AN EVALUATION OF THE EFFECTS OF TWO NATURAL SURFACES ON THE KINEMATICS OF THE CANINE SPRINT START

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AN EVALUATION OF THE EFFECTS OF TWO NATURAL SURFACES ON THE KINEMATICS OF THE CANINE SPRINT START

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A Dissertation

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfilment of the

Requirements for the

Degree of

Doctor of Philosophy

Auburn, Alabama
May 9, 2009

AN EVALUATION OF THE EFFECTS OF TWO NATURAL SURFACES ON THE KINEMATICS OF THE CANINE SPRINT START

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Thomas Craig Angle graduated from Theodore High School in 1995 located in Mobile Alabama. He then graduated from the University of Mobile in 1999 with a B.S. in Sports Medicine. Craig attended graduate school at Auburn University in 2000 and completed a double masters degree in Exercise Physiology in 2002 and Biomechanics in 2003. While in graduate school Craig also received dual national certifications (i.e., Athletic Trainer Certified and Certified Strength and Conditioning Specialist) from the National Athletic Trainers Association and the National Strength and Conditioning Association. In May of 2003 Craig became a Research Associate at the Auburn University Veterinary Sports Medicine Program. In January of 2005 Craig began working on his Ph.D. in biomechanics and is still presently employed as a Research Associate II.

DISSERTATION ABSTRACT

AN EVALUATION OF THE EFFECTS OF TWO NATURAL SURFACES ON THE KINEMATICS OF THE CANINE SPRINT START

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Doctor of Philosophy, May 9, 2009
(Masters of Education in Biomechanics, Auburn University, 2003)
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143 Typed Pages

Directed by Wendi H. Weimar

The purposes of this investigation were to evaluate the kinematic influence of two different natural ground surfaces on the canine sprint start and to determine which surface was safer for movement initiation. The hypothesis was that there would be a significant difference in the influence of a vegetated and a non-vegetated surface on the kinematic performance of the canine sprint start and the vegetated surface would provide a safer environment for movement initiation.

Seven retired racing Greyhounds completed four movement initiation sprint trials on each of the surfaces over an eight day test period. A vegetated and a non-vegetated surface were used to mimic the surfaces commonly used for a canine athlete to initiate a sprint start. The properties of the vegetated and non-vegetated surfaces were quantified and classified. The starting kinematics were filmed by two high speed cameras and analyzed by a motion analysis system. Thirteen linear kinematic parameters and temporal stride characteristics (vertical displacement of the hip, ear, and shoulder, swing times during the follow through phase, stance times during the action phase, horizontal velocity, and forward and backward horizontal displacement of the paws) were measured. Multiple MANOVA and ANOVA statistical models were used to analyze the data.

Main effects were found for the temporal, horizontal, and vertical dependent variables. Temporal dependent variable main effects were found for swing time across end of dog and swing time for the surface*end interaction. Horizontal dependent variable main effects were found for stride length and negative displacement across surfaces, ends, and for the surface*end interaction. Vertical dependent variable main effects for surface, displacement, and the surface*displacement interaction were found for head and shoulder displacement. There was no main effect for average velocity across surfaces.

The results indicated that two like textural surfaces, one with vegetation and one without vegetation has an effect on the kinematics of the sprint start. This data suggests that a vegetated surface is safer for movement initiation than a non-vegetated surface. These findings provide objective and quantifiable data of movement initiation in the dog.

ACKNOWLEDGEMENTS

I would like to thank all of my previous professors for giving me the tools to become a thinker and to further my knowledge. Specifically, I would like to thank my major advisor Dr. Wendi Weimar for her undivided attention, guidance, and friendship. I want to thank Dr. Mary Rudisill for advisement and encouragement throughout the doctoral process and Dr. Sefton for her advisement during the dissertation process. Dr. Robert Gillette has been an outstanding mentor, boss, and friend throughout my professional and academic carrier. He has supported me in many different ways none of which have gone unnoticed. I also want to thank Dr. Robert Gillette in conjunction with the Richard G. & Dorothy A. Metcalf Veterinary Sports Medicine Program for supporting, encouraging, and funding my research. I would like to thank Dr. David Shannon for his hard work on the statistical design and interpretation of the data for this project. Furthermore, I would like to thank Lauren Jernigan, Sherry Johnston, Jenny Sanders, Justin Shroyer, Adam Knight, Andrea Sumner, Ceren Yara, Joanna Booker, and Matt Rooke for their assistance with my project.

I would like to also thank my Mom and Dad for encouraging me to seek a higher level of education and for instilling in me the desire for knowledge. To my sister and brother, thank you for your belief in me and your support. Lastly, thank you to my wife Sara for her patience, love, and support through this difficult process.

Style manual or journal used: Publication Manual of the American Psychological Association, 5th Edition

Computer software used: Microsoft Word for Windows 2003, Microsoft Excel, Peak Motus 8.1, SPSS for Windows (Version 16)

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INTRODUCTION

The varied demands of an organism's survival often require compromises in the design of the biomechanical systems. One of the most important functional trade offs of organisms is the requirements of locomotion (Pasi & Carrier, 2003). Locomotion is critical to survival in most species and depends on many anthropometrical and biomechanical factors. To a large extent, the properties of different surfaces dictate the locomotor mechanisms used by biomechanical systems to travel over the ground. The ground must allow adequate footing so that a system can overcome mass related gravitational forces as it moves. In the case of the human and dog, while one is a biped and the other is a quadruped, both species share the common task of movement and support against gravity. The human and dog's diversity is manifested in size, morphology, locomotor performance, and skeletal materials used (Biewener, 1990). This diversity contains certain biomechanical similarities and warrants further investigation into which biomechanical functions each species uses for optimal locomotion. However, since little research exists regarding canine locomotion during maximal movement initiation, conclusions will be based upon human and equine locomotion and applied to the canine. For the purposes of this dissertation the investigative focus will be placed on the movement initiation aspects of locomotion, specifically the sprint start in canine athletes. The movement initiation aspects will include both a spatial analysis and a temporal analysis.

There are many different canine sports that require a maximal or near maximal movement initiation effort (i.e., sprint start). Some of these sports include Greyhound racing, Whippet racing, agility, and field trials. In these sports, the dogs are required to initiate movement over different surfaces. Surfaces may consist of soil, grass, Astroturf, and/or rubber mats. Presently there has been little research conducted by the scientific community to evaluate these surfaces under the stresses of canine movement initiation. Further, there has also been no scientific research on the effect of these surfaces on the canine sprint start. Questions still to be answered include such basic issues as: are specific kinematic characteristics significantly different when a dog initiates movement over a vegetated versus a non-vegetated surface? If there are significant kinematic differences, which surface provides a safer more consistent start for the canine athlete? Understanding the canine sprint start and the influence of surfaces on movement are important first steps in helping canine athletes and working dogs have longer, safer careers.

While there has been no published research on the kinematic effects of different surfaces on dogs during movement initiation, there have been several studies (Zebarth & Sheard, 1985; Ratzlaff et. al.,1997; Peterson et. al., 2004; Peterson et. al., 2007; Thomason & Peterson, 2008) evaluating the dynamics of equine athletic surfaces under loads. Some of these studies have lead to efforts that attempt to provide surface consistency for athletic events however, these efforts have used less than scientific methodologies and testing equipment. In most environments, the integrity of the sprint start surface and the track/field is evaluated qualitatively by the event official or facility superintendent (Peterson et. al., 2008). As a result of this lack of consistency in the evaluation of the start surfaces, it is difficult to have a mechanical characterization of the ground surface (e.g., coefficient of friction) and its influence on the biomechanics of the dog. The complex relationship which ties these quantitative values (e.g., surface type) to the biomechanical performance characteristics of the dog is the subject of this research project. The purpose of this project is to determine the kinematics of the sprint start of dogs on two natural surfaces. This is the first step in a longer line of research that will address the dog-surface interface.

Human Sprint Starts

There is little scientific information relating to the sprint start of the dog however there is an abundance of biomechanical literature describing the human sprint start. Humans have two primary sprint movement initiation body positions, the two point and four point start. Only the four point starting position will be addressed as it most closely mimics a dog's start position. Humans used a stand up (two point) start in the early 1900's. Soon after, during the Jessie Owens' era, athletes dug holes in the track and started in a four point stance (Henson, et. al. 2002). The athletes would place their feet in the holes and push against the backside of the hole during the sprint start. The four point stance allowed them to have a quicker acceleration and the holes in the track provided something to push against during movement initiation which prevented slipping during propulsion. Therefore, there was a need for the design of an optimal starting surface. With the invention of starting blocks, sprinters stopped digging holes in the track and instead placed angled blocks onto the track. This prevented slipping and optimized propulsion by giving the sprinter a raised surface to push against during movement initiation. It also provided for a more consistent race start with little to no slipping during movement initiation. In addition, the blocks allowed sprinters to enter an optimal set position that caused the ankle, knee, and hip angles to be set in such a position that they were able to take advantage of the stretch shortening cycle in the major propulsion muscles (Mero et. al., 1983 and Harland & Steel, 1997).

The ultimate performance factor in a sprint start is the initial rapid acceleration of the Center of Gravity (CG). The acceleration of the CG of a biomechanical system is determined by three external forces: ground reaction forces (GRF), gravity, and wind resistance (Hunter et. al., 2005). Because humans cannot control the wind nor gravity, only the GRF can be manipulated. The optimum relationship between the amount of force that the sprinter exerts in a horizontal and vertical direction by active leg drive is determined by the coefficient of sliding friction between the soles of the sprinter's shoes and the ground. If the sprinter increases the horizontal drive force beyond the coefficient of sliding friction (which is the limiting value) then the sprinter's feet will slip (Bartlett, 1980). By choosing the proper shoe to ground interface (e.g., the use of cleats on grass) or block to ground interface the human athlete can apply more horizontal force without slipping. The human athlete can also manipulate his/her body positions to influence the GRF. This is accomplished by lowering or raising the hips and by leaning forward or backwards to change the position of the CG.

In human sprint starts, the muscles of the lower limb have to accelerate the body and propel it in a horizontal direction while counteracting the force of gravity in the vertical direction (Delecluse, 1997). Once the human athlete starts movement initiation the arms are brought upward and forward off the ground and therefore have no further propulsion influence, other than aiding the upward acceleration of the total body CG from the ground. With the ability to use efficient body positioning and starting blocks, human athletes are able to initiate movement consistently and safely at the start of a race.

Canine Sprint Starts

There is little published scientific information relating to the biomechanics of canine sprinting (Jayes & Alexander, 1982; Heglund et. al., 1982; Zebas et. al. 1991a, 1991b; Usherwood & Wilson, 2005; Walter & Carrier, 2007) and no scientific information on the sprint start in the dog. Just as in human sports, canine sprint sports depend on the initial rapid acceleration of the CG. Canine sprint sports also depend on the ability of the paw/ nail to ground surface interface to not exceed the coefficient of sliding friction. If the coefficient of sliding friction is exceeded during movement initiation, then the dog's paw will slide in the backwards direction. This will not allow for efficient propulsion. In addition, unlike humans who start in the set position, dogs at the present time are not taught to start in any specified position other than sitting, lying down, or free standing. Dogs use whatever starting strategy that comes natural to them, no one has researched or taught dogs to use specific starting strategies. Therefore, dogs have to raise or lower to their respective set position at the onset of a starting stimulus (e.g., race box door opening). Presently there are no alternatives for the canine athlete to optimize the sprint start. Because of the dynamics of the paw there are no shoes that a dog can wear to increase the friction between the paw and ground, nor are there any surfaces designed to ensure definite footing. Therefore, as there are no present changes that can be made to the feet or body positions, the only option that remains is to alter the surface for the canine athlete.

Summary

Human sprinters start in a four point stance which is similar to the dog. Through the years an optimal sprint starting surface has evolved that allows humans to obtain a safe and efficient start performance. This starting surface does not allow backward displacement of the feet, because it mechanically prevents slipping during movement initiation. Human sprinters also have shoes that aid in traction. On the other hand, canine athletes start on many different variations of non-vegetated and vegetated surfaces and do not have attachments to their paws that allow for optimal traction. In addition, there are no standardized values of the properties (e.g., soil properties: sand, moisture, particle size, clay, and silt content) that make up the non-vegetated and vegetated surfaces upon which canine athletes start. Therefore, there is a need to define what combination of properties within these surfaces provides optimal traction for the canine athlete. However, first there must be an understanding of how a non-vegetated and vegetated surface affect the kinematics of the canine athlete during movement initiation. The latter is the focus of this investigation.

