



The effects of increased shoe weight and decreased pastern angle on gait characteristics of the trot in one equine

by Nancy England Kingsbury

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education

Montana State University

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Abstract:

The initial objective of this study was to develop a filming technique that would produce film footage that would allow accurate biokinematical analysis of equine gait. One horse of normal conformation was selected as the subject for this study. Anatomical landmarks were identified and demarcated on the left forelimb of the subject. The subject was first filmed moving at an extended trot in a balanced/barefoot state. The subject was then filmed while wearing balanced/8-ounce, balanced/16-ounce, 8-ounce/3 degree pad and 16-ounce/3 degree pad.

Analysis of the film footage was accomplished through a digitization process and the Filmdata software program. Temporal and linear stride characteristics, general limb kinematics and a two-dimensional illustration of the arc of the foot in flight were presented.

Increased shoe weight was associated with INCREASED duration of: diagonal dissociation at initial foot contact, diagonal swing, forefoot and hindfoot stance, bipedal support and suspension. Increased vertical displacement of forestep and hindstep, increased angular displacement and angular velocity of carpal, fetlock and pastern/coffin joints and decreased resultant linear velocity of the distal joints was also observed. The height of the first one-half of the flight of the foot was greater when the subject wore the heavier shoes. The heavier shoes were also associated with a DECREASED; swing duration, propulsion, and horizontal displacement of forestep and diagonal stride.

The shoe/pad combination was associated with INCREASED duration of forefoot and hindfoot swing, diagonal swing, hindfoot stance and suspension period. Increased vertical displacement of forefoot and hindfoot was also seen.

The shoe/pad was associated with DECREASED diagonal dissociation at initial foot contact, forefoot stance duration, duration of bipedal support, and horizontal displacement of forefoot and diagonal stride.

The methodology used in this study was successful in producing data that would allow the evaluation of changes in shoeing conditions on equine gait characteristics. This study presents a baseline evaluation of one equine subject's kinematical response to changes in shoeing conditions. It is a presentation that has, in the researcher's opinion, great potential for use as a starting point for future research projects.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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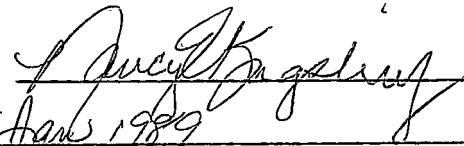
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TABLE OF CONTENTS

	Page
LIST OF TABLES.....	viii
LIST OF FIGURES.....	x
ABSTRACT.....	xii
1. INTRODUCTION.....	1
Statement of the Problem.....	3
Delimitations.....	4
Limitations.....	4
Definition of Terms.....	5
2. REVIEW OF LITERATURE.....	8
General Equine Locomotion.....	8
Specific Horseshoeing Conditions.....	11
Limb Kinematics.....	15
Summary.....	22
3. METHODS AND PROCEDURES.....	25
Subject Description.....	25
Anatomical Landmarks.....	25
Lateral View.....	25
Shoeing Conditions.....	26
Pilot Study Data Collection.....	28
Evaluation of Pilot Study.....	31
Final Study Data Collection.....	32
Shoeing Conditions.....	33
Filming Sequence.....	34
Film Data Retrieval.....	34
Method of Film Data Analysis.....	36
Summary.....	41
4. RESULTS AND DISCUSSION.....	43
Temporal Stride Characteristics.....	43
Diagonal Dissociation.....	43
Swing Duration.....	49

TABLE OF CONTENTS--Continued

	Page
Diagonal Swing Duration.....	50
Stance Duration.....	52
Deceleration and Propulsion Phases of the Stance Period.....	54
Duration of Bipedal Support.....	55
Duration of Suspension Phase.....	57
Linear Stride Characteristics.....	59
Step Height.....	60
Horizontal Displacement of Individual Limbs.....	62
Diagonal Length.....	64
Kinematics of the Left Forelimb.....	66
Angular Displacement.....	67
Angular Velocity.....	78
Linear Velocity of Carpal, Fetlock and Tip of the Hoof.....	83
Arc of the Foot in Flight.....	86
Summary.....	87
5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.....	92
Summary of Findings.....	92
Conclusion.....	96
Recommendations.....	97
REFERENCES CITED.....	99

LIST OF TABLES

Table	Page
1. Frame numbers of specific points of the stride of the left forelimb as identified on the pilot study film.....	39
2. Frame numbers of specific points of the stride of all limbs, as identified on the final film study.....	39
3. Duration of diagonal dissociation of one equine subject at initial foot contact at left and right diagonals.....	45
4. Duration of diagonal dissociation of one equine subject at toe-off of right and left diagonals.....	49
5. Average duration of the swing phase of one equine subject's forefoot and hindfoot.....	50
6. Duration of diagonal swing phase in left and right diagonal of one equine subject.....	51
7. Average duration of one equine subject's stance phase in forefoot and hindfoot.....	52
8. Duration of deceleration and propulsion phases of the stance period of one equine subject.....	55
9. Duration of bipedal support phase of left and right diagonals of one equine subject.....	56
10. Duration of the suspension phase of right and left diagonal of one equine subject.....	57
11. Vertical displacement of forestep of one equine subject.....	60
12. Vertical displacement of hindstep of one equine subject.....	61
13. Horizontal displacement of individual limbs of one equine subject.....	63

LIST OF TABLES--Continued

Table	Page
14. Horizontal displacement of the left and right diagonal pair of one equine subject.....	64

LIST OF FIGURES

Figure	Page
1. Lateral view of equine forelimb with anatomical landmarks highlighted.....	27
2. Pastern angle measurement of left forelimb of equine subject, in barefoot/balanced condition.....	28
3. Diagram of test range used during pilot study filming....	30
4. Diagram of test range used during final filming.....	32
5. Illustration of left forelimb and the landmarks that form the carpal, fetlock, anterior and posterior pastern/coffin joints.....	37
6. Block diagram of ideal footfall pattern of synchronized trot.....	45
7. Block diagram of footfall pattern of diagonal dissociation at initial foot contact and at toe-off at the trot.....	47
8. Block diagram of dissociation at initial foot contact as observed in subject at the trot in all conditions.....	48
9. Overview of temporal components of average diagonal stride.....	59
10. Vertical height of average forestep and diagonal hindstep.....	63
11. Horizontal displacement of average diagonal pair.....	65
12. Angular displacement of the carpal joint in the barefoot and 16-ounce conditions.....	68
13. Maximum carpal joint angular displacement in barefoot and 16-ounce conditions.....	69
14. Angular displacement of fetlock joint in barefoot and 16-ounce conditions.....	70

LIST OF FIGURES--Continued

Figure	Page
15. Maximum fetlock joint angulation.....	71
16. Angular displacement of anterior pastern/coffin joint in barefoot and 16-ounce conditions.....	72
17. Angular displacement posterior pastern/coffin joint barefoot and 16 ounce.....	73
18. Maximum angulation of the anterior pastern/coffin joint in the barefoot and 16-ounce conditions.....	75
19. Angle-angle carpal (Y)/fetlock barefoot.....	76
20. Angle-angle carpal (Y)/fetlock 16 ounce.....	77
21. Angular velocity carpal joint barefoot and 16 ounce.....	80
22. Angular velocity fetlock joint barefoot and 16 ounce.....	81
23. Angular velocity posterior pastern/coffin joint barefoot and 16 ounce.....	82
24. Resultant linear velocity of carpal-fetlock-toe in the barefoot condition.....	84
25. Resultant linear velocity of the carpal-fetlock-toe in the 16-ounce condition.....	85
26. Arc of flight of the left forefoot toe in bare, 8-ounce, and 16-ounce state.....	88
27. Arc of flight of the forefoot toe in bare, 8-ounce/pad and 16-ounce/pad.....	89

ABSTRACT

The initial objective of this study was to develop a filming technique that would produce film footage that would allow accurate biokinematical analysis of equine gait. One horse of normal conformation was selected as the subject for this study. Anatomical landmarks were identified and demarcated on the left forelimb of the subject. The subject was first filmed moving at an extended trot in a balanced/barefoot state. The subject was then filmed while wearing balanced/8-ounce, balanced/16-ounce, 8-ounce/3 degree pad and 16-ounce/3 degree pad.

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CHAPTER 1

INTRODUCTION

The scientific investigation of the functional anatomy of the equine foot did not begin until the 18th century. Largely due to the lack of more sophisticated instruments, the early studies were based primarily on cadavar dissections. These studies proved helpful to practioners attempting to identify pathologies of the equine foot and standardize methods of treatment.

During the early 20th century, the advent of the automobile and tractor virtually eliminated the horse as an American necessity. Scientific research on equines, the field of farriery in particular, was no longer in such high demand. However, increased leisure time and the legalization of parimutual betting rejuvenated the equine industry during the post-World War II years. As horse racing became one of the largest spectator sports in the nation, the equine athlete increased steadily in popularity and value.

Encouragement in the form of financial support from equine enthusiasts provided an incentive for the investigation of scientific areas related to equine movement such as biomechanics, physiology of exercise, and equine sports medicine. Electrogoniometry and high-speed cinamatography were adapted to the equine subject and the needs of the equine researcher.

During the last two decades, researchers have become increasingly interested in the potential of high-speed cinematography in the study of equine gait. Specific areas of interest include the effects of fatigue on gait and gait adaptations to race track design.

One important aspect of interest that remains relatively uninvestigated is the study of farriery conditions and the effect of the horseshoe on equine gait patterns. Whether the subject is a race horse, polo pony, barrel racer or show horse, one common denominator among successful equine athletes is the horseshoe.

Horseshoeing has long been considered a necessary evil in the world of the working equine athlete. The type of horseshoe worn by an individual equine depends on factors such as his unique gait pattern or the style of action desired by his trainer. The specific effects of a change in horseshoe condition are often measured simply by the discretionary eye of a farrier or the hands of the stopwatch.

Many assumptions based on common sense and trial and error have been handed down from one generation of farriers to the next. Disagreements and contradictions in terminology and methodology are an expected obstacle in the study of the science of horseshoeing.

The effects of increased weight on gait pattern or style is an area that remains relatively uninvestigated. Although an increase in the weight of the horseshoe is thought to change the action of the foot in flight, to this researcher's knowledge the assumption has not been objectively substantiated.

A study that would provide baseline information as to the effects of the basic horseshoe might assist practitioners in the

objective evaluation of common farriery techniques. The following study was designed to provide baseline data for future research on the effects of various horseshoe conditions of equine gait.

Quantitative and qualitative measurements of angular and linear variations in the coordinative movements and style of gait due to increased shoe weight and decreased pastern angle were the desired end-results.

One challenging problem of the study was to develop a cinematographic technique that would allow collection of sufficient data for the investigation of changes in equine gait mechanics as affected by variation in shoeing conditions.

Statement of the Problem

The general purpose of the study was to identify and describe the kinematics of the equine limbs with changes in horseshoe weight and pastern angle. Specific problems were:

1. to identify and describe changes in temporal characteristics of a diagonal pair of limbs during a symmetrical two-beat gait;
2. to identify and describe changes in linear characteristics of a diagonal pair of limbs during a symmetrical two-beat gait;
3. to describe general kinematics including angular displacement and angular velocity of, and linear velocity the carpal, fetlock, anterior and posterior pastern/coffin joints of the forelimb measured in the sagittal plane; and

4. to illustrate the changes in the arc of the foot, during its trajectory of flight in the sagittal plane.

Delimitations

The study was delimited to one, four-year-old grade quarter horse gelding in Bozeman, Montana. The subject was of normal conformation. The subject was not chosen to be representative of all horses nor even the Quarter Horse breed, but simply one equine's response to specific horseshoeing conditions.

Limitations

The study was limited to the use of a single normal subject. There was no control over the method of foot care and trimming previous to the study.

To the author's knowledge, there was no available information as to the length of time necessary for the equine to adapt to horseshoeing changes. During the study, an adaptation period of approximately five minutes was allowed prior to each test run.

An experienced farrier was used throughout the study. His ability to perform with consistent competence was an accepted limitation.

Due to the unavailability of a specialized equine treadmill, the speed of the subject during the trials was regulated solely by use of an automobile. Therefore, the study was limited to the reproduction of consistent speed by the driver of the automobile and the precision of the odometer.

Definition of Terms

ARC OF FOOT FLIGHT - The curvilinear path of the foot from the moment of toe-off to the moment of foot contact with ground surface as described by the marker on the lateral tip of the toe.

BALANCED FOOT - The ground surface of the foot is perpendicular to the longitudinal axis of the foot (Butler, 1976).

BIPEDAL SUPPORT - The time during which the two diagonal hooves are in contact with the ground (Drevemo, Fredricson, Dalin and Bjorne 1980b).

BREAKOVER - The period of time from initial hoof contact to toe-off (Butler, 1976).

DIAGONAL DISSOCIATION - The forelimb and the diagonal hindlimb do not touch the ground or take off simultaneously at the trot (Drevemo, et al; 1980b).

DIAGONAL LENGTH - The distance in the x-direction of one diagonal stride, including the linear displacement of both diagonal limbs as measured from the toe of the hindfoot to the toe of the diagonal forefoot.

DIAGONAL SWING - The period of time, during a diagonal stride, from the moment when one limb of the diagonal pair toes-off to the initial hoof contact of one of the same diagonal pair (Fredricson, and Drevemo; 1972a).

GAIT - A cyclical pattern of movement that is repetitive in sequence and timing (Hildebrand, 1965).

KINEMATICS - The study of the temporal and spatial motion of a system (Kreighbaum & Barthels, 1985).

MID-STANCE - The position during stance phase when the carpus or tarsus (forelimb or hindlimb, respectively) is in vertical position (Fredricson, et al; 1972a; Pratt & O'Connor, 1977).

PROPULSION - The stage of stance support lasting from mid-stance until toe-off (Fredricson, et al; 1972a; Pratt & O'Connor, 1977).

RESTRAINT - The stage of stance support lasting from initial foot contact with ground surface until mid-stance occurs (Fredricson, et al; 1972a; Pratt & O'Connor, 1977).

SKILL - when a general pattern of movement is adapted to the constraints of a particular activity (Kreighbaum & Barthels, 1985).

STANCE - The period of time during a stride when the foot is in contact with the ground (Fredricson, et al; 1972a; Drevemo, Dalin, Fredicson and Hjerten; 1980a).

STEP - The horizontal displacement of the limb, from toe-off to heel-touch.

STEP HEIGHT - The vertical displacement of the foot, from toe-off to the height of the swing, as measured by the tip of the toe.

STRIDE DURATION - The time of one complete gait cycle; i.e. the time interval between any two identical events of a cycle (Hildebrand, 1965).

STYLE - The use of individual modifications, such as unique timing or movements, within the parameters of a given technique (Kreighbaum & Barthels, 1985).

SUSPENSION PHASE - The period of time during which the horse has no physical contact with the ground surface (Gray, 1968).

SWING - The period of time, during a stride, when the foot has no contact with the ground surface (Fredricson, et al: 1972a).

TECHNIQUE - A particular way of performing the same skill (Kreighbaum & Barthels, 1985).

CHAPTER 2

REVIEW OF LITERATURE

The advent of the multi-million dollar racehorse is a reflection of the overall increase in value of all breeds of equine athletes. Therefore, it is not surprising that equine trainers have become increasingly interested in research that suggests more effective means of training, conditioning and outfitting that might promote improved racing, show ring, or other performance.

The following review of literature represents a review of research that was considered by the author to be relevant to the present study. The literature is presented under the topics of general equine locomotion, specific horseshoeing conditions and equine limb kinematics.

General Equine Locomotion

Equine locomotion is generally described in terms of gait. The aesthetic appearance of a specific gait may often vary according to factors such as breed, style and training. For example, the trot is defined as a symmetrical, two-beat diagonal gait, yet there appears to be little similarity between the streamlined racing trot of the Standardbred and the animated part trot of the Saddlebred or Morgan.

Although the trot is a skill innate to most horses regardless of breed, training and heredity account for the development of a

specific technique that is desirable for the situation. The individual equine athlete also develops its own unique style, modifying the technique due to anatomical limitations or an altered sense of timing.

Regardless of technique or style, horses travel in specific gaits. Historically, the study of equine locomotion has been plagued with confusing variations in terminology for specific components of those gaits (Leach & Dagg, 1983).

In a study of the gaits of the horse, Hildebrand (1965) described a stride as one full cycle of motion. The limbs move in rhythmic pendulum-like motion in a sagittal plane. Because the sequence of movement is diligently repetitive, any point in the pattern may be designated as the beginning of a stride (Hildebrand, 1965; Gray, 1968).

The two main parts of a stride are the SUPPORT phase, wherein the hoof is in contact with the ground, and the SWING phase, wherein the hoof travels through the air (Pratt & O'Connor, 1978). Gray (1968) stated that the length of the swing phase varies inversely with the length of the support phase, that is, the shorter the period of support, the longer the period of swing. Gray (1968) illustrated that theory with the examination of an equine subject's change in gait from a walk to a fast trot. During the transition from walk to trot, the equine demonstrated three changes in limb movement:

1. The frequency of limb movement increased.
2. The duration of the support phase decreased.

3. Gait pattern changed from a four-beat gait at the walk to a two-beat diagonal relationship between a forelimb and contralateral hind limb at the trot.

The trot is therefore referred to as a diagonal two-beat, gait. The diagonal may be described as right or left, according to which forelimb is in the swing phase.

When the diagonal pairs are perfectly coordinated, the body is supported by alternating diagonal pairs of limbs with intervening periods when all feet are off the ground (Gray, 1968). The period of time when two legs, a single diagonal pair, support the full weight of the body is called OVERLAP, (Pratt & O'Connor, 1976) or BIPEDAL SUPPORT (Drevemo, Fredricson, Dalin, and Bjorne, 1980b).

Several authors have attempted to describe the phases of the stride using a variety of terminology. Adams (1971) divided an individual stride into anterior and posterior phases. The ANTERIOR phase was the portion of the stride that occurred in front of the print of the opposite foot. That half of the stride that occurred in back of the opposite foot print was said to be the POSTERIOR phase.

Gary (1968) also divided the stride into two phases. Any forward displacement of the limb, relative to shoulder (forelimb) or hip (hindlimb), was identified as PROTRACTION; any backward displacement of the limb, relative to the shoulder or hip, was identified as RETRACTION.

Pratt and O'Connor (1976) recongized the swing phase but chose to identify the support phase as a STANCE period. The stance phase

ended at TOE-OFF, which was preceded by HEEL-OFF. BREAKOVER time was the interval from heel-off to toe-off.

Grogan (1951) identified the period of time when the hoof was on the ground as the CONTACT period. The FLIGHT period was when the hoof was off the ground.

Pratt and O'Connor (1976) further divided the stance phase by defining the MIDSTANCE position. In the forelimb, midstance occurs when the metacarpus is vertical to the ground. The midstance signifies a change in the horizontal component of hoof-ground interaction. A DECELERATION phase occurs from initial hoof contact to midstance; and a PROPULSION phase occurs from midstance to liftoff.

