THE EFFECTS OF SHOE TYPE ON FOOT FUNCTIONING AND CONTACT PRESSURES DURING WALKING PERFORMANCES

THESIS

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By

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The purpose of this study was to evaluate the functional effectiveness of a selection of women's walking shoes with particular attention being directed towards an assessment of specific shoe modifications which were included in a prototype model to theoretically reduce the undesirable characteristics associated with flexible shoes. Nine female subjects performed three trials for each of five shoe conditions. The prototype model decreased the encountered pressures and pressure integrals in the region of the second metatarsal-phalangeal joint. The use of the prototype shoe did not appear to unduly affect the gait of the subject.

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CHAPTER I

INTRODUCTION

Studies of the incidence of foot problems of unshod peoples have revealed that these populations are generally free of disabilities commonly experienced by people who habitually use some form of footwear, i.e., hallux valgus, bunions, hammertoes, and painful feet (Stewart, 1970; Stewart, 1972). However, it is to be recognized that the members of unshod populations are not confined to walking on flat rigid surfaces. For those individuals who live in modern urban settings, it would seem that for at least reasons of protection, support, and social restraints, footwear is necessary (Gorecki, 1978).

The choice of footwear is generally not determined on the basis of desirable functional characteristics, in that fashion considerations often enter into the selection process. It is also likely that on many occasions the dictates of fashion and function are not mutually complementary.

Although there exists the temptation to attribute many acquired foot disorders to shoes, per se, much of the supportive evidence gleaned from the survey studies conducted by Cole (1959), Charlesworth (1959), and Helfand

(1969) have failed to establish a causal relationship. According to Gorecki (1978) the implications of these studies are primarily hypothetical. It would therefore appear that shoe related deformities may be caused by potentially interacting factors such as demographic effects, shoe design, shoe fit, shoe construction materials, and terrain. Despite the likelihood of a multiplicity of potential causative factors for foot problems, consumers are almost unanimous in their conviction that ill-fitting shoes are a major health problem. Based on the results of a survey study, Fass, Passet and d'Amico (1978) found that 94.8% of the population questioned believed that improperly fitting shoes lead to chronic foot problems. In addition, 66% had foot problems and 88% of them stated that shoes were either the only factor or the major contributory factor in their pathology. Sixty percent of the respondents also claimed that they had difficulty in obtaining shoes that fit properly.

Some attempts have been made to suggest appropriate design characteristics for shoes. For example, Schuster (1978) implied that shoes should function in concert with the motion characteristics of the untrammeled foot. That is, a shoe should bend, be rigid, and be stable in those regions where the foot displays these characteristics during normal gait.

In recognition of the inadequacies of the currently available shoes, a recent attempt was made to design a women's walking shoe[1] which both minimizes local areas of stress concentration and forefoot joint motion. In order to restrain forefoot mobility and maintain the foot in a stable slight equinus posture with the metatarsal-phalangeal joint at 15 to 20 degrees of dorsiflexion, the shoe includes a molded rigid sole. To eliminate any tendency for the heel to break contact with the shoe following the midstance gait phase and thus result in metatarsal-phalangeal joint motion and localized areas of stress, the shoe also includes a so-called "rockered" sole of varying longitudinal curvatures. The theoretical net effects are that immediately after the heel of the shoe breaks contact with the ground the location of the transferred resultant force is distal to the locus of rotation of the shoe. The eccentricity of the force causes the shoe to maintain contact with the foot. As the contact phase progresses, the continuing forward movement of the location of the resultant reaction force maintains the contact between the rear of the shoe and the heel. Some indirect support for the design characteristics of the shoe has been provided by Perry and Gronley (1981).

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[1]Designed and constructed by Donald Mauldin, M.D., Dallas, Texas; Dean Morgan, C.PED., Professional Shoe Service, Dallas, Texas; and Thomas Taylor, D.P.M., Bedford, Texas.

Purpose of the Study

The purpose of this study was to evaluate the functional effectiveness of a selection of women's walking shoes with particular attention being directed toward an assessment of specific shoe modifications which were included in a prototype model to theoretically reduce the undesirable characteristics associated with flexible shoes.

Delimitations of the Study

The delimitations in the analysis of the walking shoes included the following.

1. Only females were used as subjects.
2. None of the subjects were experiencing any clinical or structural lower limb abnormalities or discomfort at the time of the study.
3. The support phase of the walking gait cycle of each subject was evaluated on the basis of three performances for each condition.

Limitations of the Study

The limitations in the analysis of the walking shoes included the following.

1. Normal cinematographical analysis limitations were recognized.
2. The assumption was made that the subject movements occurred in planes perpendicular and

parallel to the optical axis of a single camera.

3. The anatomical reference points necessary to make various computations were estimates for approximating the actual locations of these points on each subject.
4. The recorded pressures were indicative of the pressures experienced over the left second metatarsal-phalangeal joint.

Definition of Terms

The following definitions are presented to clarify terms that appear in the text and might be ambiguous:

Equinus. Position of the foot in which the heel is elevated and the forefoot is in plantar flexion.

Pronation. Eversion and abduction of the calcaneous relative to the midline of the lower leg.

Supination. Inversion and adduction of the calcaneous relative to the midline of the lower leg.

Support Phase. The phase of the gait cycle for each foot which begins when the heel first makes contact with the walking surface and ends when the foot leaves the walking surface.

CHAPTER II

REVIEW OF LITERATURE

A review of literature revealed that attempts have been made to scientifically determine the effects of shoe design and poor shoe fit on foot functioning. Studies by Adrian and Karpovich (1969) and Gollnick, Tipton, and Karpovich (1964) have demonstrated foot deformities and dysfunction accompanying the use of high heels. Gollnick et al. (1964) measured knee joint and ankle joint angles in young girls wearing high heels. It was found that high heels increased the ankle joint extension and resulted in decreased knee flexion during the swing phase. Adams (1967) attributes foot strain, heel cord tightness, and posterior calcaneal spurs to inappropriate shoe design. Improperly fitting shoes have been cited as a causative factor in metatarsal strain, callus development inter-digital neuroma, and bunions (Adams, 1967).

Schuster (1978) attributes many of the problems associated with inappropriate shoe design and ill-fitting shoes to the reluctance of the shoe industry to provide shoes which are compatible with the spectrum of structural and functional foot characteristics. An illustration of the design inertia of the shoe industry is provided by

Holscher and Hu (1976) who revealed, that historically shoes have been built on lasts with an inflare alignment of about 6 degrees. This inflare is incompatible with the straight or abductory tendencies of the average foot and is thus a distorting force contributing to foot abuse. The problem is compounded by the apparent lack of standards regarding last sizes (Adams, 1967).

A further complication concerns the basis of selection of an appropriate shoe by the consumer. Fashion considerations often enter into the selection process and it is likely that on many occasions the dictates of fashion and function are not mutually complementary. Indirect evidence for the effect of fashion is provided by Schuster (1978) who stated that many of his patients complain that for years they did well with a certain type shoe and then find it is no longer on the market.

The functioning of the lower extremity during the support phase of walking gaits has been subject to some scientific scrutiny. Considerable attention has been directed toward determining the nature of the foot contact pressures. The combined results of recent studies are summarized as follows.

1. Simon et al. (1981) showed that the lower limb is subjected to a high frequency impulsive load at heel strike. The severity of this load was found to vary with the individual, the velocity and angle with which the limb

approaches the ground, and the compliance of the contacting materials.

2. In examining the center of pressure, Cavanagh and Ae (1980) found that peak rearfoot pressure occurs on the rear lateral border of the heel 60 msecs after heel strike, or 17% into the support phase. Grundy et al. (1975) found that this peak does not occur until both the heel and forefoot are in contact with the ground.

3. Pressure magnitudes decrease at 140 msecs as the center of pressure moves anteriorly. The center of pressure moves almost directly from the heel to the metatarsal-phalangeal heads, bypassing the midfoot region (Cavanagh & Ae, 1980; Grundy et al., 1975).

4. At 220 msecs (35% into the support phase), simultaneous pressure concentrations exist in the heel and forefoot regions. Within 50 msecs or 40% into the support phase, the pressures are concentrated in the forefoot region (Cavanagh & Ae, 1980; Grundy et al., 1975; Scranton & McMaster, 1976).

5. At 320 msecs (50-55% into the support phase), the center of pressure moves beyond the metatarsal-phalangeal heads (Cavanagh & Ae, 1980). The prolonged location of forces in the forefoot region is also supported by the results of Grundy et al. (1975) and Scranton and McMaster (1976).

6. At 500 msecs (85-90% of the support phase), there is a slight decrease in the magnitudes of the pressures. The pressures in the metatarsal-phalangeal head regions reach their highest value during the toe-off phase (580 msecs) (Cavanagh & Ae, 1980; Grundy et al., 1975; Scranton & McMaster, 1976).

7. At the conclusion of the toe-off phase (600 msecs) the pressure in the metatarsal-phalangeal head regions decline rapidly. Pressures of small magnitude are experienced on the plantar surfaces of the first and second toe at the conclusion of the support phase (Cavanagh & Ae, 1980; Grundy et al., 1975).

Of particular interest is the prolongation and high magnitudes of the pressures experienced in the metatarsal-phalangeal joints region. These results would appear to correlate with the prevalence of acquired foot problems in this region, i.e., metatarsal strain, callus development, interdigital neuroma, and bunions (Adams, 1967).