Statement of the Problem

There is a significant challenge for canine event officials to provide a consistent and safe surface in which canine athletes can compete. A specific area of concern is the surface in which these athletes initiate movement at the start of the event. Currently there is a wide variety of surfaces used for the canine athletes to initiate movement. The kinematic performance of the dogs on these surfaces are evaluated by officials, trainers, and organizations using less than scientific methodologies and testing equipment. A sound scientific experiment evaluating the kinematic influence of movement initiation over non-vegetated and vegetated surfaces is needed.

The ability to develop large horizontal propulsive forces during movement initiation is imperative to success in a sprint start. For example, in humans, the horizontal propulsive forces during sprint movement initiation have been reported to be 46% higher than the same force generated during ground contact at maximum velocity (Mero, 1988). The sprint start is not only a critical component to human athletic endeavors but also to the animal world, specifically canine athletes. Canine athletes engage in many sports that involve maximum horizontal propulsion to initiate movement. This involves a paw to ground surface interaction where the paw pads and toe nails must grip the ground surface and prevent the paw from moving in the backward direction during propulsion. Therefore, the frictional force between the paw and the ground must exceed the horizontal propulsive force. If the frictional force between the paw and ground surface does not exceed the horizontal propulsive force, then the paw will displace in the backward direction.

Dogs may experience backward paw displacement during movement initiation on natural surfaces. These surfaces may not provide optimal traction during the high horizontal propulsive forces generated during sprint movement initiation. A surface that causes inadequate footing prevents optimal performance due to backward paw displacement at the start of an event. Backward paw displacement also produces abnormal forces on the various anatomical structures of the canine athlete and increases the risk of injury during movement initiation and the first few strides there after. It is intuitive that starts during which the canine athlete experiences backward paw displacement during movement initiation can lead to compromises in balance and propulsion. Injuries that occur during movement initiation produce a decrease in the health and well being of the dog. It also causes an emotional and economic strain to the owner, trainer, governing sport organization, and industry. Furthermore, backward paw displacement during the start of the event produces decreases in performance, which creates performance inconsistency. A better vegetated and non-vegetated standardized starting surface needs to be designed to reduce injuries, optimize performance, and provide event consistency. These standardized surfaces can only be designed after there is a kinematic understanding of how canine athletes move over non-vegetated and vegetated surfaces. Once this kinematic understanding is made, then the properties of the surfaces can be manipulated to optimize traction for the canine athlete.

Purpose of the Study

The purpose of this study is to investigate the influence of two different natural ground surfaces on the kinematics during movement initiation of the canine athlete. Kinematic measures such as vertical displacement of the hip, ear, and shoulder, swing times during the follow through phase, stance times during the action phase, horizontal velocity, and forward and backward horizontal displacement of the paws will provide the necessary data to investigate this influence. This research will provide a kinematic understanding of movement initiation on two different natural surfaces.

Hypotheses

- There will be a significant difference in the influence of a vegetated and non-vegetated surface on the kinematic performance (vertical displacement of the hip, ear, and shoulder, swing times during the follow through phase, stance times during the action phase, horizontal velocity, and forward and backward horizontal displacement of the paws) of the canine sprint start.
- The vegetated surface will provide a safer environment for movement initiation.

Primary Objective

- The primary objective is to determine the influence of a vegetated and a non-vegetated surface on the kinematic performance of the canine sprint start.

Secondary Objective

- The secondary objective is to determine which surface provides a safer start performance (as measured by the magnitude of the backward horizontal displacement of the paws).

Assumptions

The assumptions influencing this study were:

- Presently there is no way to test perceived exertion or maximum effort in the dog. The assumption has been made that all the dogs will give a maximum effort sprint start for each trial.

Delimitations

The delimitations setting the scope of this study were:

- Only mature healthy Greyhounds were included in this study. This reduced the variance in breed morphology that would affect the kinematic outcome measures.
- The Greyhounds were trained to stand erect and move only with the movement of a lure. The lure served as the stimulus to initiate movement.

Limitations

The limitations to this study are listed below:

- Eight healthy Greyhounds above the age of 3 with similar experience in Lure Coursing were used in the study. This reduced the variance in breed morphology and health factors that would affect the kinematic outcome measures.
- The dogs were required to initiate movement at maximum effort over a vegetated and non-vegetated surface. This limited the surface effect on the kinematic variables to be a result of the presence or lack of vegetation.
- Dog order of run was not randomized, running order was flipped. This caused the running order of dogs to be Dog 1, Dog 2, Dog 3, and Dog 4, then they were

flipped to run Dog 4, Dog 3, Dog 2, and Dog 1. Therefore, the dogs running in the middle of the order always stayed in the middle.

Operational Definitions

Action Phase: The Action Phase starts the frame after the Set Position and ends at the frame before the limb is off the ground. Each limb has its own action phase.

Block Velocity: The velocity of the CG in the action phase of movement during a sprint start.

End: This refers to the crainial/front limb or caudal/rear limb end of the dog.

Event: Any canine athletic occasion that involves a sprint start such as Greyhound racing, dock jumping, field trials, and agility.

Event Consistency: This occurs when there is no significant variation in the repetitive performance of a canine athlete.

Follow Through: The follow through phase starts the frame when the limb comes off the ground and ends the frame before the limb contacts the ground. Each limb has its own follow through phase.

Grass Shoot Density: A grass shoot is a horizontal stem that extends outward from the vertical stem. The shoot can be under or on top of the ground and can have the presence of a root system holding it in place. The shoot density counts the number of shoots per square inch.

Lead Slipped: A technique commonly used to release sight hounds (e.g., Greyhound) without a starting box.

Movement Analysis: The description of the movements of the body and body parts relative to the ground and other body parts (Collier, 2002).

Set Position: The Set Position refers to the frame before the dog starts movement initiation during the Action Phase.

Spatial Analysis: The description of the position of the body and body parts in space relative to the ground and other body parts (Collier, 2002).

Soil Bulk Density: This refers to the mass of soil per unit volume and the soils bulk density is normally expressed in g/cm^{-3} (mass divided by volume). Normally the dry weight and therefore the dry bulk density are determined. A very compacted soil perhaps due to hoof compaction would have a bulk density of 1.4 to 1.6 $g\ cm^{-3}$. An open friable soil with good organic matter content will have a bulk density of $< 1.0\ g\ cm^{-3}$.

Sprint Start: The point at which maximal movement initiation occurs at the beginning of an event.

LITERATURE REVIEW

Introduction

The purpose of this study is to investigate the influence of two different natural ground surfaces on the kinematics during movement initiation of the canine athlete. This chapter presents the review of literature on the topic of human and canine sprint starts and is divided into the following topics: (a) surfaces, (b) kinetics of the human sprint start, (c) kinematics of the human sprint start, (d) kinetics and kinematics of the canine sprint start, (e) comparative analysis of the sprint start, and (f) summary.

The results of a successful sprinting performance depend on numerous neuromotor, bioenergetic, morphological and biomechanical parameters. The dynamics of sprinting speed consist of four phases: the start, start acceleration, maximum running speed, and finish. The key factors of the sprinting performance are the start and start acceleration. According to some researchers the start and start acceleration contribute 50% to 65% of the final result in a 100 m sprint (Coh, 1996). Therefore, sprint start optimization plays a major role in the sprinting performance of human athletes and warrants further research into the sprint start of the canine athlete. For the purposes of this dissertation, the focus will be placed on the kinematics of the sprint start and its relation to the surface upon which the canine initiates movement. In addition, while there is a lack of scientific literature for the canine sprint start, there is an abundance of scientific literature in humans. Therefore, the literature regarding human sprint starts will be limited to only that material that is applicable to the canine sprint start.

Surfaces

Research into sports surfaces for human athletic competition has been directed towards performance and safety differences between natural and synthetic surfaces. Meyers and Barnhill (2004) conducted a 5-year study investigating the differences in injuries on two common playing surfaces (new generation synthetic turf or "FieldTurf" and natural grass) in high school football. They found that each playing surface was associated with unique injury patterns. Nigg and Yeadon (1987) stated that data from epidemiological studies strongly suggests that the surface is an important factor in the etiology of injuries. Injury frequencies were reported to vary significantly for different surfaces in several sports. Ford et. al. (2006) stated that the introduction of new technology in sport surfaces makes new studies of the relative effects of the surface on athletic performance, movement biomechanics and injury risk, necessary and important. Therefore, it is important to study the movement mechanics of an athlete on different surfaces because each surface has its own performance and safety issues.

There are many important factors in selection of a sports surface. They include functionality for the sport, wear, durability, chemical consistency, water permeability, price, cushioning, and frictional properties. From an injury and performance point of view, cushioning and frictional properties of a surface are considered to be the most important (Nigg, 1990). These properties are considered to cause surface related injuries and in many cases, are speculated to increase the loads on structures beyond healthy limits. These properties should benefit an athlete's performance without causing excessive stress to joints or ligaments. For the purposes of this dissertation cushioning properties in the human literature will not be discussed as they relate to falling and impact injuries, however, frictional properties will be discussed in detail.

In the literature on human athletes, surface to shoe interaction has been termed footing and has been described as traction or friction. Footing is used to describe both smoothed-soled and studded footwear. Furthermore, the term friction is usually applied to smooth-soled footwear and the term traction has been applied to footwear having cleats, studs, or spikes to provide extra grip (McNitt et. al., 1996). Bowers and Martin (1975) state that on natural surfaces traction results from cleat-surface friction and cleat penetration into the surface. Because there are both smooth (i.e., pads) and cleated (i.e., nails) portions of the dog paw used to grip the surface, the term traction will be used universally in this dissertation to describe the combination of friction and traction.

Friction between two surfaces is determined by the resistance of these surfaces to relative movement. Specifically the coefficient of friction (i.e., static friction unless otherwise specified in the paper) is dependent on the material of the two surfaces, the structural pattern of the two surfaces, and the relative velocity between the two surfaces (Nigg, 1990). The magnitude of the frictional force is determined by the magnitude of the normal force, the type of materials, roughness of the materials, and nature of the contacting surfaces. This relationship is expressed by the equation $F = \mu N$ (where F is the force of static friction, μ is the coefficient of static friction and N is the normal force). The maximum value of F before slipping occurs between the shoe/block to ground interface and is fixed by N and the limiting value of μ. The value called the coefficient of sliding friction (μ) is a unique value for the interaction of the interface's type of material, roughness, and nature of contacting surfaces. In the case of a start without blocks, the coefficient of friction between the shoe and ground is the most important, and can be enhanced by fastening spikes to the soles of the shoes. However, the coefficient of friction between the blocks and the track is most important for a start using blocks and this can be enhanced by nailing the blocks to the track (Bartlett, 1980).

The coefficient of friction varies between different natural surfaces. With natural surfaces there are many different structural influences between and within non-vegetated and vegetated matrixes that can have an affect on the coefficient of friction. McNitt, et.al. (1996) described a model for the factors affecting human athletic natural playing surfaces. The factors included the nature of the vegetation, including its soil and plant constitutes; rainfall; mowing and irrigation; pests; and the amount of wear. The dynamic interactions between soil and vegetation, with respect to the coefficient of friction, are not easily separated from one another. Soil factors such as bulk density and particle size distribution may affect the coefficient of friction directly by influencing soil shear strength or indirectly through the effects on the vegetation. It has been shown that coefficient of friction on rootless soils increases with increasing soil bulk density. However, on athletic fields, higher soil bulk densities are associated with the areas of greatest wear and have lower coefficient of friction values due to a lack of vegetation cover (i.e., worn or damaged areas).

Vegetation and soil impart an influence on coefficient of friction individually; however, traction on a vegetated surface is often controlled by their combined effects (McNitt et. al., 1996). Natural turf and synthetic surfaces can have some of the same frictional issues because they can degrade over time. Bowers and Martin (1975) studied the alterations associated with use and exposure in cleat-surface friction of AstroTurf®. Tests were carried out with and against surface grain under wet and dry conditions. They found that with use and exposure the surface friction of AstroTurf® does change, affecting both player performance and safety. Therefore, there are many factors that can influence the frictional components of natural and synthetic surfaces and these factors can affect both the performance and safety of the athlete.

Kinetics of the Human Sprint Start

The kinetics of the four point start in humans with and without a starting block involves Newton's Third Law of Motion. In the four point start there is a vertical and horizontal force acting on the ground by the sprinter's feet that increase once the hands have left the ground. During movement initiation, the sprinter drives down and back on the ground/blocks, which pushes the sprinter upward and forward. This constitutes a separate vertical and horizontal force where the vertical component (N) and its relation to the sprinters weight (W) will determine whether the center of gravity (CG) is accelerating upwards ($N > W$), moving horizontally ($N = W$) or accelerates towards the ground ($N < W$). The horizontal component (F) of the driving force is equivalent to the frictional force between the soles of the sprinters shoes and the ground in the absence of starting blocks. With starting blocks the horizontal component (F) of the driving force is equivalent to the frictional force between the base of the blocks and the ground (Bartlett, 1980).