Specific Horseshoeing Conditions

In the world of the working equine athlete, horseshoeing has long been considered a necessary evil. Variations in environment and surface conditions may accelerate the natural wearing of the hoof wall, causing uneven breaking and detrimental cracking. The application of horseshoes provides an artificial barrier effectively preventing most hoof wall breakage.

There is a trade-off, however. The steel horseshoe greatly limits the natural expansion and compression of the frog, effectively decreasing the venous "pumping" of blood through the hoof structures and back up the equine limb (Adams, 1971). Therefore, the ideal horseshoe should interfere as little as possible with the natural

physiological function of the equine foot, yet still accomplish the protective purpose of the shoe's application.

According to the War Department (1941) the design and fit of the individual horseshoe affects not only the position of the foot at breakover, but also the speed of breakover and the flight of the foot during the swing phase.

Within the show ring world of the Tennessee Walking Horse, Morgan, and the American Saddlebred, one common horseshoeing characteristic that may vary a great deal is that of weight. An increase in horseshoe weight is thought to increase the height of the step and the length (horizontal distance) of the stride, (Butler, 1976; Adams, 1971) as well as promote a "knee-snapping" action, a trait desirable in the animated show trot of the best saddle and fine harness horses. Weight may also be added to the forefeet of the racing trotter who habitually breaks from a trot to a gallop in an attempt to stabilize the timing of the diagonal limbs and balance them at speed (Butler, 1976).

It would be a logical assumption to expect that increased horseshoe weight would also cause an increase in fatigue of the performance horse. Thus, the sixteen ounce toe-weight shoe of the saddle horse might indeed prove disastrous to the Thoroughbred race horse.

Weight may be evenly distributed throughout the horseshoe or the shoe may be toe-weighted or heel-weighted. According to Butler (1976), the application of toe-weighted shoes will result in increased action of the forequarters, as well as increase the height

of the last one-half of an individual stride. A heel-weighted shoe would increase the height of the first one-half of an individual stride.

The pastern-coffin joint angle, as measured by a hoof protractor, is another factor that influences the speed of breakover and the pattern of the foot in flight. The pastern-coffin joint angle may be temporarily increased or decreased with the addition of a 3-degree pad. Usually made of neoprene, the pad is sandwiched between the horseshoe and the sole of the hoof. The pad may be used to either elevate the heel or the toe, depending upon which way the wedge is fitted. The pad is commonly used to correct faulty conformation or simply to protect the sole of the hoof (Simpson, 1971).

According to Butler (1976), the normal range for the pastern-coffin joint angle in the equine forelimb is approximately 45 to 55 degrees. A steeper angle results in a quicker breakover of the foot, increased vertical height of the step and decreased length of stride arc. Conversely, lowering the heels and thereby decreasing the pastern angle would result in a slower breakover of the foot, decreased height, and increased length of stride (Butler, 1976; Simpson, 1971).

To the author's knowledge, Nilsson (1973) is the only researcher to use high-speed cinematography to investigate the influence of alteration of horseshoeing conditions. The conditions investigated were the effects of the application of toe grabs and heel caulks on equine limb kinematics.

The purpose of the application of toe-grabs is to increase the maximum pastern/coffin joint angle at heel-off, which would result in increased tension of the deep flexor tendon and an increase in pressure on the navicular (distal sesmoid) bone. Heel caulks elevate the heel, causing a reduction of the maximum pastern/coffin joint angle, facilitating heel-off (Nilsson, 1973).

Nilsson (1973) conducted intraindividual comparisons using ten Standardbred trotters. The subjects were filmed at a slow trot with no implements applied, again with toe-grabs, and once more with heel caulks. Without the provocative agents, the height of the step of the foreleg was consistently higher than in the contralateral hindleg. The application of toe-grabs and heel caulks did not noticeably alter step height or change the amount of foot slide during ground contact. According to Nilsson (1973), the toe-grabs did cause the pastern/coffin joint angle at heel-off to be greater in both front and hindlegs. Conversely, the heel caulks reduced that same angle in both front and hindlegs.

Dalin, Drevemo, Fredricson, Jonsson, and Nilsson (1973) utilized high speed cinematography for analyzing locomotor asymmetry of horses trotting through turns. While trotting at racing speed, some horses travel in a LINE-GAIT, that is, due to the adduction of the distal part of the limbs, the diagonal hooves (foreleg and contralateral hindleg) are usually placed close to or on the line of motion. The line of motion represents the projection of the horse's mid-sagittal plane on the track. Crossing the sagittal line of motion is a condition identified as OVERCROSSING.

INWARD INCLINATION is a technique used when the horse leans into a turn at racing speed. The line-gait becomes more or less pronounced, depending on the amount of adduction of extremities. A variety of lower leg alignments seem to stem from the subject's body position. As seen from the front, the carpus may seem to medially deviate, resulting in a varus positioning of the fetlock. The contact pattern of the hoof is also affected. At the moment of initial hoof contact with the track surface, the subject may exhibit a lateral heel contact, with the outside edge of the hoof touching first and then rolling inward to the flat foot position (Dalin, et al. 1973).

Limb Kinematics

Electrogoniometry was used to measure the angular displacement of the joints of the equine leg by Taylor, Tipton, Adrian and Karpovich (1966). The goniogram provided a permanent record of joint angulation during locomotion. The goniograms were recorded for the walk (3 mph) and the trot (6 mph) of the normal equine subject. Specific joints of interest were the metacarpophalangeal (fetlock) joint and the carpal joint of the forelimb. The following characteristics were observed:

1. The standing fetlock angle was determined to be 210 degrees, as measured posteriorly. At a walk, movement at the fetlock joint ranged from 201 degrees at hoof contact, to 188 degrees at hoof lift, continuing to a maximum 182

degrees of flexion during forward swing. At a trot, the range of movement was increased by 65 percent.

2. The standing angle for the carpus was 180 degrees. The range of motion at the walk was 123 to 182 degrees. The greatest amount of flexion occurred during the swing phase. At the trot, an increase from 116 to 186 degrees was evident.
3. During both walk and trot, flexion of the fetlock joint was faster than extension. The reverse was true in the carpal joint.

The supposition that increased linear speed of gait resulted in increased velocity and magnitude of joint angulation was supported by Adrian, Grant, Ratzlaff, Ray, and Boulton (1977). In that study, four mature Thoroughbreds (ages 5 to 9 years) were used as subjects. One of the animals, chosen to be the control subject, was examined clinically and radiographically and determined to be of "normal" conformation. Three of the horses were selected as subjects on the basis of having symptomatic pathologic change in the metacarpophalangeal joint of one forelimb.

The effects of fetlock joint lameness on forelimb kinematics were measured electrogoniometrically. The goniograms of the three clinically lame horses indicated a decreased amount of fetlock joint flexion, as compared with the subject's own normal fetlock, as well as the control subject. The differences in range of motion in all subjects increased with a corresponding increase in speed from walk to trot.

In order to analyze the kinematics of fast-moving Standardbred trotters, Fredricson and Drevemo (1972a) adapted a computerized three-dimensional analysis program that was originally developed for testing prototype aircraft during flight. The three-dimensional analysis program was used to identify attitude angles of the hoof, specifically PITCH, YAW and ROLL. The HOOF PITCH identified the movement of the hoof around its frontal axis. YAW movements occurred around the hoof's longitudinal axis. The ROLL of the hoof occurred around its sagittal axis.

The RESULTANT JOINT COORDINATION PATTERN (RJCP), which consists of pitch, yaw and roll components, is a three-dimensional illustration of hoof movement. The spatial orientation of the hoof could be considered to result from the movement of the forelimb's articulations and may be considered to reflect that extremity's coordinated joint movements (Fredricson, et al. 1972a).

The hoof trajectory, when filmed from a lateral view, presented a two-dimensional pattern. The two-dimensional RJCP was compared with the three-dimensional RJCP for one stride of the right forelimb of each of the ten test subjects. The results showed strong agreement between the three-dimensional and two-dimensional RJCP's of each subject. Fredricson, et al (1972a) suggested that two-dimensional analysis was a suitable choice for future researchers who desired to measure hoof trajectory during flight.

Fredricson and Drevemo (1972c) suggested that the equine subject possesses a very consistent pattern of locomotion. A schematic two-dimensional RJCP was graphically presented, identifying minimal and

maximal angulations during the swing phase of each stride.

Contralateral strides and consecutive strides were shown to be highly consistent in pattern. Such consistency prompted the researchers to theorize that analysis of a single stride would be sufficient in future studies of equine locomotion.

Duration of support and swing phases of consecutive strides of the forelimb and hindlimb varied minimally. There was minimal variation in the duration of both phases, when comparing forelimb to contralateral and ipsilateral hindlimb (Fredricson et al., 1972c).

The description of forelimb joint kinematics in Standardbreds traveling at a racing trot by Fredricson and Drevemo (1972c) shows that not only does the equine seem to have minimal linear displacement variations among strides, it also has very consistent joint angulation patterns. When comparing the values of the angles of consecutive forestrides of each individual equine subject, the fetlock, carpal and elbow joints exhibited minimal variation from one stride to the next. The greatest variation was seen in the pastern/coffin joint, where differences in angulation of consecutive strides were as high as ten degrees. The researchers suggested that one possible explanation for such angular variation was the subject's attempt to react to the minor variations inherent to the racetrack surface.

Previous studies have shown that fast-moving Standardbreds have remarkable consistency in locomotion (Drevemo, Dalin, Fredricson and Bjorne, 1980c; and Fredricson and Drevemo, 1972a, c). Such stability suggests a finely-tuned timing process within the central nervous

system of the equine allowing consistent coordination between the limbs moving at racing speed.

Drevemo, Fredricson, Dalin and Bjorne (1980b) sought to analyze the ability of the horse to maintain constant rhythmic control during the racing trot. Results of the analysis of the coordination between the limbs of fast-moving Standardbreds were the following:

1. The mean duration of the right fore- and hindsteps was 225 msec. The mean duration of the left fore- and hindsteps was 229 and 230 msec. The right and left foresteps measured 273 and 272 cm, while the right and left hindsteps measured 270 and 275 cm, respectively.
2. The overall mean duration for bipedal support was 99 msec for both diagonals. The diagonal length was 105 cm for the left diagonal and 102 cm for the right.
3. The overreach duration is the time interval from the event when one forehoof leaves the ground to the movement when the ipsilateral hindhoof touches it. The overall mean overreach duration was 123 msec on the left side and 119 msec on the right.
4. The suspension period represents the time period when the horse has no contact with ground surface. The mean duration of the left and right suspension was 99 msec. Sixty-six percent of the horses showed differences between right and left suspension periods, indicating that a horse may have a stronger or weaker diagonal.

Drevemo, Dalin, Fredricson and Bjorne (1980c) supported Fredricson and Drevemo's (1972a) statement regarding the horse's ability to maintain consistent gait patterns. Twenty-two horses were filmed twice during the same day, under the same conditions, at the same gait. The subject's ability to maintain short-term reproductibility of length of stride, and duration of: stride, stance, swing, propulsion, diagonal dissociation at landing, step and suspension, were shown to have little variation ($p < 0.05$) using Students t test.

Drevemo, Dalin, Fredricson and Hjerten (1980a) established several linear stride characteristics using the methodology established by Fredricson and Drevemo (1972b). The following characteristics were found to be demonstrated by 30 clinically sound Standardbreds trotting at racing speed:

1. The overall mean stride length was 545 cm.
2. The overall mean lengths of strides ranged from 488 to 607 cm. The differences were explained by the variation in height and limb lengths.
3. The overall mean stride duration was 455 msec.
4. The stance phase lasted from the moment of heel contact until the moment toe-off occurred. The stance phase duration was somewhat longer in the hindlimbs than in the forelimbs.
5. The stance phase was subdivided into DECELERATION and PROPULSION stages. The deceleration phase, although somewhat longer in the hindlimbs than the forelimbs,

represented 40 to 45 percent of the stance phase. The propulsion stage durations, 64.3 to 67 msec in length were equal in all limbs.

6. The swing phase was begun the moment the foot was lifted from the ground. Of the total duration of a stride, 25% corresponded to the stance phase while 75% was said to be swing phase.

Fredricson, Drevemo, Dalin, Hjerten, Bjorne and Rynde (1983) described the development of a treadmill specially designed to accommodate the exercising and controlled testing of equine subjects. Such an instrument may represent a breakthrough in the analysis of equine locomotion as well as other areas of interest such as equine exercise physiology. The equine treadmill could be inclined as much as 10 degrees longitudinally and 7.5 degrees transversely and accommodate a horse running at racing speed.

Fredricson, et al. (1983) reported the test results of a Standardbred trotter filmed while trotting on a treadmill and then on a racetrack. In a comparison of gait patterns, at a consistent speed, only minor differences in stance phase and limb synchronization within individual strides was noted. However, the swing phase duration, as well as stride and step length, were significantly shorter ($p < 0.001$) and had a higher frequency on the treadmill as compared with the gait pattern on the racetrack.

Summary

Equine locomotion is commonly described in terms of specific gaits. Regardless of the degree of animation, the trot is a gait that may be identified by its symmetrical two-beat diagonal movement.

A problem commonly encountered when attempting to interpret previous research in equine locomotion is that of confusing variation in terminology for the components of a gait pattern. This apparent lack of standardization creates confusion for those attempting to understand the terminology describing equine locomotion.

For instance, the period of time when an individual leg supports the animal's bodyweight may be called the stance, contact, support or breakover period. This phase may be further divided into initial hoof contact, deceleration phase, mid-stance, propulsion, heel-off and ending with toe-off, or lift-off.

An individual stride may be divided into an anterior or posterior phase, and/or a protraction/retraction phase. The period of time when the hoof travels through the air may be called a swing or flight phase. In the trot, when the body is supported by a diagonal pair (forelimb and contralateral hindlimb) it may be termed to be bipedal support or overlap.

Many of the theories concerning cause-effect of common horseshoeing techniques have simply been handed down from one generation of farriers to the next. For instance, it is a common technique, among trainers of fine show horses, to increase horseshoe weight in order to produce a 'knee-snapping' action on their fine

show horses. Although a factor such as increased horseshoe weight was thought to increase the height and length of an individual stride, to the researcher's knowledge, the kinematical evaluation of those effects, or others, has not previously been attempted.

Much of the previous research using high-speed cinematography have used Standardbred trotters traveling at racing speed. These studies have produced a great deal of valuable data supporting the theory that the equine moves in a very consistent gait pattern and that it is possible to achieve valid results while analyzing a single stride of a particular subject. Filming technique and the establishment of aspects for analysis were also valuable contributions of these earlier studies.

These studies, however, utilized a great deal of highly-specialized equipment including a camera car and a smoothly groomed oval racing track. The further development of a heavy-duty treadmill equipped specially for the needs of the equine subject was a significant breakthrough. Although costly to purchase and maintain, this piece of equipment would allow indoor filming, eliminating the effect of inclement weather and unreliable lighting conditions.

This review of literature presented previous research in the categories of equine locomotion, specific horseshoeing conditions, and equine limb kinematics. The researcher attempts to illustrate the general lack of standardization of terminology within the study of equine locomotion as well as the lack of objective analysis of common horseshoeing conditions. Also presented were several previous

studies utilizing accepted methodology of high-speed cinematography and analysis of equine gait.

CHAPTER 3

METHODS AND PROCEDURES

Data collection methods were based on techniques described in previous studies and from knowledge gained from the pilot study. The desired end-results of this study were 1) quantitative descriptions of limb kinematics, as induced by increased horseshoe weight, and 2) qualitative assessments of variations in gait kinematics as induced by a) increased shoe weight and b) decreased pastern/coffin joint angle.

Subject Description

The subject was a four-year old, bay grade Quarter Horse gelding. The subject was selected partly because of its dark bay color and lack of white leg markings that might blend in with the background. The subject was of normal conformation with no obvious deformities and was determined by an experienced equine veterinarian to be clinically sound.

Anatomical LandmarksLateral View

Previous to the filming session, anatomical landmarks were selected and reference points marked. Each landmark was identified

and palpated by an experienced equine anatomist, and are shown in Figure 1. Specific landmarks were:

1. Distal lateral epiphysis of radius
2. Proximal lateral splint bone
3. Distal lateral metacarpal bone, anterior to proximal sesmoid
4. Distal lateral P-1 (1st phalanx)
5. Posterior-lateral hoof wall, distal to heel bulb
6. Anterior hoof wall, distal lateral tip of toe

The hair over the area was closely shaven. A piece of approximately two-inch square white surgical adhesive tape was attached directly to the skin over the landmark area. An orange 3/4-inch diameter round adhesive sticker was attached to the white tape square, directly over the palpable landmark.

Shoeing Conditions

The subject was originally filmed in a balanced barefoot condition. The balancing of all limbs was accomplished by an experienced farrier. A hoof protractor was used to measure the pastern angle. The pastern angle of the right forelimb was 52 degrees and the left was 51 degrees (see Figure 2).

Toe length was measured using a conventional measuring tape. In the barefoot condition, the toe length was 3 1/2 inches from the tip of the toe to the proximal edge of the hoof wall. A maximum toe length of 4 3/4 inches was measured upon the application of the neoprene pad with the sixteen ounce plate.

neoprene pad with the sixteen ounce plate. The pad was placed such that it effectively raised the toe.

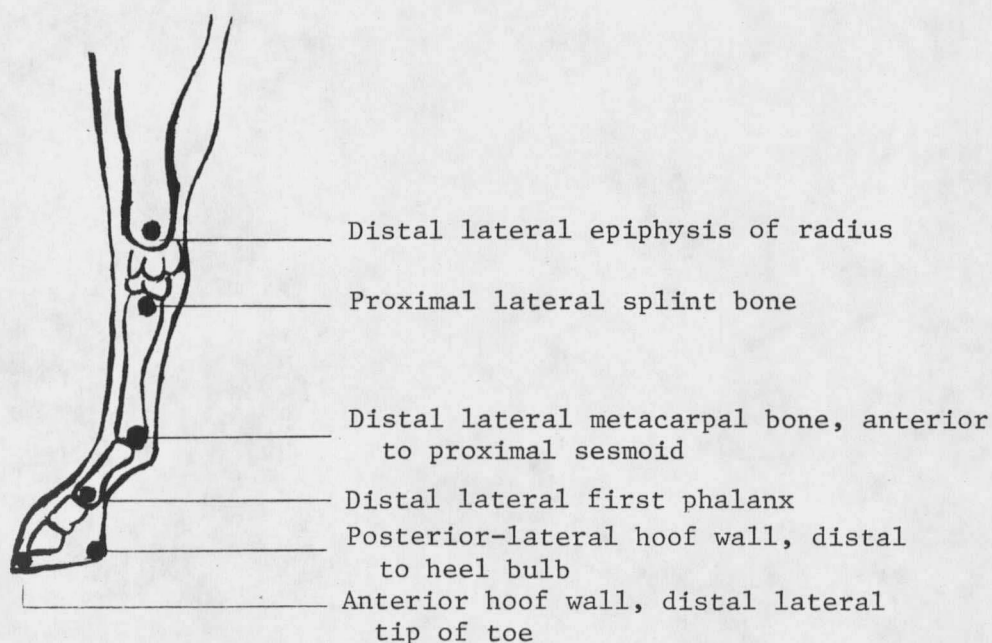


Figure 1. Lateral view of equine forelimb with anatomical landmarks highlighted.

