests for validating the success of the new shoes have not been developed. Therefore, there is a need for
studying the effects of running shoes that are designed to prevent excessive pronation in men and women runners.

Statement of the Problem

The problem of this study was to investigate the relationship of shoes and running patterns. The investigation involved a two dimensional biomechanical analysis of the effects of running shoes on selected kinematic variables of the lower extremities. Specifically the investigation involved the following subproblems:

1. The effects of selected running shoes on the pronation/supination of the right and left legs at foot strike and midstance.

2. The effects of selected running shoes on the Q-angles and leg angles of the right and left legs at foot strike and midstance.

Purpose of the Study

The purpose of this investigation was to provide scientific information concerning the effects of different models of shoes on the gait pattern of runners. The results from a biomechanical analysis of runners could benefit both the consumer and the shoe salesperson in the selection of proper footwear for running. It was believed that the results of this investigation would be useful in the continued search for the ultimate running shoe for each individual runner.
Need for the Study

The literature has indicated evidence of shoe development designed to prevent excessive pronation/supination. The only comparative study between the shoes of different manufacturers has been done by the Runner's World staff for their annual shoe report. However, the tests that were used involved mechanical devices designed to simulate the stress on shoes caused by running. Since these tests did not consider the human factors involved in running, there is a need to study pronation/supination with human subjects.

Delimitations

The study was delimited to: (a) Twenty-three runners, age 21 or older, residing in Kalamazoo, Michigan; (b) Two dimensional cinematographical analysis; (c) Kinematic variables of the lower extremities; (d) Six different pairs of running shoes; (e) Treadmill running, and (f) Subjects not presently competing in intercollegiate track competition.

Limitations

Limitations of the study were: (a) All shoes used in this study were new and thus were not "broken in" by the individual subjects; (b) Running speed was not controlled by the investigator but varied with individual subjects, and (c) Subjects were selected randomly and were not screened
for structural abnormalities or anthropometric measures.

Assumptions

Assumptions for the study were: (a) Subjects ran at their own comfortable speed; (b) Subjects were in good health at the time of data collection; and (c) The mechanics of running on a treadmill are the same as the mechanics of running over level terrain.

Hypotheses

It was hypothesized that different degrees of pronation would be evident with different models of shoes at foot strike and midstance. It was also hypothesized that the Q-angle and the leg angle would be unchanged at foot strike and midstance.
Definition of Terms

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

1. **Counter.** A counter is a support cup for the heel that supports laterally and protects vertically. (Burger, 1978)

2. **Foot strike.** Foot strike occurs at initial ground contact of any part of the foot during locomotion.

3. **Kinematics.** Kinematics is the study of motion without consideration of mass and force.

4. **Leg angle.** Leg angle is formed by the greater trochanter, the center of the ankle joint, and a vertical line passing through the ankle joint.

5. **Midstance.** Midstance occurs when the foot is firmly on the ground and can bear weight.

6. **Neutral position.** Neutral position is when the calcaneus is aligned with the midline of the achilles tendon.

7. **Pronation.** Pronation occurs when the ankle turns medially causing the fibula and tibia to rotate inward, with a resultant stress on the knee. (Cavanagh, 1980)

8. **Q-angle.** Q-angle is formed by the line of pull of the quadriceps muscle and patellar tendon. (Brody, 1980)

9. **Supination.** Supination is the outward rotation of the foot.
10. **Toe-off.** Toe-off is the push off phase that propels the body forward.

11. **Valgus.** Valgus occurs when the foot turns away from the midline of the body.

12. **Varus.** Varus occurs when the foot turns toward the midline of the body.

13. **Zero starting position.** Zero starting position is the alignment of the heel with the midline of the tibia. (Heck, Hendryson, & Rowe, 1965)
CHAPTER II

REVIEW OF LITERATURE

Running gait is a repetitive movement that involves the whole body and consists of a stance phase, push-off phase, flight phase, and contact phase. At the beginning of the stance phase the foot strikes the ground near the center of gravity of the body. Adduction of the leg externally rotates the tibia causing the foot to maintain supination before heel strike. (Brody, 1980) The contact phase varies among runners but is usually at the rear, lateral border of the shoe. Right after the contact phase the foot pronates as weight shifts to the forefoot. Pronation occurs naturally as the tibia rotates internally to absorb stress and adapt to the running surface. (Subotnick, 1978)

During the push-off phase the foot becomes more rigid and slightly supinates to provide a strong forward and upward movement. It is necessary that the push-off phase be stable to provide maximum time for the opposite leg to swing forward. (Broer, 1979) It is at this time, between the push-off phase and contact phase, that the runner is in the flight phase, a period of no support. After the flight phase the cycle commences with the opposite foot.
History

Not until the first marathon race in 1896, at the modern Olympic Games in Athens, did an interest grow in the development of footwear for the distance runner. Before the games, going as far back as 10,000 years, the first recorded "running shoes" were sandals made of crushed sagebrush bark. The sandals were found in Oregon and are believed to have been running shoes because of the construction and the tread on the bottom of the sandal. (Cavanagh, 1980)

Athletic shoes were not introduced until the early 1700s when short running races became popular. The year 1839 brought a significant change in footwear when Charles Goodyear discovered the process of vulcanization of rubber. In 1861 spiked shoes were made for the then popular track and field events. During this time the spiked track shoes were selling for six dollars. (Cavanagh, 1980)

Running continued to grow both in popularity and distance. In the last half of the nineteenth century the 500 mile race evolved. The contestants wore high-top leather boots and ran continually for six days and six nights on a track. The contestant who covered the farthest distance was declared the winner. But due to betting, drug use, and other illegal occurrences, the 500 mile race disappeared in spite of the increased interest in running competition. Thus, in the 1896 Olympic Games a new competition was added, the marathon.
The marathon was to commemorate the famous distance runner Pheidippides, who purportedly ran from the Plains of Marathon to Athens to announce victory over the Persians. The marathon introduced the idea that running did not have to be done on a track, therefore a shoe was needed to aid the marathoner over many different terrains.

The first distance running shoe, developed by Spalding, was a black leather shoe that resembled an Army boot. Before the running shoe, runners ran without shoes or with their every day shoes. After running the New York race in 1908, Matt Maloney said he would prefer a sturdy shoe which would prevent excessive pronation. Spalding heard the runner's request and developed a new distance running shoe with a sturdy heel and "gum rubber" sole. (Cavanagh, 1980)

Interest in marathon running increased up to 1910 and then did not grow again until 1927. A good measuring tool was the number of participants in the Boston Marathon: in 1910 there were 193 runners; in 1964 there were 300 runners; and in 1979 there were 7,877 runners. The increase of the number of runners stimulated shoe manufacturers in designing a wider variety of running shoes which still needed considerable improvements. (Cavanagh, 1980)

During the 1920s Adolf and Rudi Dassler, from West Germany, began to design athletic shoes. Dasslers' shoes immediately became very popular with athletes and in 1925 their first running shoe was manufactured. From then on
business grew considerably and the Dassler shoe became an international word. In 1948 the Dassler brothers split and formed their own shoe companies: Adidas and Puma. (Glover & Shepherd, 1977)

A predecessor of the Dassler brothers, the Hyde Athletic Company in England, now producing Saucony running shoes, began developing athletic shoes in 1898. In the 1950s the Hyde Athletic Company was recognized for making the best domestic shoe, and later was recognized for their running shoe. (Cavanagh, 1980)