Exploitation of this frictional force and Newton's Third Law of Motion is critical during the acceleration phase of the sprint start. In the acceleration phase, sprinters must impart a vertical and horizontal force on the ground in order to accelerate the CG upward and forward. This means that the feet must remain in contact with the ground to impart propulsion forces. Harland and Steele (1997) found that mean ground contact times for elite male sprinters ranged from 160 to 194 ms for the first contact, and 150 to 181 ms for the second ground contact. These contact times accounted for 82 and 76 % of the total step time (contact + flight times). This means that the horizontal and vertical forces where imparted on the surface by the feet for 82 and 76 % of the total step time. Therefore, a large percentage of the start time is spent imparting forces to the ground and the ground must be of sufficient strength and yield: (a) to impart optimal forces to the sprinter and (b) to keep the sprinter balanced and moving forward in a safe manner.

Kinematics of the Human Sprint Start

An optimal start should use the athlete's strengths to his or her advantage. The athlete should be set in the optimal position to provide the quickest clearance time, and set the athlete in proper sprinting form after the initial steps. Tellez and Doolittle (1984) state that clearance time from the starting blocks accounts for approximately 5% of the total 100 m race time in humans. A good start can contribute more to a race than reducing block clearance times, for it can align and balance the sprinter for efficient propulsion down the track. Efficient propulsion over the first portion of the race is influenced by the way a sprinter is positioned in the blocks at the set command and the mechanics of how they leave the blocks at the start. Helmick (2003) stated that there are specific joint angles that produce the optimal loading and yield the most force in a short amount of time. Thus, the proper set position is important for an efficient and powerful acceleration phase, the performance of the athlete during the race, as well as the outcome of the race.

The set position precedes the acceleration phase. The set position allows the athlete to position the body in the most efficient position to obtain maximum propulsion at the onset of movement initiation in the beginning of the acceleration phase. The set position in the blocks is individual and depends on the athlete’s morphologic characteristics and motor abilities (Coh et. al. 1998). The set position is a key component to proper kinematic alignment during movement initiation. It optimally positions the joints and segments to propel the CG forward. Once the sprinter leaves the blocks, he/she must prepare for subsequent ground contacts to develop maximal sprint velocity. If the position of the first foot to leave the ground after leaving the blocks is posterior to the CG at ground contact, the sprinter is immediately able to maximize posterior horizontal force application. However, if the contact position of the first foot moves anterior to the CG a horizontal braking force may be experienced until the CG travels over the base of support. Positioning the CG ahead of the base of support for the first two post block steps encourages increased horizontal force production (Harland & Steel, 1997). Mero et. al. (1983) studied a group of sprinters and found that the CG in the set position had an average height of 0.605 m and moved both upward and forward during the action phase. They also reported that running velocity of the subjects in the acceleration phase was strongly related to horizontal and vertical forces in the blocks. In addition, this study showed that the pathway of the CG in the acceleration phase affected running velocity (Mero et. al. 1983). At toe off of the first step out from the blocks, mean horizontal velocity values for the CG have been reported as high as 4.65 to 5.16 m/sec (Harland & Steel, 1997). Furthermore, one study reported a mean horizontal velocity of the CG at 5.7 m/sec at toe off of the second post-block step for skilled male sprinters (Mero et. al., 1983).

Mean horizontal velocity values during movement initiation will depend upon the set position, specifically trunk and knee alignment. Trunk and knee alignment of skilled sprinters in the set position has been quantified in several studies. Borzov (1980) stated that an optimal set position exists for highly skilled sprinters irrespective of body stature. Mero et. al., (1983) stated that the stronger the sprinter the more acute the joint angles (i.e., front knee 111°, rear knee 134°, and trunk lean -29°) can become in the set position. That is, stronger sprinters can use a greater range of joint extension to gain greater velocity when leaving the blocks (Mero, 1988). With optimal joint and postural alignment in the set position, athletes can experience greater block velocities.

The angle between the horizontal line of the track and the line joining the CG to the front toe at the loss of front block contact (thrust angle) has been reported to range from 32º to 42º and has been indicative of allowing the athlete to generate high forces in the horizontal direction. The high horizontal forces have been cited as critical elements in generating fast sprint times (Harland & Steel 1997). Knee angles in the set position have been recorded at approximately 90° and 130° respectively, with the hips held moderately high. The sprinter must be able to develop a high force rate combined with a high maximum force, especially in the horizontal direction in order to achieve maximum velocity. The ability to create high force underlies other important indicators of starting performance such as minimum block clearance time, maximum block leaving velocity, and maximum block leaving acceleration (Harland & Steel, 1997). During acceleration, speed development depends mainly on powerful extensions of all leg joints. Once the athlete reaches higher velocities in the maximum running speed phase, it will be more important to rotate the legs forward and backwards relative to the hip joints to further increase running speed (Delecluse, 1997).

Kinetics and Kinematics of the Canine Sprint Start

The canine paw is a complex structure that gives support and balance during standing and provides the required restraint and propulsion during gait. During the stance phase the paw has to adapt to the changing pattern of loading and must be relatively compliant while maintaining its functional integrity (Besancon et. al., 2004). The paw plays a vital role in adaptation to the ground surface and griping of the ground surface during propulsion. This is accomplished because four out of the five pads on the bottom of the dog's paw are moveable and can displace in 3 dimensions according to the ground surface in which the dog is upon. In addition, the nails which are attached to the four moveable pads can enter the surface acting as cleats to provide extra grip and the roughness of the pads themselves help to aid in increasing the coefficient of friction between the dog's pads and ground. It is important to note that the nails are attached to bone and are part of the dog's anatomy. Therefore, nails are not cleats which are attached to a shoe on humans, but do act as cleats when gripping the ground.

When a dog's limb contacts the ground it experiences a ground reaction force (GRF). The vertical component of the GRF serves to support the weight of the dog, while the horizontal components allow the dog to accelerate, negatively accelerate, balance, and maneuver (Biewener, 2003). The vertical component of the GRF represents the force of gravity that is pulling the dog's CG downward as well as the force that represents the projection of the dog's CG upward. The horizontal components are broken into anterior and posterior forces and medial and lateral forces. The anterior force represents braking during the initial portion of the stance phase and the posterior force represents propulsion during the later portion of the stance phase. The medial and lateral forces are responsible for balancing and maneuvering and are typically smaller in magnitude when the dog is travelling in a straight line such as during a race start. Resolving the GRF into components facilitates an understanding of the affects of the component forces during the gait cycle.

In the quadruped, forces that tend to rotate the body about its pitch axis can be opposed by the front limb or hind limb of the support pair. The pitch axis occurs in the sagital plane about the bilateral axis. The support pair of limbs will depend on the type of gait used but will involve a front and rear limb to resist the pitch. In addition, forces that tend to rotate the body about its role axis can be opposed by the right and left limb of the support pair (Lee, et. al., 1999). The role axis occurs in the frontal plane about the anterior posterior axis. Therefore, if a dog slips during movement initiation, rotation may occur about one or both axes and the dog will have abnormal forces placed upon the supporting structures. The abnormal forces may result in injury to the dog in the first few strides of the race. That is, it may take a number of strides for the dog to regain balance during the acceleration phase. Also this slippage can have adverse outcomes with regard to the athletic event from a kinematic performance perspective as well as a success perspective.

Humans start a sprint by calmly positioning themselves in the blocks in the set position. Unlike the calm human in the set position, dogs often bounce around with excitement prior to dropping into their set position. Dogs do not hold themselves in the set position; instead they employ a counter movement to reposition themselves in the set position, once the start signal is given. Biewener (2003) states that a counter-movement represents an initial flexion of the limb, which lowers the body's CG. During the counter movement the force exerted on the ground briefly falls below an animal's body weight. This is immediately followed by rapid extension of the limbs to propel the animal's body forward by a dramatic increase in the GRF. By performing a counter movement the muscles are forcibly stretched in an eccentric contraction, followed by a brief ammorization period, and then concentrically contracted. This allows the muscles to develop force rapidly and to a great magnitude by the combined effects of the use of elastic energy in the muscle and stretch reflex potentiation (i.e., activation of the myotatic stretch reflex caused by a rapid stretch of the muscle) of the muscle (Baechle, 1994).

Comparative Analysis of the Sprint Start

While little research has been conducted on the dog paw to surface interface, other quadrupeds such as horses have received attention. This research has focused on the horse at a gallop but not a horse during the start. However, it does give an indication of the hoof to surface interaction during propulsion. At each phase of gait, a combined horizontal and vertical response from the ground is required. When a horse gallops on the track, the non-vegetated surface or vegetated surface is loaded both vertically and horizontally. As the horse hoof enters the surface during impact there is a forward horizontal shear force applied to the surface of the track. During propulsion the load on the track surface is fully reversed in the backward direction and a backward horizontal shear force is applied to the track. Equine researchers have studied vegetated surfaces to determine what properties of the surface increase shear strength of the surface which will help reduce backward hoof displacement during propulsion. Ratzlaff et. al. (1997) studied turf racing surfaces in race horses and found that grass roots were responsible for increased impact resistance (hardness) and resistance to shear. Therefore, the shear strength of the soil must exceed the backward horizontal force (i.e. propulsion) produced by the horse or the hoof will displace in the backward direction. Peterson et. al. (2007) studied non-vegetated horse race track surfaces and concluded that soft tissue injuries are generally associated with shear failure of the soil (i.e., hoof displaces in backward direction) in the propulsive force of gait.

Summary

The optimal starting surface (i.e., starting blocks) has been researched and developed for humans, but there has been no scientific research conducted on starting surfaces for the benefit of dogs. The focus in the equine and canine sporting industries has been on the track or arena surface as a whole. No research has been conducted on the specific and unique biomechanical factors involved with the sprint start. The canine sporting industries have completed no scientific comparative analysis between and within starting surfaces to determine if a particular surface has a biomechanical influence on a dog when compared to another surface. If there are significant kinematic influences between and within surfaces it will illustrate an avenue of research to develop an optimal surface that provides both consistent and safe kinematics.

METHODS

The purpose of this study was to investigate the influence of a vegetated and a non-vegetated surface on the kinematics of canine movement initiation. This chapter presents the methodology of this project and includes the following sections: (a) participants, (b) equipment, (c) procedure, and (d) statistical analysis. The research protocol for this project has been approved by the Auburn University Institutional Animal Care and Use Committee (see Appendix C) for research involving animal subjects.

Participants

Eight Greyhounds were selected based upon the absence of orthopedic conditions that would prevent the canine from successfully completing the necessary trials. The Greyhounds had a mean age of 6.5 ± 2.6 years-old, a weight of 30.9 ± 5.2 kg, a height of 67.5 ±3.7 cm and a length of 72 ± 3.4 cm. An experienced veterinarian specializing in veterinary sports medicine and orthopedic assessment administered a thorough orthopedic exam. Exclusion criteria for the study included (1) any lack of joint stability, (2) any significant acute or chronic injury, (3) any significant pathological condition, or (4) any other neuromuscular condition that may interfere with the dog's ability to efficiently and effectively execute a sprint start. The eight Greyhounds were randomly selected from a group of healthy Greyhounds that were undergoing a long term six month sprint conditioning program. The Greyhounds used in the study were housed at the Auburn University Lab Animal Health Facilities at the College of Veterinary Medicine Campus.

Equipment

Surface Construction

Two ground surfaces were used to mimic the surfaces commonly used for a canine athlete to initiate a sprint start. The two natural surfaces used were a non-vegetated (i.e., soil only no vegetation) and vegetated surface. Both surfaces were level and measured 1 meter x 4 meters. The vegetated surface consisted of a level area of grass presently used by the Auburn University Veterinary Sports Medicine Program Lure Coursing Greyhounds. The vegetation was cut so that the length did not exceed three centimeters from the surface. Neither surface was watered unless it rained (no rain occurred during the project).

The properties of the vegetated and non-vegetated surfaces were quantified. Core samples (i.e., approximately 4 cubic inches) were taken of the two surfaces and sent for analysis at the Auburn University Soils Laboratory. On the first three days of the study one core sample was taken each day from a specified point on the surface and was submitted for textural analysis. The three samples over the three different points in the surface allowed a textural property average to be calculated for each surface. The textural analysis revealed the percent of sand, silt, and clay in the soil. The textural analysis also revealed the textural class of the soil. The textural properties of a surface do not change from day to day, however the soil bulk density and moisture content of the surface do change. On all eight days of the study core samples were submitted for soil bulk density and moisture analysis. In addition, a sample of the vegetated surface was sent to the Auburn University Agronomy Department for analysis. The analysis consisted of testing the vegetated surface shoot density per square inch and identifying the species.

