The Effect of the Hapad Longitudinal Metatarsal Arch Pad on Ground Reaction Forces and Rear Foot Angle

William F. Rocker

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THE EFFECT OF THE HAPAD LONGITUDINAL METATARSAL ARCH PAD ON GROUND REACTION FORCES AND REAR FOOT ANGLE

by

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I could ever put into words. I look forward to our new family.

William F. Rocker Jr.
The effectiveness of the Hapad Longitudinal Metatarsal Arch Pad (HLMAP) to correct for pronation was investigated using 30 female volunteer student subjects. The investigation consisted of measuring ground reaction forces measured by a force plate and rear foot angle (RFA) measured by video digitization. The repeated measures design consisted of 1 grouping variable with 3 levels, supinators, mild-pronators, and over pronators, and 2 research variables, 10 trials, and pad/no-pad. The results indicated (a) no significant difference for medial or lateral force, propulsive force, vertical thrust, negative torque among groups, or between pad/no-pad; (b) a significant difference was found for the interaction effect of groups by pad/no-pad and positive torque; (c) RFA was not significant at foot flat or push-off; (d) RFA was significant at heel strike between the pad/no-pad. The researcher concluded the HLMAP: (a) was effective in controlling positive torque for the over pronators, had no effect on the mild pronators, and a contraindicative effect on the supinators; and (b) caused a greater RFA at heel strike.
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CHAPTER I

INTRODUCTION

Physical fitness in the United States is becoming a larger part of peoples daily lives than ever before. People are walking, running, weight training, and bicycling in record numbers. Staying physically active is important but it is not without cost. Large numbers of people are becoming injured due to poor mechanics that result from (a) overuse, and (b) contraindicated exercise associated with specific skeletal systems.

One injury common to runners is plantar fasciitis. This is known as an overuse injury and can be related to improper training techniques or the skeletal system alignment. It is the result of over pronation in the propulsion phase in the runner's gait. Many innovations have been developed to correct these problems. One example is the Hapad longitudinal metatarsal arch pad (HLMAP). This pad is a combination of a longitudinal metatarsal pad and a scaphoid pad. It gives more support to the entire arch of the foot than the two pads do by themselves.

It is important to understand that pronation is normal in the gait cycle. It is only a problem when it becomes excessive. James, Bates, and Osternig (1978) stated, "some
pronation is normal for the weight-bearing foot, but excessive pronation is a compensatory motion secondary to malalignment of the heel-foot or leg-foot alignment" (p. 42). In order for the foot to function optimally it is important for the subtalar joint to be at or near its neutral position. The use of orthotic devices helps to correct malalignment problems, allowing the foot to function properly during the support phase of the gait cycle. It is the lack of documented research concerning the effect of the HLMAP that prompted this study.

Problem Statement

The problem of the study was to determine the effectiveness of the HLMAP in reducing the severity of pronation in women while jogging. Specifically, rear foot angle (RFA) and ground reaction forces for subjects jogging with and without the HLMAP were compared.

Significance of the Study

The purpose of the study was to further develop a knowledge concerning the benefits of using the HLMAP as an orthotic to reduce the ill effects of over pronation in runners. The importance of staying injury free while maintaining a physically fit life style is paramount for these athletes. The information gleaned from this study will help clinicians and athletes alike evaluate the benefits of
using the HLMAP as an orthotic device to reduce the risk of injury to the lower extremity caused by overpronation. The benefits of reducing injury potential to the athlete would be less time spent away from his or her mode of fitness and less money spent on medical care.

**Delimitations**

The study was delimited to the following:

1. Female student volunteers from Western Michigan University between the ages 18 to 35 years served as subjects for this study.

2. All participants wore their own running shoes.

3. Only the HLMAP (Hapad Incorporated, Bethel, PA) was studied.

4. Rear foot control was determined by digitizing video tape images of the leg and foot during the support phase of a gait cycle.

5. Ground reaction forces were measured by a Kistler force plate.

6. Data were recorded during the support phase only.

**Limitations**

The study was limited by the following:

1. The shoes for each subject were not the same; different models and different wear patterns existed.

2. Although there are instructions for placement of
the pad, exactness was not possible from subject to subject due to foot differences.

Assumptions

The researcher assumed the following:

1. Stride length and frequency were consistent for each trial.

2. The video camera and force plate were functioning properly, thus assuring a synchronized match with respect to time.

Hypotheses

This investigation was designed to address the following research hypotheses:

1. The HLMAP condition will have smaller rear foot angles than the no HLMAP condition.

2. The no HLMAP condition will have greater maximal negative torques than the HLMAP condition.

3. The HLMAP condition will have greater maximal lateral torques than the no HLMAP condition.

4. The maximum medial force will be the same for both the HLMAP condition and the no HLMAP condition.

5. The maximum positive torque will be the same for both the HLMAP condition and the no HLMAP condition.

6. The maximum propulsion force will be greater for the HLMAP condition than for the no HLMAP condition.
7. Vertical thrust will be the same for both the HLMAP and the no HLMAP conditions.

8. RFA will be smaller during the stance phase for the HLMAP condition than for the no HLMAP condition.

Definition of Terms

The following terms were defined for clarification and understanding:

1. Pronation: This is movement of the foot associated with eversion and dorsiflexion.

2. Rear foot control: This is characterized as stabilization in the subtalar joint.

3. Stance Phase: This is the weight-bearing phase of the running gait cycle, initiated at heel strike and completed at push-off.

4. Supination: This is movement of the foot associated with inversion and plantarflexion.
CHAPTER II

REVIEW OF RELATED LITERATURE

Anatomy of the Subtalar Joint

The subtalar joint is one of the joints that make up the ankle. Morris (1977) described the joint as having three articulations between the talus and the calcaneus: (1) anterior, (2) middle, and (3) posterior. The anterior articulation is made up of the convex underside of the head of the talus and a small concave facet on the calcaneus. The middle articulation consists of the facet on the underside of the talus and the sustentaculum tali of the calcaneus. The posterior articulation is made up of the concave facet of the talus and the convex facet of the calcaneus.