The Tiger Shoe Company in Japan made their debut in the mid-1950s with a very unusual product: The Marathon shoe. The toe of the Marathon shoe was constructed with a wide separate compartment for the big toe. (Cavanagh, 1980) The Riley Company, which later introduced New Balance, was originally a company for orthopedic shoes. It was their knowledge of orthopedic shoes that helped to improve the running shoe. (Cavanagh, 1980)

The Riley Company developed the New Balance Trackster with the "rippled sole". At first the shoe was ridiculed but it has since been named as the first running shoe of the twentieth century. The Trackster also was the first running shoe with a heel wedge, though not the kind of wedge used in running shoes today. It was similar to a dress shoe with a separate heel. (Cavanagh, 1980)

The sixties provided an important influence for runners
and the running shoe: Cooper's Aerobics (1968) strongly suggested running as a leisure time activity, New Balance made major changes in shoe construction, and Bob Anderson wrote Distance Running News which later became Runner's World. The first shoe survey was done in 1967 by Anderson on 15 running shoes, the entire field at the time. (Cavanagh, 1980)

The 1970s brought even more change as well as competition to running shoe manufacturers. A disagreement over distribution rights split the parent Tiger Company with the United States Tiger Company and the Nike Company emerged. (Glover & Shepherd, 1977) Rivalries among shoe companies heightened as star athletes began promoting certain brands after their personal victories. The materials that were earlier used in shoe construction were discarded for more favorable materials. Nylon uppers, heel counters, and waffle outsole design were tested and measured against rival products annually by Runner's World staff in their annual shoe survey.

Shoe Testing

In 1975 Anderson, a writer for Runner's World, compiled the first annual shoe survey. The criteria for the 1975 ranking included price, number of users, and subjective assessment of the upper softness, the shank support, and the sole.
The primary consideration in the construction of a running shoe was the importance in having more cushion under the heel. Initially very little thought was given to the forefoot, but it was later considered an important area. The top rated shoe was Adidas SL76. A running shoe called the Drake, manufactured by Brooks, made its debut. (Runner's World, 1975)

In 1976 New Balance 320 was ranked as the best running shoe. Etonic was introduced as a new running shoe manufacturer. Nike promoted the flared heel which later was proven unsatisfactory for the purpose it was originally designed. For the first time nylon uppers became popular and canvas uppers were replaced on the top 15 shoes. (Cavanagh, 1980)

In 1977 the shoe surveys were changed to shoe testing. The tests measured shock absorption, flexibility and sole wear. The purpose of the tests was to study shoe construction and properties so that running shoe manufacturers could design better shoes. (Runner's World, 1977)

The Brooks' Vantage was the number one shoe for 1977. The shoe had many notable features including a "sock liner" that replaced the arch support. A major change in this running shoe was the introduction of the varus wedge. The varus wedge added a four degree increase in heel height on the medial side of the shoe. Subotnick, a podiatrist, was a consultant with Brooks and suggested the addition. He believed the varus wedge would prevent excessive pronation,
which is often the cause for running injuries. (Runner's World, 1977)

Further material and construction changes occurred over the following years. By 1980, a great concern developed among manufacturers for special features that might help eliminate common running injuries. Through lab tests forefoot and rearfoot impact properties were improved by modification of the sole, of the shoe, and its properties. A raised achilles tendon protector was added, and new tests were developed to measure rearfoot control and traction. (Runner's World, 1980) The three new tests to measure rearfoot control were the heel-counter stiffness test, the rearfoot stability test and the penetration test. The tests were designed to identify whether or not a running shoe controlled excessive pronation during foot strike. The Runner's World (1980) staff strongly believed that a firm midsole, a firm wedge, and a firm outsole would reduce the excessive movement that produces many running injuries.

The heel-counter stiffness test determined the strength of the heel while a computer measured the amount of force applied to the heel-counter. The higher the force needed to deform the heel-counter, the better the shoe was in preventing excessive motion. (Runner's World, 1980)

The stability test measured the maximum angle of the midsole and wedge while a mechanical hammer simulated compression to the medial border. According to Runner's
World (1980), a larger angle of deformation of the sole indicated poor control, leading to excessive pronation.

While the stability test may or may not have indicated poor shoe control, there was a possibility that it might indicate poor shock absorption. The runner takes from 800 to 1200 steps for every mile he/she runs. The stress on the joints, as well as other parts of the body may be up to three times the person's weight. Shock absorption is extremely important in minimizing stress in joints and bones. Therefore a shoe with a large angle of deformity may indicate lack of shock absorption rather than poor foot control.

The third test was the penetration test. This test measured the deformation of the inside of the shoe during the rearfoot impact test. A large deformation in the penetration test was judged an indicator of poor shoe control for the runner. (Runner's World, 1980)

Running Injuries

Cavanagh (1980) found, when examining the history of injuries common to runners, that very little research had been done. An early study was done on marines during their ten-week training camp in 1975. Bensel, who monitored the study of 879 young men, found that during the ten-week boot camp thirty-seven percent had lower extremity problems. The largest problem was blisters, followed by heel problems, lace irritations, stress fractures, and so on.
Today we don't run in combat boots, but comparisons can be made between marine recruit and beginning runners. It should be recognized that the activity in which the marines participated was not just running; they marched, climbed ladders, hiked and performed other military feats.

The injuries most common with beginning runners were similar to the injuries in which the marines rated high. The similarity was probably due to poor shoe fit and the foot adjustment to the type of trauma to which the foot was subjected. The army boot was not designed for the shock absorption or flexibility required for a running shoe. Because of the evolution of running shoes, other comparisons are difficult to make between a runner and a marine. (Cavanagh, 1980)

Two methods that have been utilized to study running injuries are the survey and the self-report. Runner's World did a running injury survey in 1971. Runners were asked the type of injury and the duration of the injury. The results were: 17.9% knee injuries, 14% injuries related to the achilles tendon, 10.6% shin splints, 6.9% arch problems, and 6.4% ankle injuries. The other noted injuries were metatarsal fractures, stone bruises, calf pulls, heel bone damage and hip related injuries.

Some of the injuries cited above might have been caused by the lack of knowledge of running technique, i.e. the importance of warm-up, preventive medicine, or proper
training methods. There is still room for improvement in shoe construction and doctors are only beginning to understand the different ailments suffered by runners.

In 1973 another survey was conducted and the same injuries were listed in much the same order. However, there was a noticeable increase of knee and achilles related injuries. Sheehan compared a 1973 study to an earlier one and developed guidelines to assist the medical field in treating running injuries. He noted that most running injuries occurred from the ankle up. He also noted that the 1973 runners increased their mileage and intensity compared to the earlier study. Sheehan concluded that injuries were interrelated with the increase in mileage, and the model of shoe worn. (Cavanagh, 1980)

A survey was completed by James, Bates, and Osterning, (1977) on 180 injured runners. The runners were examined while standing. This study revealed the injury list changed by percentage, but not by order. Knee injuries increased while shin splints and achilles tendon injuries dropped. The examination showed twenty-two percent of the subjects maintained a neutral rearfoot alignment. Fifty-eight percent of the runners showed pronation during stance. From this observation, body alignment was thought to be connected with running injuries.

There are numerous structural differences between runners. A few differences may promote a more advantageous
running gait, while some might cause one, or several, running related injuries. Structural abnormalities which might cause problems may be different leg lengths, muscle imbalance between the flexors and the extensors, limited range of motion and flexibility of the joints in the lower extremity, etc. D'Ambrosia and Drez (1982) suggested that any abnormality may produce an injury because of the large stress loads placed on the runner's musculoskeletal system.