After each trial the non-vegetated surface was smoothed and returned to a consistent condition prior to the start of the next trial with the next dog. Because multiple dogs can damage vegetation over time, no more than four dogs were allowed to start in a specific area on a particular day. Each day the dogs started on a new area of the vegetated surface.

Kinematic Analysis

The starting kinematics were filmed by two synchronized Troubleshooter High Speed Cameras (Fasttec Imaging Inc.). The Troubleshooter cameras produced an uncompressed avi (Audio Video Interleave) video file that was uploaded to a motion analysis software system. The cameras were placed perpendicular to the test surface and canine athlete. One camera was placed on each side of the dog with the camera view aligned perpendicular to the sagital plane of the dog. The cameras sampled at a rate of 125 pictures per second, with a shutter speed of 1/650 (i.e., 5 x the frame rate). Calibration of the video system was performed by filming four stationary reflective markers with known coordinates prior to each trial. In addition, both cameras captured one marker (i.e., Vx Marker) on the dog simultaneously. The Vx marker was seen in both camera views for every trial and a horizontal velocity value was calculated for each camera view. The respective values were then compared for significant differences to establish that the cameras had a true orthogonal relationship.

A Peak Performance Motus 8.1 Motion Analysis System (Peak Performance Technologies, Inc.) was used to process the video collected by the Troubleshooter cameras. The software package was used to calculate the two-dimensional spatial positions of the retro-reflective markers placed on each side of the subject. The positional data was extracted from the Motus System and placed in Microsoft Excel for calculation of the dependent variables from the positional data (see Appendix A for the equations).

Small half spheres approximately 2.5 cm in diameter made of Styrofoam and covered in 3M Retro Reflective tape were used as markers. The markers were glued to small 5 cm x 5 cm strips of blue 3M Masking tape. The masking tape was placed over specified anatomical points on the dog prior to the markers being glued. Smith and Victor 650 watt lights were placed beside the lens of the Troubleshooter cameras. The lights illuminated the retro reflective properties of the markers. The markers were used by the motion analysis software to locate the x and y coordinates for specified anatomical locations. The coordinates were used to define kinematic parameters of the sprint start and to determine differences in movement strategies on each testing surface during each phase of movement initiation. Five markers were fitted to each side of the dog at specified anatomical locations prior to filming and one marker was placed on the dorsal aspect of the dog to be viewed in both cameras. There was a total of 11 markers placed on the dog (refer to Figure 1).

An 11 marker model of the Greyhound's body was defined by the coordinates of 11 anatomical reference points. One marker was placed over each greater tubercle of the scapulohumeral joint (shoulder marker), three inches caudal to the mid point of the scapula (Vx marker) over the dorsal aspect of the spine, distal lateral aspect of the fifth metacarpal bone (front paw marker), eminence of the greater trochanter of the femur (hip marker), the distal lateral aspect of the fifth metatarsus (rear paw marker) and one inch inferior to the ear canal (ear marker) (refer to Figure 1).

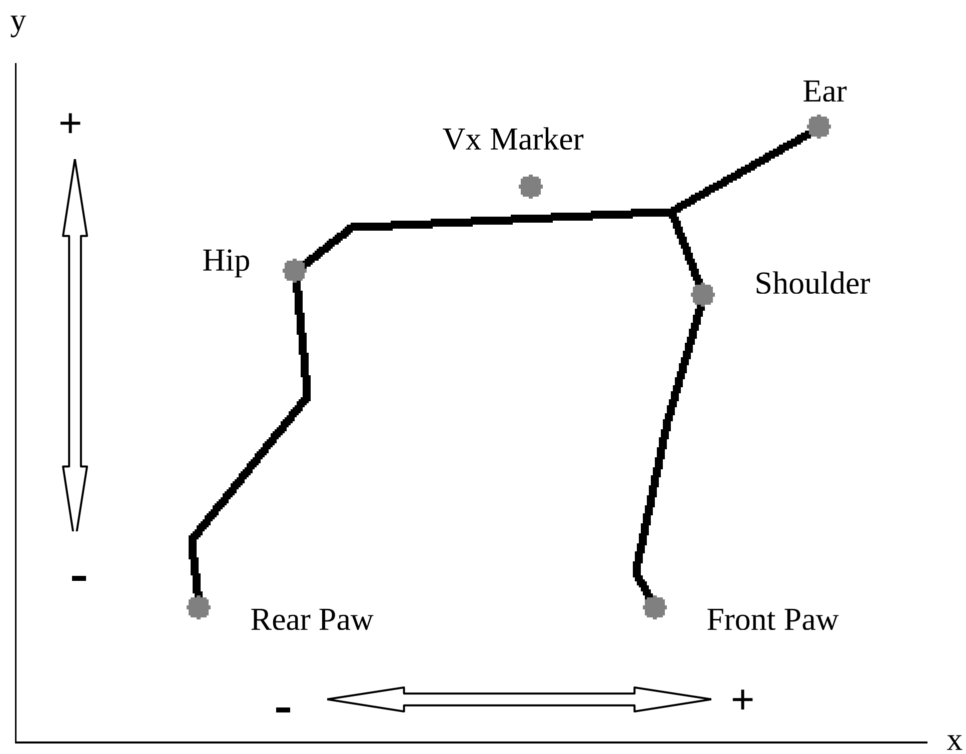

Figure 1**.** This figure represents the six anatomical points [greater tubercle of the scapulohumeral joint (shoulder marker), three inches caudal to the mid point of the scapula on dorsal aspect of spine (Vx marker), distal lateral aspect of the fifth metacarpal bone (front paw marker), eminence of the greater trochanter of the femur (hip marker), the distal lateral aspect of the fifth metatarsus (rear paw marker) and one inch inferior to the ear canal (ear marker)] that are marked by the retroreflective markers.

There are three main events during movement initiation. The first event is the Set Position which is referenced by a lowering of the center of gravity and refers to the frame before the dog starts movement initiation during the Action Phase. The second event is the Action Phase which starts the frame after the Set Position and ends at the frame before the limb (i.e., each individual limb has its own phase) is off the ground and is characterized by the first shift in the CG forward. The last event is the Follow Through Phase. The Follow Through Phase starts when the limb comes off the ground and ends at the point where the same limb contacts the ground. The Follow Through Phase is characterized by no surface contact between each individual limb and the ground.

The following is a list of kinematic variables that were calculated by the motion analysis system and Microsoft Excel. All horizontal and vertical values were first measured in meters and then normalized to each dog by dividing the value by the height or length (see Appendix A). Table 1 contains the abbreviation, definition, and measurement value of the kinematic variables. The following list describes the specific definitions of each kinematic variable.

- *Average Horizontal Velocity of the Vx Marker*- A marker was placed on the dog's back three inches caudal to the mid point of the dog's scapula and on the dorsal aspect of the dog. This measurement was calculated in meters per second during the Action and Follow Through Phases.
- *Negative Horizontal Displacement of the Rear Limb Paws and Front limb Paws during the Action Phase*- A marker was placed over the distal, lateral aspect of the fifth metacarpal bone and the distal lateral aspect of the fifth metatarsus. The motion analysis software measured the amount of backward horizontal displacement of the front and rear paws during the action phase of movement initiation. This measurement was calculated in meters.
- *Forward Horizontal Displacement of the Rear Limb Paws and Front limb Paws during the Follow Through Phase*- A marker was placed over the distal lateral aspect of the fifth metacarpal bone and the distal lateral aspect of the fifth

metatarsus. The motion analysis software measured the amount of forward horizontal displacement of the front and rear paws during the Action Phase of movement initiation. This measurement was calculated in meters and provided the calculation of the rear and front limb stride lengths.

- *Stance Times during the Action Phase*- The stance times were calculated by taking the total number of frames in which the Action Phase occurs for a specific limb and multiplying the frames by 0.008 seconds. This revealed the total time in which the limb was in contact with the ground and was calculated in seconds.
- *Swing Times during the Follow Through Phase*- The swing times were calculated by taking the total number of frames in which the Follow Through Phase occurs for a specific limb and multiplying the frames by 0.008 seconds. This revealed the total time in which the limb was in flight and was calculated in seconds.
- *Vertical Displacement of the Head, Hip, and Shoulder*- The vertical displacement of the hip, head, and shoulder was calculated by assessing the vertical distance between the hip/shoulder/head marker and the reference marker (i.e., vertical position of the rear paw marker). These measurements were calculated in meters and were sampled at the Set Position.

Table 1.

Abbreviation, Definition, and Unit of Measurement of the Kinematic Variables

Abbreviation	Measure	Measurement Value
RrStan1Time	Rear Stance Time	Seconds
FtStanTime	Front Stance Time	Seconds
RrSwingTime	Rear Swing Time	Seconds
FtSwingTime	Front Swing Time	Seconds
RrStepDist	Rear Step Distance	% Body Length
FtStepDist	Front Step Distance	% Body Length
RrPaw1NegDisplx	Rear Paw Negative Displacement	% Body Length
FtPawNegDisplx	Front Paw Negative Displacement	% Body Length
yDisplSetShould	Vertical Displacement of the Shoulder	% Body Height
yDisplSetHip	Vertical Displacement of the Hip	% Body Height
yDisplSetEar	Vertical Displacement of the Head	% Body Height
AvgVx	Average Velocity	m/s

Procedure

Kinematic measurements were calculated during the first complete movement initiation gait cycle, defined as one full stride, beginning with the set position and ending with the completion of the swing phase for each of the four limbs in consecutive order. The linear kinematic parameters and temporal stride characteristics were measured. All kinematic data was calculated at the 125-Hz sampling rate for one complete stride using vector algebraic parameters predefined within the software model. All kinematic parameters were reported relative to three events (i.e., Set Position, Action Phase, and Follow Through Phase). A fourth order Butterworth filter with a 6 Hz cut off frequency which is incorporated within the Peak Performance analysis software, was used to filter the kinematic data (Robertson and Dowling, 2003).

Each Greyhound completed one movement initiation sprint trial each day over an eight day test period. The greyhounds alternated surfaces each day so that after the eight day test period, each dog completed 4 trials on the vegetated surface and four trials on the non vegetated surface. A two way counter balanced design was applied by group and by dog order of run. The dogs were divided into two groups of four dogs. Each test day the groups were assigned to conduct one movement initiation trial on a specified surface (Refer to Table 2). This counter balance ensured that there would be no intra-day differences between the two surfaces because a group would be conducting trials on each surface for each day of the study. In each group the dogs were given a running order of 1-4. Every two days the running order was flipped so that the dogs ran 4-1 instead of 1-4. Previous research by Gillette et. al., (2006) has shown that significant physiological effects occur with the dog in relation to anticipation of exercise. By flipping the order of the run, the anticipation times were altered. This reduced and balanced any fatigue effects within the groups due to the effects of anticipation.

Table 2.

Two way counter balance by group and order of run over the first four days of the study.

Surface	Day 1	Day 2	Day 3	Day 4
Non-vegetated	G1/1- 4	G2/1- 4	G1/4-1	G2/4-1
Vegetated	G2/1- 4	G1/1- 4	G2/4-1	G1/4-1

G = Group, 1 – 4 indicates order of run

Subjects were started using a method called a "slip lead" on the respective surface. Slip Leading is a technique commonly used in canine athletics to release dogs without a starting box. The same experienced handler was used to slip lead he dogs throughout the data collection process. The dogs were previously trained to pursue a lure that is placed in front of them. The lure consists of a squawker encased in a synthetic material with a fluffy tail on the end. The lure was accelerated by a motorized lure machine which was controlled by the same lure operator for each trial. The lure operator kept the lure in front of the dog for approximately 30 meters. At this point the lure was stopped and the dog stopped at the lure. The dogs were released by the handler upon notification that the lure operator was about to accelerate the lure. This process was used for each dog and kinematic data was collected from each trial. Care was taken to insure that handler/lure operator error did not influence the performance of the canine. This was achieved by using the slip lead so that the dog was quickly released and by the lure operator keeping the lure in front of the dog. The slip lead start was videotaped for review and was part of the consideration in determining that a viable trial was obtained.

A viable trial was one in which the dog was standing still, straight, erect with limbs extended, and eyes focused on the lure, prior to lure movement initiation.