It would appear as though few attempts have been made to identify the effects of different shoe sole materials on foot functioning. Most of the studies have been concerned with running performances (Bates et al., 1978). Grundy (1975) found that although the forefoot sustained only slightly greater loads than the heel, it did so for a much longer period. His results suggested that the load-bearing function of the forefoot was about three times that of the heel. When shoes were worn the load-bearing function of the forefoot was progressively reduced as the rigidity of the sole increased. Perry and Gronley (1981) investigated a rocker shoe as a walking aid for multiple sclerosis patients. It was found that improvements in gait while wearing rocker shoes varied with clinical classification. In addition, normal velocity and stride characteristics were accompanied by significant decreases in net energy expenditure.

In summary it would appear as though little scientific attention has been directed toward an examination of the effects of walking shoe design on both experienced contact pressures and the functioning of the lower limbs.

CHAPTER III

PROCEDURES

The purpose of this study was to evaluate the functional effectiveness of a selection of women's walking shoes with particular attention being directed toward an assessment of specific shoe modifications which were included in a prototype model to theoretically reduce the undesirable characteristics associated with flexible shoes.

Subjects

Nine (9) females from North Texas State University (Denton, Texas) and Denton (Texas) communities served as subjects in the study. The only requirement for subject selection was that they were experiencing no lower limb abnormalities or discomfort at the time of the testing sessions.

Instrumentation

Pressure Measurements Elements and Amplification System

A pressure transducer (Model 281P, Orthoflex Data Acquisition System and Force/Pressure Transducer, Hercules Incorporated, Cumberland, MD 21502) was adhered to the plantar surface of the left foot of the subject on the skin overlying the distal head of the second metatarsal.

Voltage changes occurring as a result of pressure exerted in the region of the transducer were transmitted via fine wires to a preamplifier which was strapped to the back of each subject. The preamplifier was, in turn, connected to amplification and recording apparatus. The specifications for the pressure transducers and preamplifier system appears in Appendix A.

Cinematographical Instrumentation

A high speed 16-mm motion-picture camera (DBM-55 Teledyne Camera Systems, Arcadia, California 91006) was used to obtain film records of the movements of the subjects. The camera was operated at 100 frames per second and positioned such that the optical axis was directed toward the rear of each subject. A plane mirror was vertically orientated at 0.78 radians to the anticipated plane of motion of each subject. The arrangement was such that both the rear and left lateral perspectives of the subjects were recorded on film. Appropriate alignment and leveling of the camera and mirror ensured that the entire range of motion of the left lower limb during the support phase in the marked target area was recorded. The location of the equipment was as shown in Figure 1.

Three numbered-coded cards were included in the field of view of the camera and filmed during each trial. The identification codes corresponded to the assigned subject,

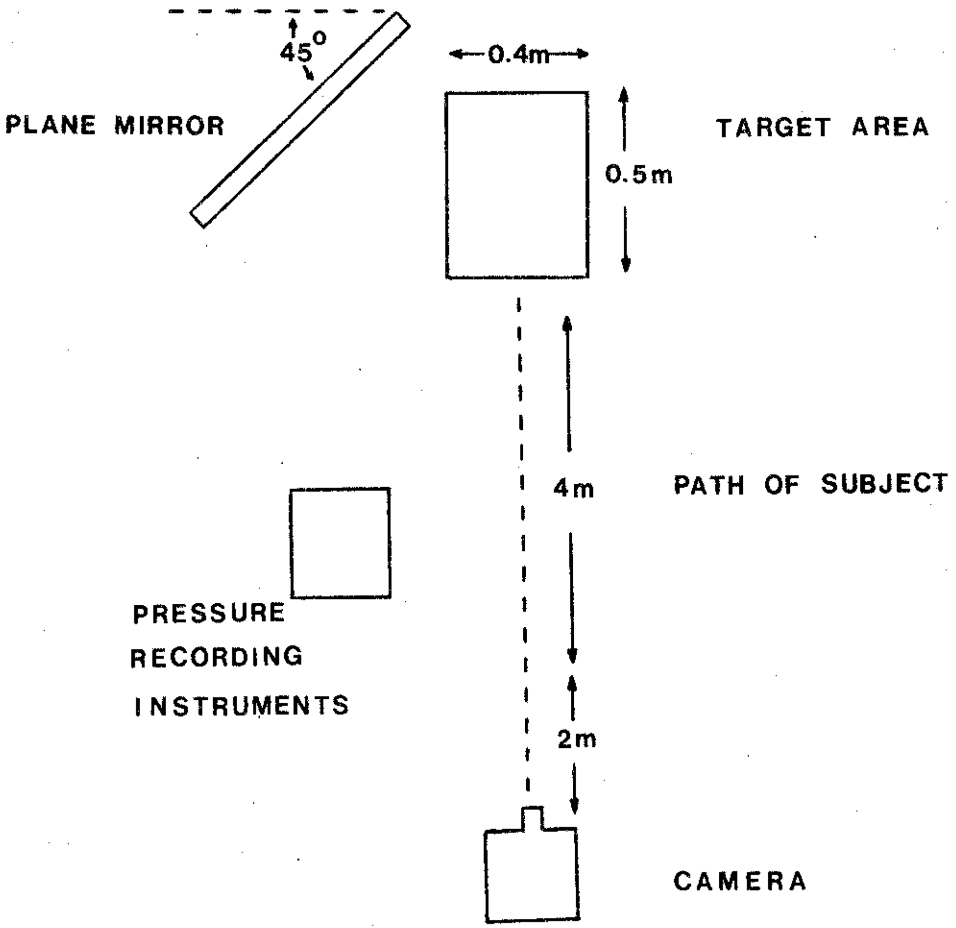

Fig. 1--Location of Testing Equipment Used to Collect Data.

trial, and shoe condition numbers. A linear and vertical reference was placed in the optical field of the camera to facilitate the subsequent determination of linear measurements from the film. Temporal scales were obtained by means of a timing light system used in conjunction with a motion-picture camera.

Shoes

Five (5) shoe conditions were examined in the study. The shoes examined were a commercially available flexible sole shoe (flexible), a subject-preferred walking shoe (preferred), a commercially available flexible "ripple sole" shoe (ripple), a rigid rockered sole shoe (rockered), and a barefoot control condition (barefoot). The basis of selection of the shoes was that they both represented the spectrum of commercially available women's walking shoes and included two shoes which had unique sole characteristics. The flexible shoe was typical of the walking shoes generally worn by women. The characteristics of the shoe included flimsy construction, minimal sole thickness and extreme shank flexibility. The preferred shoe was a shoe owned by each subject and personally judged to be the most comfortable in their possession. The ripple sole was a commercially available shoe which had a relatively thick flexible sole with an undulating plantar surface. The rockered sole shoe was a prototype model which had the design characteristics of a molded rigid and rockered sole of varying curvatures. With the exception of the preferred shoes, all of the shoes had comparable heel heights and ankle restraints.

Testing Procedures

All of the testing sessions were conducted in the Biomechanics Laboratory, Division of Physical Education, North Texas State University, Denton, Texas. Prior to the testing session the pressure transducer was calibrated by the imposition of known forces. The recorded outputs were subsequently equated to the applied pressures during each trial. At the beginning of each testing session, measurements of each subject's weight and standing height were recorded.

Each subject performed fifteen trials, corresponding to three trials for each of the five shoe conditions. The performance order of each trial was randomly assigned to each subject. At the beginning of the testing session, each subject was asked to read and sign a consent form for participation (Appendix B). Prior to the commencement of the first trial by each subject, the capacitive pressure transducer was adhered to the plantar surface of the left foot on the skin overlying the distal head of the second metatarsal. To facilitate the location of selected anatomical reference points each subject wore shorts. A clearly visible mark was drawn on the lateral border of the sole of each left shoe. The mark was located in line with the head of the second metatarsal. For all trials, additional marks were drawn on the skin overlying the lateral projection of the left knee and ankle joints. A straight line was also drawn down the middle of the posterior surface of the leg. This line extended from the lower border of the left calcaneous to the popliteal fossa. Prior to the commencement of each trial the subject was permitted to walk around the confines of the testing site until she had "adjusted" to any perceived peculiarities in the shoe condition. In addition, each subject practiced walking along a defined path until she could place her left foot within a marked area without making overt adjustments to her gait. During each trial the motion of the left lower limb when it was in contact with the marked target area was recorded on film. Synchronization of the film and pressure recordings was provided by simultaneously inputting an analogue signal into both the timing light system incorporated into the camera and a channel of the pressure recording system. After each subject had completed all of the trials for each shoe condition she was asked to rank the shoes in order of perceived comfort. At the conclusion of the testing sessions the lower limbs of each subject were statically and dynamically evaluated by a certified podiatrist.[2]

Data Acquisition Procedures

The motion of each subject during each trial from the depicted instant five film frames before left foot contact to the depicted instant five film frames after left foot contact was analyzed with the aid of a Lafayette 16-mm stop-action analyzer (Lafayette Instrument Co., Lafayette, Indiana 47906) in conjunction with a Numonics Electronic Digitizer (Model 1200, Numonics Corp., North Wales, Pennsylvania 19454), which was interfaced to a Tektronix 4052 Graphics Calculator (Tektronix Inc., Beaverton, Oregon). The x- and y- coordinates of the following landmarks were digitized and recorded for each film frame:

1. greater trochanter of the left femur
2. lateral epicondyle of the left femur
3. lateral malleolus of the left fibula
4. the marked landmark on the shoe
5. the two points on the line drawn on the back of the leg above a line linking the left malleoli
6. two points on the line drawn on the skin over the posterior surface of the left calcaneous

The data thus obtained was used in conjunction with a series of computer programs which computed the x- and y-

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[2]Thomas Taylor, D.P.M., Bedford, Texas.

displacements of each of the landmarks, the angle of foot pronation, the angle of inclination of the sole of the shoes, the leg and thigh angles, and the angles at the knee and ankle joints. All of the above parameters for each trial were "smoothed" using cubic spline curve fitting techniques. Instantaneous values of each of the kinematic parameters were extracted for subsequent statistical analysis. All of the angular parameters were averaged by shoe condition. The pressure records of each trial were digitized, "smoothed" and normalized by dividing by subject body weight. The temporal characteristics of each trial relative to the instant of heel-strike as depicted in the film records, the mean pressure magnitudes, the maximum pressure magnitudes and the algebraic pressure impulses were computed and recorded for subsequent statistical analysis. An average pressure/time record was also computed for each shoe condition.