According to Edington, Frederick, and Cavanagh (1990) the subtalar joint allows for two separate movements for the foot, pronation and supination. If viewed from the cardinal planes, pronation is characterized by the components of external rotation, dorsiflexion, and calcaneal eversion, while supination is characterized by internal rotation, plantar flexion, and calcaneal inversion. They further clarify this statement by adding that pronation
does not imply any motion of dorsiflexion at the talocrural joint, the joint between the tibia and talus. "The position of the foot does become dorsiflexed in relation to the leg, but in pure pronation it is entirely as a result of motion at the subtalar joint" (Edington et al., p. 141). Brody and Netter (1980) described this motion in relation to the tibia. As the foot approaches heel strike, the tibia is rotated externally, which causes the foot to supinate slightly. During pronation the tibia rotates internally on the talus.

James et al. (1978) measured the total range of motion about the subtalar joint in 188 subjects. A goniometer was used to measure the amount of eversion and inversion of the heel in relation to the leg. They admit this is a crude way of measuring the motion of the foot, however their values were in agreement with values found by other investigators. The total range of motion for eversion was 8' ± 4' and the total range of motion for inversion was 23' ± 6'.

Biomechanics of Subtalar Joint

The subtalar joint allows the foot to function both as a shock absorber and a rigid bar, depending on what phase one examines in the gait cycle. At heel strike the foot is slightly supinated to allow for stability upon landing. As the runner moves through the gait cycle, the foot begins to pronate which unlocks the foot for surface adaptation. This
occurs for the first 55% to 60% of the heel-strike-to-toe-off cycle. The foot is then supinated creating a rigid lever for toe off and is kept in this position for the next heel strike (Brody & Netter, 1980). Buchbinder, Napora, and Biggs (1979) described the action of the subtalar joint similarly. "During the support phase, the foot must first act as a mobile adapter and then quickly convert to a rigid lever for a propulsive toe-off" (Buchbinder et al., 1979, p. 159). This adaptation is accomplished by the foot being supinated at heel strike "and as weight is accepted pronation occurs until the forefoot is securely fixed to the supporting surface" (p. 159). Winter (1984) examined the moments of force associated with the ankle, knee, and hip. Data for his study were compiled from six years of research in a gait analysis laboratory. He found that the moments about the ankle illustrated the supination-pronation-supination motion of the foot. "The ankle initially had a small dorsiflexor moment to lower the foot to the ground, followed by a major build-up of plantarflexor activity reaching a peak at push-off (50% stride)" (Winter, 1984, p. 58). This cycle is necessary to allow the foot to be a mobile adapter after heel strike and change to a rigid bar for a propulsive push off with each step throughout the gait cycle.
Orthoses

Eggold (1981) described an orthosis as follows:

An orthosis (es) is a straightening or balancing device, often referred to as an orthotic device, orthotic, or custom-made appliance. It is very different from a simple arch support. Its main objective is to balance the foot in its neutral position throughout the walking and running gait cycle, preventing excessive inefficient compensatory motions and maximizing performance (p. 126).

Orthotic devices according to James et al. (1978) "can be thought of as a type of 'shim' placed between the foot and shoe" (p. 46) which positions the foot near its neutral position.

Orthotic devices have been found to reduce initial pronation, which is directly related to the maximum velocity of pronation, in the gait cycle. The reduction of those two factors, initial pronation and maximum velocity of pronation, reduced total rear foot motion (Edington et al., 1990).

Flexible Orthoses

Flexible orthoses are made of leather, foam rubber, thin plastic, cork, or some sort of felt material. These devices can be made in the doctors office or purchased in a retail outlet. The orthosis used in this study was a flexible type device. It was made of wool felt that had an adhesive backing to affix it to the shoe. This particular
pad is a hybrid of a longitudinal metatarsal pad and a scaphoid pad.

Flexible orthoses can be used as a temporary or semi-permanent measure. They are usually lighter in weight and cost less than rigid orthoses.

**Rigid Orthoses**

Rigid orthoses are made of plastic from the neutral cast of the foot. There are many techniques used to form the neutral plaster cast, three are

1. The subject lies supine or prone and the talus is palpated to find the neutral position (James et al., 1978);

2. The subject sits on the edge of a table with the knee and ankle flexed at 90°, as measured by a goniometer, and the foot is wrapped in plaster and placed on a soft stool to allow for correct molding (Brody & Netter, 1980); and

3. The subject’s heel to leg relationship is measured in the frontal plane in a non-weight condition (Eggold, 1981).

After the cast is made it is then sent to an orthotist to be used to make the orthosis. The rigid orthosis a heavier device, is more durable and gives unchanging support to the foot.
Rear Foot Angle

As stated above, an orthotic device is designed to keep the foot in a neutral position. This in turn minimizes the extent to which the rear foot angle (RFA) changes throughout the gait cycle. RFA is the angle created by the calcaneus and the lower leg. By reducing the overall change in RFA the runner is less likely to sustain injury. There have been two approaches devised for measuring RFA, relative and absolute. Edington et al. (1990) described the relative measurement of RFA as follows: two sets of markers are arbitrarily placed on the heel or shoe and posterior aspect of the leg. The subject then stands in view of a camera or optoelectronic device. The angle between the foot and lower leg markers is measured. The angle used as the initial RFA can be either the acute or obtuse angle created by the foot and leg, because the angle measured from this initial standing position is considered to be 0°. This initial RFA angle is then subtracted from all subsequent angles measured throughout the study.

The absolute measure of RFA is described by Clarke, Frederick, and Hamill, (1984) and Smith, Clarke, Hamill, and Santopietro, (1986). The measure is made by placing the subject on wooden blocks with the subjects heels 5 cm apart and externally rotated 7°. This allowed for an easily repeatable stance for all subjects involved in the study.
The two leg markings were placed 15 to 20 cm apart with the distal marker placed at the midline of the Achilles tendon between the medial and lateral malleolus. The proximal marker was placed below the belly of the gastrocnemius. The line formed by these two markers bisected the leg at the level of the popliteal fossa.

The heel markings were placed into a right and left half to bisect the posterior aspect of the calcaneus. This was estimated to the best of their ability based on the presence of the shoe. The researchers noted that it was important to draw the line in relation to the calcaneus and not the vertical. This placement of the markings for the leg and foot are thought to produce more precise measurements of RFA than the relative approach. Expression of the angle formed by these two lines varies depending on the researcher. Some chose to make pronation the negative number when subtracted from 180°, while others reverse the sign and make supination the negative number. Still others chose to use the actual number derived from the measurement of the angle. No one method of expression was better than another as long as it was consistent (Clark et al., 1984 & Smith et al., 1986).