Statistical Analysis

Four separate statistical analyses were performed. The data was divided into four kinematic components of time, horizontal displacements, vertical displacements, and velocity. A (2) X (2) (Surface X End) MANOVA with surface as between subjects and end as within subjects variables, was employed to evaluate rear and front stance time and rear and front swing time. A (2) X (2) (Surface X End) MANOVA with surface as between subjects and end as within subjects variables, was used to evaluate rear and front stride length and rear and front negative displacement. A (2) X (3) (Surface X Displacement) ANOVA with surface as between subjects and displacement as within subjects variables, was used to evaluate the vertical displacement of the head, shoulder, and hip in the set position. Last, a One Way ANOVA was used to evaluate average horizontal velocity. The two MANOVA models and two ANOVA models were used to determine; (1) if differences exist between two different natural surfaces (vegetated and non-vegetated) on multiple dependent kinematic variables during the first stride of movement initiation and (2) if differences exist in the magnitude of two kinematic variables (negative horizontal displacement of the front and rear paws). If statistical differences were present between dependent variables during the MANOVA test then a post hoc comparison using univariate ANOVAS was applied. Follow up paired t-tests were used to evaluate specific differences between surface, end, and displacement values post MANOVA and ANOVA evaluations. In addition, paired t-test were used to verify that the cameras captured the same positional data for each trial. For all analyses, significance was set at an alpha level of $p \leq 0.05$.

RESULTS

The purpose of this study was to investigate the influence of a vegetated and a non-vegetated surface on the kinematics of movement initiation of a canine athlete. It was hypothesized that there would be a significant difference in the influence of a vegetated and non-vegetated surface on the kinematic performance (vertical displacement of the hip, ear, and shoulder, swing times during the follow through phase, stance times during the action phase, horizontal velocity, and forward and backward horizontal displacement of the paws) of the canine sprint start. To test these hypotheses, the data was divided into four kinematic components: time, horizontal displacements, vertical displacements, and velocity; with four separate statistical analyses performed. A (2) X (2) (Surface X End) MANOVA with surface as between subjects and end (i.e. rear and front) as within subjects variables was employed to evaluate rear and front stance time and rear and front swing time. A (2) X (2) (Surface X End) MANOVA with surface as between subjects and end as within subjects variables was used to evaluate rear and front stride length and rear and front negative displacement. A (2) X (3) (Surface X Displacement) ANOVA with surface as between subjects and displacement (i.e. position of head, shoulder, and hip) as within subjects variables was used to evaluate the vertical displacement of the head, shoulder, and hip in the set position. Lastly, a one way ANOVA was used to evaluate average horizontal velocity. Follow up paired t-test were used to evaluate specific differences between surface, end, and displacement values post significant MANOVA and ANOVA findings. This chapter presents the results of this project and includes the following sections: (a) surface quantification, (b) camera verification, and (c) gait kinematics.

One participant was dropped from the study on the fourth day of data collection. The participant sustained a spider bite over the right tarsal joint and health concerns precluded this participant from completing all trials. The participant was not replaced and all of the participant's data was removed, therefore all reported results were out of seven participants instead of eight.

Surface Quantification

The textural analysis revealed that both the vegetated and non-vegetated surfaces were classified as loamy sand. Means and standard deviations for the outcome measures of both the vegetated and non-vegetated surfaces are shown in Table 3. Analysis of the vegetated surface revealed the species was a Paspalum Notatum (Bahiagrass) with a shoot density of 1.6 shoots per square inch.

Table 3. Mean and standard deviation values from the soil analysis

Surface	% Sand		% Clay		% Silt		% Moisture		Bulk Density g/cm^3	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Non-Vegetated	83.3	2.0	10.4	.7	6.3	1.6	4.6	2.7	1.43	.07
Vegetated	81.8	3.5	9.1	2.3	9.2	1.4	5.1	2.5	1.23	.09

Camera Verification

A paired t-test was used to test the differences in spatial camera video capture. This was verified by testing the velocity (m/s) of the Vx marker at lead foot touch down (see Table 4) between the cameras within each trial (n = 28). The velocity tested the positional values sampled by each camera. A paired *t*-test was used to test for a main effect. No main effects were found between the two cameras for the non-vegetated surface (mean difference = .057, *SD* = .192, t (27) = 1.591, p = .123) nor the vegetated surface (mean difference = .069, *SD* = .349, t (26) = 1.032, p = .311). This verified that the cameras had an orthogonal relationship to the sagital plane of the dog and allowed the left and right side values to be grouped together for further analysis.

Table 4. Mean horizontal velocities and standard deviations for the Vx marker at lead foot touch down.

Camera	Vegetated		Non-vegetated	
	M	*SD*	*M*	*SD*
Color TS	6.53	.61	6.21	.86
Monochrome TS	6.60	.68	6.15	.83

Gait Kinematics

This section presents the results from the overall and follow-up statistical analyses conducted for hypothesis testing of the surface, and end main effect and the surface*end interaction for gait kinematics. Due to a technical error, the data for Dog 3 in Group 1 on the vegetated surface was lost. A linear equate model was applied to predict the missing data for the lost trial. To linear equate the data for the first trial with Dog 3 in Group 1, a series of multiple regression analysis were conducted using the first trial for each variable as the dependent variable and the second, third, and fourth trials for each variable as the predictor variables (Peterson et. al., 1989). For example, A1 was the dependent variable, and A2, A3, and A4 were the predictor variables. The unstandardized predicted value was saved and replaced the missing data for Dog 3 in Group 1 trial 1 only.

Temporal

A (2) X (2) (Surface X End) MANOVA with surface as between subjects and end as within subjects variables was employed to evaluate rear and front stance time and rear and front swing time. Table 5 contains the mean and standard deviation values for the temporal variables. A multivariate test was used to test the main effect for surface, end, and surface*end interaction. The Pillai's Trace was used to report the multivariate test results for surface $F(2, 5) = 4.377$, $\eta^2 = .636$, $p = .080$; end $F(2, 5) = 39.018$, $\eta^2 = .940$, $p = .001$; and surface*end interaction $F(2, 5) = 7.792$, $\eta^2 = .757$, $p = .029$. There was a main effect for end and the surface*end interaction. Univariate tests for surface, end, and surface*end interaction were conducted on each dependant variable and the results are reported in Table 6. No main effects were found for swing time and stance time for the surface effect. Main effects were found for swing time for the end effect and swing time for the surface*end interaction. The significant surface*end interaction for swing time (see Figure 3) illustrates that the front swing time behaved differently across surfaces than did the rear swing time. Furthermore, inspection of Figures 2 & 3 indicates that the rear swing time remains relatively unchanged and the front swing time is shorter on grass than on soil. In addition, there was a significant difference between end of dog for swing time within surface, indicating that the swing time for the front end of the dog was significantly different from the swing time for the rear end of the dog for both soil and grass conditions. Follow up paired *t*-tests were used to describe the differences across and within surface. Table 7 shows the follow up paired *t*-test values.

Table 5. Mean and standard deviation values for the temporal variables reported in seconds.

		Non-vegetated Surface		Vegetated Surface	
	N	*M*	*SD*	*M*	*SD*
RrStan1Time (sec)	7	.198	.020	.202	.017
FtStanTime (sec)	7	.178	.029	.184	.035
RrSwingTime (sec)	7	.126	.011	.126	.007
FtSwingTime (sec)	7	.168	.010	.155	.013

Table 6. Univariate test results for temporal variables for surface, end, and surface*end interaction.

Measure	*df*	*SS*	*MS*	*F*	*p*	η^2
Surface						
Stance Time	1	.000	.000	1.547	.260	.205
Swing Time	1	.000	.000	9.993	.020	.625
End						
Stance Time	1	.002	.002	2.517	.164	.295
Swing Time	1	.009	.009	52.241	<.001	.897
*Surface*End*						
Stance Time	1	5.849	5.849	.161	.702	.026
Swing Time	1	.000	.000	.8.608	.026	.589

Table 7. Surface and end paired *t*-test results for the temporal variables

Measure	*df*	*T*	*p*
Surface			
Rear Swing Time	6	.318	.761
Front Swing Time	6	3.402	.014
End			
Stance Time Soil	6	1.711	.138
Stance Time Grass	6	1.420	.206
Swing Time Soil	6	-8.194	<.001
Swing Time Grass	6	-5.282	.002

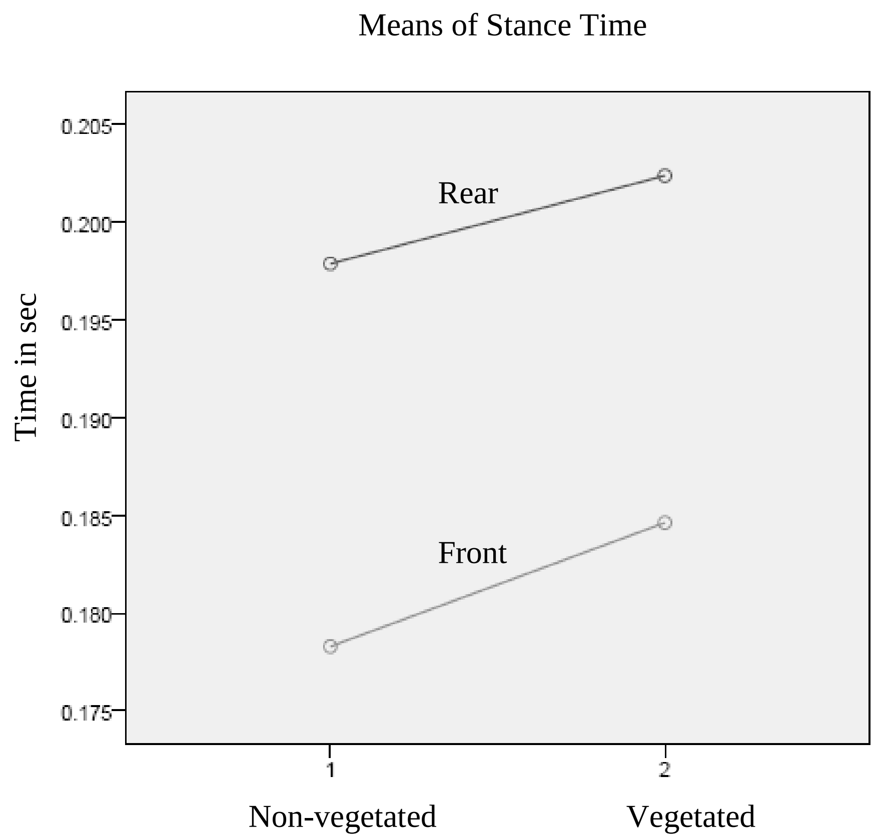

Figure 2. Rear and front stance time means across surface

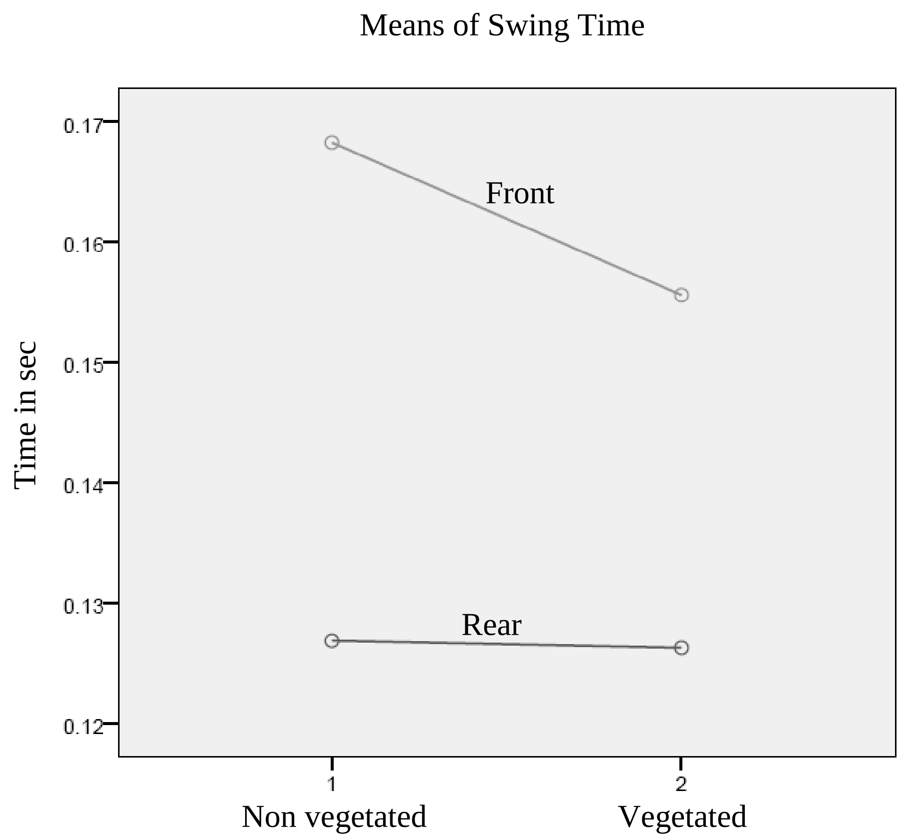

Figure 3. Rear and front swing time means across surface

Horizontal

A (2) X (2) (Surface X End) MANOVA with surface as between subjects and end as within subjects variables was employed to evaluate rear and front stride length and rear and front negative displacement. Table 8 contains the mean and standard deviation values for the horizontal variables. A multivariate test was used to assess the main effect for surface, end, and surface*end interaction. The Pillai's Trace was used to report the multivariate test results for surface $F(2, 5) = 35.956$, $\eta^2 = .935$, $p = .001$; end $F(2, 5) = 46.549$, $\eta^2 = .949$, $p = .001$; and surface*end interaction $F(2, 5) = 22.908$, $\eta^2 = .902$, $p =$