Statistical Analysis

A statistical analysis ($p < 0.05$) utilizing repeated measures analysis of variance procedures was conducted to ascertain if differences existed between the shoe type conditions, with the instantaneous temporal, kinetic, and kinematic characteristics of the left foot contact phase entered as dependent variables.

CHAPTER IV

RESULTS

The purpose of this study was to evaluate the functional effectiveness of a selection of women's walking shoes with particular attention being directed toward an assessment of specific shoe modifications which were included in a prototype model to theoretically reduce the undesirable characteristics associated with flexible shoes.

Subjects

The subjects used in this study ranged in age from 18 to 42 years ($\bar{x}$ = 25.1, SD = 7.3 years), in height from 1.55 to 1.80 meters ($\bar{x}$ = 1.63, SD = 0.08 meters), and in weight from 47.2 to 74.8 kilograms ($\bar{x}$ = 58.36, SD = 10.01 kilograms). The results of the clinical examination of the lower limbs and selected anthropometric characteristics of each subject appear in Appendix C and D.

Results

The results of the kinetic analysis revealed unique average pressure curves for each shoe condition (Figure 2). The statistical analysis conducted on the extracted temporal and kinetic variables yielded no significant trial by shoe condition interactions or trial main effects.

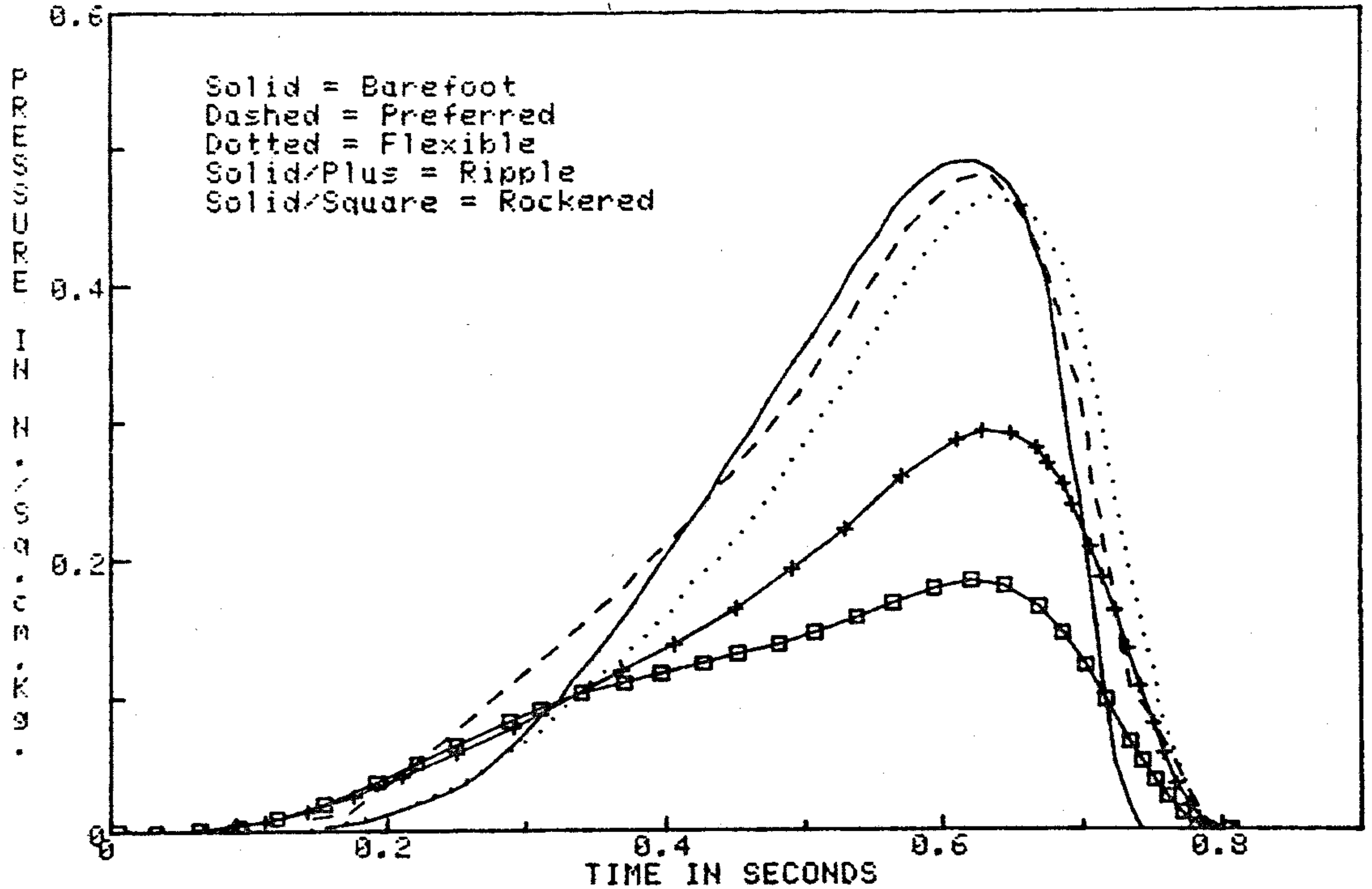

Fig. 2--Average Pressures Exerted on the Second Metatarsal-Phalangeal Joint

Significant differences were found between the shoe conditions for the duration of the pressures, algebraic pressure impulses, mean pressure impulses, and maximum pressures. A summary table of the results of the statistical analysis appears in Table 1.

The duration of the pressures on the skin overlying the second metatarsal-phalangeal joint was found to be significantly less for the barefoot condition than for the preferred shoe, flexible shoe, and rockered sole shoe conditions. The duration of the pressures for the barefoot condition were also less than those recorded for the ripple sole shoe although the differences were not statistically significant. The duration of the pressures for the five shoe conditions are shown in Figure 3.

Both the algebraic pressure impulses and mean pressure impulses were found to be of lesser magnitude for the rockered sole shoe and the ripple sole shoe than for the remaining shoe conditions. In addition, for both of these parameters, the recorded magnitudes for the rockered sole shoe were less than those for the ripple sole shoe (Figure 4). For both the preferred and flexible shoe conditions, the recorded maximum pressures were greater than those for both the rockered sole and ripple sole shoes. No significant differences between the shoe conditions were found for the times to maximum recorded pressure (Figure 5).

Table 1

Summary Table of Post Hoc Evaluation

Group[a] Comparison	MF	AI	TN	MI	MT
1-2					*
1-3					*
1-4		*		*	
1-5		*		*	*
2-3					
2-4	*	*		*	
2-5	*	*		*	
3-4	*	*		*	
3-5	*	*		*	
4-5		*		*	

[a] 1 = Barefoot
2 = Preferred
3 = Flexible
4 = Ripple
5 = Rockered

MF Maximum Force exerted over second metatarsal-phalangeal joint
AI Algebraic Impulse exerted over second metatarsal-phalangeal joint
TM Time to maximum force over second metatarsal-phalangeal joint
MI Mean pressure impulses exerted over second metatarsal-phalangeal joint
MT Maximum time of force on the second metatarsal-phalangeal joint