Heel length in the barefoot condition was $1 \frac{3}{4}$ inches from the point of the heel to the bulb of the hoof. In the sixteen ounce plate with neoprene pad condition, the heel length was $2 \frac{1}{4}$ inches.

The shoes were attached with three standard horseshoe nails per horseshoe bar. The hindlimbs remained in the barefoot and balanced condition throughout the filming runs.

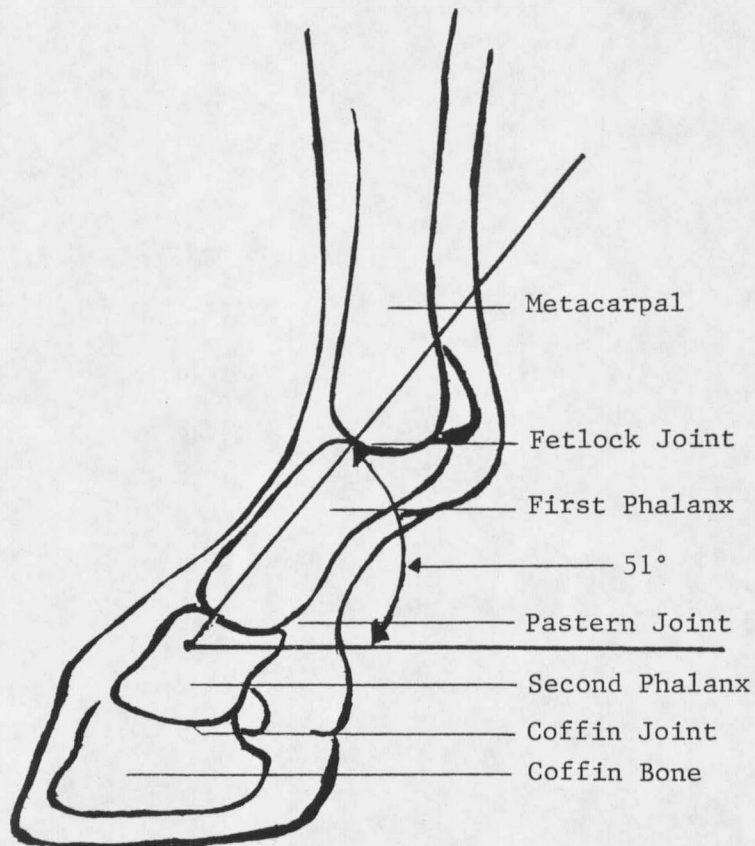


Figure 2. Pastern angle measurement of left forelimb of equine subject, in barefoot/balanced condition.

Pilot Study Data Collection

A pilot study was conducted during December of 1983. The main objective of the study was to determine the filming technique that would produce acceptable results for analysis. The location of

anatomical landmarks were those described previously. Bright fluorescent orange round stickers were attached to the white squares, directly over the palpable landmarks,

Two cameras were used. Camera A, a 16mm Photec IV was operated at a film transport speed of 200 frames per second (fps). An internal timing light allowed verification of actual filming speed.

Camera B, 16mm Beaulieu, was operated at a film speed of 64 frames per second. During the filming process, both cameras were mounted on tripods to minimize camera response to external interference and to stabilize positioning. During the filming process, both cameras were operated simultaneously; however, the cameras were not synchronized.

Camera A, the Photec IV, was placed 33.3 meters from the center of the test range (see Figure 3). The view of the camera was perpendicular to the sagittal plane of the subject thus recording movement of the subject in that plane.

Camera B was positioned at the front of the course, 16.5 meters from the center of the test range. Camera B recorded movement of the subject in the frontal plane.

The test range was a 6.2 meter section of level asphalt located outside Rano H. Sales stadium on the Montana State University campus. Two orange plastic cones, approximately 24 inches high, were used to demarcate the beginning and end of the test range.

A reference marker, in the form of a meter-stick, was held by the researcher within the view of both cameras, yet not obstructing the view of the subject's gait.

The subject was guided through the course by a handler who was positioned on the rear of a 1976 Subaru station wagon. The purpose of the vehicle was to monitor the speed and maintain the direction of the subject. The subject completed several practice runs in order to allow him to become familiar with the test range and to develop a consistent speed of movement.

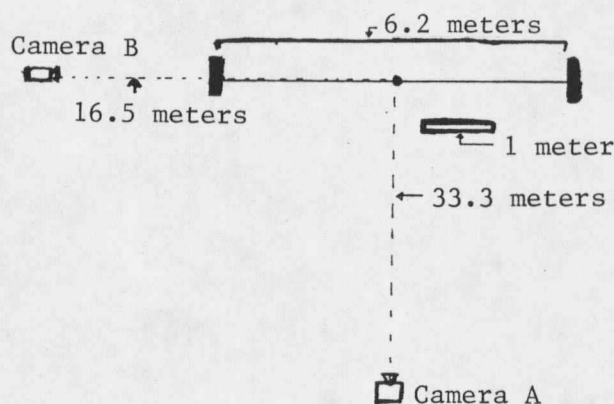


Figure 3. Diagram of test range used during pilot study filming.

Filming was initiated when the subject was approximately one stride away from entering the test range which insured that at least one full stride was successfully recorded on film. Each test run was subjectively evaluated as to the subject's consistency of speed, direction and trueness of gait by a committee made up of an experienced farrier, a veterinarian, a cameraperson experienced in biokinematical data collection and the researcher. If the test run was perceived as inconsistent by any one committeeperson the same test run was repeated.

Each test run was assigned a number with the corresponding condition recorded. A cardboard number which identified the specific test run was attached to the front bumper of the test vehicle within view of Camera B. A similar number was placed within the view of Camera A.

The subject was first filmed in a balanced barefoot condition at an extended trot (nine miles per hour). The trot was then slowed to six miles per hour. The final barefoot condition was filmed with the subject moving at a normal walk, approximately three miles per hour.

The subject was then fitted with sixteen-ounce shoes and filmed at an extended trot, a slow trot, and then at a walk, maintaining the speeds aforementioned.

Evaluation of Pilot Study

A single-frame, stop-action projector was used to make a subjective visual inspection of quality and content of the pilot study films. In order to improve the contrast provided by the orange landmarks, the decision was made to apply black landmarks on white square patches for the final filming.

The decision was made to film the subject traveling in an extended trot only, in order to avoid duplication of time and film, and to vary the horseshoe weight and pastern angle during the final filming. These changes would efficiently produce kinematical data that would allow the evaluation of two variations in common horseshoeing conditions: a) increased shoe weight, and b) decreased pastern angle.

Final Study Data Collection

The same anatomical landmark system, described previously, was used during the final filming session. In order to improve the visual identification of the round landmarks, however, black stickers were used.

The camera locations also remained the same, although the test range distances were modified as shown in Figure 4. The reference marker, in the form of a narrow meter-long board with the ends demarcated with white adhesive tape, was placed in the foreground of the test range within view of Camera A.

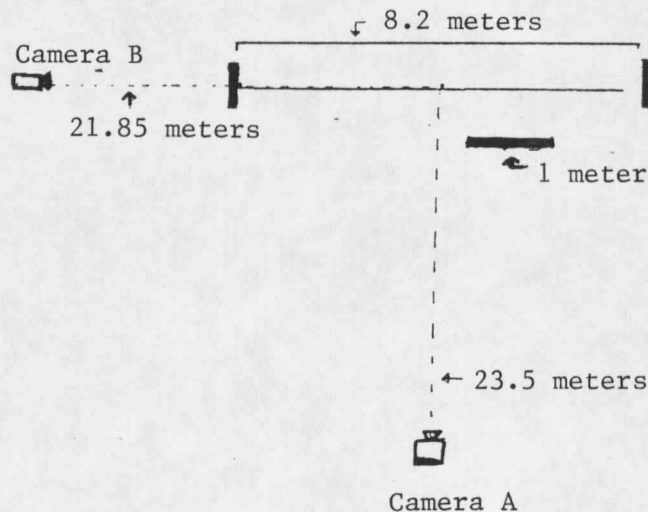


Figure 4. Diagram of test range used during final filming.

Two one-and-a-half inch strips of adhesive athletic tape, approximately 12 inches in length, were applied directly to the asphalt surface to demarcate the beginning and end of the test range distance.

The subject was guided through the course by a handler who was positioned on the rear of a 1981 Mazda pickup. The subject completed several practice runs in order to allow him to become consistent in his speed and direction of movement.

Filming was initiated when the subject was approximately one stride away from entering the test range which insured that at least one full stride was successfully recorded on film. Each test run was subjectively evaluated as to the subject's consistency of speed, direction and trueness of gait by the testing committee, made up of an experienced farrier, a veterinarian, a cameraperson experienced in biokinematical data collection and the researcher. If the test run was perceived as inconsistent by any one committee person, the same test run was repeated.

Each test run was assigned a number with the corresponding condition recorded. A cardboard number, which identified the specific test run, was attached to the front bumper of the test vehicle within view of Camera B. A similar number was placed within the view of Camera A.

Shoeing Conditions

The balancing of all limbs was accomplished by an experienced farrier. A hoof protractor was used to measure the pastern angle. The pastern angle remained the same as recorded during the pilot study.

After filming the subject in the barefoot and the two balanced conditions, a three degree neoprene pad was applied between the sole

surface and the shoes. The purpose of the pad was to raise the toe of the forelimb three degrees which in effect lowered the heels, thereby decreasing the pastern joint (hoof wall) angle.

Filming Sequence

The following sequence was followed during the final filming session:

1. Barefoot and balanced
2. Balanced and 8 ounce plates
3. Balanced and 16 ounce plates
4. Sixteen ounce plates and 3-degree pad
5. Eight ounce plates and 3-degree pad

The subject maintained an extended trot (10 miles per hour) during each test run. The hindlimbs remained in the barefoot and balanced condition during the entire filming session.

Film Data Retrieval

The 16mm film was projected onto a 36" by 36" piece of frosted glass to which a Graf/Pen sonic digitizer was attached. The digitizer was interfaced to a TEKTRONIX 4025 terminal which was linked to a HONEYWELL CP6 computer.

The software program, FILMDATA, was originally designed by biomechanists at Washington State University for the analysis of human movement. Computer scientists at Montana State University adapted Filmdata for use on the Honeywell CP6. A stick figure

graphics program was added to the original Filmdata package in order to display the data points more effectively.

During the data-gathering process a cursor, placed on each anatomical landmark, generated hypersonic impulses which were then converted into X-Y coordinates by the internal software thus defining the point in space. At the beginning of the Filmdata program, the two end-points of the reference marker in the foreground of the test range were digitized, supplying the Filmdata program with a scale distance. During each frame the cursor was first placed on a fixed reference point and then on each of the anatomical landmarks, always maintaining the same order of digitization.

Four sets of data were retrieved. The first two sets of data were obtained from the film produced during the final filming session. The last two sets were from pilot film.

During the first set, the toe of each limb was digitized in every fifth frame. This process was done to provide general linear information during the gait pattern and a graphical illustration of the arc of the foot in flight.

During the second set of data collection, the following key points in time were identified for each limb's stride:

1. Initial hoof contact
2. Toe-off
3. Re-touch of same hoof

Each stage was visually identified on the film and the frame number recorded. The specific frame number was identified by an

automatic video display frame counter connected to the film projector.

Each stage was visually identified on the film and the frame number recorded. The specific frame number was identified by an automatic video display frame counter connected to the film projector.

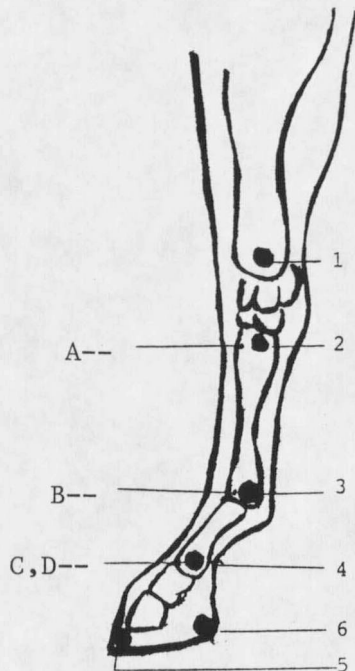
The third and fourth sets of data were extracted from the film obtained during the pilot study. Each point was visually identified on the film and the frame number recorded. The following points in time of an individual stride were identified:

1. Initial Hoof Contact
2. Mid-Stance (Metacarpus is vertical)
3. Toe-Off
4. Re-Touch of Same Hoof

Every fifth frame of the pilot study film was digitized to produce the fourth set of data. Each of the anatomical landmarks on the left forelimb was plotted. Figure 5 illustrates the carpal, fetlock, anterior and posterior pastern/coffin joints and the anatomical landmarks that comprised each joint.

Method of Film Data Analysis

A combination of methods was used to identify the temporal, linear, graphical and kinematical effects of the variation in horseshoe conditions on the gait of the equine subject. Four sets of data were retrieved from the final film and the pilot study film.



- A: CARPAL ANGLE - Describes flexion/extension as identified by landmarks 1, 2 & 3.
- B: FETLOCK ANGLE - Describes flexion/extension as identified by landmarks 2, 3 & 5.
- C: ANTERIOR PASTER/COFFIN ANGLE - Describes flexion/extension as identified by landmarks 3, 4 & 5.
- D: POSTERIOR PASTER/COFFIN ANGLE - Describes flexion/extension as identified by landmarks 3, 4 & 6.

Figure 5. Illustration of left forelimb and the landmarks that form the carpal, fetlock, anterior and posterior pastern/coffin joints.

As described in the previous section, manual retrieval of the film was used to collect two of the four sets of data. Key points of each stride were identified and the frame number recorded from both the pilot study and the final filming.

To determine the duration of each of the phases described below, the total number of frames within each phase is multiplied by 0.005 or 1/200th of a second. Tables 1 and 2 show the frame numbers of each key point of the stride for each condition. Specific phases of

the stride and the method used to determine the total number of frames representing those phases are as follows:

1. DIAGONAL DISSOCIATION at INITIAL FOOT CONTACT: Subtract the frame number representing the moment of initial hoof contact of the hindfoot from that of its diagonal forefoot.
2. DIAGONAL DISSOCIATION at TOE-OFF: Subtract the frame number representing the moment of toe-off of the forefoot from that of the diagonal hindfoot.
3. SWING TIME of the DIAGONAL: To determine the duration of the swing phase of a specific diagonal, subtract the frame number representing the last diagonal limb to toe-off from that of re-touch of the first diagonal limb to regain contact with ground surface.
4. SWING TIME of an INDIVIDUAL LIMB: Subtract the frame number of the limb's toe-off from the number representing the re-touch of that same limb.
5. STANCE TIME of an INDIVIDUAL LIMB: Subtract the frame number of the initial hoof contact of a limb from that of the toe-off of that limb.
6. BIPEDAL SUPPORT: Subtract the frame number representing the last of the diagonal pair to have initial hoof contact from the first toe-off of that pair.
7. TIME OF SUSPENSION PHASE: Subtract the frame number representing toe-off forelimb of the first diagonal pair from that of the initial hoof contact of the hindfoot of the next diagonal pair.

8. DECELERATION TIME of an INDIVIDUAL STEP: Subtract the frame number representing the initial hoof contact of the limb from that of the mid-stance.
9. PROPULSION TIME of an INDIVIDUAL STEP: Subtract the frame number representing the mid-stance from that of the toe-off of the limb.

Table 1. Frame numbers of Specific Points of the Stride of the Left Forelimb as Identified on the Pilot Study Film.

CONDITION	Toe Off	Heel Touch	Mid-Stance	Toe Off
Barefoot	892	974	996	1032
16-Ounce	4919	5005	5030	5064

Table 2. Frame Numbers of Specific Points of the Stride of All Limbs, as Identified on the Final Film Study.

CONDITION	Fore IFC	Hind IFC	Fore TOff	Hind TOff	Fore ReTouch	Hind ReTouch
Bare (L)Diag.	0	0	42	42	110	105
(R)	45	45	100	100	-	165
8oz (L)	5	0	50	50	115	110
(R)	60	55	105	105	-	171
16oz (L)	0	0	53	53	120	120
(R)	65	55	111	111	-	174
16oz/(L)	75	68	125	125	-	190
Pad (R)	15	15	57	57	135	130
8oz/ (L)	83	80	130	130	-	200
Pad (R)	25	20	73	73	140	135

The Filmdata software program was used to retrieve the remaining two sets of data. The Filmdata software program produced "scaled"

displacement and then "smoothed" it prior to further calculation.

The method of collecting the necessary information from the printout produced by the Filmdata program is as follows:

1. STEP HEIGHT: Subtract the minimum value of the Y-coordinate from that of the maximum value. Because the unit of measurement of linear displacement was metric, this vertical displacement was expressed in meters.
2. DIAGONAL LENGTH: Subtract the minimum X-displacement of the diagonal forefoot from the maximum X-displacement of its partner hindfoot. This value represents the horizontal distance traveled by the diagonal pair.
3. ARC OF THE FOOT IN FLIGHT: The graphical presentation of the arc of the foot during the swing phase was obtained by digitizing the tip of the toe of each limb and then graphing the X-Y displacement of that point.
4. ANGULAR DISPLACEMENT: The Filmdata program allowed one to identify specific joints and the landmark points that make up that joint. As mentioned previously, Figure 5 illustrates the landmarks that represent the carpal, fetlock, anterior and posterior pastern-coffin joints. The program printout identified the minimum and maximum angular displacement for each joint. Total angular range-of-motion could then be obtained by subtracting the minimum from the maximum value. The angular displacement of a joint under one condition could then be compared with that of another

by graphically presenting the angular displacement of that joint as a function of time.

5. ANGULAR VELOCITY: The software program identified the velocity of angulation for each joint. These values could then be compared by graphically presenting the angular velocity as a function of time.

Summary

One equine subject was used throughout the course of the study. Specific anatomical landmarks were identified and demarcated by applying adhesive stickers directly to the skin over each landmark.

One pilot study was done. The purpose of that study was to establish correct filming technique, distance and test range construction. The subject was filmed traveling at a walk, a slow trot and an extended trot. The subject was filmed while in a barefoot condition and also when wearing 16-ounce shoes.

Improvements identified after reviewing the pilot study film included changing the color of the anatomical landmarks to black in order to avoid washout due to glare, filming the subject traveling in an extended trot only, and variation in horseshoeing condition in order to evaluate the effectiveness of this filming technique for kinematical evaluation of equine gait.

The final filming was of the subject in the barefoot condition, wearing 8-ounce plates and 16-ounce plates. A second variation in the shoeing condition was achieved by sandwiching a three-degree pad

between the shoe and the hoof surface which decreased the pastern-coffin joint angle at toe-off.

Two methods were used to retrieve the data from both filming sessions. The film was visually inspected by the researcher, who identified specific key points of each stride and recorded the frame number of that phase.