Summary

Research exists regarding subtalar joint anatomy, biomechanics, rearfoot motion, and the effect orthotics
have on gate. The research regarding rearfoot motion varies depending on which gait pattern is analyzed. The analysis of the walking gait yields vastly different results than the running gait, due to the nature of the gait cycle. The lack of an airborne phase accounts for many of the differences. It was difficult to draw viable comparisons between the walking and running cycles. The literature regarding running gait was more appropriate for this study. Evidence of the effectiveness of using orthotics to correct for gait cycle abnormalities was abundant. Orthotics were found to be helpful in correcting for such things as shinsplints, knee pain, plantar fasciitis and arch pain, and hip pain. However, the literature was noticeably lacking in regards to the Hapad Longitudinal Metatarsal Arch pad as an orthotic device.
CHAPTER III

PROCEDURES

Introduction

The purpose of this study was to determine the effectiveness of the HLMAP in reducing pronation as measured by ground reaction forces and RFA. These two variables were analyzed for two conditions; with and without the HLMAP. This chapter was organized as follows: (a) subjects, (b) research design, (c) instrumentation, (d) testing procedures, and (e) data analysis.

Subjects

The 30 subjects were female students from Western Michigan University. The subjects were all volunteers meeting the following criteria: (a) subjects were between the ages of 18 to 35 years, (b) subjects were injury free of orthopedic injuries to both lower extremities for at least one year prior to participation in this study, and (c) no other orthotic devices were worn during testing.

All subjects received oral instructions explaining the extent of their participation prior to signing an informed consent statement. The informed consent can be seen in Appendix A. Subjects were protected as prescribed by the
Human Subjects Institutional Review Board (HSIRB) of Western Michigan University. The HSIRB approval letter is in Appendix B.

Research Design

Research Variables

The design for this study involved three research variables: (1) pad/no pad, (2) rear foot angle (RFA), and (3) trials. The pad variable and trials were repeated by all subjects. Each subject participated in the pad/no pad condition in a random order. For each level of the pad/no pad condition each subject performed 15 trials. RFA served as a grouping variable for the subjects. The variable, RFA, was measured in a standing, anatomical position, for each subject. The measurement represents the angle formed between two lines-- (1) the longitudinal line of the heel counter of the shoe and (2) the longitudinal line of the shank or calf. Based on the magnitude of this angle, subjects were divided into three groups (1) supinators, (2) mild pronators, and (3) over pronators. Criteria for establishing the three groups was based on the natural breaks that occurred in the frequency distribution for the rear foot angle as measured for all subjects. RFA was believed by the researcher to be a confounding variable. Subjects with high RFA and low RFA would by virtue of the
measure have greater and smaller forces, respectively than subjects with average RFA. By grouping subjects according to RFA, more accurate results concerning differences or lack of differences would be apparent for the pad no-pad conditions.

**Dependent Variables**

The following variables measured by the force plate or extracted from the video served as the dependent variables for this study. All definitions apply for the right lower extremity’s stance phase.

1. **Maximum Medial Force**: The maximum force measured in the frontal plane from the subject’s right to left, indicated by a positive number.

2. **Maximum Lateral Force**: The maximum force measured in the frontal plane from the subject's left to the right, indicated by a negative number.

3. **Maximum Propulsion Force**: The maximum force measured in the sagittal plane from the back to the front, indicated by a positive number.

4. **Vertical Thrust**: The maximum force in an upward direction measured after the initial impact force, indicated by a positive number.

5. **Maximum Positive Torque**: The maximum torque measured for medial (internal) rotation in the counterclockwise direction in the transverse plane, indicated by a
positive number.

6. Maximum Negative Torque: The maximum torque measured for lateral (external) rotation in the clockwise direction in the transverse plane, indicated by a negative number.

7. RFA: An angle calculated for all frames in the braking and propulsion phases of the stance portion of a gait cycle. The RFA was measured as the angle between the longitudinal line of the heel counter of the shoe and the longitudinal line of the calf.

Instrumentation

Longitudinal Metatarsal Arch Pad

The Hapad longitudinal metatarsal arch pad (HLMAP) Hapad, Incorporated, Bethel, PA, was the orthotic device used for this study. Sizes used for this study ranged from extra small to medium depending on foot size and arch height of the subjects. The HLMAP can be described as the combination of a scaphoid pad and a metatarsal arch pad, providing support to a larger area of the foot than either pad by itself. The pad has adhesive to secure it to the shoe, but for this study, velcro was adhered to the pad so it could be removed without leaving the adhesive backing in the shoes of the participants.
Metronome

The Pico Club metronome by Seiko (Japan) was used for setting the jogging cadence. The metronome had visual and audio cadence capabilities. It had a range of 25 to 250 beats per minute. It was battery operated and credit card sized. These features would not interfere with the movement patterns of subjects who carried the metronome while participating in this study.

Force Plate

The force plate used for the study was the Kistler Type 9281B, Kistler Instrument Corporation, Amherst, NY. Amplification of the signal and range setting were controlled by the Kistler 9861A amplifier. The analog data were converted to a digital signal by an Analog Digital Interface, 16 Channel Unit, connected to a DT2821 analog-to-digital board. This analog-to-digital board was connected to an Event Synchronization Unit (ESU) 4000D for matching force data to video data. The ESU unit was used to trigger the interfaced equipment during data collection. A Tenex 486 DX-2 computer ran the Peak 5.2 Analog Sampling Module Software, Peak Performance, Inc., Englewood, CO, during data analysis. The analog digital interface unit and the ESU Unit were manufactured by Peak Performance Technologies, Inc., Englewood, CO.
Camera

The camera used for this study was the Panasonic WV-D5100HS video camera, Panasonic Industrial Factory Service Center, Secaucus, NJ. It is a high speed video camera with a zoom lens and is interfaced with a Panisonic model AG 7350 SVHS video recorder.