Foot Pronation

Pronation is a normal action of the foot during heel-strike. Pronation occurs at the subtalar joint. The action is to help absorb the stress and also assist the foot in preparation for toe-off. (Subotnick, 1978) A problem exists when the ankle joint over pronates, and causes stress on the joints, the ligaments and the musculature. (D'Ambrosia & Drez, 1982)

Another factor in injuries related to pronation is the time interval in which pronation occurs. In walking, pronation is 25% of the stance phase. If a person walked at a normal pace of 120 steps per minute, pronation would be completed in about 150 milliseconds. If a person were running a six-minute mile, however, pronation would be completed within 30 milliseconds - with total stance time of 200 milliseconds. By studying high-speed film one discovers that the foot strike is usually in a slightly inverted posi-
tion; the calcaneus quickly crosses over into eversion while 2 1/2 times the body weight is applied to the subtalar joint. The remainder of the weight and the rest of the pronation is at a slower rate, while dorsiflexion of the ankle joint and flexion of the knee help with absorption. (D'Ambrosia & Drez, 1982)

This sequence of events is often seen with: flat feet or a cavus foot (D'Ambrosia & Drez, 1982); women because of the larger Q-angle (Cavanagh, 1980); tibia vara (bow legs), muscular imbalance; and hindfoot and forefoot varus (Broer, 1979). Subotnick (1978) strongly believes that various structural abnormalities of the leg and foot result in many different injuries. The foot does not recover from instability at foot strike, therefore the foot never becomes a rigid lever at toe off. The result of inefficient and overused gait patterns will more likely cause an injury.
CHAPTER III

EXPERIMENTAL PROCEDURES

The problem of this study was to investigate the relationship of running shoes and running patterns. The procedures utilized in this investigation are found under the following headings: (a) Subjects; (b) Cinematographical Procedures; (c) Data Analysis Procedures; and (d) Statistical Analysis.

Subjects

The subjects selected for this investigation were 23 male runners, age 21 to 56 years, from Kalamazoo, Michigan. The subjects were asked to participate in the study because (a) of their current regular running program, and (b) they ran between 15 and 80 miles per week.

Cinematographical Procedures

Data collection took place in the Biomechanics Laboratory at Western Michigan University between July 5-15, 1983. One Photo Sonic 1-PL, 16mm camera, was placed perpendicular to the frontal plane and posterior to the subjects as they ran on the treadmill. The camera was outfitted with Kodak Ektachrome, Tungsten Video News Film and was fitted
with an Augenieux-zoom 12 x 120 lens.

Two mini-Brute, 9 light banks, set at 45 degree angles to the field of view illuminated the filming area. The camera was positioned 25 feet from the center of the treadmill at a height of 4 feet above the floor. Details of the filming site are diagrammed in Figure 1.

A light emitting diode set at .01 second was used to calibrate the camera speed. Camera speed was set at 150 frames per second with a 120 degree shutter factor and an f/stop of 8.0.

Subjects were filmed running on a Quinton Model 643 Programmed exercise treadmill. Each subject performed seven trials. In trial one, the subjects ran without shoes and then ran in shoes, trials two through seven. The order of the six trials with shoes was randomized for each subject. Three complete strides were filmed for each trial.

The subject's heel was aligned with the midline of the tibia and was marked where the achilles tendon and the gastrocnemius meet, at the subtalar joint, and on the tuberosity of the calcaneus. Shoes were marked on the heel one inch from the floor and on the estimated point of the subtalar joint. A vertical line was drawn through the marks to distinguish the neutral position for determining degree of pronation.
Figure 1. Camera and treadmill placement for filming sessions.
Data Analysis Procedures

A Vanguard projector was used to view the film. An image was projected on a table which allowed selected frames to be analyzed. The X and Y coordinate points on the designated frames were digitized with a Numonics Electronic Graphics Calculator, Model 1224, interfaced to Western Michigan University's DEC-10 computer.

Frames chosen for analysis were: (a) foot strike, and (b) midstance. Three strides were analyzed and the mean was used as the dependent variable for the six pairs of running shoes.

A computer program was written to calculate degree of pronation, Q-angle, and leg angle. The program language was Fortran (see Appendix A).

Degree of pronation was calculated using Vectors A and B (see Figure 2). Vector A represents the zero starting point, or neutral position, when the calcaneous is aligned with the midline of the achilles tendon. When Vector B is not aligned with Vector A, the foot is in pronation or supination. When Vector B falls to the medial side the foot is in pronation and the magnitude of pronation is preceded by a negative sign. When Vector B falls to the lateral side the foot is in supination and the magnitude of supination is preceded by a positive sign. Zero starting point, or neutral position, is designated by 0 degree.
Figure 2. Vector diagram illustrating neutral position, pronation, and supination of right leg.
Degree of the $Q$-angle was calculated on the right and left legs using Vector $C_1$ (see Figure 3). Vector $C_1$ was defined by the greater trochanter and the patellar tendon. The $Q$-angle was the angle formed by Vector $C_1$ and a vertical line passing through the patellar tendon. Degree of the leg angle was calculated on the right and left legs using Vector $C_2$. Vector $C_2$ was defined by the greater trochanter and calcaneous. The leg angle was the angle formed by Vector $C_2$ and a vertical line passing through the ankle joint.

Statistical Analysis

The data were analyzed using Analysis of Variance. The ANOVA Design was a randomized block factorial with two factors. (Kirk, p. 239, 1968) The independent variables (factors) were, (a) legs with two levels, right and left, and (b) shoes with seven levels, barefoot and six different models of running shoes. Six different ANOVA's were calculated using different dependent variables. The dependent variables were, (a) pronation at foot strike, (b) pronation at midstance, (c) $Q$-angle at foot strike, (d) $Q$-angle at midstance, (e) leg angle at foot strike, and (f) leg angle at midstance.

The University of California, Los Angeles, BMDP Series Computer package was utilized in calculating the ANOVA. The specific program used was the Analysis of Variance and Covariances with repeated measures, BMDP2V.
Figure 3. Vector diagram illustrating the calculation of Q-angle and leg angle.
CHAPTER IV

ANALYSIS OF DATA

The problem of this study was to investigate the rela-
tionship of shoes and running patterns. The investigation utilized 23 male subjects from the Kalamazoo area and were recruited with the aid of the Kalamazoo Track Club. Cinematographical techniques were utilized to collect data. One high speed camera was positioned posterior to the sub-
jects as they ran on a treadmill. For purposes of clarity this chapter was divided into two headings, (a) Results, which included the following subheadings, pronation at foot strike, pronation at midstance, Q-angle at foot strike, Q-angle at midstance, leg angle at foot strike, and leg angle at midstance, and (b) Discussion.

Results

Pronation at Foot Strike

The hypothesis that different degrees of pronation at foot strike would be evident with different models of shoes was not supported. An analysis of variance was done without shoes and with six different pairs of shoes. The dimensions of the analysis were: (a) Subjects (twenty-three males); (b) Legs (left vs. right); (c) Shoes (without shoes and six different
pairs of shoes); and (d) Leg x shoe interaction effect. The ANOVA summary table for pronation at foot strike is presented in Table 1.