A Graf/Pen sonic digitizer, interfaced with a Tektronix 4025 terminal and linked with a Honeywell CP6 computer was used to identify the X-Y coordinates of each anatomical landmark. A software program, Filmdata, was used to smooth the new data and to calculate and graphically present the linear displacement of each landmark and the angular displacement and velocity of the carpal, fetlock, anterior and posterior pastern-coffin joints.

CHAPTER 4

RESULTS AND DISCUSSION

The results of the data analysis are presented under the categories of: temporal and linear stride characteristics given increased horseshoe weight (eight and sixteen ounce) and decreased pastern angle; general kinematics of the left forelimb given increased horseshoe weight; and a two-dimensional presentation of the arc of the foot in flight given increased horseshoe weight and decreased pastern angle.

Temporal Stride Characteristics

Temporal stride characteristics were analyzed in the attempt to identify the changes associated with increased weight and decreased pastern angle on the kinematics of one equine subject. Temporal characteristics were: duration of diagonal dissociation at initial foot contact and toe-off, swing of forestep and hindstep, diagonal swing, stance, deceleration and propulsion phases of the stance period, bipedal support and suspension phases.

Diagonal Dissociation

In the perfectly synchronized trot, the diagonal limbs land and take-off at exactly the same moment. Figure 6 illustrates the footfall patterns of the ideal synchronized trot (Gray, 1968).

Diagonal dissociation occurs when the diagonal limbs land and/or take-off at different moments. Figure 7 illustrates dissociation occurring at initial foot contact and at toe-off (Gray, 1968). During this pattern, the hindfoot of the diagonal pair is the first to make ground contact, followed by a period of bipedal support when that hindfoot and its diagonal forefoot partner carry the weight of subject. The hindfoot then is the first of the diagonal pair to toe-off, allowing the forefoot to solely support the body. The diagonal pair is said to be "dissociated" with the duration of dissociation representing the period of single leg support.

The block diagram in Figure 8 illustrates the average diagonal dissociation pattern exhibited by the equine subject when wearing weighted horseshoes, with and without three-degree pads. The subject displayed diagonal dissociation at initial foot contact, however, synchronization was regained at the moment of toe-off. This footfall pattern is illustrated in Figure 8.

Table 3 shows the duration of diagonal dissociation at foot contact. In the barefoot condition, the subject displayed a synchronized two-beat gait with no diagonal dissociation at initial foot contact.

In the eight-ounce condition, the subject displayed a 25 msec period of dissociation at initial foot contact in both left and right diagonals. In the 16-ounce/balanced, as well as both of the three-degree pad conditions, the left and right diagonal varied in duration of dissociation.

Table 3. Duration of diagonal dissociation of one equine subject at initial foot contact at left and right diagonals (msec).

DIAGONAL	CONDITION				
	Barefoot	8oz	16oz	8oz/Pad	16oz/Pad
Left	0 msec	25 msec	0 msec	15 msec	35 msec
Right	0 msec	25 msec	50 msec	25 msec	0 msec
Average	0 msec	25 msec	25 msec	20 msec	17.5 msec

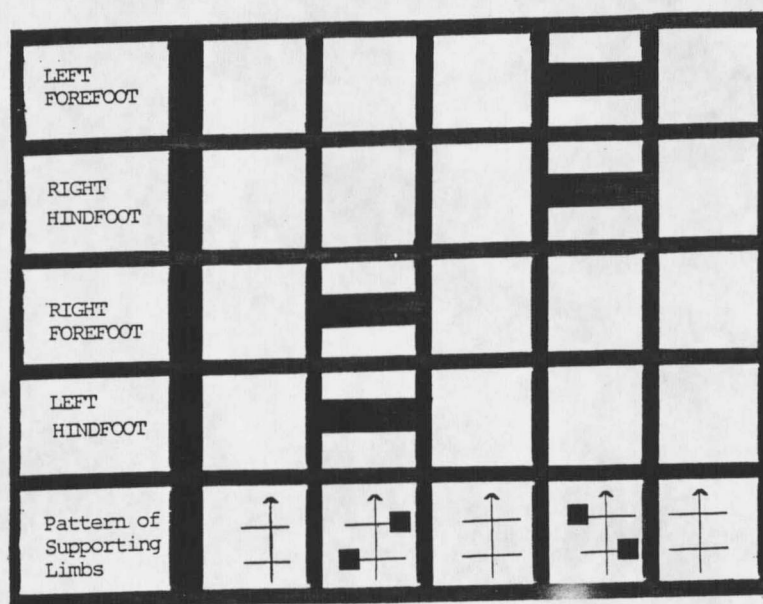


Figure 6. Block diagram of ideal footfall pattern of synchronized trot (from J. Gray, Animal Locomotion, 1968).

As much as the descriptive data show, the left and right diagonals varied inconsistently from one condition to the next. Therefore, the average of the two diagonals was calculated which provided a more concise overview of the characteristics of a stride as changed by increased horseshoe weight or decreased pastern angle.

It would seem logical to expect that increasing the weight of the horseshoe carried by the forefoot, while having its diagonal hindfoot partner remain bare, would alter the coordinated timing of the two-beat diagonal footfall pattern. One might also logically expect that the amount of dissociation would be exaggerated by an increase in shoe weight. However, the average duration of dissociation at initial foot contact remained at 25 msec in the condition of largest weight.

Butler (1976) suggested that of the trotter the practice of weighting the forefoot only was a common method of attempting to "balance" or stabilize the equine moving at racing speed. In this subject, both the eight-ounce and the 16-ounce shoes were associated with a change in the timing of the trot in both cases, the hindfoot was the first to strike the ground surface followed by its partner forefoot.

The average duration of dissociation with the 3-degree pad was less than the balanced horseshoe in each weight condition. The duration of dissociation in the eight-ounce condition was 20 msec and 17.5 msec in the 16-ounce state. To the researcher's knowledge, no previous investigator has suggested a reason for this occurrence. The variation in dissociation observed at initial foot contact may be

a result of variation in the swing phase of forefoot and/or hindfoot. A discussion of the swing phase will follow under a separate heading.

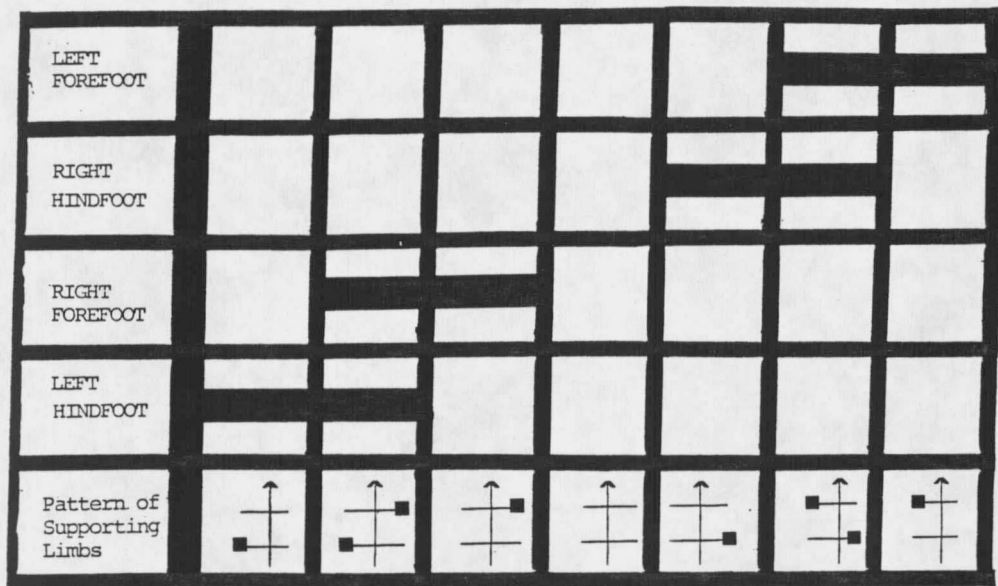


Figure 7. Block diagram of footfall pattern of diagonal dissociation at initial foot contact and at toe-off at the trot (from J. Gray, Animal Locomotion, 1968).

Table 4 presents the duration diagonal dissociation at toe-off for all conditions. The toe-off of both diagonal limbs in all cases was perfectly synchronized, with no dissociation recorded.

According to Butler (1976), raising the toe thereby decreasing the pastern angle would result in a slower breakover of the foot. Butler's (1976) statement was based entirely on his

personal observation and experience as a farrier rather than concrete biokinematical data.

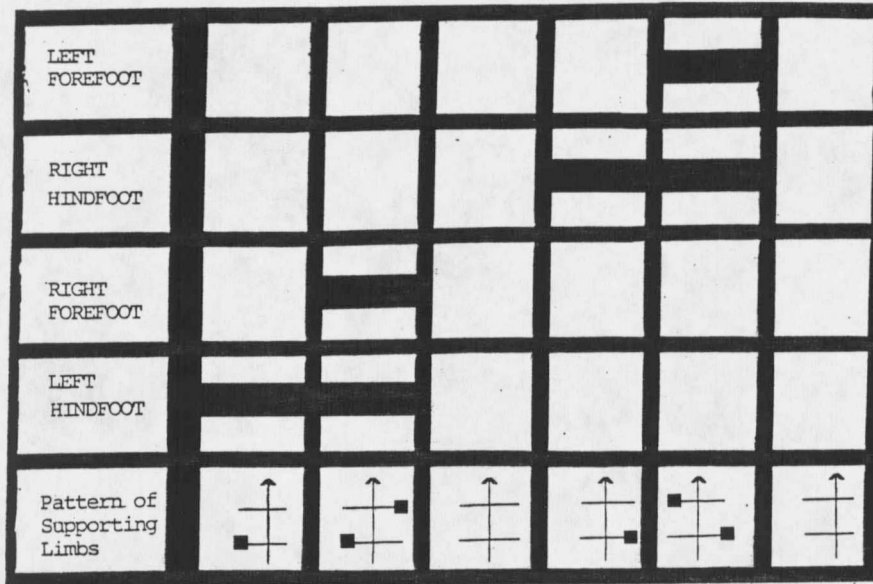


Figure 8. Block diagram of dissociation at initial foot contact as observed in subject at the trot in all conditions.

A logical expectation would be that if the breakover of the forefoot were slowed, a dissociation between hindfoot and diagonal forefoot would occur. For this subject, however, no dissociation at toe-off occurred.

Table 4. Duration of diagonal dissociation of one equine subject at toe-off of right and left diagonals (msec).

CONDITION					
DIAGONAL	Barefoot	8oz	16oz	8oz/Pad	16oz/Pad
Left	0 msec	0 msec	0 msec	0 msec	0 msec
Right	0 msec	0 msec	0 msec	0 msec	0 msec

The toe-off of hindfoot and diagonal forefoot in all conditions remained synchronized. The researcher might suggest that either a) the changes in shoeing conditions were not extreme enough to produce a noticeable difference and/or, b) the subject's internal timing mechanism was successful in maintaining the coordinated diagonal toe-off despite the altered shoe conditions.

Swing Duration

The swing phase of an individual step begins when the foot is lifted from ground surface and ends as the foot once again contacts the ground.

Table 5 presents the duration of the swing phase for the forestep and hindstep under each condition. The duration of forefoot swing was 340 msec in the barefoot state. A shorter swing duration of 325 msec was recorded for the eight-ounce condition. With 16-ounce shoes, the swing duration was 335 msec. The greatest duration of swing, 390 msec, was seen in the 16-ounce/pad condition, an increase of 55 msec from the swing duration displayed in the eight-ounce/pad state.

Table 5. Average duration of the swing phase of one equine subject's forefoot and hindfoot (msec).

CONDITION	Forefoot Swing Duration	Hindfoot Swing Duration
Barefoot	340 msec	320 msec
8 ounce	325 msec	315 msec
16 ounce	335 msec	325 msec
8 ounce/pad	335 msec	330 msec
16 ounce/pad	390 msec	345 msec

The duration of swing in the hindfoot was 320 msec in the bare forefoot condition. A 315 msec hindfoot swing duration was recorded when the forefoot wore an eight-ounce shoe 325 msec swing duration was recorded for the 16-ounce condition.

In the eight-ounce/pad condition the swing duration of the hindfoot was 330 msec. When the subject wore the 16-ounce/pad shoes on the forefeet, the average hindfoot swing duration was 345 msec.

The aforementioned diagonal dissociation at initial foot contact could have been caused by the inequality of swing duration ratio of forefoot and diagonal hindfoot. The shortened swing period of the forefoot may have been a result of the effect of the gravitational acceleration force on the increased shoe mass.

Diagonal Swing Duration

The swing phase of the diagonal represents the period of time that the diagonal pair of limbs have no contact with the ground surface. Therefore, the swing phase begins the moment the last diagonal limb toes-off (in this case, both limbs toed-off together)

and ends the moment the first diagonal limb initiates hoof contact with the ground surface.

Table 6 presents the duration of the diagonal swing phase for each diagonal as well as the average of the two. As mentioned previously, the average duration is presented in order to provide a more concise description of stride characteristics.

Table 6. Duration of diagonal swing phase in left and right diagonal of one equine subject (msec).

DURATION			
CONDITION	Left Diagonal	Right Diagonal	Average
Barefoot	315 msec	325 msec	320 msec
8 ounce	300 msec	330 msec	315 msec
16 ounce	335 msec	315 msec	325 msec
8 ounce/pad	350 msec	310 msec	330 msec
16 ounce/pad	325 msec	365 msec	345 msec

The average duration of diagonal swing was 320 msec in the barefoot state, 315 msec in the eight-ounce, and 325 msec in the balanced/16-ounce condition. When wearing the shoe/pad combination, the subject displayed a swing duration of 330 msec in the 8-ounce/pad and 345 msec in the 16-ounce/pad condition.

To the researcher's knowledge, no previous investigator has established the effect of decreased pastern angle on the swing phase of equine in motion. In this case, the duration of the diagonal swing phase was longer in the padded conditions. Also, both of the

diagonal swing durations for the padded conditions were greater than the maximum duration recorded for the balanced 16-ounce.

One possible explanation for the increased diagonal swing duration and the duration of individual forestep and hindstep swing in the padded conditions may be found in the Drevemo, Dalin, Fredricson and Bjorne (1980c) study. The researchers stated that the duration of the swing phase lengthens over a long-term (three years) training period due to the training effect and maturation process.

The eight-ounce/pad and 16-ounce/pad conditions were the final trial runs to be filmed. The subject may still have been adjusting its stride characteristics which may have been the cause of the variations in swing duration.

Stance Duration

The stance phase of a step lasts from the foot's initial contact with ground surface until toe-off. Table 7 presents the average duration of the stance phase of foreleg and hindleg.

Table 7. Average duration of one equine subject's stance phase in forefoot and hindfoot (misc).

CONDITION	Forefoot Duration	Hindfoot Duration
Barefoot	240 msec	240 msec
8 ounce	220 msec	250 msec
16 ounce	245 msec	270 msec
8 ounce/pad	235 msec	255 msec
16 ounce/pad	230 msec	245 msec

The stance duration observed during the barefoot condition was 240 msec. A decrease of 20 msec of the forefoot stance duration was observed for the eight-ounce condition. A maximum of 245 msec was recorded for the balanced 16-ounce condition.

The subject displayed a forefoot stance duration of 235 msec in the eight-ounce/pad and decreased to 230 msec in the 16-ounce/pad condition. The decrease in forefoot stance duration is produced when the foot breaks over more quickly. The purpose of applying the three-degree pad was to decrease the pastern angle and consequently to slow speed of breakover, resulting in a longer stance period (Butler, 1976; Adams, 1971).

The opposite effect was observed in this subject. Possible explanations might be that the subject did not have a suitable amount of time to adapt to the change in pastern angle, or that the angle change was not large enough. Another explanation would be that the subject hastened the forefoot breakover in an effort to maintain the synchronized timing of the diagonal pair.

The shortest hindfoot stance duration, 240 msec, was observed in the barefoot state. As the shoe weight increased, the stance phase became longer in duration. A duration of 250 msec was recorded for the eight-ounce condition. A maximum of 270 msec was observed for the 16-ounce state. The hindfoot stance duration was 255 msec in the eight-ounce Greater horseshoe weight resulted in a longer stance period, 250 msec in the eight-ounce and a maximum of 270 msec in the balanced 16-ounce condition. The stance phase duration in the eight-

ounce/pad condition was 255 msec and 245 msec in the 16-ounce/pad state.

As noted by Drevemo, Dalin, Fredricson and Bjorne (1980a), the hindfoot stance duration was longer than the forefoot in all conditions. In this subject, the breakover of the hindfoot was slowed while the speed of the breakover of the forefoot was quickened, producing the aforementioned synchronized toe-off of the diagonal pair.

Deceleration and Propulsion Phases of the Stance Period

The deceleration phase of the stance period extends from the moment of initial hoof contact with ground surface until the occurrence of mid-stance. The propulsion phase of stance lasts from mid-stance to the moment of toe-off.

Table 8 presents a comparison of the duration of the deceleration and propulsion phases of the stance period of the left forelimb of the subject in the barefoot and the 16-ounce conditions. The total duration of the stance period in the barefoot condition was 290 msec. An increase of 0.05 more than that recorded for the barefoot condition.

In the barefoot condition, the duration of the deceleration phase was 110 msec or 37% of the total stance period. In the 16-ounce condition, the deceleration period increased to 125 msec or 42% of the total stance period.

Table 8. Duration of deceleration and propulsion phases of the stance period of one equine subject (msec).

CONDITION	Total Stance Duration	Deceleration Period	% of Total	Propulsion Period	% of Total
Barefoot	290 msec	110 msec	37%	180 msec	62%
16-ounce	295 msec	125 msec	42%	170 msec	57%

Drevemo, Dalin, Fredricson and Hjerten (1980a) reported the duration of the deceleration phase in trotters moving at racing speed to be 40 to 45 percent of the stance period. In this subject, increased horseshoe weight was associated with a greater period of deceleration, a point not previously discussed to the researcher's knowledge.

The propulsion period in the barefoot condition lasted 180 msec which was 62% of the total stance. The increase in shoe weight to 16 ounces was associated with a decreased propulsion phase of 170 msec for this subject, which was 57% of the total stance period.

According to the Drevemo, et al (1980a) study, the propulsion phase in fast-moving trotters represented 55 to 60 percent of the total stance period. The single equine subject in this study displayed a shorter period of propulsion when wearing the 16-ounce shoes.

Duration of Bipedal Support

The bipedal support phase represents the period of time when the subject maintains contact with ground surface with both of the diagonal limbs. Table 9 presents the duration of the bipedal

support period for the left and right diagonal and the average of the two.

The average duration of the bipedal support in the barefoot condition was 240 msec. A smaller duration of 225 msec was recorded in the balanced/8-ounce condition, while a greater duration of 245 msec was noted in the 16-ounce.

Table 9. Duration of bipedal support phase of left and right diagonals of one equine subject (msec).

CONDITION	Left Diagonal	Right Diagonal	Average
Barefoot	210 msec	270 msec	240 msec
8 ounce	225 msec	225 msec	225 msec
16 ounce	265 msec	230 msec	245 msec
8 ounce/pad	235 msec	240 msec	235 msec
16 ounce/pad	250 msec	210 msec	230 msec

An average bipedal support period of 235 msec was recorded for the eight-ounce/pad condition. A duration of 230 msec was recorded when the subject wore the 16-ounce shoes with the three-degree pad.