Digitizing

The digitizing equipment consisted of a Panasonic model AG 7350 SVHS video recorder attached to a Sony Trinitron 13" diagonal video monitor. The software used to digitize the film was Peak 5.2, version 1.2, Peak Performance Technologies, Inc., Englewood, CO.

Testing Procedures

Filming Procedures

Procedures for filming subjects consisted of the following:

1. The camera was placed at a distance of 45 ft from the center of the force plate at a height of 1 ft.

2. The camera recorded motion in the frontal plane, posterior view.

3. Super VHS video tape was used for filming. The camera speed and scaling factor were set at 60 Hz and centimeters, respectively.
Force Plate Procedures

Force plate procedures were as follows:

1. The computer was programmed to collect continuous readings for 3 s, 1 s prior to trigger time plus 2 s after trigger time. This timing scheme ensured data collection from the time of foot impact to the point of push off, which represents the entire stance phase.

2. When the subject was approximately one step from the force plate, the computer was triggered by the researcher to begin data collection.

3. Sampling rate was set at 480 samples per second. Thus, every video picture was matched with eight samples of force data from each force channel.

Pretesting Procedures

The following pretesting procedures were used:

1. Questions were asked to determine the eligibility of the subject before any other procedures were carried out. The researcher determined if: (a) the subject had been injured in the previous year, and (b) the subject was within the required age limit.

2. Potential subjects were then given the informed consent to read and sign.

3. The subject's right shoe and lower leg were marked for filming purposes. Markings were made as follows: (a)
two marks were placed approximately 5 cm apart on the longitudinal line of the heel counter of the shoe, (b) a third mark was placed on the Achilles tendon just above the back of the shoe, and (c) a fourth mark was placed at the midpoint of the calf. All marks were made with a black marker on a piece of white tape placed at the appropriate locations described above. These markings were video taped while the subject was standing in an anatomical position, to establish the initial RFA of the subject. Measures from this procedure allowed the subjects to be grouped according to RFA. These same markings were used to calculate RFA during each trial.

4. Subjects were randomly assigned to pad/no pad testing order by a coin toss.

5. To establish a consistent approach to the force plate, verbal instructions were given by the researcher as follows: (a) start from the middle of the force plate; (b) beginning with the left foot take 12 jogging steps at the cadence of 140 beats per minute set by the metronome; (c) at the foot plant for the 12th step, place a piece of tape on the floor to mark the starting point for the trials.

6. Subjects were then given an opportunity to practice keeping pace with the metronome so that on the 12th step the right foot would hit the force plate. If necessary, the subject adjusted the starting point (mark) to insure that the right foot made contact with the approximate center of
the force plate. This procedure was used as a warm-up. The warm-up lasted for 5 min, or until the subject was able to consistently hit the force plate with her right foot.

**Testing Procedures**

The following testing procedures were utilized:

1. Because pad placement was critical, subjects and the researcher placed and adjusted the pad for a proper and comfortable fit.

2. Subjects were given three practice trial runs with the pad in the shoe to become accustomed to the device.

3. Data were collected for 15 trials under both conditions, pad and no pad.

4. A successful trial was recorded when both the subject and the researcher believed the subject completed the run without the perception or sensation of changing the gait to reach the force plate; e.g., the subject did not shorten or lengthen the stride or speed up or slow down the pace to hit the force plate.

**Video Digitizing Procedures**

Analysis of 10 out of 15 trials was conducted. The criterion for the selection of the 10 trials was the consistency of the force plate data: maximum medial force, maximum lateral force, maximum propulsion force, vertical thrust, maximum positive torque, and maximum negative
torque. Trials showing extraneous data that were either above or below those values that most commonly occurred for a given subject, were discarded. Thus, the 10 most consistent trials were analyzed.

Video Digitizing was performed as follows:

1. The analysis started at foot impact and ended when the foot lost contact with the force plate.

2. Phases were defined as follows: (a) the braking phase began when the foot made contact with the force plate and ended when the hip was directly over the center of the support foot and, (b) the propulsion phase began when the hip moved in front of the center of the support foot and ended when the foot lost contact with the force plate.

3. The digitized video data were matched to the analog data using the digitized data file. Therefore, only the force data that matched the support phase of the frames digitized were analyzed.

Data Analysis

Each dependent variable was analyzed by a split-plot, repeated measures Analysis of Variance (ANOVA) design. The pad/no pad condition and the 10 trials were repeated by all subjects. The grouping variable, RFA measured in the anatomical position, caused the split-plot ANOVA design.
CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to determine the effectiveness of the HLMAP in reducing pronation as measured by ground reaction forces and RFA. These two variables were analyzed for two conditions; with and without the HLMAP. This chapter was organized as follows: (a) results and (b) discussion.

Results

This study consisted of 30 female volunteer subjects from Western Michigan University. Each subject participated in 30 trials, 15 with the HLMAP in the shoe and 15 without. The subjects were filmed from the frontal plane rear view in order to measure rearfoot angle (RFA) and compare it to force plate data. The subjects neutral RFA was obtained prior to each subject starting the study. This neutral RFA was measured from a rear view with the subject standing in an anatomical position. This RFA angle was used as a grouping variable. The 30 subjects were placed into three groups: (1) supinators, (2) mild pronators, and (3) over pronators. The mean and range were determined for each
group. The mean for the supinators was 2.54° with a range of 2.54°. The mean for the mild pronators was 4.02° with a range of 5.06°, and the mean for the over pronators was 8.92° with a range of 5.30°. The RFA groups, supinators, mild pronators, and over pronators consisted of n = 8, 13, and 9, respectively. The groups were determined by natural breaks in the distribution of RFA's.

The design for this study involved three research variables: (1) pad/no pad; (2) rear foot angle (RFA), supinators, mild pronators, and over pronators; and (3) trials, ten. The dependant variables for this study were: (a) maximum medial force, (b) maximum lateral force, (c) maximum propulsive force, (d) vertical thrust, (e) maximum positive torque, (f) maximum negative torque, and (g) RFA at heel strike, foot flat, and push off. These variables were compared using a split plot ANOVA and when necessary a post hoc test (Tukey HSD) for multiple group comparisons and a simple main effect test. The level of significance for the study was .05.