$*p < 0.05$

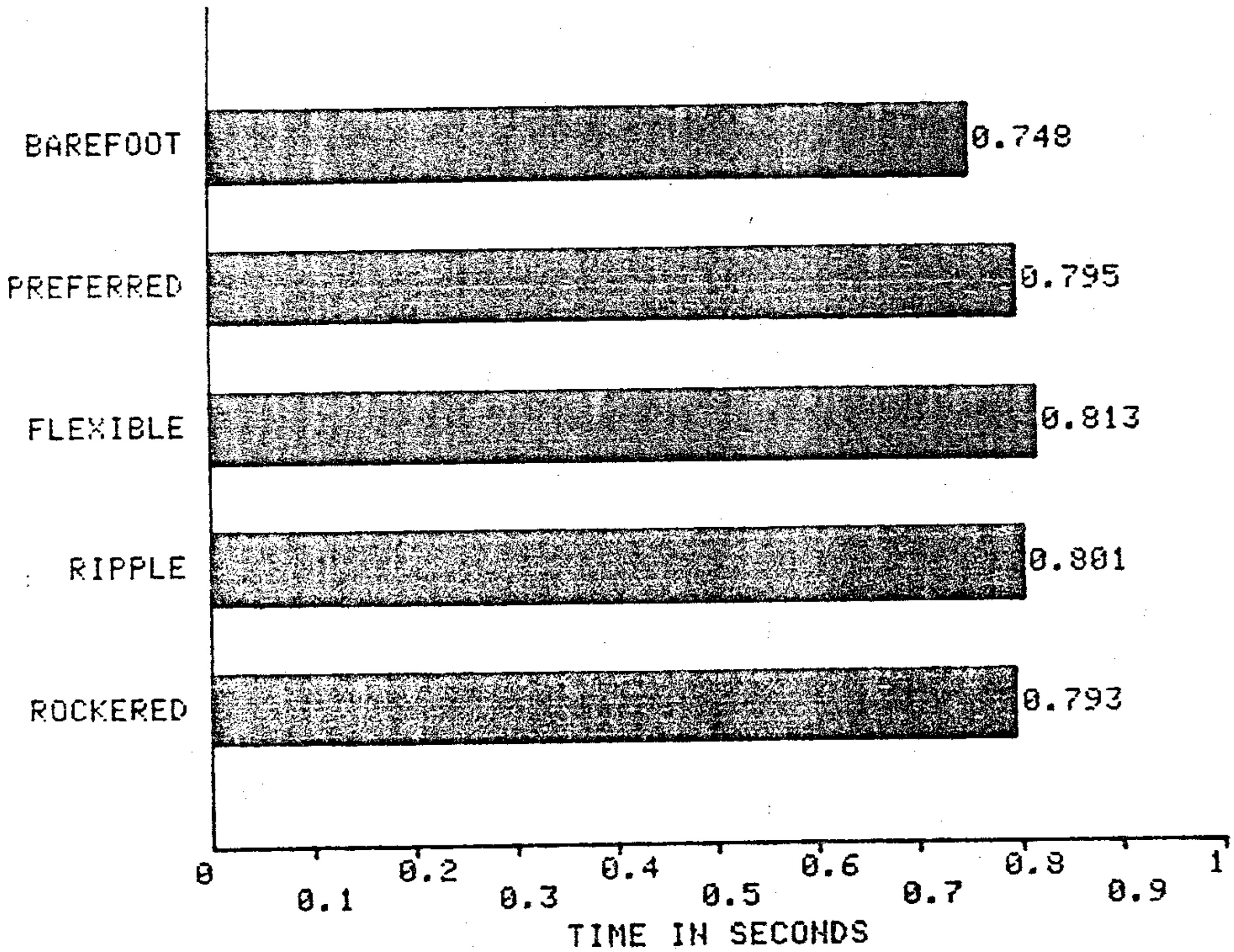

Fig. 3--Duration of the Pressures Exerted Over the Second Metatarsal-Phalangeal Joint.

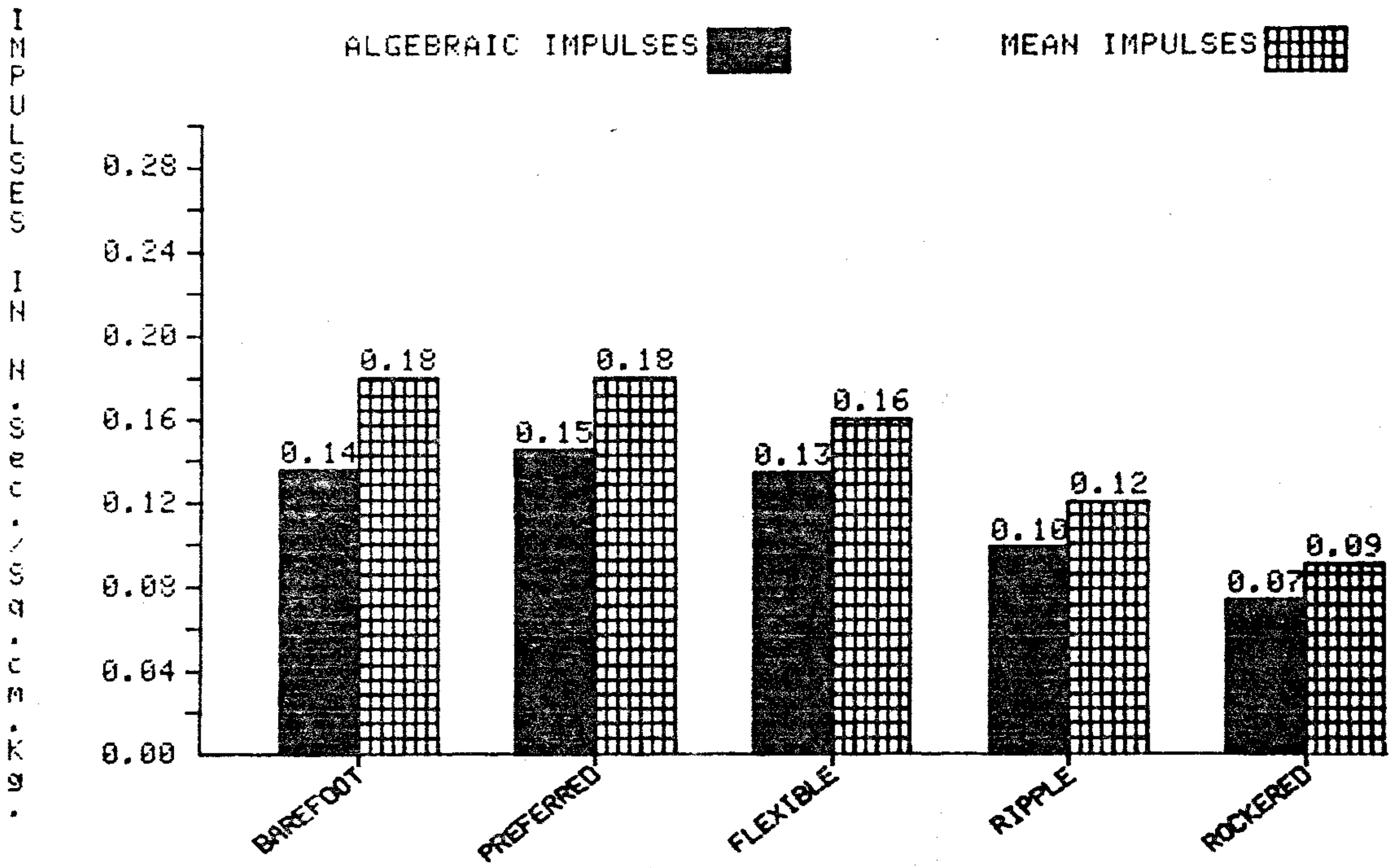

Fig. 4--Algebraic and Mean Pressure Impulses Exerted Over the Second Metatarsal-Phalangeal Joint.

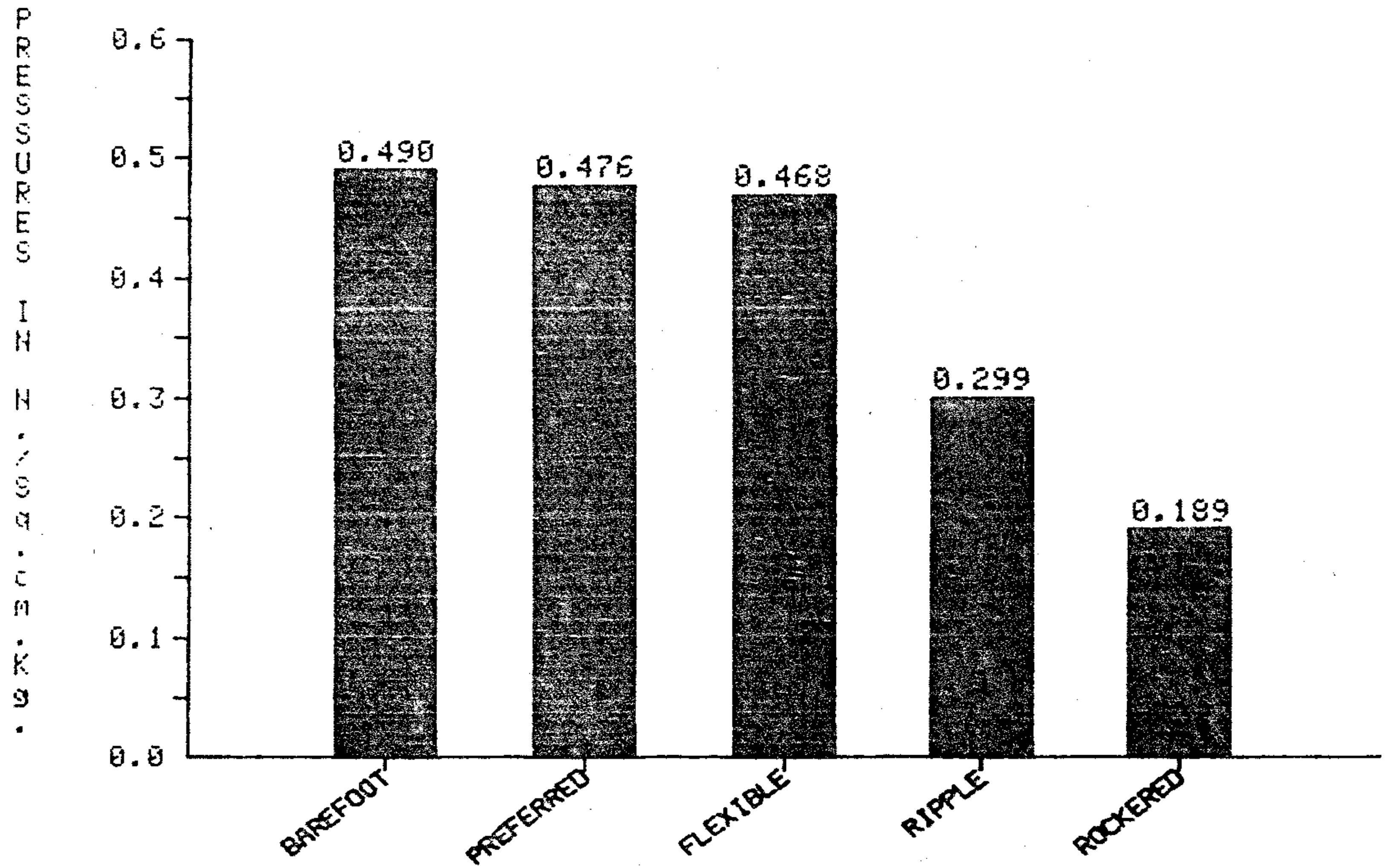

Fig. 5--Maximum Pressures Exerted Over the Second Metatarsal-Phalangeal Joint.