### Table 1

**Analysis of Variance in Pronation at Foot Strike**

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>292.17</td>
<td>3</td>
<td>97.39</td>
<td>31.42*</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>14.47</td>
<td>1</td>
<td>14.47</td>
<td>4.67**</td>
</tr>
<tr>
<td>Shoes</td>
<td>23.73</td>
<td>6</td>
<td>3.96</td>
<td>1.28</td>
</tr>
<tr>
<td>Leg x shoe</td>
<td>138.26</td>
<td>6</td>
<td>23.04</td>
<td>7.43***</td>
</tr>
<tr>
<td>Residual</td>
<td>121.05</td>
<td>39</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>297.51</td>
<td>55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* F(3,39)=2.84, p < .05  
** F(1,39)=4.08, p < .05  
*** F(6,39)=2.34, p < .05

The source of variation for subjects, with an obtained F of 31.42, had the largest significant difference with 3 and 39 degrees of freedom. A critical value of 2.84 was required to reject at the .05 level of significance. Legs showed a significant difference with 1 and 39 degrees of freedom. A critical value of 4.08 was required to reject at the .05
level of significance. A significant difference was found in leg x shoe interaction with 6 and 39 degrees of freedom. A critical value of 2.34 was required at the .05 level of significance to reject. No significant difference was found between shoe with 6 and 39 degrees of freedom. A critical value of 2.34 was required to reject at the .05 level of significance.

Since the obtained F value for the shoes was 1.28, the null hypothesis was not rejected. Therefore the hypothesis that different degrees of pronation would be evident with different models of shoes at foot strike was not supported.

Performance on the dependent variable, pronation, was measured at seven levels, without shoes and with six different models of running shoes. Means and standard deviations for twenty-three subjects are shown in Table 2. Descriptive data indicated differences between the right and left foot with respect to footwear. The ranges were 3.32, 2.05, 3.22, 2.01, 4.51, 3.56, and 3.69 for barefoot, Shoe 1, Shoe 2, Shoe 3, Shoe 4, Shoe 5, and Shoe 6 respectively. With respect to the right foot, Shoe 1, Shoe 3, and Shoe 5 have similar means, -9.66, -10.27, and -9.75 respectively. Barefoot, Shoe 2, Shoe 4, and Shoe 6 have similar means, -6.58, -5.86, -4.90, and -6.33 respectively. The difference between these two groups was 3.95 degrees. Descriptive data for the left foot showed few differences between the means. Shoe 5 with a mean of -6.19 had the lowest value. The range, for the left foot, between the rest of the shoes including barefoot was 2.41.
Table 2

Means and Standard Deviations in Pronation at Foot Strike

<table>
<thead>
<tr>
<th></th>
<th>Barefoot</th>
<th>Shoe 1</th>
<th>Shoe 2</th>
<th>Shoe 3</th>
<th>Shoe 4</th>
<th>Shoe 5</th>
<th>Shoe 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right leg</td>
<td>-6.58</td>
<td>-9.66</td>
<td>-5.86</td>
<td>-10.27</td>
<td>-4.90</td>
<td>-9.75</td>
<td>-6.33</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.00</td>
<td>2.75</td>
<td>2.96</td>
<td>3.60</td>
<td>1.24</td>
<td>4.10</td>
<td>4.03</td>
</tr>
<tr>
<td>Left leg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.47</td>
<td>1.58</td>
<td>4.50</td>
<td>3.73</td>
<td>3.50</td>
<td>2.21</td>
<td>2.24</td>
</tr>
</tbody>
</table>
**Pronation at Midstance**

The hypothesis that different degrees of pronation would be evident with different models of shoes at midstance was not supported. An analysis of variance was done without shoes and with six different pairs of running shoes. The dimensions of the analysis were: (a) Subjects (twenty-three males); (b) Legs (left vs. right); (c) Shoes (without shoes and six different pairs of shoes); and (d) Leg x shoe interaction effect. The ANOVA summary table for pronation at midstance is presented in Table 3.

**Table 3**

**Analysis of Variance in Pronation at Midstance**

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>140.95</td>
<td>3</td>
<td>46.98</td>
<td>16.78*</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>15.24</td>
<td>1</td>
<td>15.24</td>
<td>5.44**</td>
</tr>
<tr>
<td>Shoes</td>
<td>29.38</td>
<td>6</td>
<td>4.90</td>
<td>1.75</td>
</tr>
<tr>
<td>Leg x shoe</td>
<td>267.79</td>
<td>6</td>
<td>44.63</td>
<td>15.94***</td>
</tr>
<tr>
<td>Residual</td>
<td>109.20</td>
<td>39</td>
<td>2.80</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>321.56</td>
<td>55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* F(3,39)=2.84, p < .05
** F(1,39)=4.08, p < .05
*** F(6,39)=2.34, p < .05
The source of variation for subjects, with an obtained F of 16.78, had the largest significant difference with 3 and 39 degrees of freedom. A critical value of 2.84 was required to reject at the .05 level of significance. Legs, with an obtained F of 5.44, showed a significant difference with 1 and 39 degrees of freedom. A critical value of 4.80 was required to reject at the .05 level of significance. A significant difference was found in leg x shoe interaction, with an obtained F of 15.94, at 6 and 39 degrees of freedom. A critical value of 2.34 was required at the .05 level of significance to reject. No significant difference was found between shoes with 6 and 39 degrees of freedom. A critical value of 2.34 was required at the .05 level of significance to reject. Since the obtained F value for the shoes was 1.75, the null hypothesis was not rejected. Therefore the hypothesis that different degrees of pronation would be evident with different models of shoes at midstance was not supported.

Performance on the dependent variable, pronation, was measured at seven levels, without shoes and with six different models of running shoes. Means and standard deviations for the twenty-three subjects are shown in Table 4. Descriptive data indicated differences between the right and left foot with respect to footwear. The ranges were 1.99, 4.05, 5.38, 2.96, 7.21, 4.16, and 4.49 for barefoot, Shoe 1, Shoe 2, Shoe 3, Shoe 4, Shoe 5, and Shoe 6 respectively. With
Table 4.
Means and Standard Deviations in Pronation at Midstance

<table>
<thead>
<tr>
<th></th>
<th>Barefoot</th>
<th>Shoe 1</th>
<th>Shoe 2</th>
<th>Shoe 3</th>
<th>Shoe 4</th>
<th>Shoe 5</th>
<th>Shoe 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right leg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X (degrees)</td>
<td>-2.06</td>
<td>-5.96</td>
<td>0.06</td>
<td>-5.60</td>
<td>1.47</td>
<td>-5.35</td>
<td>-1.59</td>
</tr>
<tr>
<td>SD (degrees)</td>
<td>3.18</td>
<td>0.73</td>
<td>3.12</td>
<td>1.16</td>
<td>0.55</td>
<td>2.78</td>
<td>3.17</td>
</tr>
<tr>
<td><strong>Left leg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X (degrees)</td>
<td>-4.05</td>
<td>-1.91</td>
<td>-4.74</td>
<td>-2.64</td>
<td>-5.74</td>
<td>-1.19</td>
<td>-6.08</td>
</tr>
<tr>
<td>SD (degrees)</td>
<td>4.70</td>
<td>1.10</td>
<td>1.42</td>
<td>2.89</td>
<td>1.61</td>
<td>1.53</td>
<td>2.23</td>
</tr>
</tbody>
</table>
respect to the right foot, Shoe 1, Shoe 3, and Shoe 5 had similar means, -5.96, -5.60, and -5.35 respectively. Barefoot, Shoe 2, Shoe 4, and Shoe 6 had similar means, -2.06, 0.06, 1.47, and -1.59 respectively. The range between these two groups was 4.97 degrees. Descriptive data for the left foot showed similar differences between the means. Shoe 5, with a mean of -1.19, had the lowest value. The range for the left foot, between the rest of the shoes including barefoot, was 4.89.

Q-angle at Foot Strike

The hypothesis that the Q-angle would be unchanged at foot strike was supported. An analysis of variance was calculated without shoes and with six different pairs of shoes. The dimensions of the analysis were: (a) Subjects (twenty-three males); (b) Legs (left vs. right); (c) Shoes (without shoes and six different pairs of shoes); and (d) Leg x shoe interaction effect. The ANOVA summary table for Q-angle at foot strike is presented in Table 5.