.003. There was a main effect for surface, end, and surface*end interaction. Univariate tests for surface, end, and surface*end interaction were conducted on each dependant variable and the results are reported in Table 9. Main effects were found for stride length and negative displacement across surfaces, end, and for the surface*end interactions. The significant surface*end interaction (see Figure 4 and Figure 5) illustrates that there is a difference for surface and end. Visual inspection of Figure 4 demonstrates that the rear stride length remains relatively unchanged across surfaces, but that the front limbs stride length is larger on soil than on grass. Visual inspection of Figure 5 indicates that rear negative displacement demonstrated a slight difference between surfaces with the rear negatively displacing more on soil than on grass. However, the front negative displacement change between surfaces is more dramatic and the probable source of the interaction. Visual inspection of Figure 5 shows that the front negative displacement is greater on soil than on grass. These findings from visual inspection are supported by the results of follow-up paired *t*-tests. In addition, there was a significant difference between end of dog for stride length and negative displacement within surface. This is evidenced by the disparity between the front and rear variables within each surface. Specifically, the front end of the dog had significantly longer mean stride lengths than the rear end of the dog for both soil and for grass. In addition, the rear end of the dog had significantly smaller negative displacement on both grass and on soil than did the front end of the dog. Table 10 shows the surface and end Paired *t*-test results for the horizontal variables.

Table 8. Mean and standard deviation values for the horizontal variables reported in percent body length.

		Non-vegetated Surface		Vegetated Surface	
	N	*M*	*SD*	*M*	*SD*
Rear Stride length (%BL)	7	164.273	10.241	164.432	8.694
Front Stride length (%BL)	7	190.110	10.446	177.933	11.330
Rear Negative Displacement (%BL)	7	-6.687	2.554	-5.298	1.921
Front Negative Displacement (%BL)	7	-21.423	2.628	-17.253	3.828

Table 9. Univariate test results for horizontal parameters for surface, end, and surface*end interaction.

Measure	*df*	*SS*	*MS*	*F*	*p*	η^2
Surface						
Stride length	1	252.736	252.736	9.898	.02	.623
Negative Displacement	1	54.083	54.083	13.605	.01	.694
End						
Stride length	1	2708.097	2708.097	33.707	.001	.849
Negative Displacement	1	1246.724	1246.724	60.293	<.001	.909
*Surface*End*						
Stride length	1	266.349	266.349	13.161	.011	.687
Negative Displacement	1	13.528	13.528	9.208	.023	.605

Table 10. Surface and end Paired *t*-test results for the horizontal variables

Measure	*df*	*t*	*P*
Surface			
Rear Stride length	6	-.079	.940
Front Stride length	6	4.073	.007
Front Negative Displacement	6	-3.549	.012
Rear Negative Displacement	6	-3.323	.016
End			
Stride length Soil	6	-5.565	.001
Stride length Grass	6	-5.037	.002
Negative Displacement Soil	6	9.386	<.001
Negative Displacement Grass	6	6.083	.001

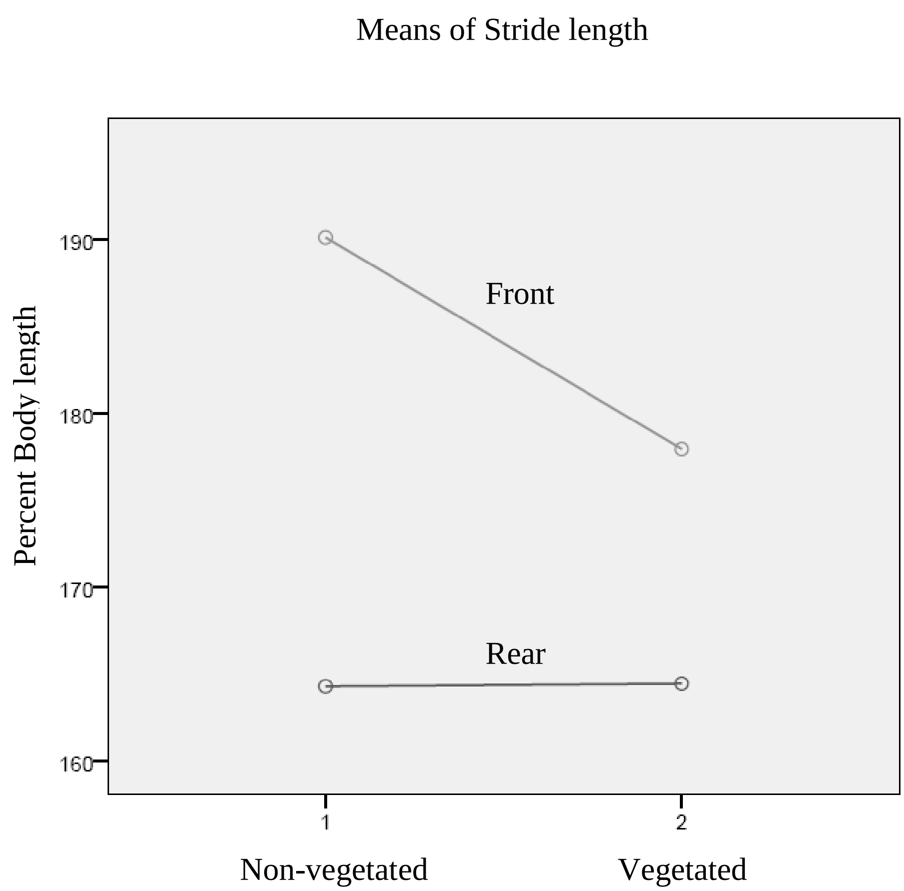

Figure 4. Rear and front stride length means across surface

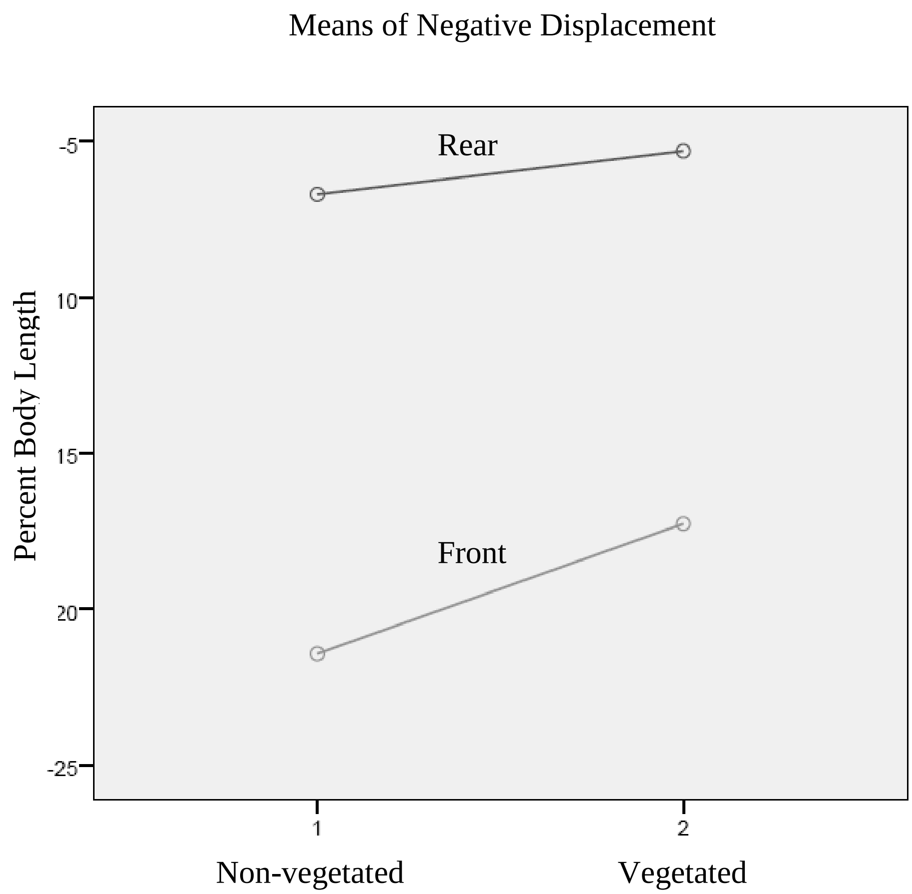

Figure 5. Rear and front negative displacement means across surface

Vertical

A (2) X (3) (Surface X Displacement) ANOVA with surface as between subjects and displacement as within subjects variables was employed to evaluate vertical displacement of the head, shoulder, and hip. Table 11 contains the mean and standard deviation values for the vertical displacement variables. A univariate test was used to test the main effect for surface, displacement, and surface*displacement interaction. The test results were for surface $F(1, 6) = 37.700$, $\eta^2 = .863$, $p = .001$; displacement $F(1, 6) = 102.247$, $\eta^2 = .971$, $p = .001$; and for surface*displacement interaction $F(1, 6) = 8.906$, η^2

= .760, *p* = .028. Univariate tests for surface were conducted on the dependant variable and the results are reported in Table 12. There was a main effect for surface, displacement, and the surface*displacement interaction. The surface*displacement interaction (see Figure 6) illustrates that there is a difference across surface dependent upon part (head, shoulder, and hip) of dog. A follow up paired *t*-test show that the difference across surface is accounted for by the head and the shoulder (see Table 13). Visual inspection of Figure 6 indicates that the head and shoulder behave in a like manner across surfaces, with mean vertical displacements yielding larger values on grass than on soil, however, the hip mean vertical displacement was not larger for soil than for grass. A one way repeated measures ANOVA was used to evaluate the difference for part of dog (i.e. displacement). The test results for soil [$F(1, 6) = 158.36$, $\eta^2 = .963$, $p = < .001$] and grass [$F(1, 6) = 203.23$, $\eta^2 = .971$, $p = <.001$] show that there is a significant within surface difference between part of dog. Follow up paired *t*-test were used to determine what part of the dog was significantly different for displacement (see Table 14).

Table 11. Mean and standard deviation values for the vertical variables reported in percent body height.

		Non-vegetated Surface		Vegetated Surface	
	N	*M*	*SD*	*M*	*SD*
Shoulder (%BH)	7	57.335	2.635	59.403	2.594
Hip (%BH)	7	62.021	3.984	61.606	4.345
Head (%BH)	7	87.201	8.691	89.292	7.957

Table 12. Univariate test results for vertical variables for surface, end, and surface*end interaction.