Maximum Medial Force

The maximum medial force was defined as the maximum force measured in the frontal plane from the subject's right to left, indicated by a positive number. The ANOVA for maximum medial force (see Table 1) indicated the following:
Table 1

ANOVA Summary Table for Maximum Medial Force

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<th>MS</th>
<th>F</th>
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1. No significant difference was found among RFA groups for maximum medial force, \( F(2, 27) = 1.11, p = .35 \). The means were -44.77 N, -52.15 N, and -65.17 N for supinators, mild pronators, and over pronators, respectively.

2. No significant difference in maximum medial force
was found between the pad and no-pad conditions, $F(1, 27) = 1.36, \ p = .25$. The means for the pad and no-pad conditions were 56.05 N and 52.12 N, respectively.

3. No significant difference in maximum medial force was found among the 10 trials, $F(9, 243) = 1.10, \ p = .37$. The means for the 10 trials were 54.47 N, 49.43 N, 54.95 N, 59.50 N, 50.60 N, 50.52 N, 59.78 N, 55.78 N, 50.97 N, 54.88 N, respectively.

4. The first- and second-order interaction effects were not significant.

**Maximum Lateral Force**

The maximum lateral force was defined as the maximum force measured in the frontal plane from the subject’s left to the right, indicated by a negative number. The ANOVA for maximum lateral force (see Table 2) indicated the following:

1. No significant difference in maximum lateral force was found among RFA groups, $F(2, 27) = 0.07, \ p = .93$. The means for the RFA groups, supinators, mild pronators, and over pronators were 45.91 N, 43.87 N, and 41.94 N, respectively.

2. No significant difference in maximum lateral force was found between pad and no-pad conditions, $F(1, 27) = 0.89, \ p = .35$. The means for the pad and no-pad conditions were 42.66 N and 45.01 N, respectively.
Table 2

ANOVA Summary Table for Maximum Lateral Force

<table>
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</table>

3. No significant difference in maximum lateral force was found among the 10 trials, \( F(9, 243) = 0.53, \) \( p = .85 \). The means for the 10 trials were 40.22 N, 46.45 N, 40.23 N, 40.23 N, 47.93 N, 47.03 N, 44.42 N, 43.85 N, 43.85 N, and 44.15 N, respectively.

4. The first- and second-order interaction effects
were not significant.

**Maximum Propulsive Force**

The maximum propulsive force was defined as the maximum force measured in the sagittal plane from the front to the back, indicated by a positive number. The ANOVA for the maximum propulsive force (see Table 3) indicated the following:

1. No significant difference was found for maximum propulsive force among groups, $F(2, 27) = 0.23$, $p = 0.79$. The means for RFA groups, supinators, mild pronators, and over pronators were 132.66 N, 130.70 N, and 123.89 N, respectively.

2. No significant difference was found for maximum propulsive force between the pad and no-pad conditions, $F(1, 27) = 0.05$, $p = 0.82$. The means for the pad and no-pad conditions were 129.62 N and 128.74 N, respectively.

3. No significant difference was found for maximum propulsive force among the 10 trials, $F(9, 243) = 1.62$, $p = 0.11$. The means for the 10 trials were 130.48 N, 132.55 N, 131.68 N, 129.73 N, 128.32 N, 124.40 N, 132.03 N, 131.80 N, 121.27 N, and 130.03 N, respectively.

4. The first- and second-order interaction effects were not significant.
Table 3

ANOVA Summary Table for Maximum Propulsive Force

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**Vertical Thrust**

The vertical thrust was defined as the maximum force in an upward direction measured after the initial impact force, indicated by a positive number. The ANOVA for vertical thrust (see Table 4) indicated the following:
# Table 4

ANOVA Summary Table for Vertical Thrust

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</table>

*Significant at the $p \leq .05$.

1. No significant difference was found for vertical thrust among the RFA groups, $F(2, 27) = .46, p = .64$. The means for the three RFA groups, supinators, mild pronators, and over pronators, were 109.95 N, 111.65 N, and 114.28 N,
respectively.

2. No significant difference was found for vertical thrust between the pad and no-pad conditions, \( F(1, 27) = 0.18, p = .68 \). The means for the pad and no-pad conditions were 111.82 N, and 112.78 N, respectively.

3. A significant difference was found for vertical thrust among the 10 trials, \( F(9, 243) = 2.20, p = .02 \). The means for the 10 trials were 110.55 N, 114.95 N, 112.03 N, 112.85 N, 113.62 N, 112.82 N, 110.87 N, 113.33 N, 105.03 N, 113.83 N, respectively.

4. The first- and second-order interaction effects were not significant.

Maximum Positive Torque

The maximum positive torque was defined as the maximum torque measured for medial (internal) rotation in the counterclockwise direction in the transverse plane, indicated by a positive number. The ANOVA for maximum positive torque (see Table 5) indicated the following:

1. No significant difference was found for maximum positive torque among the RFA groups, \( F(2, 27) = 3.00, p = .07 \). The means for the RFA groups, supinators, mild pronators, and over pronators, were 26.66 N·m, 20.70 N·m, and 21.23 N·m, respectively

2. No significant difference was found for maximum positive torque between the pad and no-pad conditions, \( F(1,
27) = 0.00, $p = .95$. The means for the pad and no-pad conditions were 22.48 N.m and 22.41 N.m, respectively.

Table 5

ANOVA Summary Table for Maximum Positive Torque

<table>
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<th>Source</th>
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</table>

* Significant at $p \leq .05$

3. A significant difference was found for maximum positive torque among the 10 trials, $F(9, 243) = 2.94$, $p =$
.00. The means for the 10 trials were 23.03 N-m, 22.24 N-m, 21.68 N-m, 22.34 N-m, 22.87 N-m, 23.78 N-m, 23.28 N-m, 22.37 N-m, 20.31 N-m, 22.59 N-m, respectively.

4. A significant difference was found for maximum positive torque between the interaction effect of groups by pad/no-pad condition, $F(2, 27) = 4.36, \ p = .02$.

A simple main effects test was computed to determine which variables were significant in the interaction effect. The test (see Table 6) indicated the following:

1. A significant difference was found among groups for the pad condition, $F(2, 270) = 170.36, \ p < .05$. The means for the group were 279.31 N•m, 206.08 N•m, and 201.02 N•m for the supinator, mild pronator, and over pronator groups, respectively.