The source of variation for subjects, with an obtained F of 14.73, had the only significant difference with 3 and 39 degrees of freedom. A critical value of 2.84 was required to reject at the .05 level of significance. Shoes showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 was required to reject at the .05 level of significance. Leg x shoe interaction (F=1.86) showed no
significant difference with 6 and 39 degrees of freedom that required a critical value of 2.34 at the .05 level of significance to reject. No significant difference was found between legs with 1 and 39 degrees of freedom. A critical value of 4.08 was required to reject at the .05 level of significance. Since the obtained F value for the legs was .07, the null hypothesis was not rejected. Therefore the hypothesis that the Q-angle would be unchanged at foot strike was supported.

Table 5
Analysis of Variance in Q-angle at Foot Strike

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>43.73</td>
<td>3</td>
<td>14.58</td>
<td>14.73*</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>0.07</td>
<td>1</td>
<td>0.07</td>
<td>.07</td>
</tr>
<tr>
<td>Shoes</td>
<td>10.16</td>
<td>6</td>
<td>1.69</td>
<td>1.71</td>
</tr>
<tr>
<td>Leg x shoe</td>
<td>11.03</td>
<td>6</td>
<td>1.84</td>
<td>1.86</td>
</tr>
<tr>
<td>Residual</td>
<td>38.49</td>
<td>39</td>
<td>.99</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>103.48</td>
<td>55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* F(3,39)=2.84, p < .05

Performance on the dependent variable, Q-angle, was measured at seven levels, without shoes and with six different
models of running shoes. Means and standard deviations for the twenty-three subjects are shown in Table 6. Descriptive data indicated differences between the right and left foot with respect to footwear. The ranges were 0.61, 1.89, 1.06, 0.84, 0.85, 0.99, and 0.08 for barefoot, Shoe 1, Shoe 2, Shoe 3, Shoe 4, Shoe 5, and Shoe 6 respectively. With respect to the right foot there were little differences between the means with a range of 1.90. Descriptive data for the left foot reflect few differences between the means. The range between the means of the left foot was 1.62, not enough to indicate a significant difference.

Q-angle at Midstance

The hypothesis that the Q-angle would be unchanged at midstance was supported. An analysis of variance was calculated without shoes and with six different pairs of shoes. The dimensions of the analysis were: (a) Subjects (twenty-three males); (b) Legs (left vs. right); (c) Shoes (without shoes and six different pairs of shoes); and (d) Leg x shoe interaction effects. The ANOVA summary table for Q-angle at midstance is presented in Table 7.

The source of variation for subjects, with an obtained F of 9.82, had the only significant difference with 3 and 39 degrees of freedom. A critical value of 2.84 was required to reject at the .05 level of significance. Shoes (F=0.48) showed no significant difference with 6 and 39 degrees of
<table>
<thead>
<tr>
<th></th>
<th>Barefoot</th>
<th>Shoe 1</th>
<th>Shoe 2</th>
<th>Shoe 3</th>
<th>Shoe 4</th>
<th>Shoe 5</th>
<th>Shoe 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right leg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{X}$</td>
<td>20.82</td>
<td>22.72</td>
<td>21.60</td>
<td>22.43</td>
<td>21.67</td>
<td>22.03</td>
<td>21.08</td>
</tr>
<tr>
<td>(degrees)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.06</td>
<td>1.11</td>
<td>1.68</td>
<td>0.07</td>
<td>1.07</td>
<td>1.35</td>
<td>1.99</td>
</tr>
<tr>
<td><strong>Left leg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{X}$</td>
<td>21.43</td>
<td>21.43</td>
<td>22.66</td>
<td>21.59</td>
<td>22.52</td>
<td>21.04</td>
<td>21.16</td>
</tr>
<tr>
<td>(degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.03</td>
<td>2.13</td>
<td>1.45</td>
<td>1.68</td>
<td>0.76</td>
<td>1.21</td>
<td>1.35</td>
</tr>
</tbody>
</table>
freedom. A critical value of 2.34 was required to reject at the .05 level of significance. Leg x shoe interaction ($F=2.42$) showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 was required at the .05 level of significance to reject. No significant difference was found between legs with 1 and 39 degrees of freedom. A critical value of 4.08 at the .05 level of significance to reject. Since the obtained $F$ value for the legs was 0.24, the null hypothesis was not rejected. Therefore the hypothesis that the Q-angle would be unchanged at midstance was supported.

Table 7
Analysis of Variance in Q-angle at Midstance

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>29.15</td>
<td>3</td>
<td>9.72</td>
<td>9.82*</td>
</tr>
<tr>
<td>Treatment</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>0.24</td>
<td>1</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Shoes</td>
<td>2.85</td>
<td>6</td>
<td>0.48</td>
<td>0.48</td>
</tr>
<tr>
<td>Leg x shoe</td>
<td>14.41</td>
<td>6</td>
<td>2.40</td>
<td>2.42</td>
</tr>
<tr>
<td>Residual</td>
<td>38.62</td>
<td>39</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>85.27</td>
<td>55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $F(3,39)=2.84$, $p < .05$
Performance of the dependent variable, Q-angle, was measured at seven levels, without shoes and with six different models of running shoes. Means and standard deviations for the twenty-three subjects are shown in Table 8. Descriptive data indicated differences between the right and left foot with respect to footwear. The ranges were 0.43, 0.91, 1.38, 0.44, 0.27, 1.34, and 1.52 for barefoot, Shoe 1, Shoe 2, Shoe 3, Shoe 4, Shoe 5, and Shoe 6 respectively. With respect to the right foot there were little differences between the means with a range of 1.44. Descriptive data for the left foot reflect few differences between the means. The range between the means of the left foot was 1.59, not enough to show a significant difference.

**Leg Angle at Foot Strike**

The hypothesis that the leg angle would be unchanged at foot strike was supported. An analysis of variance was calculated without shoes and with six different pairs of shoes. The dimensions of the analysis were: (a) Subjects (twenty-three males); (b) Legs (left vs. right), (c) Shoes (without shoes and six different pairs of shoes); and (d) Leg x shoe interaction effects. The ANOVA summary table for leg angle at foot strike is presented in Table 9.

The source of variation for subjects, with an obtained $F$ of 92.53, had the only significant difference with 3 and 39 degrees of freedom. A critical value of 2.84 was re-
Table 8

Means and Standard Deviations in Q-angle at Midstance

<table>
<thead>
<tr>
<th></th>
<th>Barefoot</th>
<th>Shoe 1</th>
<th>Shoe 2</th>
<th>Shoe 3</th>
<th>Shoe 4</th>
<th>Shoe 5</th>
<th>Shoe 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(degrees)</td>
<td>22.31</td>
<td>23.52</td>
<td>22.62</td>
<td>23.34</td>
<td>22.96</td>
<td>23.75</td>
<td>22.35</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(degrees)</td>
<td>1.18</td>
<td>1.67</td>
<td>1.29</td>
<td>0.86</td>
<td>1.20</td>
<td>0.72</td>
<td>1.65</td>
</tr>
<tr>
<td><strong>X</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(degrees)</td>
<td>22.74</td>
<td>22.61</td>
<td>24.00</td>
<td>22.90</td>
<td>23.23</td>
<td>22.41</td>
<td>23.87</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(degrees)</td>
<td>1.28</td>
<td>1.40</td>
<td>0.91</td>
<td>1.35</td>
<td>0.76</td>
<td>1.72</td>
<td>1.23</td>
</tr>
</tbody>
</table>
quired to reject at the .05 level of significance. Shoes, with an obtained $F$ of 1.00, showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 was required to reject at the .05 level of significance. Leg x shoe interaction ($F=1.75$) showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 was required to reject at the .05 level of significance. No significant difference was found between legs with 1 and 39 degrees of freedom. A critical value of 4.08 was required to reject at the .05 level of significance. Since the obtained $F$ value for the legs was 1.25, the null hypothesis was not rejected. Therefore the hypothesis that the leg angle would be unchanged at foot strike was supported.