A comparison among all of the conditions for all of the measured kinetic and temporal parameters appears in Table 2.

The results of the statistical analysis conducted on the instantaneous kinematic parameters revealed the existence of no trial by shoe condition interactions, no differences among the trials, and no differences among the shoe conditions. The graphical displays of the average angular displacements of the left thigh, left leg, left foot, left knee joint, left ankle joint, and the left-foot pronation appear in Figures 6 through 11.

The angular displacements of the left ankle joint appear to range less for the rocker shoe than for the other shoe types (Figure 9). However, a statistical analysis of the maximum minus minimum values yielded no statistical differences between the shoe conditions. The apparent difference for the barefoot condition can be accounted for by the initial joint orientation which was, in part, affected by the placement of the landmark used to compute the angular displacements.

Although there were no statistically significant differences between the recorded maximum minus minimum angles of pronation, the graphical display shown in Figure 10 illustrates that both the flexible and rockered shoes effectively eliminated this form of forefoot motion.

Table 2

Percentage Comparison Among the Shoe Conditions for Each of the Temporal and Kinetic Parameters

	Shoe Condition				
	Flexible	Barefoot	Ripple	Rockered	Preferred
Preferred					
b		94.1		99.7	
c	86.7	93.3	66.7	46.7	
d	88.9	100.0	66.7	50.0	
e	98.3		62.8	39.7	
f		96.9		99.7	
Rockered					
b		94.3			
c					
d					
e					
f		97.2			
Ripple					
b	93.4			99.0	99.3
c				70.0	
d				75.0	
e				63.2	
f		96.1		98.9	96.1
Barefoot					
b					
c	92.9		71.4	50.0	
d	88.9		66.7	50.0	100.0
e	95.5		61.0	38.6	97.1
f		96.1			
Flexible					
b		92.0	98.5	97.5	97.8
c			76.9	53.8	
d			75.0	56.2	
e			63.9	40.4	
f		94.8	98.6	97.5	97.8

[a] Magnitudes of each variable for each shoe condition column expressed as a percentage of the row shoe conditions