2. A significant difference was found among groups for the no pad condition, $F(2, 270) = 541.72, \ p < .05$. The means for the group were 253.92 N•m, 307.98 N•m, and 223.35 N•m for the supinator, mild pronator, and over pronator groups, respectively.

3. A significant difference was found between the pad and no-pad conditions for the supinator group, $F(1, 243) = 91.90, \ p < .05$. The means were 279.31 N•m and 253.92 N•m for the pad and no-pad conditions.

4. No significant difference was found between the pad and no-pad conditions for the mild pronator group, $F(1, 243) = .84, \ p < .05$. The means were 206.08 N•m and 307.98 N•m for the pad and no-pad conditions.
N·m for the pad and no-pad conditions.

5. A significant difference was found between the pad and no-pad conditions for the over pronator group, $F(1, 243) = 78.61$, $p < .05$. The means were 201.21 N·m and 223.35 N·m for the pad and no-pad conditions.

Table 6

Summary Table for Simple Main Effect Test for Maximum Positive Torque

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<tr>
<td>Group x Subjects</td>
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<td>243</td>
<td>28.06</td>
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</table>

*Significant at $p \leq .05$
Maximum Negative Torque

The maximum negative torque was defined as the maximum torque measured for lateral (external) rotation in the clockwise direction in the transverse plane, indicated by a negative number. The ANOVA for maximum negative torque (see Table 7) indicated the following:

1. No significant difference was found for maximum negative torque among groups, $F(2, 27) = 1.19, p = .32$. The means for the RFA groups, supinators, mild pronators, and over pronators, were -15.19 N·m, -11.56 N·m, and -13.95 N·m, respectively.

2. No significant difference was found for maximum negative torque between the pad and no-pad conditions, $F(1, 27) = .08, p = .78$. The means for the pad and no-pad conditions were 13.20 N·m and 13.28 N·m, respectively.

3. No significant difference was found for maximum negative torque among the 10 trials, $F(9, 243) = 1.30, p = .23$. The means for the 10 trials were 13.65 N·m, 13.14 N·m, 13.78 N·m, 13.74 N·m, 13.06 N·m, 12.82 N·m, 13.29 N·m, 14.19 N·m, 12.42 N·m, and 12.66 N·m, respectively.

4. The first- and second-order interaction effects were not significant.

RFA at Heel Strike

The RFA was measured as the acute angle formed between
the longitudinal line of the heel counter of the shoe and the longitudinal line of the calf at heel strike. The ANOVA for RFA at heel strike (see Table 8) indicated the following:

1. No significant difference was found for RFA at heel strike among groups, \( F(2, 27) = 2.61, p = .09 \). The means...
for the three groups, supinators, mild pronators, and over
pronators, were -.58°, 1.00°, and 1.67°, respectively.

Table 8

ANOVA Summary Table for RFA at Heel Strike

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<tr>
<td>Pad/No Pad (P)</td>
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<td>176.73</td>
<td>6.97</td>
<td>.01*</td>
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<td>17.80</td>
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</table>

* Significant at p ≤ .05

2. A significant difference was found for RFA at heel strike between the pad and no-pad conditions, F(1, 27) =
6.97, \( p = .01 \). The means for the pad and no-pad conditions were 2.17° and 1.26°, respectively.

3. No significant difference was found for RFA at heel strike among the 10 trials, \( F(9, 243) = 1.65, \ p = .10 \). The means for the 10 trials were 2.02°, .56°, .99°, 1.71°, 2.11°, 2.66°, 1.11°, 1.47°, 2.07°, and 2.45°, respectively.

4. The first- and second-order interaction effects were not significant.

**RFA at Foot Flat**

The RFA was measured as the acute angle formed between the longitudinal line of the heel counter of the shoe and the longitudinal line of the calf at foot flat. The ANOVA for RFA at heel strike (see Table 9) indicated the following:

1. No significant difference was found for RFA at foot flat among the three groups, \( F(2, 27) = 1.77, \ p = .19 \). The means for the three groups, supinators, mild pronators, and over pronators, were 10.25°, 13.31°, and 16.21°, respectively.

2. No significant difference was found for RFA at foot flat between the pad and no-pad conditions, \( F(1, 27) = 0.97, \ p = .33 \). The means for the pad and no-pad conditions were 13.67° and 13.06°, respectively.

3. No significant difference was found for RFA at foot flat among the 10 trials, \( F(9, 243) = 0.89, \ p = .54 \). The
means for the 10 trials were 12.85°, 11.91°, 12.65°, 13.64°, 13.96°, 12.93°, 13.92°, 13.05°, 13.86°, and 13.89°, respectively.

4. The first- and second-order interaction effects were not significant.

Table 9
ANOVA Summary Table for RFA at Foot Flat

<table>
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<tr>
<th>Source</th>
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<th>MS</th>
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<td>Within Groups</td>
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<td></td>
</tr>
<tr>
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<td>243</td>
<td>33.53</td>
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</tr>
</tbody>
</table>
RFA at Push Off

The RFA was measured as the acute angle formed between the longitudinal line of the heel counter of the shoe and the longitudinal line of the calf at push off. The ANOVA for RFA at heel strike (see Table 10) indicated the following:

1. No significant difference was found for RFA at push off among the three groups, $F(2, 27) = 1.08, \ p = .35$. The means for the three groups, supinators, mild pronators, and over pronators, were $-10.27^\circ$, $9.15^\circ$, and $4.24^\circ$, respectively.

2. No significant difference was found for RFA at foot flat between the pad and no-pad conditions, $F(1, 27) = 1.55, \ p = .22$. The means for the pad and no-pad conditions were $8.97^\circ$ and $6.98^\circ$, respectively.

3. No significant difference was found for RFA at foot flat among the 10 trials, $F(9, 243) = 1.01, \ p = .43$. The means for the 10 trials were $7.94^\circ$, $7.03^\circ$, $6.38^\circ$, $7.71^\circ$, $7.31^\circ$, $6.70^\circ$, $12.67^\circ$, $8.58^\circ$, $7.63^\circ$, and $7.64^\circ$, respectively.