Measure	*df*	*SS*	*MS*	*F*	*P*	η^2
Surface	1	16.343	16.343	37.700	.001	.863
Displacement	2	3740.900	3740.900	102.247	<.001	.945
Surface*Displacement	2	7.257	7.257	8.906	.004	.597

Table 13. Surface Paired *t*-test results for the vertical variables

Measure	*df*	*t*	*p*
Head Vertical Displacement	1	-6.325	.001
Hip Vertical Displacement	1	.881	.412
Shoulder Vertical Displacement	1	-4.094	.006

Table 14. Displacement Paired *t*-test results for the vertical variables

Measure	*df*	*t*	*p*
Shoulder and Hip (Soil)	6	-2.865	.029
Shoulder and Head (Soil)	6	-12.584	<.001
Hip and Head (Soil)	6	-8.172	<.001
Shoulder and Hip (Grass)	6	-1.475	.191
Shoulder and Head (Grass)	6	-14.256	<.001
Hip and Head (Grass)	6	-10.022	<.001

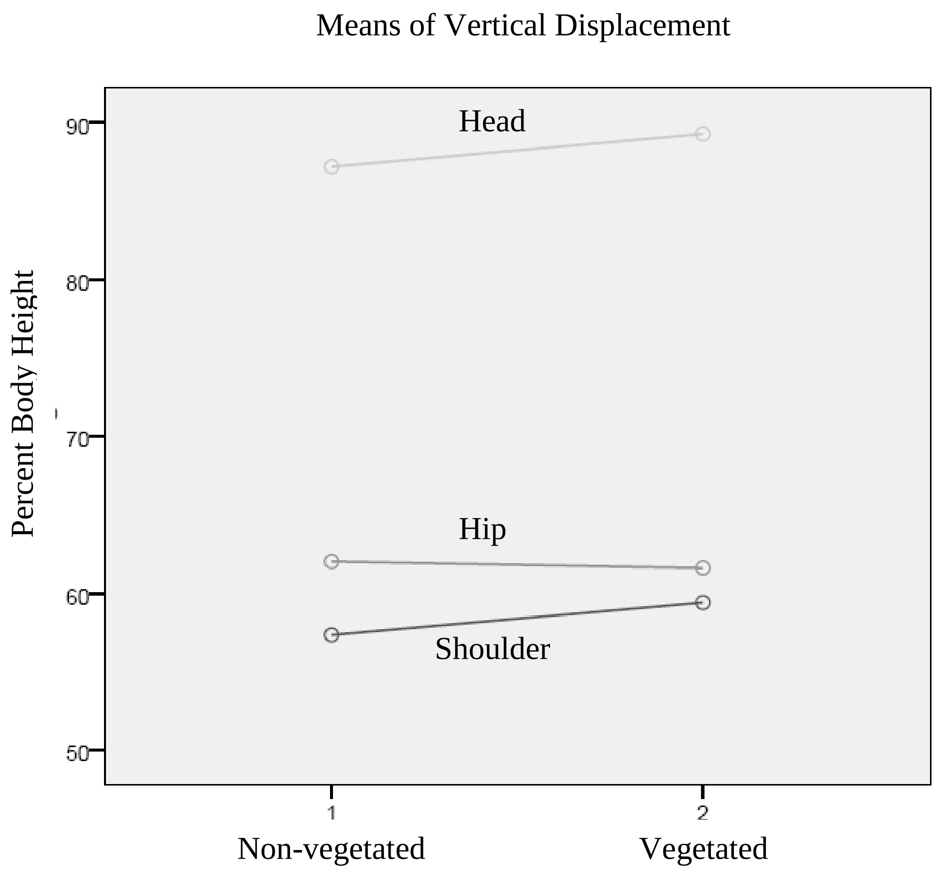

Figure 6. Vertical displacement means for head, hip, and shoulder across surface

Velocity

A one way within subjects ANOVA was employed to evaluate average horizontal velocity. Table 15 contains the mean and standard deviation values for the horizontal variables and Figure 7 shows a graphical relationship of the means. The tests of within-subjects effects was used to test the main effect for surface. There was no main effect for surface and the results are presented in Table 16. Therefore, no follow-up analysis was performed.

Table 15. Mean and standard deviation values for the velocity variable reported in meters per second.

		Non-vegetated Surface		Vegetated Surface	
	N	*M*	*SD*	*M*	*SD*
Average Velocity (m/s)	7	3.339	.243	3.421	.254

Table 16. Univariate test results for velocity variables for surface.

Measure	*df*	*SS*	*MS*	*F*	*p*	η^2
Surface						
Average Velocity	1	.024	.024	2.349	.176	.281

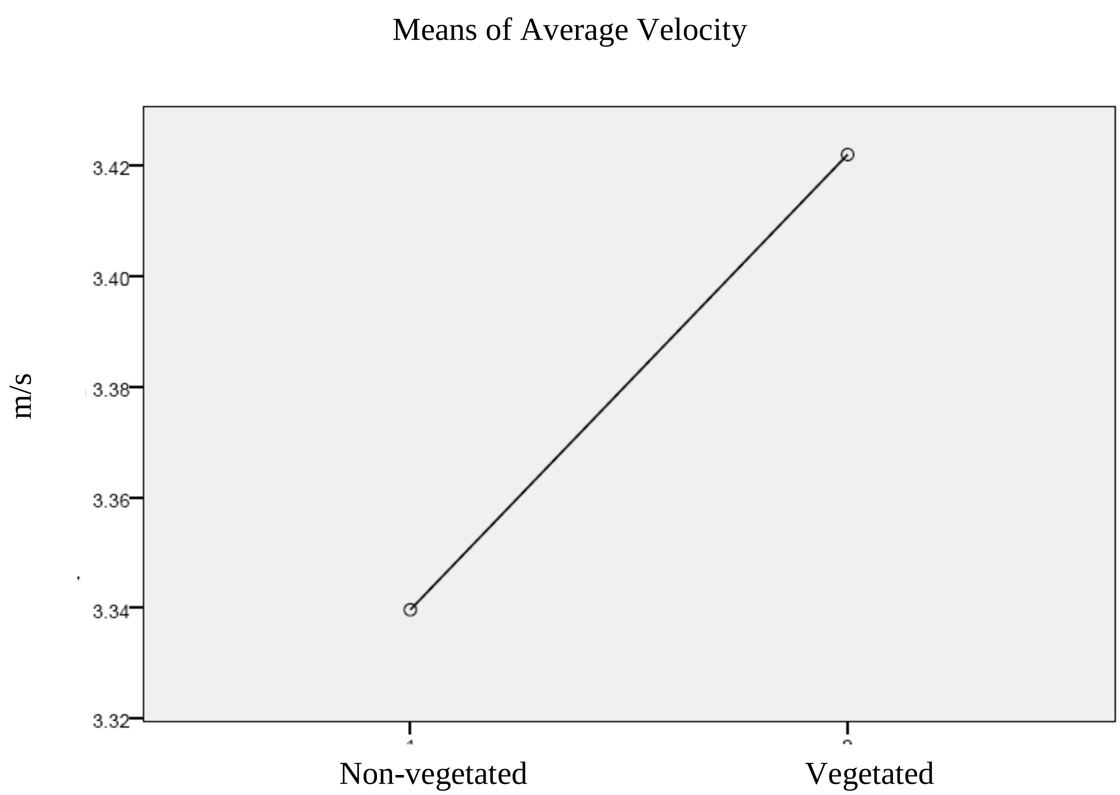

Figure 7. Average velocity means across surface

Results Summary

Main effects were found for the temporal, horizontal, and vertical dependent variables. Temporal dependent variable main effects were found for swing time across end of dog and swing time for the surface*end interaction. Horizontal dependent variable main effects were found for stride length and negative displacement across surfaces, ends, and for the surface*end interaction. The results of the surface*end interactions for the temporal and horizontal dependent variables showed that the surface had significant effects mainly on the front end of the dog. Vertical dependent variable main effects for surface, displacement, and the surface*displacement interaction were found for head and shoulder displacement. There was no main effect for average velocity for the surface effect. These findings support the hypothesis that a vegetated and a non-vegetated surface have significantly different effects on the kinematics of the canine sprint start.

DISCUSSION

The purpose of this study was to investigate the influence of a vegetated and a non-vegetated surface on the kinematics of movement initiation of a canine sprint start. This chapter presents the conclusions of this project and includes the following sections: (a) surface quantification, (b) camera verification, (c) gait kinematics, (d) overall conclusions, and (e) future research.

This study's hypothesis predicted that the type of surface upon which a dog starts would influence the dog's starting kinematics. Specifically the expectations of the study were the non-vegetated surface would have a lower shear strength compared to the vegetated surface (Ratzlaff et. al., 1997) which would cause the dogs to have greater slipping as measured by magnitude of slip distance, longer stance times, shorter strides, lower vertical set positions, and lower velocities. The vegetated surfaces would provide better traction and improve performance and safety over the non-vegetated surface.

Surface Quantification

Athletic surface quality can be defined as the suitability of a surface for a particular activity as measured or perceived in terms of the important interactions between the playing surface and the athlete (McNitt et. al., 1996). Presently no scientific studies exist describing the optimal surface arrangement for the canine sprint start. Human and equine studies (Nigg & Yeadon, 1987; Nigg, 1990; Harland & Steele, 1997; Ford et. al., 2006; Peterson et. al. 2008; and Thomason & Peterson, 2008) have shown that the surface content does have implications on performance and safety. It was not the intent of this study to interpret the effects of individual surface properties on movement, rather it was to define the surface and evaluate its effects on canine sprint start kinematics. The textural analysis revealed that both the vegetated and non-vegetated surfaces were classified as loamy sand. Therefore, the difference in treatments was that one surface was vegetated while the other surface had no vegetation. Since the textural classification of the surfaces was the same, any kinematic influence that resulted was caused by the lack of or presence of vegetation. Analysis of the vegetated surface revealed the species of vegetation was a Bahiagrass with a shoot density of 1.6 shoots per square inch.

Camera Verification

Two independent cameras positioned to capture a subject in a specified volume can obtain a variance in spatial parameters if they are not properly positioned. Differences in spatial camera video capture were verified by testing the velocity (m/s) of the Vx marker, visible in each camera, at lead foot touch down between the two cameras within each trial. No significant differences were found between the two cameras for the non-vegetated surface or the vegetated surface. This verified that the cameras were collecting the same video on respective sides of the dog and allowed the left and right side values to be grouped together for further analysis.

Gait Kinematics

The kinematic objectives of the canine sprint start are to obtain a body set position to initiate the quickest and most efficient movement possible. Once the dog initiates movement from the set position the objective is to stay balanced and moving forward at the highest rate of acceleration possible for as long as possible. In addition, the sprint start should allow the dog to assume the proper sprinting form after the initial steps to obtain maximal velocity and sustain this velocity. It was hypothesized that the surface would influence the dog's kinematic parameters during movement initiation. Significant kinematic main effects did occur due to the surface in this study.

Subjective Kinematic Gait Analysis

No previous literature has quantitatively or subjectively described movement initiation in the dog. In order to understand the quantitative effects of the surfaces on movement initiation, it is necessary to have a general understanding of the major components of the canine sprint start movement. The following subjective description was derived from high speed video of multiple trials for seven dogs sampled during this study. The following paragraphs will describe the movement in detail. Please refer to Figure 8 for sequential positions of the canine sprint start.

Counter Movement

The canine sprint start is movement initiation at maximum or near maximum effort. It consists of five primary movements (counter movement, rear limb action phase, front limb action phase, rear limb follow through phase, and front limb follow through phase). The first movement is the counter movement which is characterized by the dog moving from a standing position to a set position (Figure 8 sequential position 1 to 2). During the counter movement, the dogs negatively displace the center of gravity in the y-direction by lowering the body to the ground from the standing position. This is accomplished by the dog flexing the hip, stifle, elbow, and shoulder. The result is the dog rapidly flexing these four joints as it lifts each paw approximately 4 - 8 centimeters off the ground and the dog free falls. This movement is not a jumping motion, rather it is a rapid lifting of the paws followed by a brief free fall. The rear limbs are the first limbs to contact the ground after the free fall period. The front limbs are extended in front of the body and do not contact the ground until after the set position and after the dog initiates movement forward with the rear limbs. The free fall mechanism may be employed by the dog to use gravity to accelerate the dog's mass downward, which eccentrically loads the muscles upon contact with the ground. This will enable the dog to store and utilize the elastic potential energy developed in the elastic components of the hip and stifle extensor muscles and the tarsal flexor muscles. In addition, the rapid eccentric contraction of the muscle may stimulate the muscle spindles and evoke the stretch reflex which results in a greater concentric contraction of the associated muscle groups. The rapid eccentric contraction of the hip and stifle extensor muscles and the tarsal flexor muscles is followed by a brief amortization phase and then a rapid concentric contraction. It is during this brief amortization phase and concentric action phase that the elastic potential energy is released. The released energy is coupled with the force of the concentric contraction to begin initiation of movement forward. The dog is in the set position during the amortization phase just prior to movement initiation (Figure 8 sequential position 2).