[b] Duration of pressures

[c] Algebraic pressure impulses

[d] Mean Algebraic pressure impulses

[e] Maximum pressure

[f] Time to maximum pressure

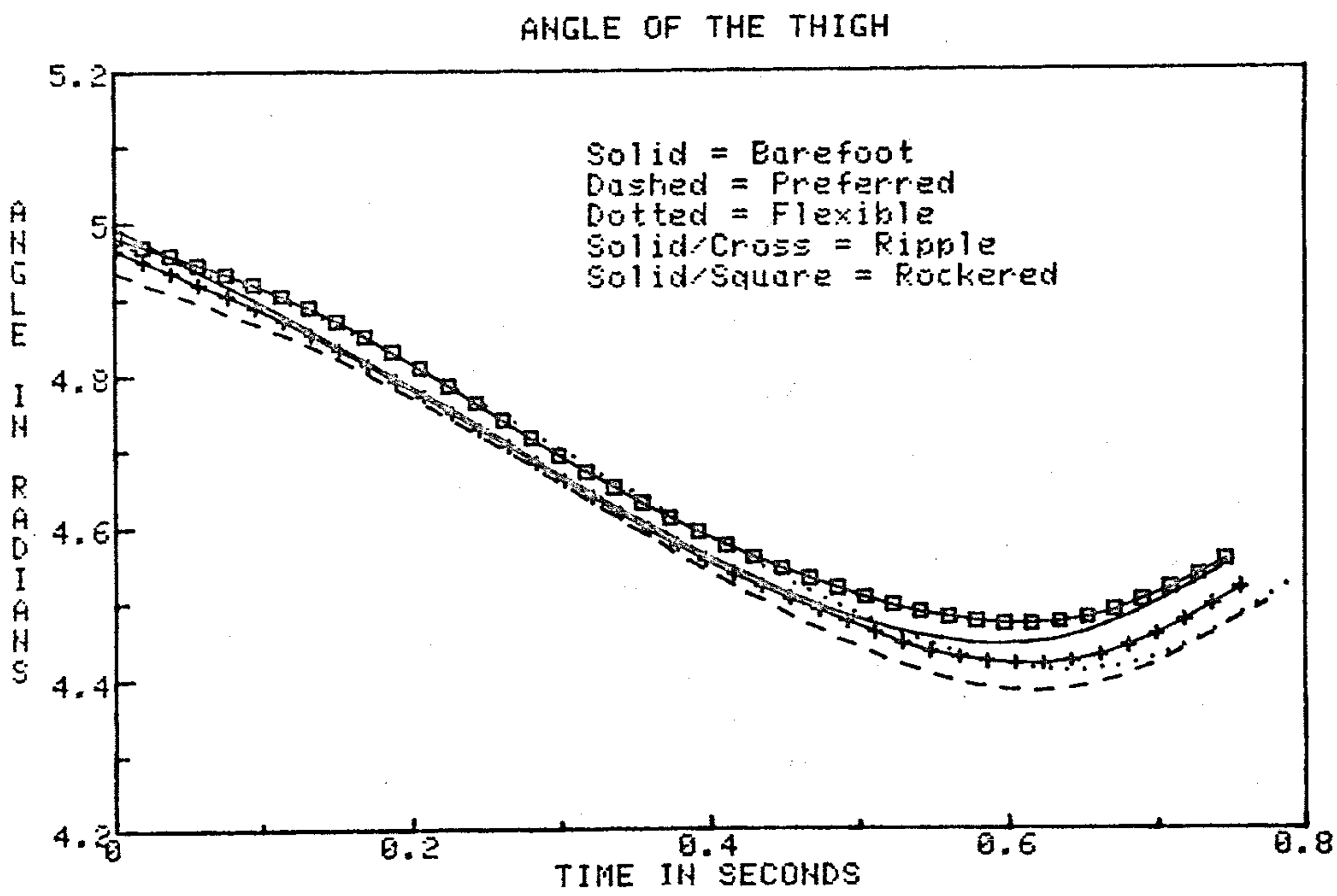

Fig. 6--Angle of the thigh

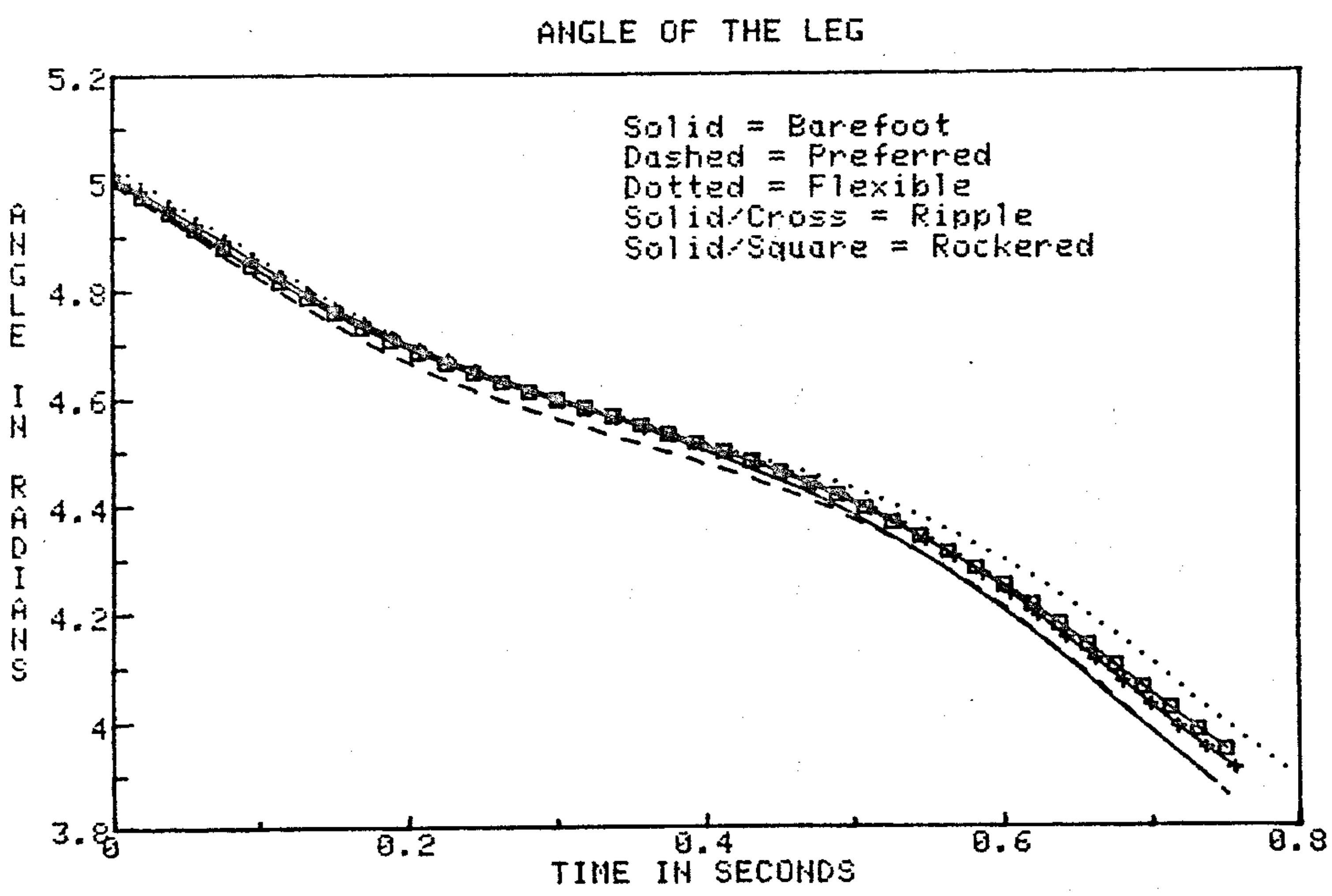

Fig. 7--Angle of the leg

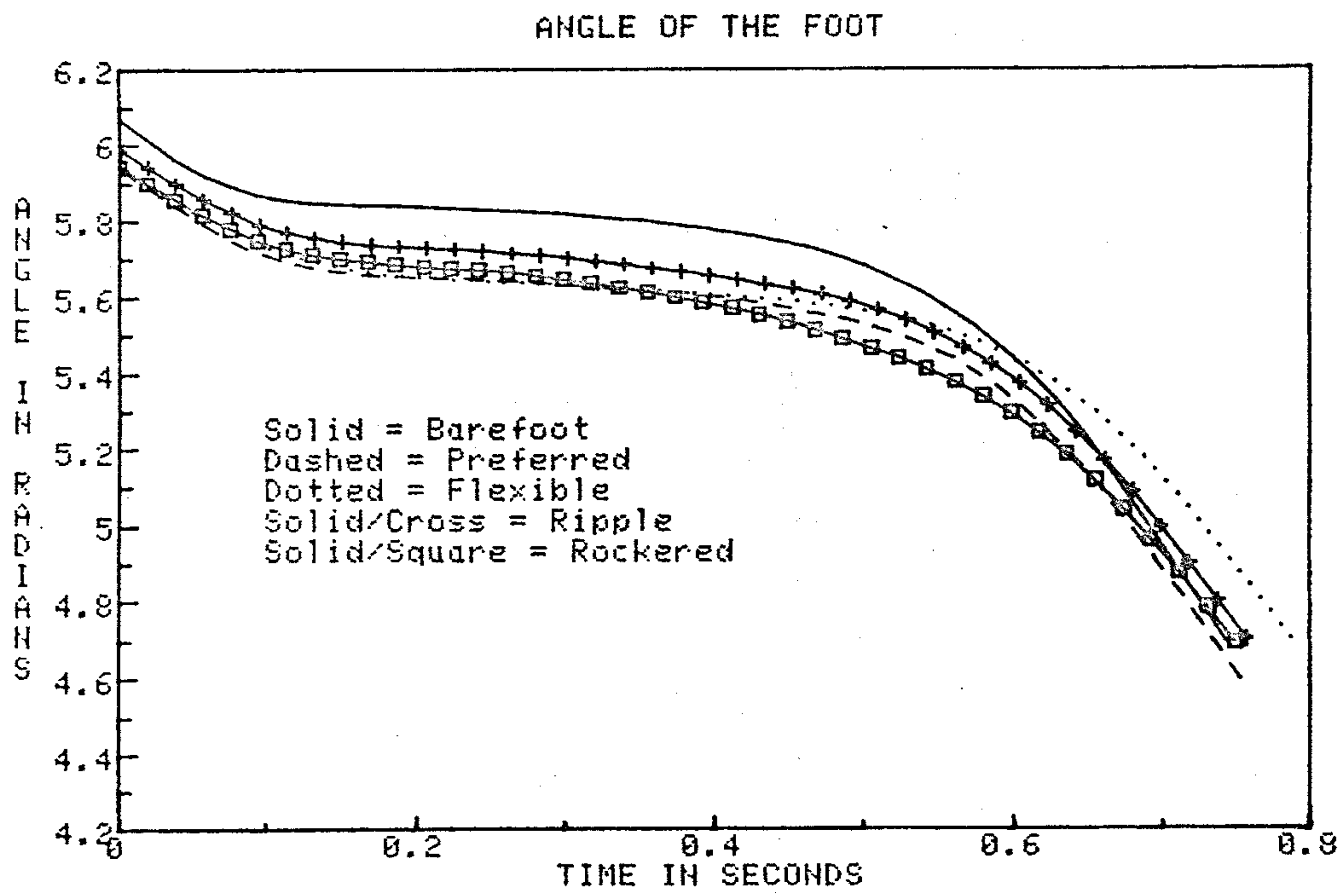

Fig. 8--Angle of the foot

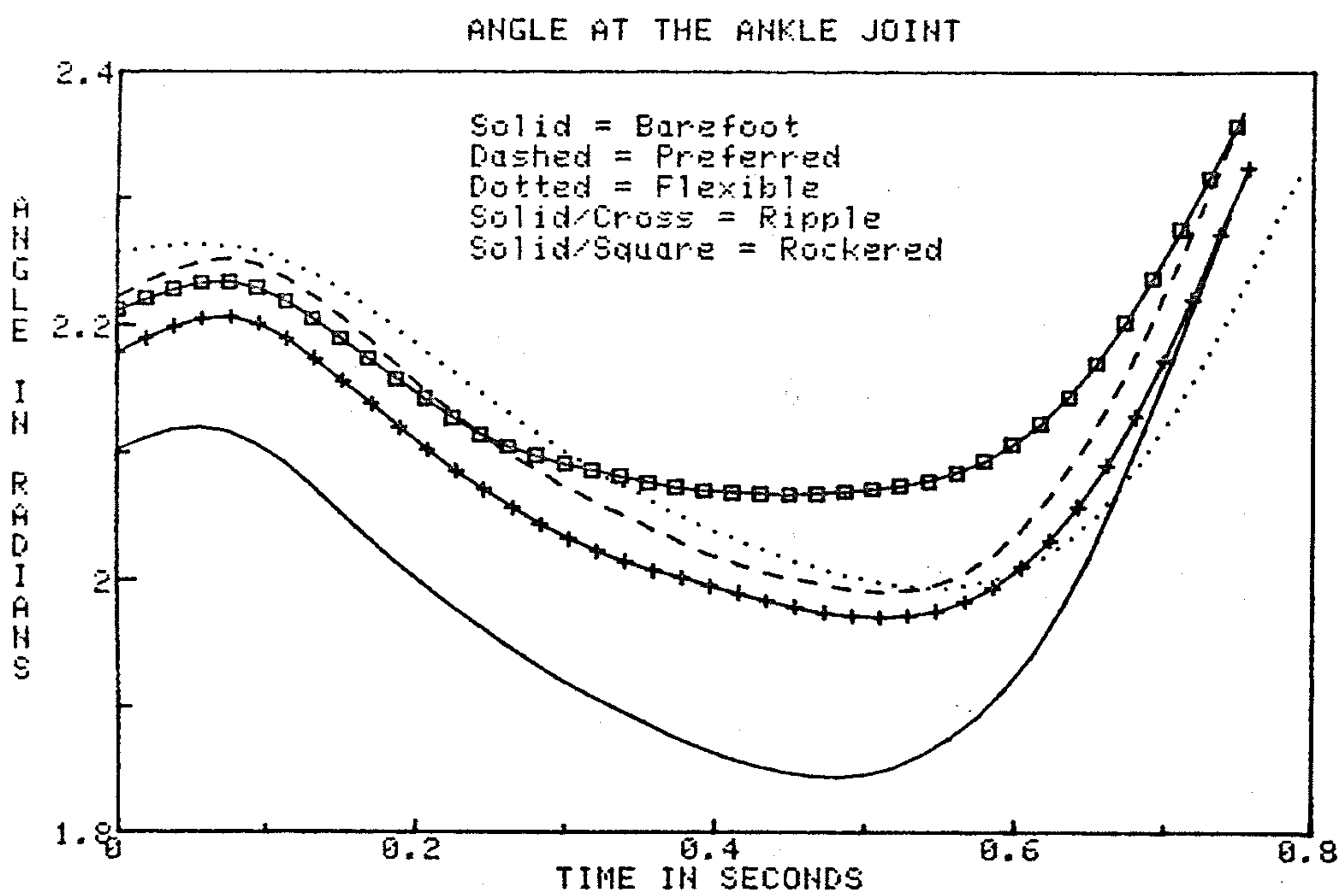

Fig. 9--Angle of the ankle joint .