4. The first- and second-order interaction effects were not significant.
Table 10
ANOVA Summary Table for RFA at Push Off

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
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<td></td>
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<td>550.94</td>
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<td>.22</td>
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<td>Within Groups</td>
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<td>Trials (T)</td>
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<td>52811.94</td>
<td>243</td>
<td>217.33</td>
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</tr>
</tbody>
</table>

Discussion

**Maximum Propulsion Force**

A significant difference was not found for maximum propulsion force between the pad and no-pad conditions.
This indicated that there was no difference in force applied to the force plate, down and backwards, between the pad and no-pad conditions. The means for the pad and no-pad conditions were 129.62 N and 128.74 N, respectively. This contradicted a study done by Eggold (1981), who concluded that orthotic devices keep the foot in its neutral position, which prevents "excessive inefficient compensatory motions and [maximizes] performance" (p. 126) of the foot during the gait cycle. In his study 146 runners were surveyed to see if orthotics were beneficial in reducing the recurrence of common overuse injuries such as shin-splints, plantar fasciitis and arch strain, knee pain, and achilles tendinitis. Eggold stated that orthotics had a significant therapeutic value in correcting the abnormalities of the gait cycle of the runner.

Buchbinder et al. (1979) talked about how the foot in the stance phase changed from a mobile adapter to a rigid lever. This change to a rigid lever allows for a propulsive push off. If the foot is not in the proper position throughout the stance phase of a gait cycle, the foot is not able to push at toe-off. For this condition the HLMAP was not able to keep the foot in a more neutral position therefore there was no significant difference in maximum propulsion for the pad condition versus the no-pad condition.
Vertical Thrust/Maximum Positive Torque and Trials

There was a significant difference found for these two variables among the 10 trials. This indicated that the subjects' gait patterns were not consistent with each trip across the force plate. The subjects were instructed to begin each pass from the same spot and to step in time with the metronome. Some subjects were able to accomplish this task with more regularity than others, however even the most consistent striders were unable to strike the force plate with exactly the same force every time.

Maximum Positive Torque

A significant difference was found for maximum positive torque between the interaction effect of groups and the pad/no-pad condition. This is in opposition to a study conducted by Bieber, Coates, Lohmann, and Danoff (1988), who studied the effect of orthoses on ground reaction forces in walkers. They found that the center of pressure moved from being more medial at heel strike to being more lateral at 25% of contact and beyond. In the running gait cycle there is a flight phase which is not present in the walking gait cycle, as was studied by Beiber et al. (1988). At heel strike, the foot must be placed further under the center of mass of a runner than that of a walker, in order to support the body during the stance phase. This placement
of the foot was defined as the crossover effect. The crossover effect was illustrated by Andrew (1986) who conducted a study which tested runners at different speeds and measured foot strike in relation to the midline of the body. He found that as the runners' speed increased from 3.6 to 4.5 to 6.0 m/s the crossover increased from 1.27 to 1.05 to -0.04 cm, respectively. As the foot crosses over the sagittal midline of the body to support a runner during the stance phase of the gait cycle, the torques associated with this foot placement increase.

In this study, the presence of the pad controlled the subject's foot after heel strike to keep it from rotating externally or laterally, as measured from the transverse plane. This was true for the over pronator group only. The negative torque values were lower for the pad condition than for the no-pad condition. Thus, the presence of the pad kept the foot in a more neutral position through the gait cycle. When the pad was not worn by this group the torque values were higher, indicating that the foot was less controlled during the gait cycle. However, the opposite was true for the supinato group. The presence of the pad caused the foot to rotate in the lateral direction. This result indicated that the pad could be contraindicated for this group. In these subjects the pad caused a less controlled gait cycle.

For those subjects in the mild pronator group the pad
had no significant effect. The pad for these subjects did not help control nor did it cause an uncontrolled gait cycle.

**RFA at Heel Strike**

A significant difference was found for RFA at heel strike for the pad/no-pad condition. Edington et al. (1990) reported that the presence of orthotic devices helped to reduce the initial pronation of the foot at heel strike. It was also found to reduce the rate of pronation. James et al. (1978) found that orthotics were beneficial in correcting maladies such as tibia varum, subtalar varus, and functional equinus. These conditions are related to how the foot contacts the ground. In this study the presence of the pad reduced the angle of the foot at the initial point of contact with the ground by supporting the foot in its neutral position. This was expected considering the purpose of the pad was to reduce the amount of pronation the foot experienced throughout the gait cycle.
CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem of this study was to determine the effectiveness of the Hapad Longitudinal Metatarsal Arch Pad in reducing the severity of pronation in women while jogging. Specifically, rear foot angle (RFA) and ground reaction forces for subjects jogging with and without the HLMAP were compared.

All subjects were female students from Western Michigan University. The subjects were all volunteers meeting the following criteria: (a) subjects were between the ages of 18 to 35 years, (b) subjects were injury free of orthopaedic injuries to both lower extremities for at least one year prior to participation in this study, and (c) no other orthotic devices were worn during testing.

The pad investigated, was the Hapad Longitudinal Metatarsal Arch Pad. Sizes extra small to large were used to accommodate the shoe size of each subject. Each subject jogged to the cadence of a Pico Club metronome by Seiko (Japan), set at 145 beats per minute. The force plate used to measure the ground reaction forces was the Kistler Type 9281B. This was interfaced to a Tenex 486 DX-2 computer.
running Peak 5.2 Analog Sampling Module Software (Peak Performance Inc., 1994). The camera used for this study was the Panasonic WV-D5100HS video camera, Panasonic Industrial Factory Service Center, Secaucus, NJ. It is a high speed video camera with a zoom lens and is interfaced with a Panisonic model AG 7350 SVHS video recorder. The digitizing equipment consisted of a Panasonic model AG 7350 SVHS video recorder attached to a Sony Trinitron 13" diagonal video monitor. The software used to digitize the film was Peak 5.2, version 1.2, Peak Performance Technologies, Inc., Englewood, CO.

Trials for each subject consisted of 15 with the pad and 15 without the pad. The 10 most consistent trials as determined by the force plate data were used for analysis. Each dependent variable was analyzed by a split-plot, repeated measures Analysis of Variance (ANOVA) design. The pad and no-pad condition and the 15 trials were repeated by all subjects. The grouping variable, RFA measured in the anatomical position, caused the split-plot ANOVA design.