A review of the data shows dissociation occurring at initial foot contact. This dissociation results in a shortened period of bipedal support. To the researcher's knowledge, no previous investigator has investigated the effect of additional horseshoe weight or decreased pastern angle on the duration of the bipedal support period. In this study of a single equine subject, eight-ounce shoes, eight-ounce shoes/pad and 16-ounce shoes/pad, applied

to the forefeet only, were associated with a diagonal gait that was not a true two-beat pattern.

Duration of Suspension Phase

The suspension phase represents the period of time when the horse has no physical contact with the ground surface. The suspension period is named for the preceding forelimb. Table 10 presents a comparison of the suspension period for each condition.

Table 10. Duration of the suspension phase of right and left diagonal of one equine subject (msec).

CONDITION	Left Diagonal	Right Diagonal	Average
Barefoot	15 msec	25 msec	20 msec
8 ounce	25 msec	25 msec	25 msec
16 ounce	10 msec	45 msec	27.5 msec
8 ounce/pad	35 msec	25 msec	30 msec
16 ounce/pad	55 msec	25 msec	40 msec

The smallest average suspension period of 20 msec was recorded for the barefoot condition. Longer periods of suspension, 25 msec in the balanced/8-ounce and 27.5 msec in the 16-ounce condition, were recorded.

In the eight-ounce/pad condition, the suspension period was 30 msec. The greatest suspension period, 40 msec, was recorded in the 16-ounce/pad condition.

Drevemo, Fredricson, Dalin and Bjorne (1980b) reported the suspension period in Standardbred trotters moving at racing speed to

be 99 msec, and that a horse may have a stronger diagonal which would result in a longer suspension period. In this study of a single equine subject increased shoe weight was associated with a greater suspension phase.

The suspension period recorded during the padded conditions was greater than in either of the balanced weight conditions. The longer suspension period might be attributed to a training effect. The padded conditions were the last two trials to be filmed which could have allowed the subject a longer period of time to adapt to the increased shoe weight.

Figure 9 presents an overview of the temporal components of an average diagonal stride, including diagonal dissociation at initial foot contact, bipedal support, swing and suspension phases. The overall duration of the diagonal increased with increased horseshoe weight.

The use of the three-degree pad further increased the duration observed during the balanced weight condition. The increase in diagonal duration was apparently magnified due to the large increase in the suspension phase observed in the padded conditions.

As Figure 9 illustrates, the use of increased horseshoe weight resulted in an increased total stance period, although the subject's bodyweight was increasingly supported by a single hindleg due to the increased dissociation observed at initial foot contact was also present in the padded conditions.

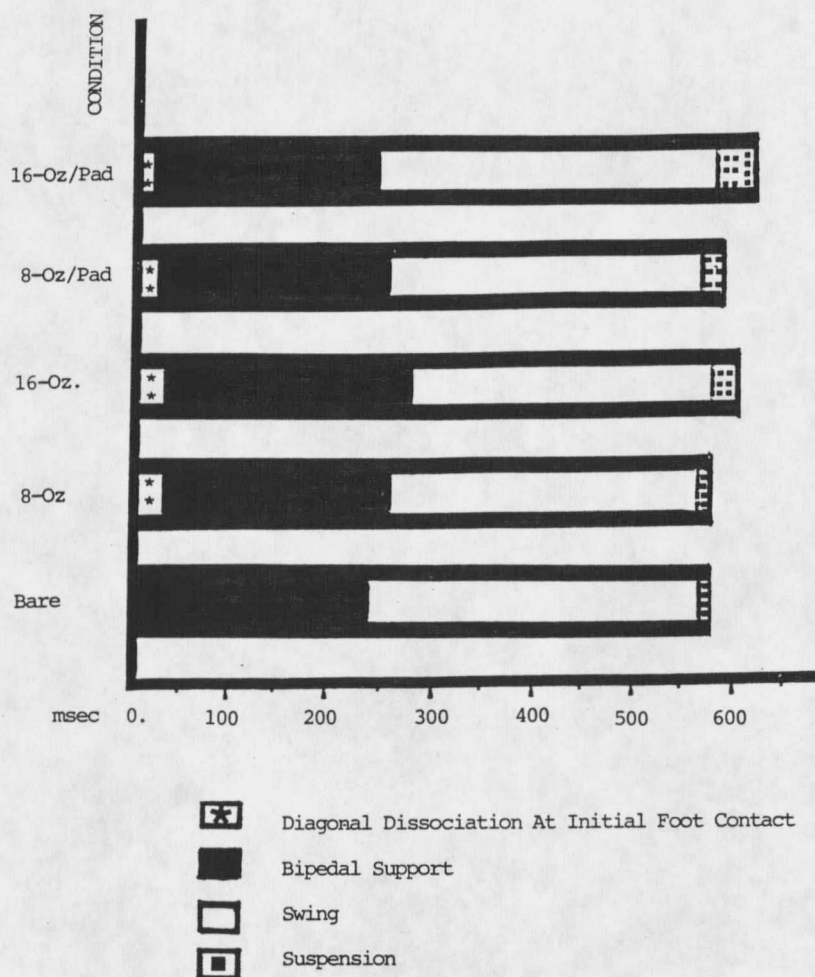


Figure 9. Overview of temporal components of average diagonal stride.

Linear Stride Characteristics

Linear stride characteristics represent the actual displacement of the foot. Characteristics investigated include step height, horizontal displacement of individual forestep and hindstep, and horizontal displacement of diagonal pairs.

Step Height

Table 11 presents a comparative overview of the vertical displacement of the right, left and average forestep for each condition. A vertical displacement of 0.16 meters was recorded for the barefoot condition. Greater vertical displacement of the toe, 0.17 meters in the 8-ounce and to 0.195 meters in the 16-ounce condition, were recorded. The vertical displacement of the foot in the padded conditions was also greater than the displacement recorded for the bare foot.

Table 11. Vertical displacement of forestep of one equine subject (meters).

CONDITION	Right	Left	Average
Barefoot	0.14	0.18	0.16
Bal/8 ounce	0.15	0.19	0.17
Bal/16 ounce	0.19	0.20	0.195
8 ounce/pad	0.16	0.21	0.185
16 ounce/pad	0.16	0.21	0.185

Table 12 shows the vertical displacement of the left, right and average hindstep. The smallest average vertical displacement, 0.12 meters, was recorded for the bare/forefoot condition. The greatest height, 0.135 meters, was recorded for both the balanced/16-ounce and the 8-ounce/pad conditions.

Table 12. Vertical displacement of hindstep of one equine subject (meters).

CONDITION	Right	Left	Average
Barefoot	0.14	0.10	0.12
Bal/8 ounce	0.12	0.14	0.13
Bal/16 ounce	0.15	0.12	0.135
8 ounce/pad	0.14	0.13	0.135
16 ounce/pad	0.12	0.13	0.125

The displacement exhibited by this equine subject supports Butler's (1976) and Adam's (1971) statement that increased horseshoe weight results in increased step height. An increase in vertical displacement was not registered between the light and heavy plates when three-degree pads were used.

It was interesting to note that the hindfoot also increased its vertical displacement although remaining bare in all cases. To the researcher's knowledge, the "cross-over" effect of increased forefoot shoe weight on the unshod hindfoot is previously unreported.

A comparative illustration of the height of forestep and diagonal hindstep is presented in Figure 10. The vertical displacement of the hindfeet remained at all times less than that of the forefeet. The vertical displacement of both the forefoot and bare hindfoot was greater in the weighted conditions, both with the pad and without, as compared with the original barefoot displacement.

In the barefoot state, the percentage of vertical displacement of hindstep to forestep was 75%. A slightly greater percentage of

76% was recorded for the balanced/8-ounce condition. A smaller percentage, 69%, was recorded for the balanced/16-ounce. A total of 72% was recorded for the 8-ounce/pad condition, a total of 4% from the balance 8-ounce condition. The minimum percentage (67%) of forefoot/hindfoot vertical displacement was produced in the 16-ounce/pad condition, a total of 2% from that of the balanced 16-ounce.

Horizontal Displacement of Individual Limbs

The horizontal displacement of each limb and the average forefoot and hindfoot displacement is presented in Table 13. The average horizontal displacement of the toe of the forefoot decreased from 2.37 meters in the barefoot condition to 2.34 meters in the balanced/8-ounce and to 2.32 meters in the balanced 16-ounce. A displacement of 2.38 meters was measured for the 8-ounce/pad condition, an increase of 0.06 meters more than the barefoot displacement. The horizontal displacement recorded for the 16-ounce/pad condition was 2.29 meters, a decrease of 0.08 meters from the barefoot placement.

The average horizontal displacement of the hindstep varied according to the shoe weight carried by the forefoot. When the forefoot carried eight-ounce shoes, whether padded or balanced, the horizontal displacement of the hindstep was 0.01 meters greater than that observed in the barefoot condition. The forefoot with 16-ounce shoes with and without the pad did not change the horizontal displacement of the hindfoot.

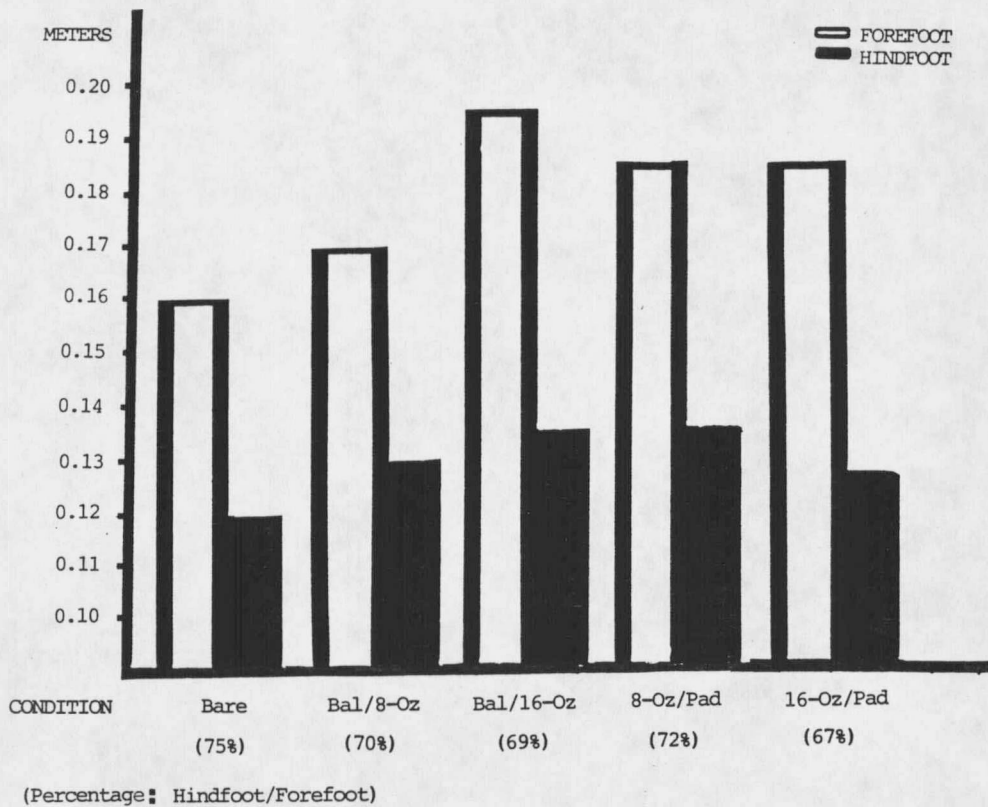


Figure 10. Vertical height of average forestep and diagonal hindstep (meters).

Table 13. Horizontal displacement of individual limbs of one equine subject (meters).

CONDITION	RF	LF	AVE.	RH	LH	AVE.
Barefoot	2.73	2.01	2.37	1.97	2.68	2.32
Bal/8 ounce	1.99	2.70	2.34	2.65	2.02	2.33
Bal/16 ounce	2.02	2.63	2.32	2.67	1.98	2.32
8 ounce/pad	2.79	1.97	2.38	1.93	2.79	2.36
16 ounce/pad	1.95	2.64	2.29	2.69	1.96	2.32

According to Butler (1976) and Adams (1971), increased horseshoe weight is thought to increase the length (horizontal distance) of the

stride. That supposition was not supported by the data produced by this equine subject. In this study, the horizontal displacement of the forefoot carrying additional shoe weight decreased, while the displacement of the bare hindfoot remained the same or slightly larger.

Diagonal Length

The horizontal displacement or length of one complete diagonal stride includes the linear displacement of both diagonal limbs. Table 14 presents the horizontal displacement of each diagonal pair and the average displacement of the diagonal stride.

Table 14. Horizontal displacement of the left and right diagonal pair of one equine subject (meters).

CONDITION	Left	Right	Average
Barefoot	2.94	3.43	3.185
Bal/8 ounce	3.52	2.72	3.120
Bal/16 ounce	3.42	2.88	3.150
8 ounce/pad	2.85	3.56	3.205
16 ounce/pad	3.43	2.80	3.115

Compared with the barefoot condition, the subject in the eight-ounce condition showed a 0.06 meter decrease in horizontal displacement of the diagonal stride. With the 16-ounce shoes, the subject displayed a displacement of 3.150 meters, which was 0.035 meters shorter than the barefoot diagonal stride.

The minimum horizontal displacement of an average diagonal stride, 3.115 meters, was recorded for the 16-ounce/pad condition. The subject displayed the greatest horizontal displacement of 3.205 meters while wearing the eight-ounce/pad shoes. Figure 11 illustrates the comparison of diagonal length as associated with increased weight and decreased pastern angle.

According to Butler (1976) and Adams (1971), additional horseshoe weight is thought to increase the length of the stride. The data generated by this equine subject showed decreased horizontal displacement of the diagonal stride to be associated with increased horseshoe weight.

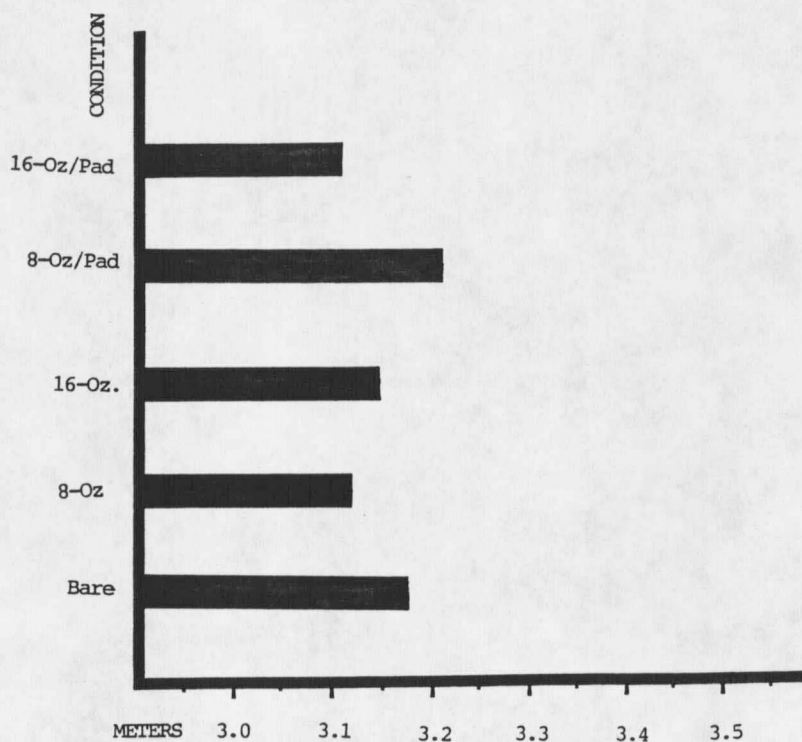


Figure 11. Horizontal displacement of average diagonal pair.

To the researcher's knowledge, no previous studies describe the relationship of decreased pastern angle with the horizontal displacement of a diagonal stride. The equine subject in this study displayed the shortest horizontal diagonal stride when wearing the 16-ounce shoe/pad combination and the greatest displacement while wearing the eight-ounce shoe/pad.

Therefore, it might be suggested in this case that the eight-ounce shoe/pad was the optimal condition for maximal horizontal displacement of a diagonal stride. It might also be surmised that the greater inertia of the 16-ounce shoe/pad condition was such that it shortened the horizontal displacement of the diagonal stride.

Kinematics of the Left Forelimb

The kinematic data were obtained from the film generated during the pilot study. Therefore, the conditions are limited to the barefoot and the balanced/16-ounce shoes.

During a single cycle of the forelimb's movement, the carpal and fetlock joints move from an extended position at toe-off, through the limb's ascent into maximum flexion and then extending through its descent until the limb again contacts the ground surface. The following description of the kinematics of the left forelimb consists of the angular displacement of the carpal, fetlock, anterior and posterior pastern/coffin joints, the angular velocity of that displacement, and the linear velocity of the carpal, fetlock and anterior tip of the hoof.

Angular Displacement

Figure 12 is an illustration of the angular displacement of the carpal joint in the barefoot and sixteen-ounce conditions. A comparative illustrative of the maximum angulation of the carpal joint is shown in Figure 13.

In the fully extended position at toe-off, the carpal joint baseline position was 181.9 degrees in the barefoot state. Maximum flexion in the barefoot condition was 263.7 degrees. Therefore, in the barefoot condition, the total range-of-motion of the carpal joint was 81.8 degrees.

The baseline extended position in the 16-ounce condition was 177.4 degrees and the maximum flexion was 263.9 degrees. Total carpal range-of-motion for the 16-ounce state was 86.5 degrees

The angular displacement of the fetlock joint in the barefoot and 16-ounce conditions in Figure 14. Figure 15 illustrates a comparison of the maximum angulation of the fetlock joint.

The baseline position for the fetlock joint at toe-off was 124.4 degrees in the barefoot state and 100.0 degrees in the 16-ounce. Maximal fetlock flexion in the barefoot condition was 204.2 degrees and 222.4 degrees in the 16-ounce. Range-of-motion of the fetlock joint in the barefoot state was 79.8 degrees and 122.5 degrees in the heavier state.

The angular displacement of the anterior pastern/coffin joint in the barefoot and 16-ounce state is presented in Figure 16. The graphical comparison of the posterior pastern/coffin joint angular displacement is shown in Figure 17.