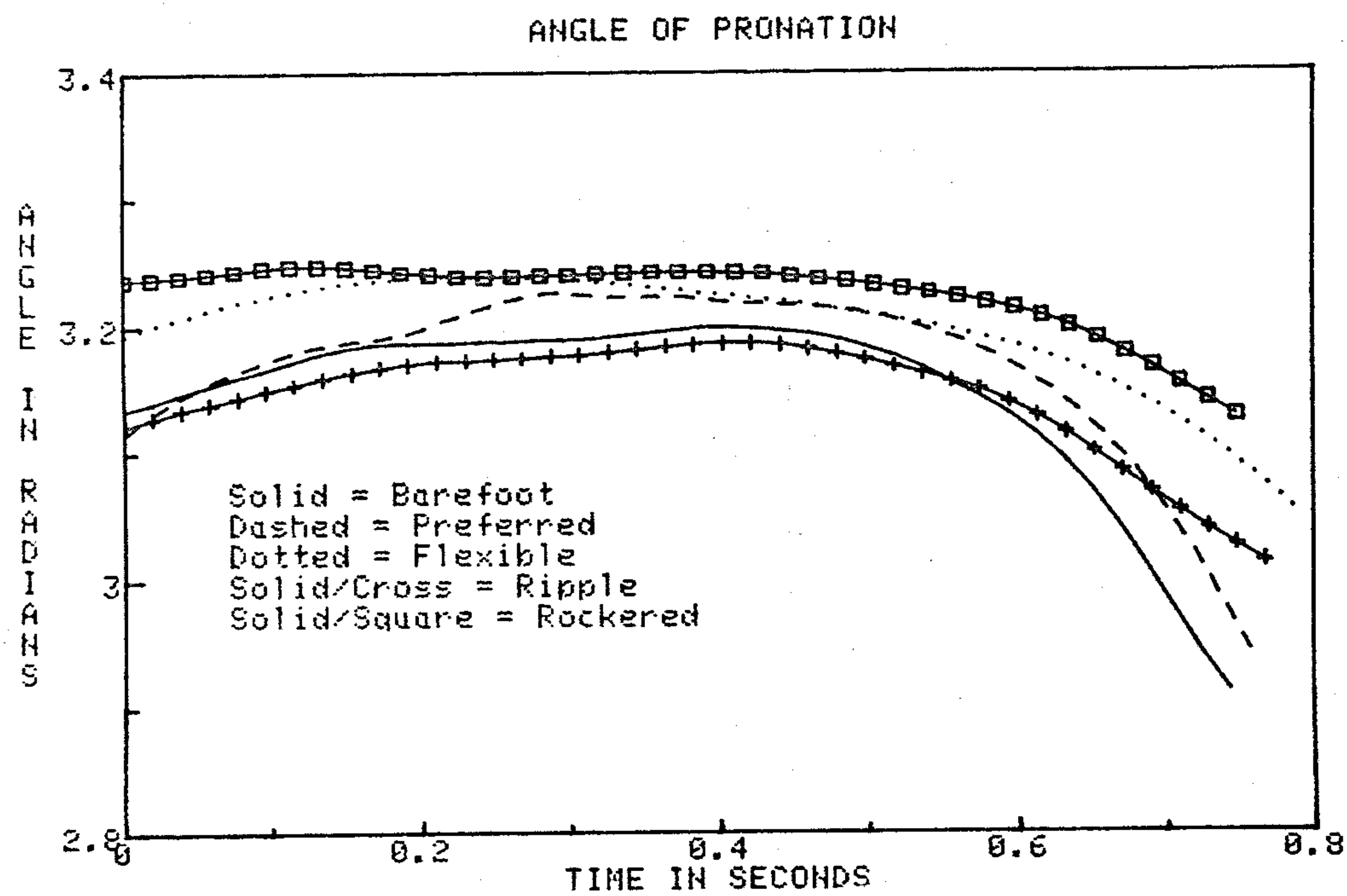

Fig. 10--Angle of pronation

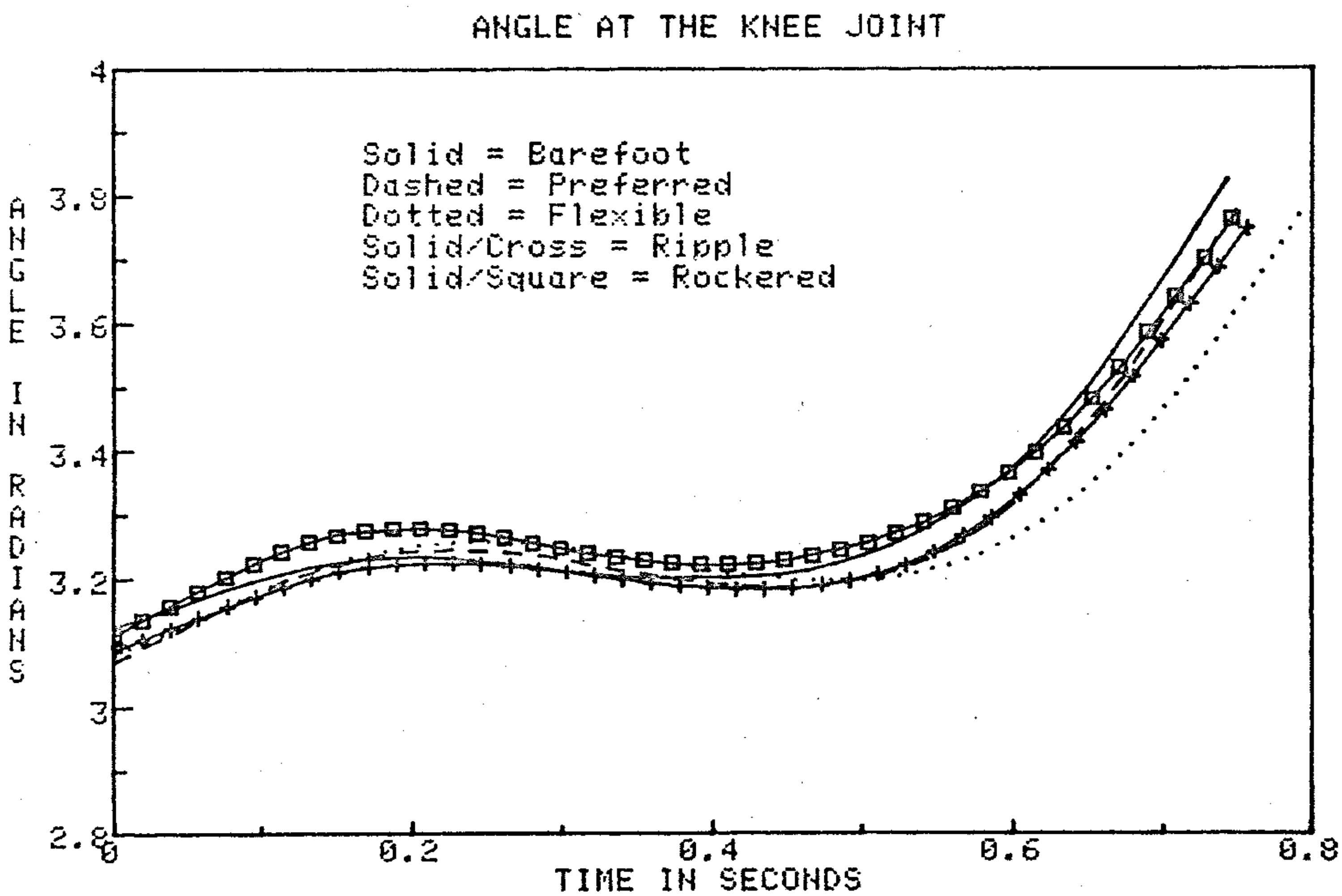

Fig. 11--Angle of the knee joint

The results of the preference survey appear in Table 3. The results clearly indicate that the subjects felt the most comfortable when barefoot. The second most

Table 3

Shoe Comfort Rankings by Each Subject

	Shoe Condition				
Subject	Barefoot	Preferred	Flexible	Ripple	Rockered
1	1	2	4	3	5
2	1	4	5	3	2
3	1	3	5	4	2
4	1	2	4	3	5
5	1	2	4	3	5
6	1	2	5	3	4
7	1	2	5	4	3
8	1	3	4	2	5
9	1	2	4	3	5
$\bar{x}$ =	1	2.4	4.4	3.1	4.0

comfortable condition was the preferred followed in order by the ripple, rockered, and flexible shoe conditions.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The purpose of this study was to evaluate the functional effectiveness of a selection of women's walking shoes with particular attention being directed toward an assessment of specific shoe modifications which were included in a prototype model to theoretically reduce the undesirable characteristics associated with flexible shoes.

Review of Literature

A review of literature revealed that few scientific studies have been conducted to analyze the effects of shoe type on foot functioning and contact pressures during walking performances. Grundy (1975) emphasized that although the forefoot sustained slightly greater loads than the heel it did so for a much longer period. His results suggested that the load bearing function of the forefoot was about three times that of the heel. In addition, when shoes were worn the load-bearing function of the forefoot was progressively reduced as the rigidity of the sole increased. Perry and Gronley (1981) investigated a rocker sole shoe as a walking aid for multiple sclerosis patients. It was found that improvements in gait while wearing rocker shoes varied with clinical classification. In addition, normal velocity and stride characteristics were accompanied by significant decreases in net energy expenditure.

Procedures

Nine female subjects were used in the study. None of the subjects were experiencing any clinical or structural lower limb abnormalities or discomfort at the time of the study.