Findings

The findings for this study were significant at the 0.05 level. The ANOVA calculations were:

1. No significant difference was not found for maximum propulsive force between the pad and no-pad conditions, $F(1, 27) = .05, \ p = .82$. 
2. A significant difference was found for vertical thrust among the 10 trials, $F(9, 243) = 2.20, \ p < .02$.

3. A significant difference was found for maximum positive torque among the ten trials, $F(9, 243) = 2.94, \ p = .00$.

5. A significant difference was found for maximum positive torque among groups for the pad condition, $F(2, 270) = 170.36, \ p < .05$. The group means for the supinators, mild pronators, and over pronators were 279.31 N·m, 206.08 N·m, and 201.21 N·m, respectively.

6. A significant difference was found for maximum positive torque among groups for the no pad condition, $F(2, 270) = 541.27, \ p < .05$. The group means for the supinators, mild pronators, and over pronators were 253.92 N·m, 207.98 N·m, and 223.35 N·m, respectively.

7. A significant difference was found for maximum positive torque between the pad and no-pad condition for the supinator group, $F(1, 243) = 91.90, \ p < .05$. The means for the pad and no-pad conditions were 279.31 N·m, and 253.92 N·m.

8. No significant difference was found for maximum positive torque between the pad and no-pad condition for the mild pronator group, $F(1, 243) = 0.84, \ p < .05$. The means for the pad and no-pad conditions were 206.08 N·m, and 207.98 N·m.

9. A significant difference was found for maximum
positive torque between the pad and no-pad condition for the over pronator group, $F(1, 243) = 78.61, p < .05$. The means for the pad and no-pad conditions were 201.21 N·m, and 223.35 N·m.

Conclusions

The conclusions for this study based on the findings were:

1. The presence of the pad did not allow for a more propulsive push during the gait cycle.

2. The significant difference observed for vertical thrust and positive torque among trials was a result of inconsistent passes over the fore plate by the subjects.

3. The presence of the pad helped to control positive torque for the over pronator group. The torque values were less for this group when the pad was worn as compared to when the pad was not. The mean values were 201.21 for the pad condition and 223.35 for the no pad condition.

4. The presence of the pad accentuated the negative torque for the supinator group. The torque values were greater for this group when the pad was worn than when the pad was not worn. The pad could be considered contraindicated for this group. The mean values were 279.31 for the pad condition and 253.92 for the no pad condition.

5. The presence of the pad had no effect on the mild pronator group. The torque values were only slightly
different for the pad and no-pad conditions. The mean values were 206.08 for the pad condition and 307.98 for the no-pad condition.

6. The RFA at heel strike was greater when the pad was worn than when the pad was not. The mean values were 2.17' for the pad condition and 1.26' for the no-pad condition.

Recommendations

The recommendations for further study include:

1. Compare the effectiveness of the HLMAP as an orthotic device with other orthotic devices.

2. Have each subject wear the same shoe. In this study each subject wore her own shoe. There was no way to control for how new or old the shoe was.

3. Include males in the study. The Q angle of women and men is different and this may yield differing results.

4. Screen the subjects for the groups before the study begins. In this case different orthotic devices could be tested on subjects with differing severities of RFA.
APPENDIX A

Informed Consent

Western Michigan University
Department of Health, Physical Education, and Recreation

Principal Investigator: Dr. Mary Dawson
Research Associate: William F. Rocker Jr.

I understand that I have been invited to participate in a research project entitled "The Effect of the Hapad Longitudinal Metatarsal Arch Pad on Ground Reaction Forces and Rear Foot Angle". The purpose of this study is to determine the effectiveness of the Hapad longitudinal metatarsal arch pad (HLMAP) to control pronation on the foot. I further understand that this project is being conducted to fulfill the theses requirements of William F. Rocker Jr.

I understand that there are no direct benefits from participation in this study. However, I understand that the knowledge gained will help clinicians make more informed decisions concerning the use of HLMAP.

I understand that I will be wearing the HLMAP while jogging at 3.5 to 4.0 mph over a forceplate and that I will also be performing the same procedures without the HLMAP. The placement of the pad will be temporary and no damage will be sustained to my shoe during the course of the study. I realize that in order to measure rear foot angle (RFA) tape will be placed on my lower right leg as well as the heel counter of my right shoe. I also realize my lower leg will be video taped during the study. The study will involve about 45 minutes of my time. The participation time will include: (a) a practice/warm-up period, (b) 15 trials with the pad, and (c) 15 trials without the pad.

I also understand that there will be no expected risks associated with my participation in this study. However, an ankle sprain is possible. If in the event of accidental injury, appropriate emergency measures will be taken; however no treatment or compensation will be provided outside of what is stated in this consent form.

I realize that my participation will be completely anonymous, and that only a number will be used to identify me as a participant. Any lists of name will be destroyed
upon completion of this study. The video tape made during the study and all other analytical data will be kept in a locked box for 3 years, to which only the primary investigator has a key. I understand that I may refuse participation at any time during the study. This refusal in no way will jeopardize my standing at Western Michigan University.

If I have questions or concerns about this study I may contact William F. Rocker Jr. (Bill) at (616) 394-0641 or Dr. Mary Dawson at (616) 381-2711 in the Health, Physical Education, and Recreation Department. I may also contact the Chair of Human Subjects Institutional Review Board at (616) 387-8293 or the Vice President for Research at (616) 387-8298 with any concern I might have.

I am covered by my own medical insurance, or otherwise accept full responsibility for any and all medical expenses I may incur as a result of my participation in this study.

My signature below indicates that I understand the purpose and requirements of my participation in this study.

Signature ____________________________ Date ________
Appendix B

Human Subjects Institutional Review Board Acceptance Letter
Date: December 13, 1995

To: William Rocker, Jr.

From: Richard Wright, Chair

Re: HSIRB Project Number 95-12-06

This letter will serve as confirmation that your research project entitled "The effect of the Hapad Longitudinal Metatarsal Arch Pad on ground reaction forces and rear foot angle" has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you must seek specific approval for any changes in this design. You must also seek reapproval if the project extends beyond the termination date. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: December 13, 1996

xc: Mary Dawson, HPER
BIBLIOGRAPHY