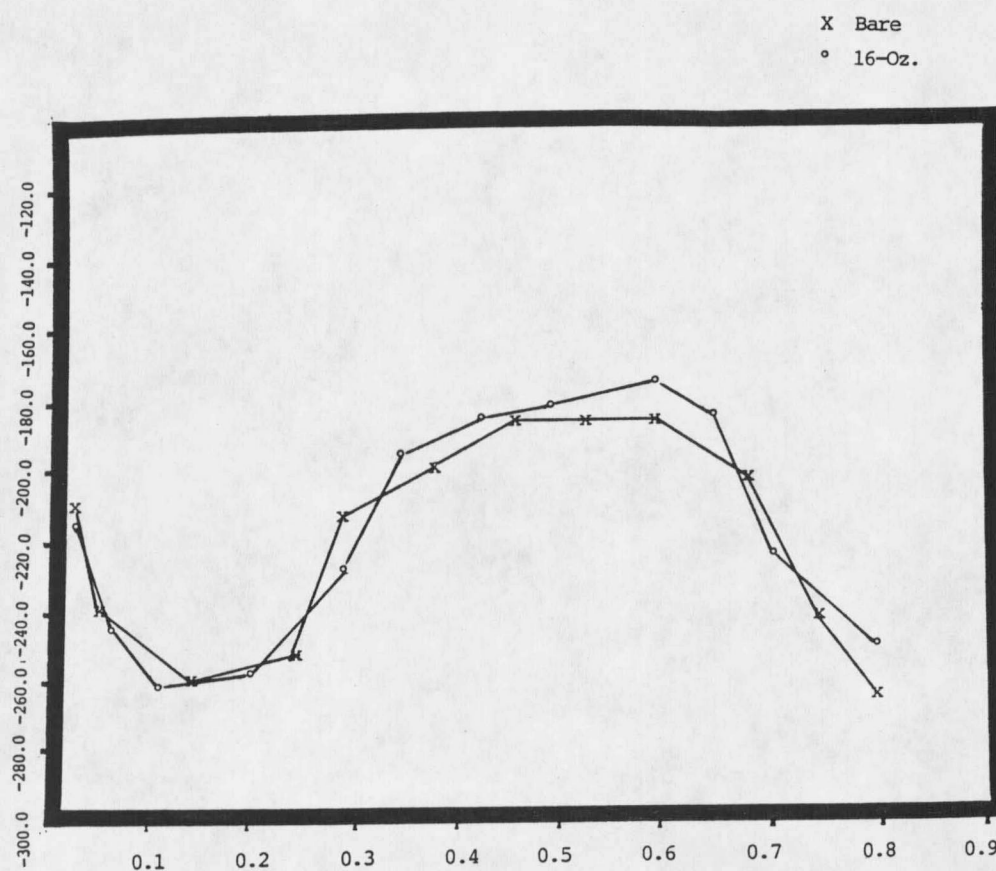
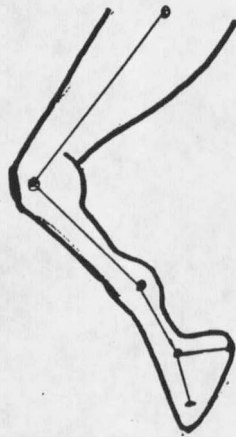


Figure 12. Angular displacement of the carpal joint in the barefoot and 16-ounce conditions.

 Barefoot



✂'s:

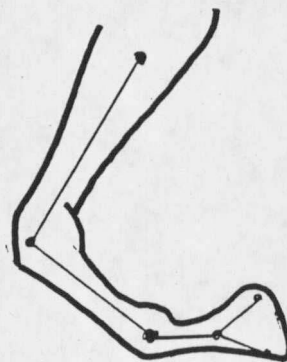
*Carpal - 263°

Fetlock - 165°

Ant. P/C - 168°

*Post. P/C - 250°

 16-ounce



✂'s:

*Carpal - 263°

Fetlock - 221°

Ant. P/C - 159°

Post. P/C - 221°

*'s = Max. ✂ displacement

Figure 13. Maximum carpal joint angular displacement in barefoot and 16-ounce conditions.

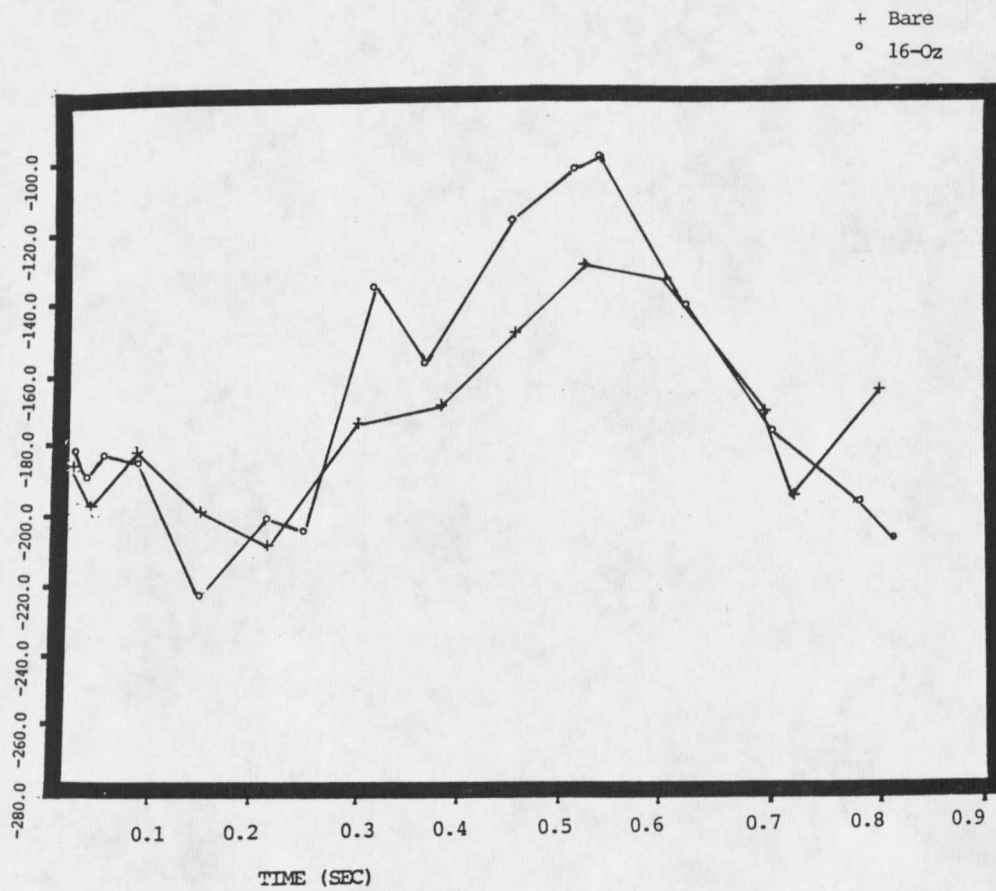
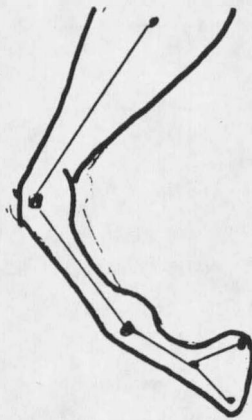


Figure 14. Angular displacement of fetlock joint in barefoot and 16-ounce conditions.

Bare



°'s:

Carpal - 250°

*Fetlock - 204°

Ant. P/C - 169°

Post. P/C - 237°

16-Ounce



°'s:

Carpal - 263°

*Fetlock - 222°

Ant. P/C - 138°

Post. P/C - 221°

Figure 15. Maximum fetlock joint angulation.

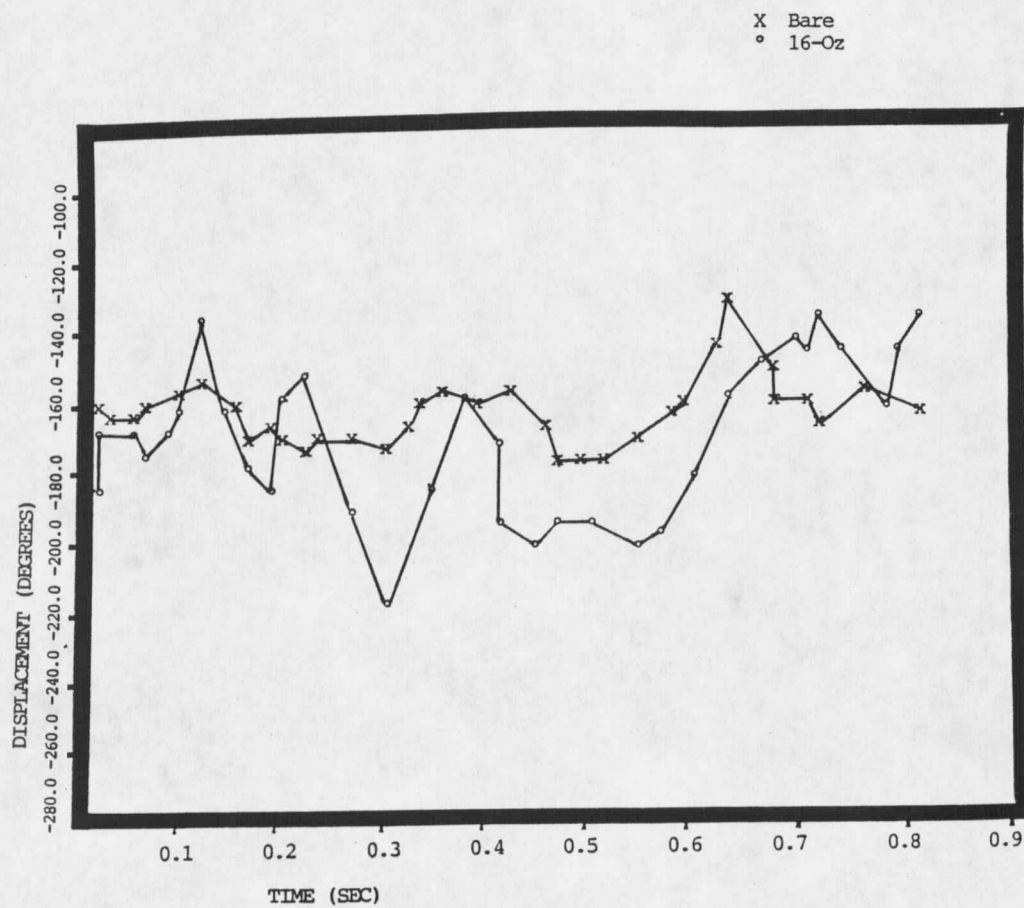


Figure 16. Angular displacement of anterior pastern/coffin joint in barefoot and 16-ounce conditions.

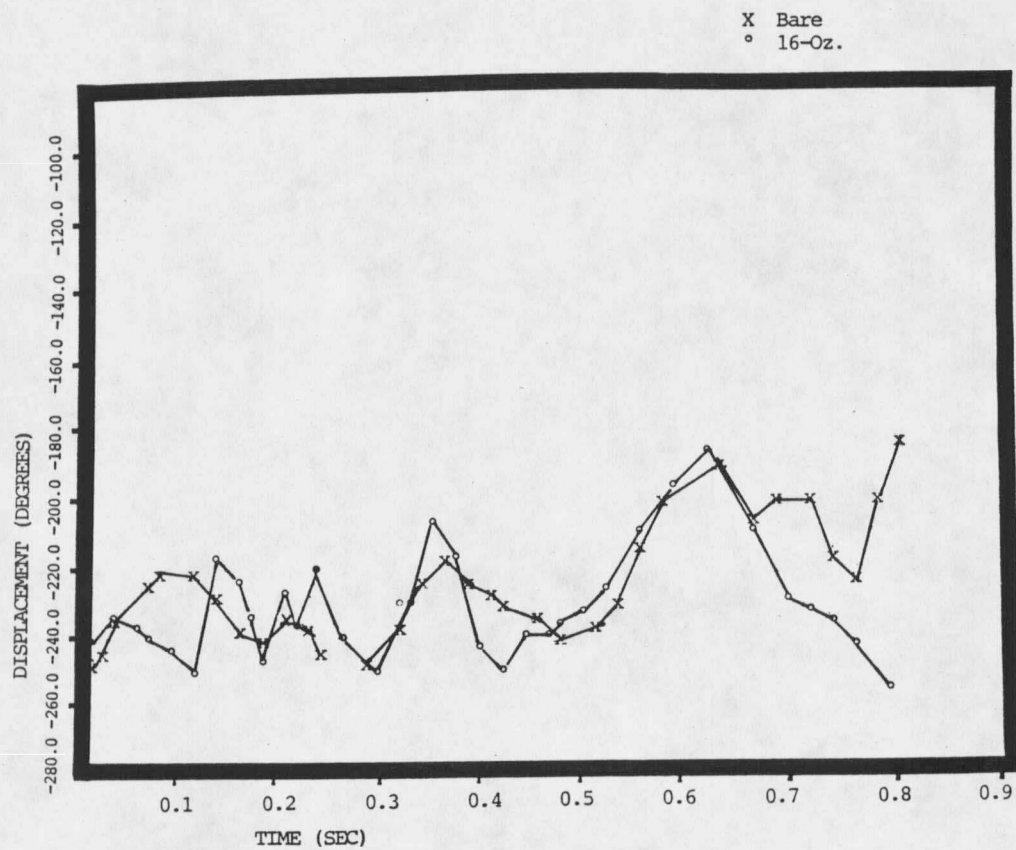


Figure 17. Angular displacement posterior pastern/coffin joint barefoot and 16-ounce.

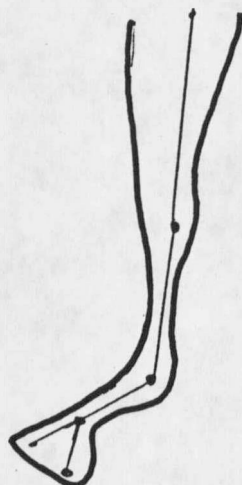
The angular displacement of the anterior pastern/coffin joint in the barefoot condition ranged from 133.4 degrees to 179.1 degrees, an amplitude of 45.7 degrees. The total range-of-motion in the 16-ounce condition was 80.7 degrees, from a lower limit of 138.7 degrees to an upper limit of 219.4 degrees. Figure 18 illustrates a comparison of the maximum angulation of the anterior pastern/coffin joint.

Angular displacement of the barefoot posterior pastern/coffin joint was 52.6 degrees, from 198.2 degrees to 250.8 degrees. In the 16-ounce condition, the total range-of-motion of the posterior pastern/coffin joint was 65.7 degrees, from 189.8 degrees to 255.5 degrees.

The angle-angle diagrams presented in Figures 19 and 20 show the relationship of the angulations of the carpal and fetlock joints in the barefoot and 16-ounce conditions, respectively.

Figure 19 shows the action of the carpal and fetlocks joints in the barefoot condition. From point 1 to 2, the carpal joint flexes while the fetlock stays relatively unchanged. From point 2 to 3, the carpal remains stable while the fetlock flexes. The sloping ascent of the line from 3 to 4 indicates both the carpal and fetlock to be extending as the limb descends into the stance position. The sloping descent of the line from 4 to 5 shows the carpal and the fetlock to be flexing as the limb begins to ascent. From 5 to 6, the carpal continues to flex and the fetlock extends as the limb moves through the swing phase.

 Barefoot



✂'s:

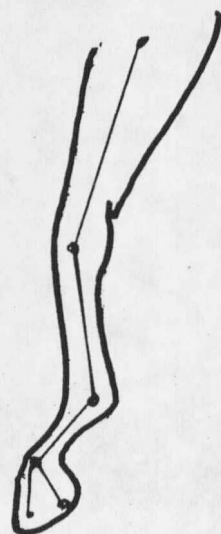
Carpal - 183°

Fetlock - 126°

*Ant. Pastern/Coffin - 179°

Post. Pastern/Coffin - 244°

 16-ounce



✂'s:

Carpal - 206°

Fetlock - 133°

*Ant. Pastern/Coffin - 219°

*Post. Pastern/Coffin - 255°

Figure 18. Maximum angulation of the anterior pastern/coffin joint in the barefoot and 16-ounce conditions.

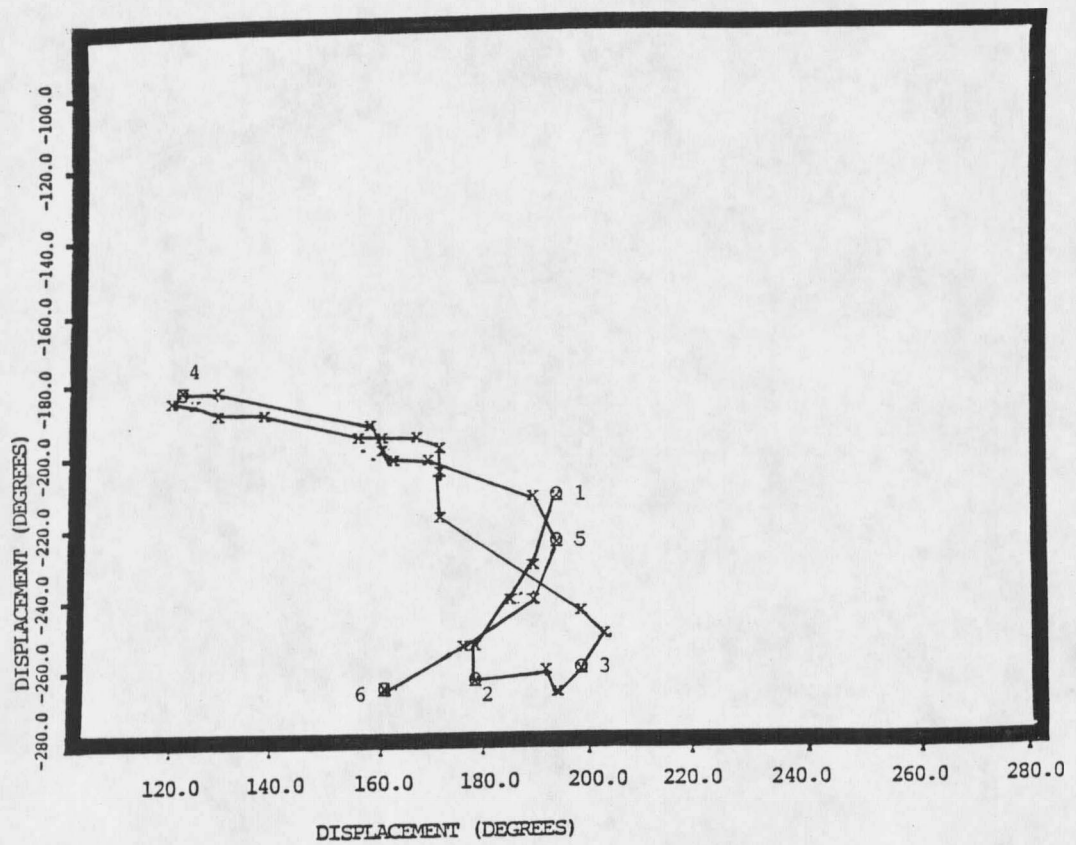


Figure 19. Angle-angle carpal (Y)/fetlock barefoot.