Performance of the dependent variable, leg angle, was measured at seven levels, without shoes and with six different models of running shoes. Means and standard deviations for the twenty-three subjects are shown in Table 10. Descriptive data indicated differences between the right and left foot with respect to footwear. The ranges were 0.06, 0.30, 0.26, 0.00, 0.60, 0.18, and 0.26 for barefoot, Shoe 1, Shoe 2, Shoe 3, Shoe 4, Shoe 5, and Shoe 6 respectively. With respect to the right foot there was little difference between the means with a range of 0.40. Descriptive data for the left foot reflect few differences between the means. The range between the means of the left foot was 0.59, not enough to show a significant difference.
### Table 9

**Analysis of Variance in Leg Angle at Foot Strike**

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>14.81</td>
<td>2</td>
<td>7.40</td>
<td>92.53*</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>0.10</td>
<td>1</td>
<td>0.10</td>
<td>1.25</td>
</tr>
<tr>
<td>Shoes</td>
<td>0.46</td>
<td>6</td>
<td>0.08</td>
<td>1.00</td>
</tr>
<tr>
<td>Leg x Shoe</td>
<td>0.82</td>
<td>6</td>
<td>0.14</td>
<td>1.75</td>
</tr>
<tr>
<td>Residual</td>
<td>2.24</td>
<td>28</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>18.43</td>
<td>43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* F(2,28)=2.84, p < .05

### Leg Angle at Midstance

The hypothesis that the leg angle would be unchanged at midstance was supported. An analysis of variance was calculated without shoes and with six different pairs of shoes. The dimensions of the analysis were: (a) Subjects (twenty-three males); (b) Legs (left vs. right); (c) Shoes (without shoes and six different pairs of running shoes); and (d) Leg x shoe interaction effects. The ANOVA summary table for leg angle at midstance is presented in Table 11.

The source of variation for subjects, with an obtained F of 81.31, showed the only significant difference with 3 and
Table 10
Means and Standard Deviations in Leg Angle at Foot Strike

<table>
<thead>
<tr>
<th></th>
<th>Barefoot</th>
<th>Shoe 1</th>
<th>Shoe 2</th>
<th>Shoe 3</th>
<th>Shoe 4</th>
<th>Shoe 5</th>
<th>Shoe 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>11.16</td>
<td>11.49</td>
<td>11.10</td>
<td>11.45</td>
<td>11.18</td>
<td>11.37</td>
<td>11.09</td>
</tr>
<tr>
<td>SD</td>
<td>0.61</td>
<td>0.61</td>
<td>0.86</td>
<td>0.49</td>
<td>0.92</td>
<td>0.90</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>11.22</td>
<td>11.19</td>
<td>11.36</td>
<td>11.45</td>
<td>11.78</td>
<td>11.19</td>
<td>11.35</td>
</tr>
<tr>
<td>SD</td>
<td>0.68</td>
<td>1.20</td>
<td>0.53</td>
<td>0.96</td>
<td>0.47</td>
<td>0.82</td>
<td>0.55</td>
</tr>
</tbody>
</table>
39 degrees of freedom. A critical value of 2.84 was required to reject at the .05 level of significance. Shoes (F=0.03) showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 was required to reject at the .05 level of significance. Leg x shoe interaction (F=1.48) showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 was required to reject at the .05 level of significance. No significant difference was found between legs with 1 and 39 degrees of freedom. A critical value of 4.08 was required to reject at the .05 level of significance. Since the obtained F value for the legs was 0.30, the null hypothesis was not rejected. Therefore the hypothesis that the leg angle would be unchanged at midstance was supported.

Performance of the dependent variable, leg angle, was measured at seven levels, without shoes and with six different models of running shoes. Means and standard deviations for the twenty-three subjects are shown in Table 12. Descriptive data indicated differences between the right and left foot with respect to footwear. The ranges were 0.24, 0.14, 0.23, 0.17, 0.27, 0.39, and .029 for barefoot, Shoe 1, Shoe 2, Shoe 3, Shoe 4, Shoe 5, and Shoe 6 respectively. With respect to the right foot there was little difference between the means with a range of 0.38. Descriptive data for the left foot reflect few differences between the means. The range between the means of the left foot was
0.42, not enough to show a significant difference.

Table 11
Analysis of Variance in Leg Angle at Midstance

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>24.69</td>
<td>3</td>
<td>8.23</td>
<td>81.31*</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td>0.03</td>
<td>1</td>
<td>0.03</td>
<td>0.30</td>
</tr>
<tr>
<td>Shoes</td>
<td>0.14</td>
<td>6</td>
<td>0.02</td>
<td>0.20</td>
</tr>
<tr>
<td>Leg x shoe</td>
<td>0.89</td>
<td>6</td>
<td>0.15</td>
<td>1.48</td>
</tr>
<tr>
<td>Residual</td>
<td>3.95</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29.70</td>
<td>39</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* F(3,39)=2.84, p < .05

Discussion

Based on the results of this study, there were no significant differences evident in the degree of pronation between running shoes. No differences were found between barefoot and running shoes. The researcher questions the procedures utilized in shoe testing by mechanical means versus shoe testing involving human subjects. The machines utilized in shoe testing were designed to measure heel counter stiffness, rearfoot stability and penetration. The results of the three tests were to identify whether or not a shoe prevents
<table>
<thead>
<tr>
<th></th>
<th>Barefoot</th>
<th>Shoe 1</th>
<th>Shoe 2</th>
<th>Shoe 3</th>
<th>Shoe 4</th>
<th>Shoe 5</th>
<th>Shoe 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right leg (\bar{x}) (degrees)</td>
<td>11.64</td>
<td>11.91</td>
<td>11.82</td>
<td>11.90</td>
<td>11.72</td>
<td>12.02</td>
<td>11.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right leg SD (degrees)</td>
<td>0.65</td>
<td>0.50</td>
<td>1.12</td>
<td>0.74</td>
<td>0.85</td>
<td>0.72</td>
<td>1.00</td>
</tr>
<tr>
<td>Left leg (\bar{x}) (degrees)</td>
<td>11.88</td>
<td>11.77</td>
<td>12.05</td>
<td>11.73</td>
<td>11.99</td>
<td>11.63</td>
<td>11.95</td>
</tr>
<tr>
<td>Left leg SD (degrees)</td>
<td>0.64</td>
<td>1.64</td>
<td>0.74</td>
<td>0.81</td>
<td>0.49</td>
<td>1.13</td>
<td>0.74</td>
</tr>
</tbody>
</table>
excessive pronation. (Runner's World, 1980) These tests may be extremely valid in testing the quality of materials used in the construction of running shoes. However, questions should be raised concerning the accuracy of such tests in simulating the complex mechanics associated with running.

Questions should be considered on whether subjects were comfortable in new shoes. Subjects were given an undetermined amount of time to run on the treadmill, in their own running shoes as well as barefoot and with the new shoes, to allow for any adjustments if needed. Whether the allotted time should have been longer or shorter is questionable. The shoes worn by the subjects were new shoes donated by the Athlete's Shop, Kalamazoo, Michigan. Whether or not new shoes in comparison with graded levels of worn shoes affect degree of pronation should be considered.