Each subject performed three trials for each of the five conditions. Each subject walked along a previously defined path. Each trial by each subject was recorded on film. The motion of the left lower limb when it was in contact with the target area was recorded. The film data was used to obtain the angle of foot pronation, the angle of inclination of the sole of the shoes, the leg and thigh angles, and angles at the knee and ankle joints. All of the above parameters for each trial were "smoothed" using cubic spline curve fitting techniques and instantaneous values extracted. All of the angular parameters were averaged by shoe condition. The pressure records for each trial were digitized, "smoothed," and normalized by dividing by subject body weight. The temporal characteristics of each trial relative to the instant of heel-strike as depicted in the film records, the mean pressure magnitudes, and the algebraic pressure impulses were computed and recorded for subsequent statistical analysis. An average pressure/time record was also computed for each shoe condition. A statistical analysis, $p < 0.05$, utilizing repeated measures analysis of variance procedures was conducted to ascertain if differences existed between the shoe type conditions, with the instantaneous temporal, kinetic characteristics of the left foot contact phase entered as dependent variables.

Results

The results of the study revealed no significant trial by shoe condition interactions or trial main effects. Significant differences were found between the shoe conditions for the duration of the pressures, algebraic pressure impulses, mean pressure impulses, and maximum pressures.

The duration of the pressures on the skin overlying the second metatarsal-phalangeal joint was found to be significantly less for the barefoot condition than for the preferred shoe, flexible shoe, and rockered sole shoe conditions. The duration of the pressures for the barefoot condition were also less than those recorded for the ripple sole shoe although the differences were not statistically significant.

Both the algebraic pressure impulses and mean pressure impulses were found to be of lesser magnitude for the rockered sole shoe and the ripple sole shoe than for the remaining shoe conditions. In addition, for both of these parameters, the recorded magnitudes for the rockered sole shoe were less than those for the ripple sole shoe.

For both the preferred and flexible shoe conditions the recorded maximum pressures were greater than those for both the rockered sole and ripple sole shoes. No significant differences between the shoe conditions were found for the times to maximum recorded pressure.

Discussion of Results

The results of the study support the use of rigid rockered sole shoes for walking and standing on level unyielding surfaces. The relative decreases in the encountered pressures and pressure integrals in the region of the second metatarsal-phalangeal joint illustrate the effectiveness of the rocker in reducing localized pressure concentrations in the forefoot region with the concomitant potential for decreasing the incidence of related foot problems. In contrast, shoes with flexible shanks appear to be ineffective in this regard.

The ripple sole shoe fared well according to the measured and computed parameters. An examination of the sole of this shoe revealed that one of the undulations corresponded in location to the rocker on the rocker sole shoe. In addition, the sole of the ripple shoe was made of relatively stiff material. It would, therefore, appear as though the ripple sole shoe functioned in a manner similar to that of the rocker sole shoe. However, the effectiveness of this shoe was considerably less than the rocker sole shoe.

The use of the rocker sole shoe did not appear to unduly affect the gait of the subjects which is supportive of the results of Perry (1981). The rigid sole effectively eliminated forefoot dorsiflexion and plantar flexion although this was adequately supplemented by the rocker. Both the rockered shoe and the flexible shoe effectively eliminated pronation although the recorded maximum minus minimum values were not statistically different from the other shoe conditions. This restriction of pronation is an anticipated consequence of walking in shoes with rigid heels. Although some pronation is necessary for the provision of intrinsic shock absorption and accommodating motion over uneven terrain the recommended use locations of the rockered shoe would minimize the necessity for such a provision, i.e. walking or standing on rigid or level surfaces.

Although the rockered sole shoe effectively reduced pressure concentrations in the region of the second metatarsal-phalangeal joint and did not appear to adversely affect the gait of the subjects it was not perceived as being a comfortable shoe. The subjects instead felt the most comfortable in their preferred shoe. A possible explanation for the poor comfort ranking of the rockered sole shoe was the sensation associated with having the joints in the forefoot region immobilized and the associated motion being compensated for by the rocker.

Conclusions

The results of this study would appear to warrant the following conclusions.

1. Rigid rockered sole shoes effectively reduce pressure concentrations in the region of the second metatarsal-phalangeal joint.
2. A rigid rocker on the sole of shoes provides adequate motion compensation for forefoot joint motion.
3. The use of rigid rockered sole shoes does not unduly affect the walking gait.

Recommendations

Based on the results of this study the following recommendations are made for future studies.

1. An examination of the effects of different heel heights on encountered pressures in the metatarsal-phalangeal joints region.
2. An examination of terrain effects on foot functioning and encountered pressures on the plantar surface.

3. An examination of the effects of different inflare shoe alignments on foot functioning.
4. An investigation of the variability of last sizes.
5. An examination of the effects of different locations of a shoe rocker on foot functioning and encountered plantar surface pressures.

APPENDICES

APPENDIX A

SYSTEM SPECIFICATIONS OF THE ORTHOFLEX-
DATA ACQUISITION SYSTEM AND
FORCE/PRESSURE TRANSDUCER

Pressure Range = 0-200 Psig

Overload limit = 100%

Environment--gases, water, acids--to 250°F

Linearity = ±2%

Hysteresis Error = Less than 2%

Transient Response = 90% of full scale in 100 microseconds

APPENDIX B

SUBJECT'S INFORMED CONSENT FORM

FOR PARTICIPATION: FORM 1

I appreciate your interest in becoming a subject in this study. Please note that your participation is entirely voluntary and that you are free to withdraw yourself as a subject at any time during the course of the study.

The purpose of this study is to evaluate the functional effectiveness of a selection of women's walking shoes with particular attention being directed toward an assessment of specific shoe modifications which will include a prototype model to theoretically reduce the undesirable characteristics associated with flexible shoes.

At the beginning of the testing session, measurements will be taken of your standing height and body weight. You will be asked to sign a release statement authorizing the taking of the measurements and the subsequent use of the data for report purposes.

You will be asked to adhere a force transducer to the plantar surface of the left foot on the skin overlying the distal head of the second metatarsal. Selected anatomical reference points will be drawn on your left leg. You will be asked to perform fifteen trials, corresponding to three trials for each of the five shoe conditions. You will be filmed as you walk through a marked target. You will be asked to sign a release statement authorizing the photographing of yourself. You will be examined by a podiatrist to determine any clinical or structural lower limb abnormalities. Opportunities will be afforded to you to view the films and to examine the final documents describing the experimental techniques and obtained results.

At least two investigators will be present at all data collection sessions and will answer all inquiries you may have concerning the procedures. You will wear shorts and bring your favorite pair of shoes to the testing site.

INFORMED CONSENT: FORM 2

USE OF HUMAN SUBJECTS

NAME OF SUBJECT: ______________________________

1. I hereby give consent to Brenda F. Raley to perform or supervise the following investigational procedure or treatment.

   a. Record anthropometric characteristics (standing height, body weight)

   b. Take motion picture records during walking performances and to use the records for data analysis and report purposes.

2. I have seen a clear explanation and understood the nature and purpose of the procedure or treatment; possible appropriate alternative procedures that would be advantageous to me; and the attendant discomforts or risks involved and the possibility of complications which might arise. I have seen a clear explanation and understand the benefits to be expected. I understand that the procedure or treatment to be performed is investigational and that I may withdraw my consent for my status. With my understanding of this, having received this information and satisfactory answers to the questions I have asked, I voluntarily consent to the procedure or treatment designated in Paragraph 1 above.

______________________ ______________________________

DATE SUBJECT

APPENDIX C

Dr. Thomas L. Taylor

Medical & Surgical Podiatry
--Foot Specialist--

April 9, 1981

Dr. Donald McIntyre
Physical Education Department
North Texas State University
Denton, Texas 76203

Dear Dr. McIntyre:

Thank you for allowing me to come and examine the ladies taking part in your gait study research. The biomechanical evaluations performed on the ladies reveals that the full range of minor biomechanical abnormalities were present. The two best subjects mechanically were, T.R. Sanders and Pam Huffman. At the other end of the scale was Jane Ramsey with a 8 to 10 degree forefoot varus (forefoot inverted on the rearfoot) which was compensated by a very active anterior tibial muscle which prevented pronation of the mid-tarsal joint until the very late stage of mid-stance. Interestingly enough, Paula Cunningham also had mechanical abnormality with a 10 degree plantarflexed first metatarsal on the right foot. She functioned with her right shoulder down and with a compensated leg length shortage type gait which may be functional in nature. Cathy Ramsey was difficult to examine since she has had an injury on her right foot, but the measurements revealed a high forefoot varus of 10 to 12 degrees. Finally Jay Lynn Johnson had a mild forefoot varus; however, she was functioning maximumly pronated and had a relatively early heel off.

I feel that none of these biomechanical abnormalities would be enough to exclude them from the study; however I would be interested in correlating their measurements with your data for my own personal enlightenment. I am enclosing a small sample of the wrapping material called Coban. It is made by 3M and most drug stores can order it for you. The same product is also purchased by veterinarian in different colors. As we previously discussed, I felt you may be interested in using this material in the ankle wrap study.

If I can be of any help in the future, please feel free to call me at any time.

Sincerely,

Thomas L. Taylor, D.P.M.

TT/cb

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APPENDIX D

SELECTED ANTHROPOMETRIC CHARACTERISTICS OF THE SUBJECTS

Subject Number	Age (Years)	Height (Meters)	Weight (Kilograms)
1	33	1.60	47.17
2	21	1.70	65.77
3	42	1.53	43.99
4	18	1.60	48.99
5	18	1.63	58.97
6	25	1.80	74.84
7	24	1.70	69.85
8	24	1.60	54.43
9	21	1.55	61.24

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