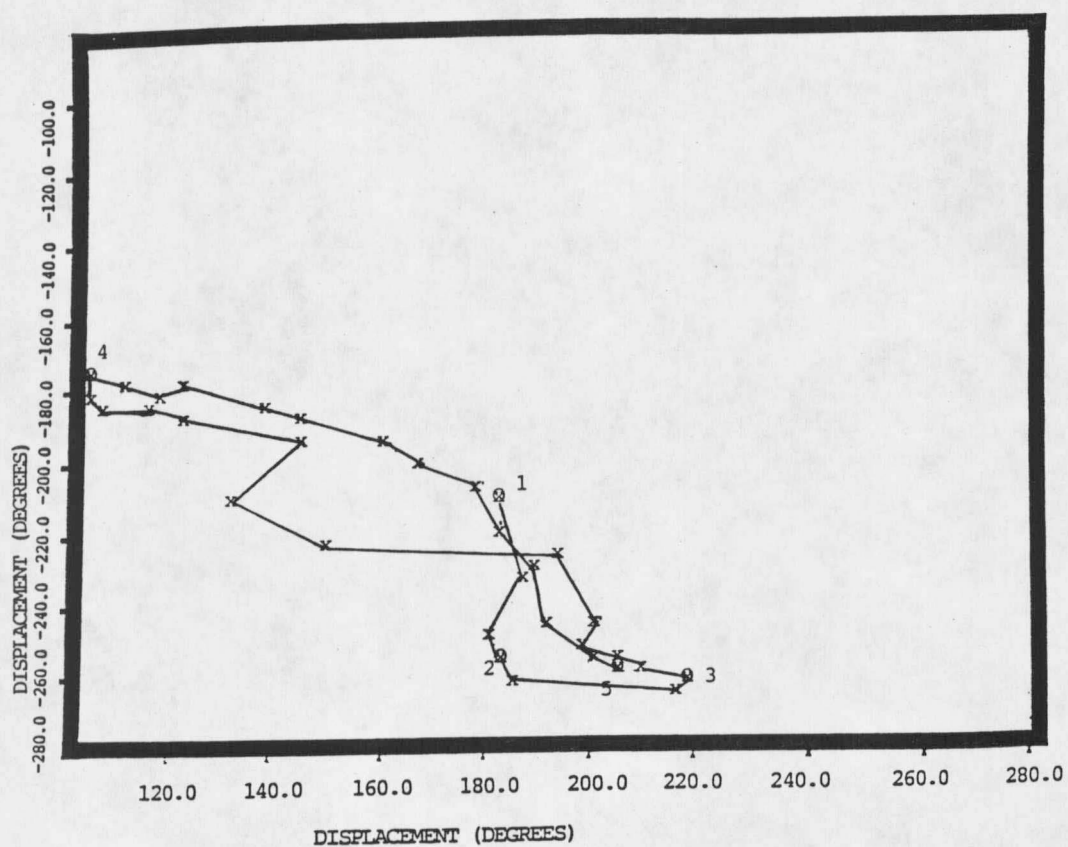


Figure 20. Angle-angle carpal (Y)/fetlock 16 ounce.

A similar pattern of movement is followed by the limb while wearing 16-ounce shoes, as shown in Figure 20. The sequential movement of carpal flexion (points 1 to 2) then fetlock flexion (2 to 3) is very similar. The simultaneous extension of the two joints (joint 3 to 4) is also similar with the exception of a 50 msec period of fetlock flexion. From points 4 to 5, both of the joints flex into the swing phase.

The angle-angle diagrams for the two conditions are very similar with the exception of the final portion of the swing phase. The 16-ounce condition shows a continual flexion of the fetlock joint. This occurrence explains the tightly flexed appearance of the forelimb swing while the subject wore the heavier shoes.

This subject displayed increased range-of-motion of the joints of the left forelimb with additional horseshoe weight. As Butler (1976) and Adams (1971) stated, a common practice in the competitive show ring of fine saddle and harness horses is the application of weighted shoes in an attempt to maximize the natural animation of the equine's gait. Review of the data shows that increased shoe weight produced increased amplitude of motion in the carpal, fetlock, anterior and posterior pastern/coffin joints of the forelimb. Therefore, the results of this study support the theory behind the common use of weighted shoes.

Angular Velocity

In the barefoot state, as the limb ascended into total flexion, carpal joint angular velocity reached a maximum of 577.2

degrees/second. Maximum angular velocity of the carpal joint during the ascent phase was 645.2 degrees/second in the 16-ounce condition. Figure 20 presents the velocity of angulation of the carpal joint in the barefoot and 16-ounce conditions.

As the carpal joint extended through the descent phase of the stride, the angular velocity reached a maximum of 479.0 degrees/second in the barefoot state and 507.4 degrees/second in the 16-ounce.

Angular velocity of fetlock joint displacement in the barefoot and 16-ounce conditions is graphically presented in Figure 21. Fetlock angular velocity reached a maximum of 507.7 degrees/second during the ascent phase in the barefoot state, as compared with 681.8 degrees/second in the 16-ounce condition.

During the descent phase, as the fetlock joint extended toward regaining ground contact, peak angular velocity in the barefoot condition was 495.4 degrees/second, as compared with 1,024.0 degrees/second in the 16-ounce state.

The maximum angular velocity of the anterior pastern/coffin joint moving through the ascent phase was 540.3 degrees/second in the barefoot state and 633.8 degrees/second in the 16-ounce condition. During the descent phase, the angular velocity peaked at 249.6 degrees/second in the barefoot and 969.3 degrees/second in the 16-ounce condition.

The posterior pastern/coffin joint reached a maximum angular velocity during the ascent phase of 600.5 degrees/second in the barefoot condition and 724.2 degrees/second for the 16-ounce state.

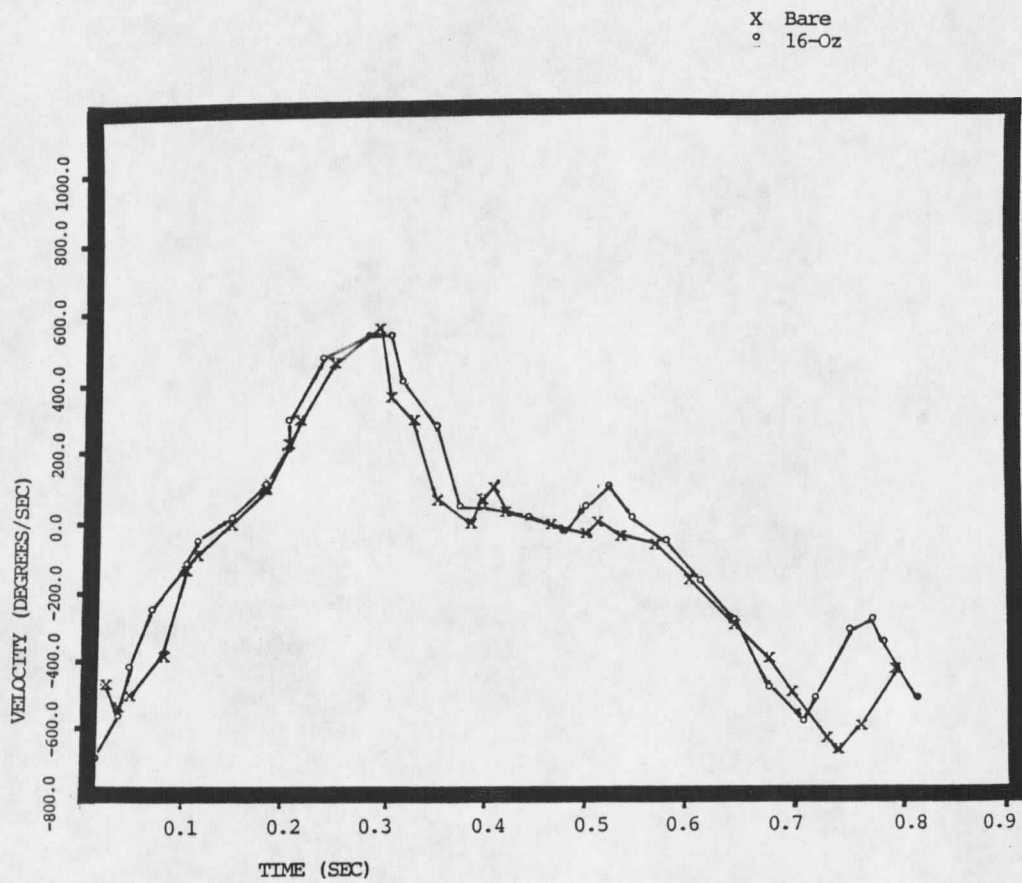


Figure 21. Angular velocity carpal joint barefoot and 16 ounce.

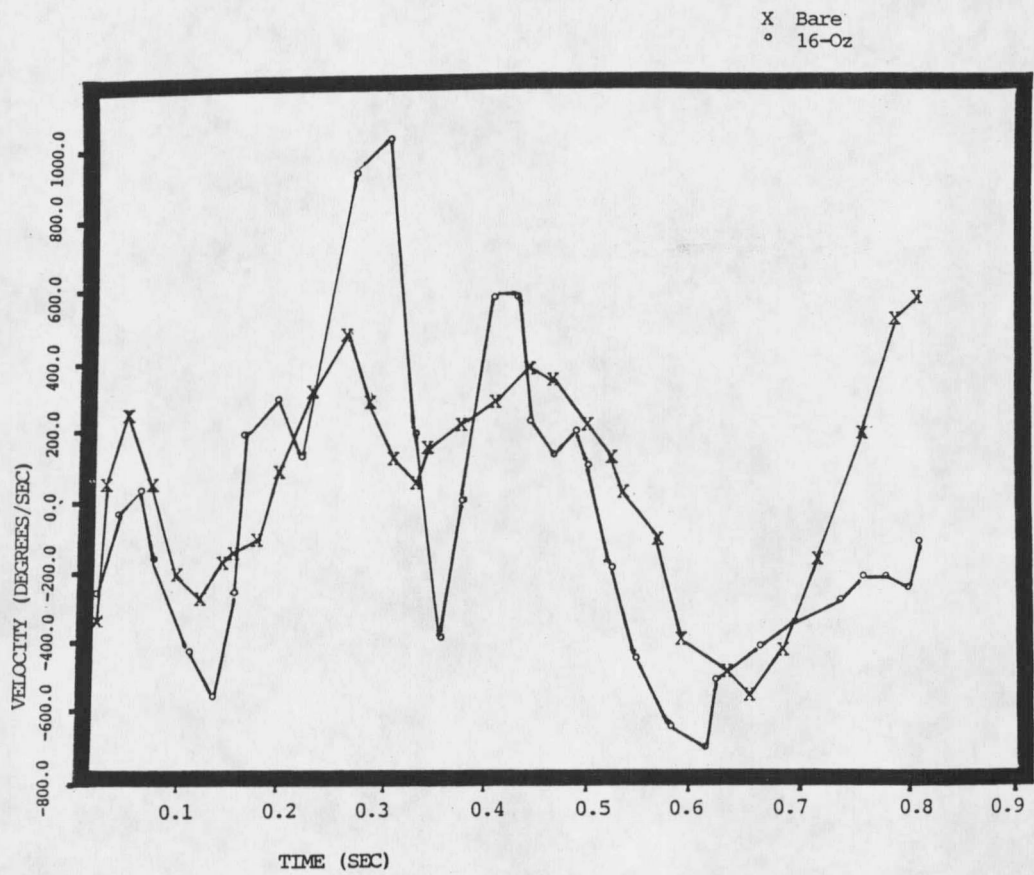


Figure 22. Angular velocity fetlock joint barefoot and 16-ounce.

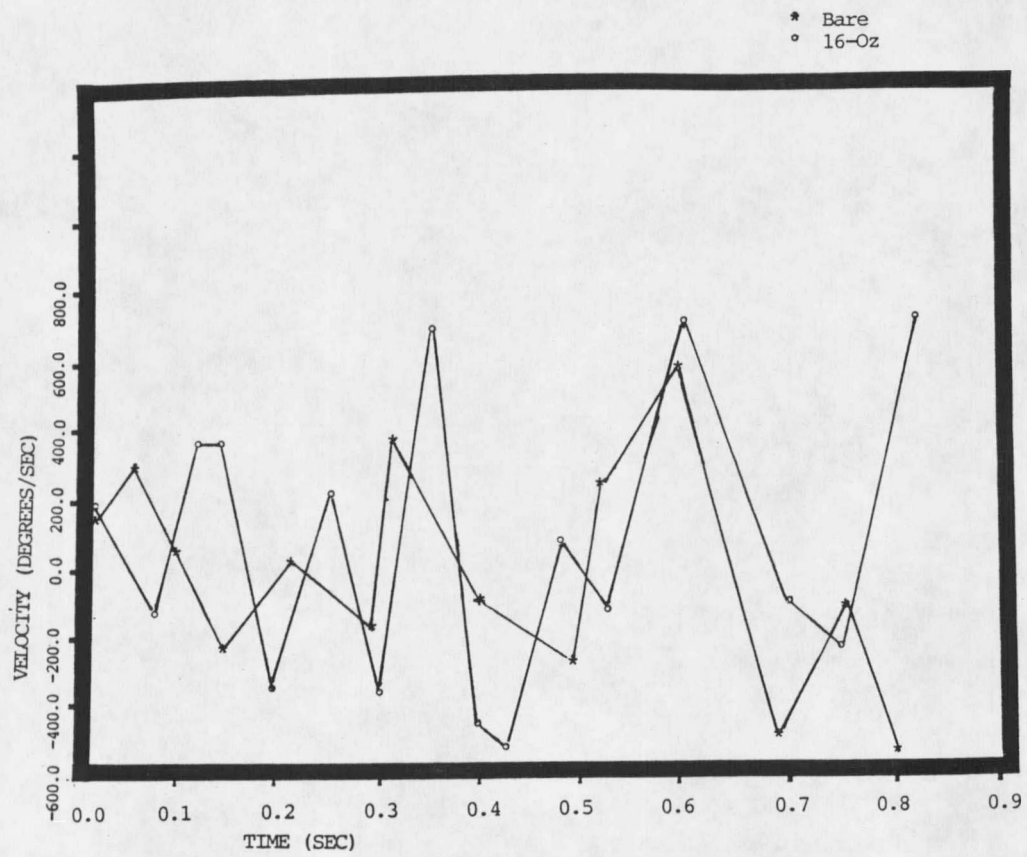


Figure 23. Angular velocity posterior pastern/coffin joint barefoot and 16 ounce.

Figure 23 shows the graphical comparison of the angular velocity of the posterior pastern/coffin joint during the barefoot and 16-ounce conditions. Maximum angular velocity during the descent phase was 367.7 degrees/second in the barefoot and 693.9 degrees/second in the 16-ounce condition.

Butler (1976) theorized that increased horseshoe weight produced a "knee-snapping" action. According to the data, the so-called "snapping" action of the carpal joint resulted from a decreased angular velocity during the ascent phase and a corresponding increase in velocity during the descent phase. The disparity between the two phases results in a transition phase that appears to be quick or "snappy."

The increased angular velocity of the joints distal to the carpal joint also contributed to the "snappiness" of the trot with the weighted shoes. The increased range-of-motion and the increased angular velocity of each joint resulted in forelimb motion that appeared more "animated" when compared with the barefoot gait.

Linear Velocity of Carpal, Fetlock and Tip of the Hoof

The resultant linear velocity of the carpal, fetlock and tip of the hoof for the barefoot condition is illustrated in Figure 24 and the 16-ounce condition in Figure 25. Phase 1 is the ascent phase of the step, Phase 2 is the descent phase to foot contact with ground surface and Phase 3 is the ascent phase following toe-off.

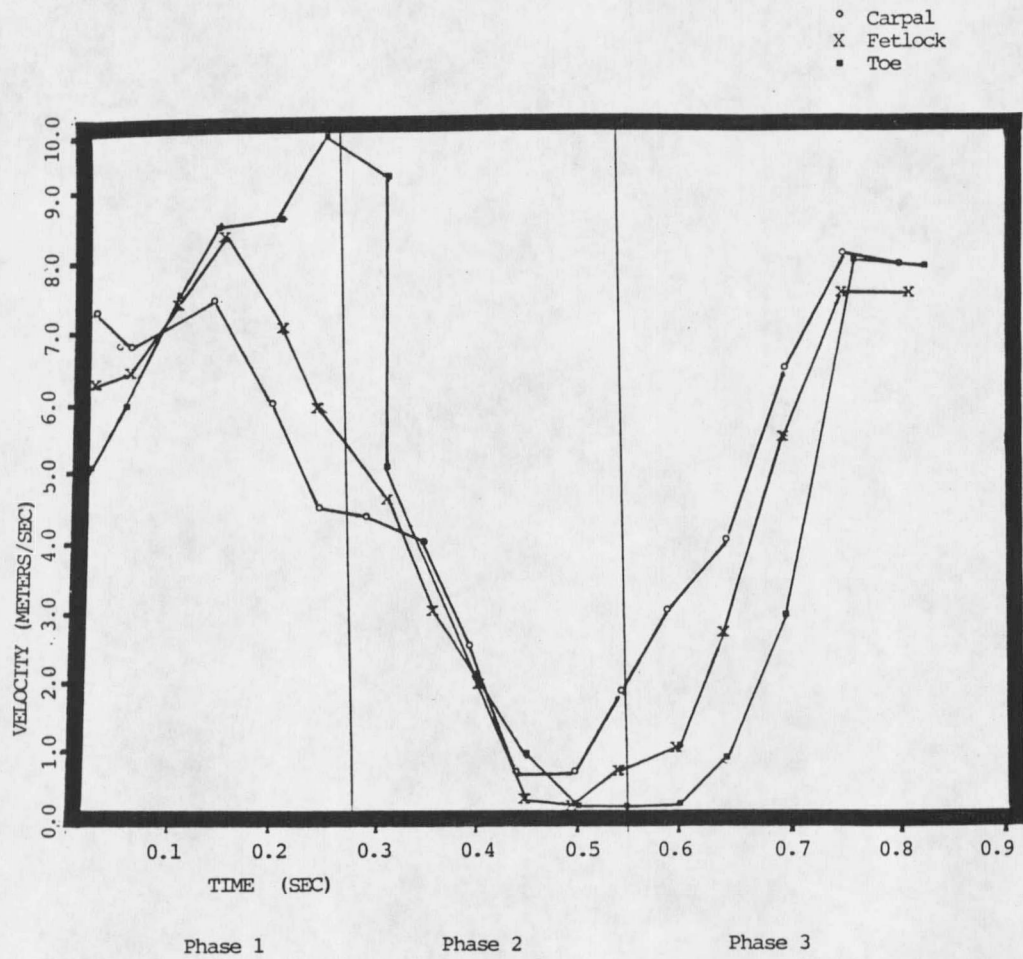


Figure 24. Resultant linear velocity of carpal-fetlock-toe in the barefoot condition.