The researcher believes that further study is needed to determine whether running mechanics change with shoe type. In foot strike, the literature reports that runners generally contact the ground at the rear, lateral border of the shoe. During midstance the foot pronates as weight shifts to the forefoot; a natural occurrence as the tibia rotates internally to absorb stress. (Subotnick, 1978) Pronation is a very fast motion occurring in a fraction of a second. Literature from different shoe manufacturers reported variations in shoe structure and material that prevented excessive pronation;
i.e. the Brooks' Vantage with the varus wedge and materials such as dual density at midsole to help reduce over pronation in the Tigers' Tigress Lt. (Tiger, 1983) This study would not support these claims.

Analysis of variance on pronation at foot strike and midstance showed several differences. Differences between the right and left foot indicate variability within each subject that suggest structural abnormalities; i.e. different leg lengths, muscle imbalance between the flexors and extensors, and limited range of motion and flexibility. The leg x shoe interaction was significant. The researcher postulates that this is due to variations in the subjects' anatomical structure. A study, by James, Bates, and Osterning (1977), on 180 runners supports this idea. Only twenty-two percent of the subjects were found to have a neutral rear-foot alignment while standing and fifty-eight percent showed pronation. Reasons for pronation during stance, as well as during running, might be due to a large Q-angle (Cavanagh, 1980), bow legs, flat feet, or hindfoot and forefoot varus (Broer, 1979). This, however, cannot be proved in the scope of this study.

It was hypothesized that there would be no difference in Q-angle and leg angle at foot strike and midstance. The data support this contention.

The statistical design utilized in this study had a limitation which caused a weakness in statistical power.
Due to loss of data (shoes not available in appropriate size and data lost on film) the degrees of freedom for subjects were reduced from 23 to 2 or 3 degrees. The researcher suggests further study be done with more subjects and fewer running shoes to eliminate the loss of statistical power.

It was hypothesized that there would be different degrees of pronation between shoes. This was not proven; therefore there was no difference between shoe models.
CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS
AND RECOMMENDATIONS

The scope of this study was to determine whether or not different degrees of pronation would be evident with different models of shoes at foot strike and midstance. The study was to determine whether or not Q-angle and leg angle would be unchanged at foot strike and midstance. This chapter was divided into four headings for clarity, (a) Summary; (b) Findings, (c) Conclusions; and (d) Recommendations.

Summary

The problem of this study was to investigate the relationship of shoes and running patterns. The purpose was to provide scientific information concerning the effects of different models of shoes on a runner's gait pattern. The investigation utilized 23 male subjects, age 21 to 56 years, who were currently on a regular running program.

Subjects were filmed running on a Quinton Model 643 programmed exercise treadmill. One Photo Sonic 1-PL, 16mm camera was placed perpendicular to the frontal plane and posterior to the subjects as they ran on the treadmill. Each subject performed seven trials. One trial the subject ran without shoes and six trials the subject ran with shoes.
Three complete strides were filmed for each trial and later the means of each trial were calculated.

The subjects' heels were marked where the achilles tendon and the gastrocnemius meet, the subtalar joint, and on the tuberosity of the calcaneous. The shoes were marked on the heel one inch from the floor and on the estimated point of the subtalar joint.

A Numonics Electronic Graphics Calculator, interfaced to Western Michigan University's DEC-10 computer, was used to digitize designated frames while viewed with a Vanguard projector. Frames chosen for analysis were: (a) foot strike, and (b) midstance.

The computer program calculated the degree of pronation, \( Q \)-angle, and leg angle. Six different ANOVA's were calculated using different dependent variables. The dependent variables were: (a) pronation at foot strike; (b) pronation at midstance; (c) \( Q \)-angle at foot strike; (d) \( Q \)-angle at midstance, (e) leg angle at foot strike; and (f) leg angle at midstance.

Findings

The hypothesis that different degrees of pronation would be evident with different models of shoes at foot strike was not supported. No significant difference was found between shoes with 6 and 39 degrees of freedom. A critical value of 2.34 was required at the .05 level of significance to reject the null hypothesis. Since the
obtained F value for shoes was 1.28, the null hypothesis was not rejected at the .05 level of significance.

The hypothesis that different degrees of pronation would be evident with different models of shoes at midstance was not supported. Shoes showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 was required to reject at the .05 level of significance. Because the obtained F value for the shoes was 1.75, the null hypothesis was not rejected at the .05 level of significance.

The hypothesis that different degrees of pronation would be evident with different models of shoes at midstance was not supported. Shoes showed no significant difference with 6 and 39 degrees of freedom and a critical value of 2.34. Because the obtained F value for the shoes was 1.75, the null hypothesis was not rejected at the .05 level of significance.

The hypothesis that the Q-angle would be unchanged at foot strike was supported. Shoes showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 at the .05 level of significance was required to reject the null hypothesis. Therefore the hypothesis that Q-angle would be unchanged at foot strike was supported.

The hypothesis that the Q-angle would be unchanged at midstance was supported. No significant difference was found in shoes with 6 and 39 degrees of freedom. A critical
value of 2.34 at the .05 level of significance was required to reject the null hypothesis. Therefore the hypothesis that Q-angle would be unchanged at midstance was supported.

The hypothesis that the leg angle would be unchanged at foot strike was supported. Shoes showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 at the .05 level of significance was required to reject the null hypothesis. Therefore the hypothesis that leg angle would be unchanged at foot strike was supported.

The hypothesis that the leg angle would be unchanged at midstance was supported. Shoes showed no significant difference with 6 and 39 degrees of freedom. A critical value of 2.34 at the .05 level of significance was required to reject the null hypothesis. Therefore the hypothesis that leg angle would be unchanged at midstance was supported.

Conclusions

Based on the results of this study the researcher concluded that different models of running shoes do not affect degree of pronation at foot strike and midstance. The results indicated that no significant difference in pronation occurred between running with shoes on and with shoes off. This provided further evidence that shoes have little effect upon pronation in running. Q-angle and leg angle were unchanged at foot strike and midstance. Data support these conclusions. Subotnick (1978), in his biomechanical
approach to running injuries, suggested that shoes do not control abnormal pronation.

Another conclusion demonstrated evidence of variation between the left and right leg of subjects. A significant difference was found between the right leg and the left leg of the subjects during pronation at foot strike and at midstance. Different authors suggested various reasons for this occurrence; i.e. muscular imbalance, bow legs, hindfoot and forefoot varus (Broer, 1979), larger Q-angle (Cavanagh, 1980), and flat feet. (D'Ambrosia & Drez, 1982)

Recommendations

The researcher recommends further study be done with more subjects and fewer running shoes. By increasing the subjects the degrees of freedom will be larger. By decreasing the number of running shoes one might eliminate the loss of statistical power due to shoes not available in the appropriate sizes.

Further study is needed on the degree of wear on running shoes utilizing human subjects rather than by mechanical testing devices. Time would be a factor and therefore it would be necessary to have a large group of subjects in order to have statistical power.

Variation as well as improvement in running shoes continues. There is need for further study on running shoes concerning their effect on running mechanics. Research
should also be done on orthotics and their effect on the mechanics of running.
APPENDICES
APPENDIX A

Computer Program Used to Compute Pronation, Q-angle and Leg Angle

DIMENSION X1(3), Y1(3), X2(3), Y2(3), RHX(3)
DIMENSION RHY(3), PRO(3), QANGA(3), QANGK(3)
DIMENSION RKX(3), RKY(3), SHOE(2), PHASE(2)
REAL LHX(3), LHY(3), LKX(3), LKY(3)
OPEN(UNIT=21, DEVICE='DSK', FILE='DATA.DAT')
WRITE(21,300)
10 WRITE(5,106)
READ(5,211)N2
WRITE(5,107)
READ(5,212)(SHOE(L), L=1,2)
WRITE(5,108)
READ(5,211)N3
WRITE(5,109)
READ(5,212)(PHASE(L), L=1,2)
WRITE(5,102)
READ(5,211)N9
DO 20 N=1,3
WRITE(5,103)
READ(5,210)XI(N), Y1(N)
WRITE(5,104)
READ(5,210)X2(N), Y2(N)
PRO(N)=ATAN((X2(N)-XI(N))/(Y1(N)-Y2(N)))*57.295779
IF(N9 .EQ. 1) GO TO 20
PRO(N)=PRO(N)*(-1)
20 CONTINUE
DO 30 N=1,3
WRITE(5,105)
READ(5,210)RHX(N), RHY(N)
READ(5,210)LHX(N), LHY(N)
CX=LHX(N)+( (RHX(N)-LHX(N)/2.0)
CY=LHY(N)-( (LHY(N)-RHY(N)/2.0)
READ(5,210)RKX(N), RKY(N)
READ(5,210)LKX(N), LKY(N)
IF(N9 .EQ. 2) GO TO 31
IF(RKX(N) .GT. RHX(N)) GO TO 32
IF(RKX(N) .LT. CX) GO TO 33
A1=ATAN((RKX(N)-RHX(N))/ (RHY(N)-RKY(N)))*57.295775
A2=ATAN((RKX(N)-CX)/ (CY-RKY(N)))*57.295779
QANGK(N)=A1+A2
GO TO 40
30 A1=ATAN((RKX(N)-RHX(N))/ (RHY(N)-RKY(N)))*57.295779
A2=ATAN((RKX(N)-CX)/ (CY-RKY(N)))*57.295779

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QANGK(N) = A2 - A1
GO TO 40
33 A1 = ATAN((RHX(N) - RKX(N))/(RHY(N) - RKY(N))) * 57.295779
A2 = ATAN((CX - RKX(N))/(CY - RKY(N))) * 57.295779
QANGK(N) = A1 - A2
GO TO 40
31 IF(LKX(N) .LT. LHX(N)) GO TO 34
IF(LKX(N) .GT. CX) GO TO 35
A1 = ATAN((CX - LKX(N))/(CY - LKY(N))) * 57.295779
A3 = LKX(N) - LHX(N)
A4 = LHY(N) - LKY(N)
A2 = ATAN(A3/A4) * 57.295779
QANGK(N) = A1 + A2
GO TO 40
34 A1 = ATAN((CY - LKY(N))/(CX - LKX(N))) * 57.295779
A3 = LHY(N) - LKY(N)
A4 = LHX(N) - LKX(N)
A2 = ATAN(A3/A4) * 57.295779
QANGK(N) = A2 - A1
GO TO 40
35 A1 = ATAN((CY - LKY(N))/(LKX(N) - CX)) * 57.295779
A3 = LHY(N) - LKY(N)
A4 = LKX(N) - LHX(N)
A2 = ATAN(A3/A4) * 57.295779
QANGK(N) = A2 - A1
GO TO 40
40 IF(N9 .EQ. 2) GO TO 41
IF(X2(N) .GT. RHX(N)) GO TO 42
IF(X2(N) .LT. CX) GO TO 43
A1 = ATAN((RHX(N) - XI(N))/(RHY(N) - Y1(N))) * 57.295779
A2 = ATAN((XI(N) - CX)/(CY - Y1(N))) * 57.295779
QANGA(N) = A1 + A2
GO TO 30
42 A1 = ATAN((RHY(N) - Y1(N))/(XI(N) - RHX(N))) * 57.295779
A2 = ATAN((CY - Y1(N))/(XI(N) - CX)) * 57.295779
QANGA(N) = A1 - A2
GO TO 30
43 A1 = ATAN((RHY(N) - Y1(N))/(RHX(N) - XI(N))) * 57.295779
A2 = ATAN((CY - Y1(N))/(CX - XI(N))) * 57.295779
QANGA(N) = A2 - A1
GO TO 30
41 IF(X1(N) .LT. LHX(N)) GO TO 44
IF(X1(N) .GT. CX) GO TO 45
A1 = ATAN((CX - X1(N))/(CY - Y1(N))) * 57.295779
A2 = ATAN((X1(N) - LHX(N))/(LHY(N) - Y1(N))) * 57.295779
QANGA(N) = A1 + A2
GO TO 30
44 A1 = ATAN((CY - Y1(N))/(CX - X1(N))) * 57.295779
A2 = ATAN((LHY(N) - Y1(N))/(LHX(N) - X1(N))) * 57.295779
QANGA(N) = A1 - A2
GO TO 30
45 A1 = ATAN((CY - Y1(N))/(X1(N) - CX)) * 57.295779
A2 = \arctan \left( \frac{(LHY(N) - Y1(N))}{(X1(N) - LHX(N))} \right) \times 57.295779
QANGA(N) = A2

30 CONTINUE
AVE1 = (PRO(1) + PRO(2) + PRO(3)) / 3.0
AVE2 = (QANGK(1) + QANGK(2) + QANGK(3)) / 3.0
AVE3 = (QANGA(1) + QANGA(2) + QANGA(3)) / 3.0
IF (N9 .EQ. 1) GO TO 50
WRITE (21, 301) N2, (SHOE(L), L = 1, 2), (PHASE(L), L = 1, 2), N3, AVE1, AVE2, AVE3, L = 1, 2
GO TO 60
50 WRITE (21, 302) N2, (SHOE(L), L = 1, 2), (PHASE(L), L = 1, 2), N3, AVE1, AVE2, AVE3, L = 1, 2
60 WRITE (5, 303)
READ (5, 211) N8
IF (N8 .EQ. 1) GO TO 10
102 FORMAT ('WHICH FOOT? RIGHT=1, LEFT=2')
103 FORMAT ('INPUT ACHILLES TENDON')
104 FORMAT ('INPUT BOTTOM OF HEEL')
105 FORMAT ('INPUT RIGHT HIP, LEFT HIP, RIGHT KNEE, AND LEFT KNEE')
300 FORMAT (2X, 'SUBJ #', T13, 'SHOE', T24, 'PHASE', T36, 'STRIDE', T44
1, 'FOOT', T53, 'PRONATION', T64, 'Q ANGLE-KNEE', T78, 'Q ANGLE-AN')
301 FORMAT (T4, I2, T11, 2A5, T21, 2A5, T38, I1, T44, 'LEFT', T50, F10.5, T63,
1, T51, T77, F10.5)
302 FORMAT (T4, I2, T11, 2A5, T21, 2A5, T38, I1, T44, 'RIGHT', T50, F10.5
1, T63, F10.5, T77, F10.5)
303 FORMAT ('DO YOU WANT TO CALCULATE ANOTHER STRIDE? YES=1, NO=2')
210 FORMAT (2F)
106 FORMAT ('INPUT SUBJECTS NUMBER')
107 FORMAT ('INPUT SHOE MODEL')
109 FORMAT ('INPUT PHASE; HEEL STRIKE, MIDSTANCE, OR PUSH-OFF')
108 FORMAT ('INPUT STRIDE NUMBER; 1, 2, OR 3')
221 FORMAT (I2)
212 FORMAT (2A5)
CLOSE (UNIT=21)
STOP
END
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