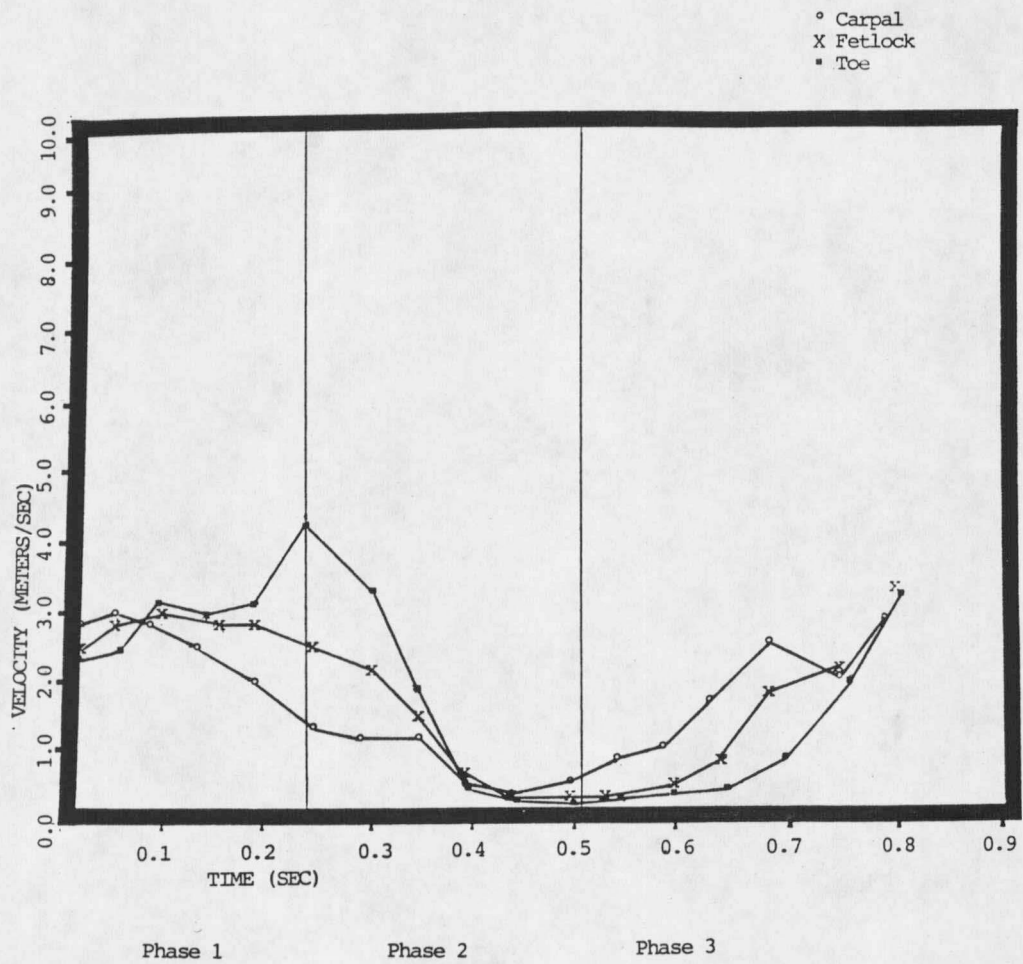


Figure 25. Resultant linear velocity of the carpal-fetlock-toe in the 16-ounce condition.

At the beginning of Phase 1 in both conditions, the carpal moved at the greatest velocity followed sequentially by the fetlock and toe. At the mid-point of Phase 1 the velocity of the carpus was decreasing while the fetlock and toe were increasing.

Kreighbaum and Barthels (1981) described the sequential interchange of velocity from proximal to distal segments as the kinetic link principle. A pattern of lagging back of the distal segments was present in both conditions and was observed in all three phases.

The lagging back of the toe compared with the fetlock was greatest at mid-swing, (the end of Phase 1) and at toe-off, (the beginning of Phase 3) in the both conditions. The decreased linear velocity of the limb while carrying the heavier 16-ounce shoe may be attributed to the increased inertia of the foot carrying the heavier 16-ounce shoe.

Arc of the Foot in Flight

Figure 26 presents a two-dimensional illustration of the arc of the forefoot in flight, as changed with increased horseshoe weight. As the diagram illustrates, increased horseshoe weight was associated with increased height of the arc, as well as a steeper slope of ascent to the height of the step.

The curves of the barefoot and those of the weighted shoes appear to follow the same general pattern of flight. However, the additional weight of the 16-ounce shoe exaggerated the height of the first one-half of the arc. The association of increased shoe weight

with an amplification of the arc of foot flight displayed by this subject supports the common practice of applying weighted shoes in order to increase the animation of the forestep of fine harness and saddle horses.

According to Butler (1976), the use of a "toe-weighted" shoe would result in increased height of the last one-half of an individual stride. As presentation of the data in Figure 26 shows the first one-half of the stride increased more than the last one-half.

Figure 27 illustrates the arc of flight of the forefoot while wearing the shoe/pad versus the balanced/barefoot arc. According to Butler (1976), the application of the three-degree pad would lower the heels and supposedly result in increased height of step and decreased stride arc. The arc of flight observed in this subject while wearing the 16-ounce shoe/pad appeared smoother in the descent phase of the step and followed the general, exaggerated arc demonstrated by the balanced 16-ounce condition.

Summary

The results of the data analysis were presented under the categories of temporal and linear stride characteristics, general kinematics of the left forelimb, and a two-dimensional illustration of the arc of the foot in flight.

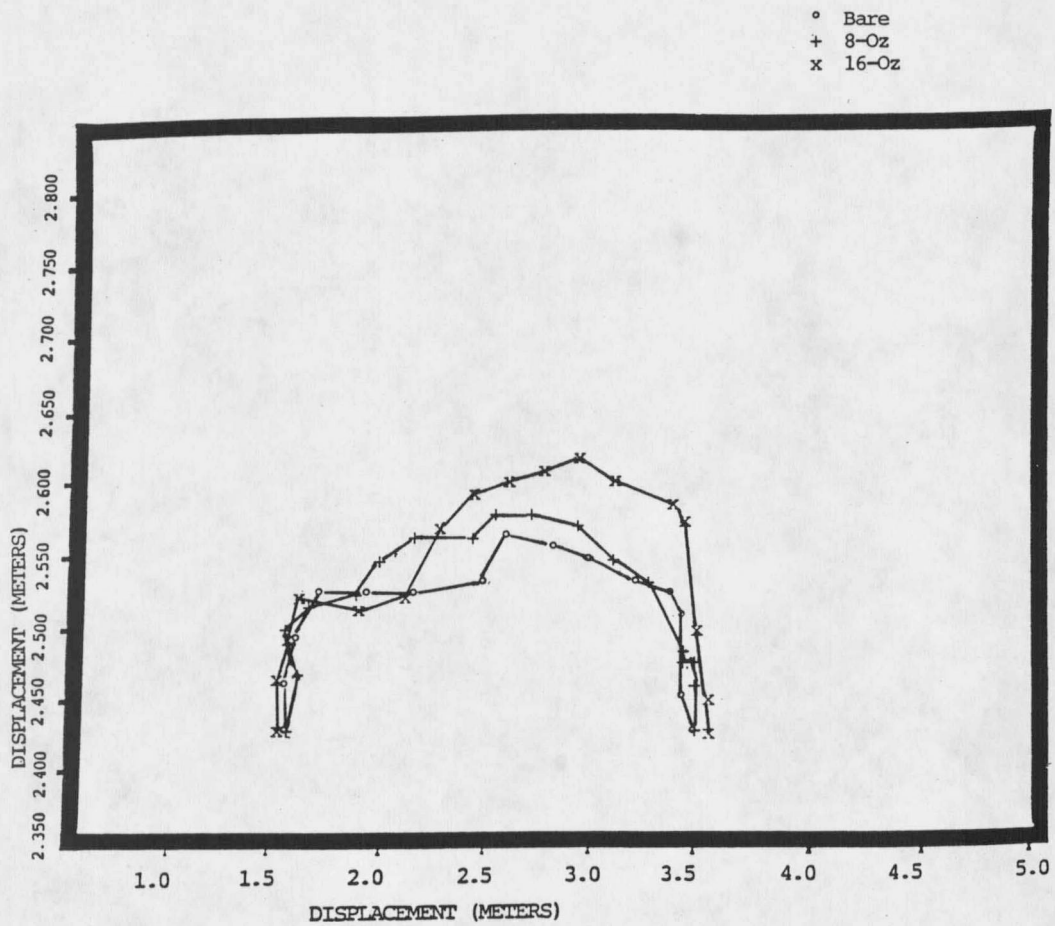


Figure 26. Arc of flight of the left forefoot toe in bare, 8-ounce, and 16-ounce state.

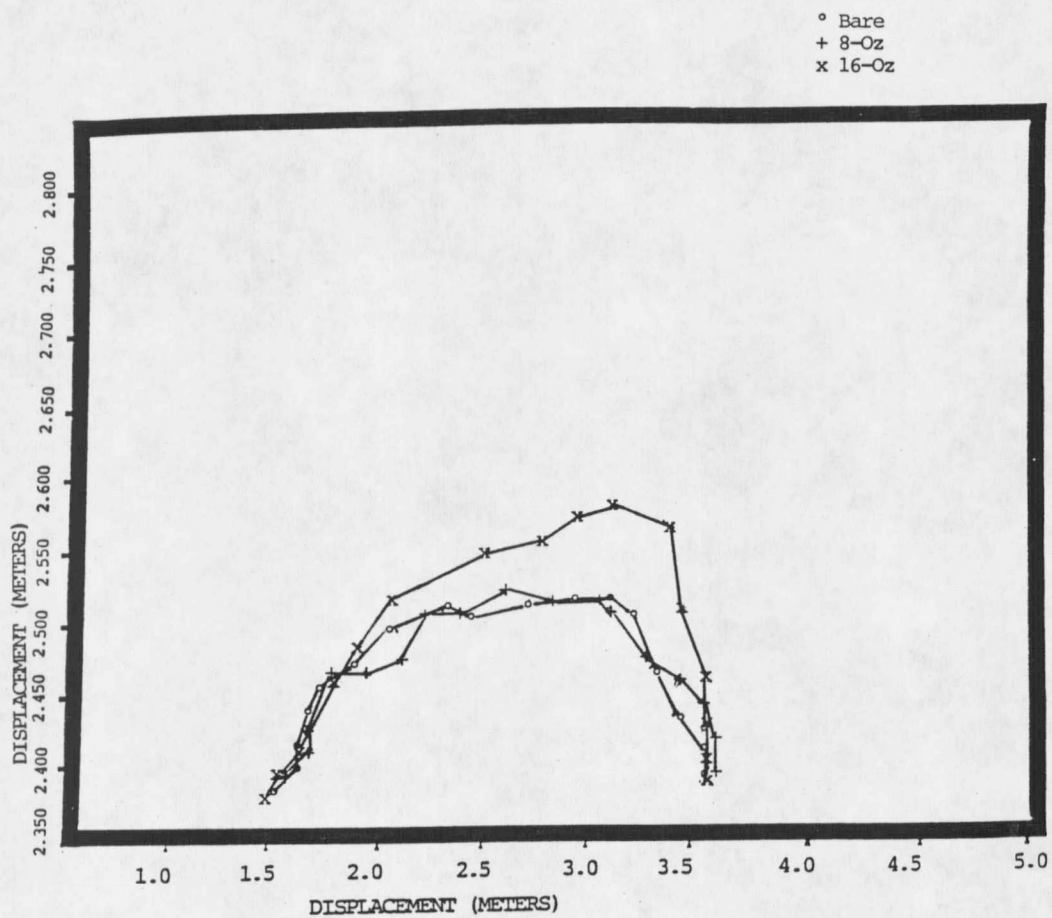


Figure 27. Arc of flight of left forefoot toe in bare, 8-ounce/pad and 16-ounce/pad.

The following review highlights changes in stride characteristics as brought about by the balanced/16 ounce shoes.

Increased horseshoe weight was seen with INCREASED duration of:

- a) diagonal dissociation at initial foot contact
- b) diagonal swing duration
- c) stance of the forefoot
- d) stance of the unaffected hindfoot
- e) bipedal support
- f) suspension

Also observed in the 16-ounce condition were increased:

- a) vertical displacement of forestep
- b) vertical displacement of unaffected hindstep
- c) deceleration period
- d) angular displacement of carpal, fetlock, anterior and posterior pastern/coffin joints
- e) angular velocity of carpal, fetlock, anterior and posterior pastern/coffin joints
- f) "lagging back" of joints distal to the carpus
- g) height of the first one-half of the arc of the foot in flight

Increased horseshoe weight was seen with DECREASED:

- a) swing duration of forestep
- b) duration of propulsion period
- c) horizontal displacement of forestep
- d) horizontal displacement of diagonal stride

Increased shoe weight did not change the diagonal dissociation at toe-off.

The use of the three-degree pad/16-ounce shoes was associated with INCREASED duration of:

- a) swing of forefoot and unaffected hindfoot
- b) diagonal swing
- c) stance of unaffected hindfoot
- d) suspension

Also observed in the pad/16-ounce condition were INCREASED:

- a) vertical displacement of forefoot.
- b) vertical displacement of unaffected hindfoot

And DECREASED:

- a) diagonal dissociation at initial foot contact, as compared with balanced/16-ounce
- b) stance duration of forefoot
- c) duration of bipedal support
- d) horizontal displacement of forefoot
- e) horizontal displacement of diagonal pair

The pad/16-ounce condition did not change the diagonal dissociation at toe-off.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary of Findings

The initial objective of this study was to develop a filming that produced film footage that would allow accurate biokinematical analysis of equine gait. The study was only partially successful in that adjustments in the amount and type of analysis that was done were necessitated due to the quality of the available film footage.

Accurate, efficient analysis of the film data was accomplished through a digitization process and the Filmdata software program. General limb kinematics, temporal and linear stride characteristics, and the two-dimensional illustration of the arc of the foot in flight were presented.

A summary of the specific findings of this study are as follows:

1. Increased horseshoe weight increased the diagonal dissociation observed at initial foot contact. Thus, the subject supported his bodyweight on a single hindleg for a greater period of time.
2. The addition of a three-degree pad decreased the diagonal dissociation over that observed during the balanced weight conditions.

3. Increased horseshoe weight resulted in a decrease in the duration of the swing phase of the individual forestep. The hindfoot swing duration varied, decreasing slightly in the eight-ounce condition and increasing slightly in the 16-ounce.
4. Swing duration in the weight/pad conditions varied also, with a slight decrease in the pad/8-ounce condition and an increase in the 16-ounce/pad. Hindfoot swing duration changed consistently with contralateral forefoot.
5. Diagonal swing duration fluctuated inconsistently with increased shoe weight, decreasing slightly with the eight-ounce and increasing slightly with the 16-ounce shoes.
6. Diagonal swing duration increased steadily with the use of three-degree pads, with a maximum recorded during the 16-oz/pad condition.
7. Duration of the stance phase of the forefoot decreased in the balanced/8-ounce condition and increased in the balanced/16-ounce. The increased stance duration observed in the 16-ounce state suggests a slower breakover of the forefoot.
8. Duration of stance in the forefoot decreased steadily with the use of the three-degree pads. This decrease suggests a quicker breakover of the foot, despite the heel being lowered by the pad.
9. The hindfoot stance phase increased steadily with each change in forefoot shoeing condition. This change in

duration of the stance phase of the uninvolved foot suggests an intrinsic timing mechanism seeking to maintain the coordinated pattern between forefoot and diagonal hindfoot, rather than a mechanical alteration of the gait pattern.

10. Increased horseshoe weight showed an increased period of deceleration during the stance phase and a decreased period of propulsion.
11. The period of bipedal support fluctuated with the balanced/weight changes, decreasing in the eight-ounce condition and increasing in the 16-ounce.
12. The use of the three-degree pads showed a decreased period of bipedal support.
13. Increased horseshoe weight produced an increase in the diagonal suspension period. The greatest increase in diagonal suspension was evident with the addition of the three-degree pad.
14. Increased horseshoe weight showed an increase in vertical displacement of the forefoot during the swing phase. The three-degree pad also produced an increase in step height, as compared with the barefoot condition.
15. The vertical displacement of the bare hindstep increased slightly in both the increased horseshoe weight and the three-degree pad conditions of the forefoot.
16. The horizontal displacement of forefoot decreased with each of the increased shoeing conditions.

17. The horizontal displacement of the forefoot increased with the eight-ounce/pad and decreased with the 16-ounce/pad.
18. The horizontal displacement of the individual hindstep increased in both of the eight-ounce conditions, and remained unchanged in the 16-ounce conditions.
19. The horizontal displacement of a diagonal stride decreased with increased horseshoe weight.
20. The horizontal displacement of an average diagonal stride increased with the eight-ounce/pad and decreased to a minimum with the use of the 16-ounce/pad.
21. Increased horseshoe weight produced an increase in angular displacement in the carpal, fetlock, anterior and posterior pastern/coffin joints.
22. Angular velocity of carpal flexion during the ascent phase of the forelimb stride, and decreased during the descent phase.
23. Angular velocity of the fetlock, anterior and posterior joints increased in both the ascent and descent phases of an individual forestep.
24. The increased horseshoe weight increased the "lagging back" of the distal segments during individual forestep.
25. The arc of the foot in flight in the increased shoe-weight conditions followed the same general path of the bare forefoot although with greater vertical displacement during the first one-half of the forefoot stride.

26. The three-degree pad produced an arc of flight that was similar in pattern yet lesser in height as compared with the balanced shoes.

Conclusions

The methodology utilized during this study was successful in producing data that would allow the biokinematical analysis of equine gait. One aspect of this methodology that needs to be refined was the camera settings, as the film footage that was produced was somewhat blurred. Despite this fact, however, a great deal of useful information as to the effect of alterations in shoeing conditions on equine gait was gathered and interpreted.

To the researcher's knowledge, this study is the first of its kind to use high speed cinematography to evaluate the effect of changes in shoeing conditions on equine gait. Due to this fact, there was some uncertainty as to the horseshoe weight that was necessary in order to observe a measurable change in gait kinematics. The shoe weights chosen indeed produced measureable changes in temporal, linear and kinematical gait characteristics.

Another question arose as to the time period the subject would need in order to begin to adapt to the change in shoeing conditions. As mentioned in the previous chapter, the inconsistent fluctuation in several of the temporal aspects of the gait pattern might be attributed to an insufficient period of adaptation.

The methodology might be improved with the use of an equine treadmill as this would allow reliable reproduction of speed and

filming conditions. The availability of such an instrument was beyond the scope of this research project.

The Filmdata software program, although actually a program designed to analyze human kinematics, presented accurate and concise data despite the fact that an equine subject was being used.

It is this researcher's opinion that this study presents a valid case study of the effect of changes in horseshoeing conditions on the gait kinematics of a single equine subject.

Recommendations

The methodology utilized during this study has, in the researcher's opinion, a great deal of potential in the future analysis of equine gait kinematics. This study presents a baseline analysis of the effect of changes in horseshoeing conditions and includes a greater number of subjects.

One aspect that warrants further investigation is that of the period of adaptation to changes in shoeing conditions. A study that investigates immediate, short-term and long-term effects of basic horseshoeing changes would be of benefit to future researchers.

Another area of possible application would be the analysis of breed-specific shoeing techniques such as those used with Tennessee Walking Horses or American Saddlebreds. Again, a larger study group would prove valuable to such a project.

In conclusion, this study presented a unique challenge: to develop an original research technique that allowed the objective evaluation of the effect of changes in horseshoeing conditions on the

gait of an equine subject. It was a challenge that required the cooperative efforts of the staff of Montana State University's Veterinary Science, Animal Science and the Physical Education departments. Due to this cooperative effort, this study presents a baseline evaluation of one equine subject's kinematical response to changes in horseshoeing conditions. It is a presentation that has, in the researcher's opinion, great potential for use as a starting point for future research projects.

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