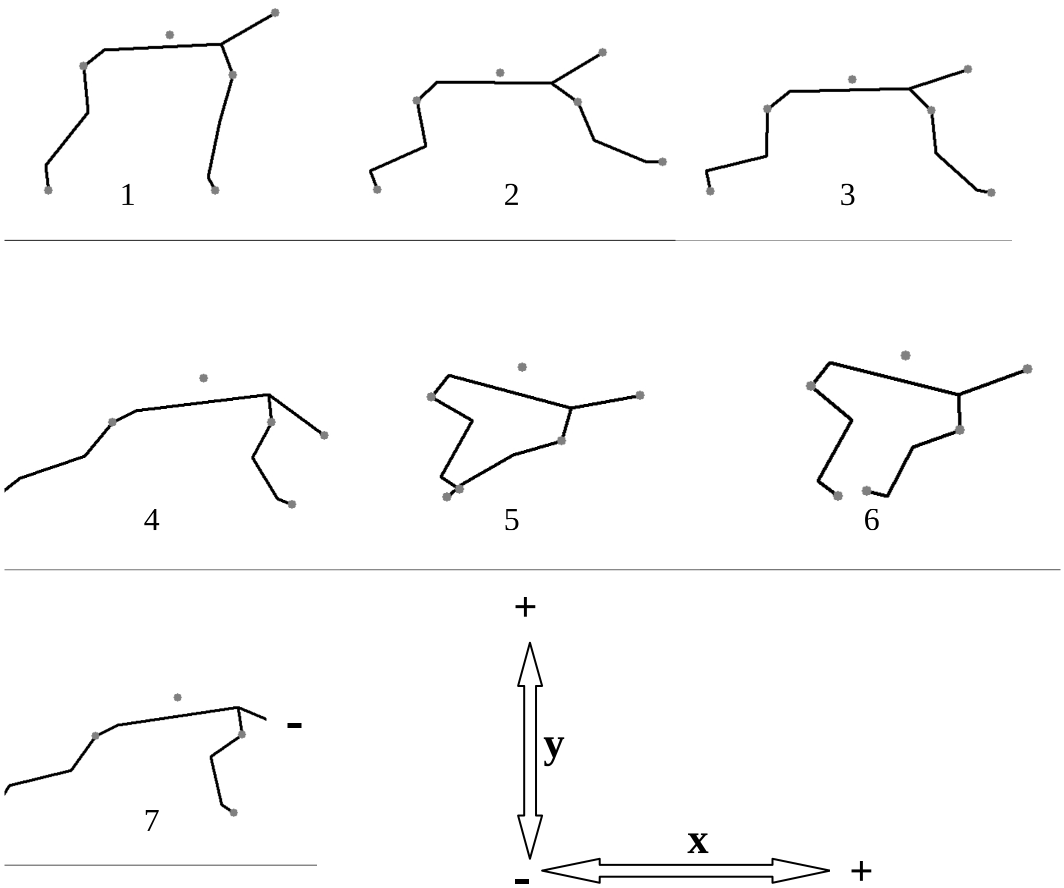

Figure 8. Sequential Positions of the Canine Sprint Start**.** This figure represents the sequential positions of the canine sprint start: (1) standing, (2) set, (3) front paw touch down, (4) rear paw take off, (5) front paw take off, (6) rear paw touch down, and (7) second front paw touch down.

Rear Limb Action and Follow Through Phase

Once the dog has lowered the body to the set position, it is now in optimal joint, segment, limb, and torso positioning to begin movement of the center of gravity forward in the positive horizontal direction. After the set position the dog enters the rear limb action phase (Figure 8 sequential position 2 to 4) where it applies horizontal and vertical propulsive forces to the ground to accelerate the body forward in the positive horizontal direction and to counteract the force of gravity in the vertical direction. The rear limb action phase is characterized by extension of the hip and stifle and flexion of the tarsal joint with a slight flexion of the thoracic and lumbar spine. At the end of the rear limb action phase, the hip as well as the thoracic and lumbar spine is in near full extension, the stifle is in full extension, and the tarsus is in full flexion. When the center of gravity passes over the front limb base of support the rear limbs come off the ground. The rear limbs leave the ground because of hip and stifle flexion, tarsal extension, and a forward movement of the torso. One of the reasons for these movements post ground contact is to draw the rear limb mass closer to the limb axis of rotation which decreases the mass moment of inertia. By decreasing the mass moment of inertia, a smaller moment is required to move the rear limb forward. As the rear limb leaves the ground, it enters the rear limb follow through phase (Figure 8 sequential position 4 to 6). In this phase the rear limb is brought forward by full hip flexion and slight spinal flexion. The rear limb is then prepared for ground contact by slight hip and stifle extension. Rear limb ground contact is made immediately after the front limbs leave the ground and enter the front limb follow through phase (Figure 8 sequential position 5 to 7).

Front Limb Action Phase

As the dog's center of gravity translates forward the front limbs are brought to the ground with the shoulder, elbow, and carpus extended. It is not known whether the dog lowers the front limbs by eccentrically contracting the shoulder flexors to counteract the force of gravity acting on the center of mass of the limb segment or if the dog is using the force of gravity and concentrically contracting the shoulder extensors to drive the front limbs down into the surface, future research may shed light on this question. It is a concentric contraction if the rate at which the paws approach the ground is greater than the acceleration due to gravity. It is eccentric if the acceleration is less than that of gravity. Once the front limbs are in contact with the ground (Figure 8 sequential position 3), the front limb action phase begins. It appears that during the front limb action phase there is a concentric contraction of the shoulder extensors, carpus flexors, and an eccentric contraction of the elbow extensors. As the center of gravity passes over the base of front limb support, the shoulder joint is in full extension and the elbow extensors concentrically contract and extend the elbow. While the elbow is extending, the shoulder joint slightly flexes and the carpal flexors eccentrically contract slightly extending the carpal joint. The elbow does not fully extend during the front limb action phase. After the center of gravity passes over the front limb base of support, the dog begins flexing the carpus, shoulder, and elbow to prepare the front limb for the front limb follow through. In the front limb follow through phase, the limb will be off the ground in an open chain position. There are two reasons for the flexing of these joints. The first reason is to keep the front limbs from touching the ground since the shoulder is at its lowest vertical position after front paw take off. The second reason (as with the rear limb) is to decrease the mass moment of inertia and produce a potentially quicker more efficient forward movement of the front limb.

Second Rear Limb Action Phase

When the front limbs leave the ground, the rear limbs make their second ground contact. There is a brief period of non-support between the front limb take off and the rear limb touch down (Figure 8 sequential position 5). At ground contact the rear limbs strike the ground at the same time. The rear limbs and spinal complex are positioned with thoracic and lumbar flexion, hip flexion, stifle flexion, and tarsal extension. The thoracic and lumbar spines immediately go into a rapid extension to vertically lift the torso and also to linearly stack the vertebrae for efficient transfer of energy and force from the rear appendicular skeleton to the axial skeleton and torso. If a large degree of front limb negative paw displacement occurs, the spine will flex as the rear limbs touch down and enter the second rear limb action phase. If the spine is flexed during the rear limb action phase the center of gravity would not receive the appropriate amount of lift. In addition, the spine would not become a linearly stacked segmental column and energy and force transfer would be lost due to the rear appendicular skeleton transferring energy and force through a curvilinear segment. A curvilinear segment would also result in elastic strain of the musculoskeletal components of the dorsal spine and compression of the ventral spine. This would result in a loss of kinetic energy to elastic strain energy in the vertebral and paravertebral structures during rear limb propulsion. However, it is important for the thoracic and lumbar spine to be flexed at rear limb contact (Figure 8 sequential position 6) to allow for the quick release of the elastic strain energy in the paraveterbral muscles as they rapidly concentrically contract to extend the spine. As rear limb propulsion continues the spine fully extends, the hip extends, the stifle fully extends, and the tarsus fully flexes. As the torso travels forward the hip continues to extend drawing the rear limbs off the ground. The rear limbs then enter the next rear limb follow through phase (Figure 8 sequential position 7).

Front Limb Follow Through Phase

As the front paws come off the ground (Figure 8 sequential position 5) there is a rapid flexion of the elbow and carpal joint. Simultaneously the shoulder joint flexes rotating the front limb through the front limb follow through phase. In this phase the front limb is brought forward and prepared for the next ground contact (Figure 8 sequential position 7). There are two second front limb ground contacts, the first ground contact is the lead limb and the second ground contact is the non-lead limb. The second front limb ground contact for the non-lead limb is where the canine sprint start stride ends and the stride of the sprinting activity begins. This analysis only pertains to the sprint start stride and will not describe the second stride of the sprinting activity.

Head and Neck Positions

The head and cervical spine positions change throughout four of the five primary movements. During the counter movement the cervical spine position stays extended (Figure 8 sequential position 1 to 2) while the head is slightly flexed so that the jaw line is parallel to the ground. It is not until the dog makes front limb ground contact that the dog flexes the cervical spine. During the beginning of the front limb action phase (Figure

8 sequential position 3 to 4) the dog rapidly flexes the cervical spine and slightly extends the head to keep the jaw line parallel with the ground. As the center of gravity passes over the base of front limb support the dog reverses the direction of the head/cervical spine complex and rapidly extends the cervical spine (Figure 8 sequential position 5 to 6). The purpose of this maneuver is to propel the center of mass of the cervical spine and head upward vertically because this is the point in the sprint start when the dog is trying to vertically lift the torso. This maneuver assists the front limbs and paravetebral muscles in an upward vertical propulsion of the torso by accelerating the head and cervical spine masses upward. The upward acceleration of the head and cervical spine masses just prior to the upward acceleration of the torso mass, separates the effective mass of the torso/neck/head complex. This provides less effective mass (i.e., mass of torso – mass of neck and head) that has to be lifted by the front limbs and paravetebral muscles which produces a more efficient movement. It also allows the upward accelerating neck and head masses to pull on the torso as the front limb and paravetebral muscles apply vertical lifting forces to the torso. As the cervical spine reaches maximum extension the head is in slight flexion. When the front limbs make ground contact again, the cervical spine flexes (Figure 8 sequential position 7) and the cycle starts over again.

Stride lengths

In order to understand stride lengths (for example, right rear limb contact to the next right rear limb contact) it is important to recognize the manner in which the rear and front limbs are in contact with the ground. How the rear and front limbs contact the ground will illustrate which rear or front propulsion mechanism (i.e. rear limbs only, front limbs only, or a combination of both rear and front limbs) is responsible for stride lengths. Rear limb and front limb horizontal propulsion are not independent of each other during the first set of stance phases. They are offset from one another, meaning that just after rear limb propulsion begins, front limb propulsion begins (Figure 8 sequential position 2 to 4) however the step lengths of the front and rear limbs will influence both the front and rear stride lengths. This is a result of the rear limbs and the front limbs being in close intermittent contact with the ground at offset times in the first set of the action phases. As the dog enters subsequent strides, the rear limbs and front limbs contact the ground independently and the dog develops a front and rear flight phase with independent rear and front limb action phases. The second rear action phase is independent of the front limb action phase (Figure 8 sequential position 6) as the second rear limb action phase occurs between the first and second front limb action phases and during the front limb follow through phase. The independent rear limb action phase in conjunction with extension of the thoracic and lumbar spine helps account for the majority of the front limb stride distance.

Quantitative Kinematic Gait Analysis

No previous literature has quantitatively described the canine sprint start. The following quantitative description was derived from high speed video, sampled during this study, which evaluated seven dogs as they conducted a sprint start. The following paragraphs will describe the quantitative values of the sprint start and the statistical findings of this study. Please refer to Tables 5 – 16 and Figures 2 - 7 in the Results section for specific values of all the kinematic results.

Stance Times and Swing Times

The total step time (stance time + swing time) for the rear limbs on the non-vegetated and vegetated surface was 0.323 sec and 0.335 sec respectively. The rear swing time accounted for 39 % of the total step time for the non-vegetated surface and 37.9 % for the vegetated surface. The total step time for the front limbs on the non-vegetated surface was 0.346 sec and 0.363 sec on the vegetated surface. The front swing time accounted for 48.5 % of the total step time for the non-vegetated surface and 46.5 % for the vegetated surface.

No main effects were observed for stance time for the surface effect (refer to Figure 9). Main effects were found for stance time and swing time for the end effect, and swing time for the surface*end interaction. The significant surface*end interaction illustrates that there is a difference for surface and end and that the difference is accounted for by the front swing time across surface (refer to Figure 10). There was also a significant end effect (refer to Figure 9 and Figure 10). The rear swing time was significantly smaller than front swing time for the non-vegetated surface (difference of means was .042 sec) as well as the vegetated surface (difference of means was .029 sec). This finding indicates that the rear and front ends of the dog's bodies moved differently across the surfaces. According to the multivariate test results rear stance time (difference of means .004 sec) and front limb stance time (difference of means .006 sec) were not significantly different across surfaces. However, univariate and paired *t*-test results show significant trends towards front limb swing time being different for surface (difference of means .013 sec). and rear swing time (difference of means <.000 sec) was not (refer to Figure 9). The increase in front limb swing time could have been a result of the larger negative displacement of the front limb paws. This larger negative displacement could have increased the extension of the shoulder joint which would have caused the dogs to move (i.e. flexion) the shoulder through a larger range of motion. The larger range of motion could account for the increased swing time as the limb would have a larger angular distance through which to travel in order to prepare the front limb for contact with the ground in front of the dog.

Means of Stance Time

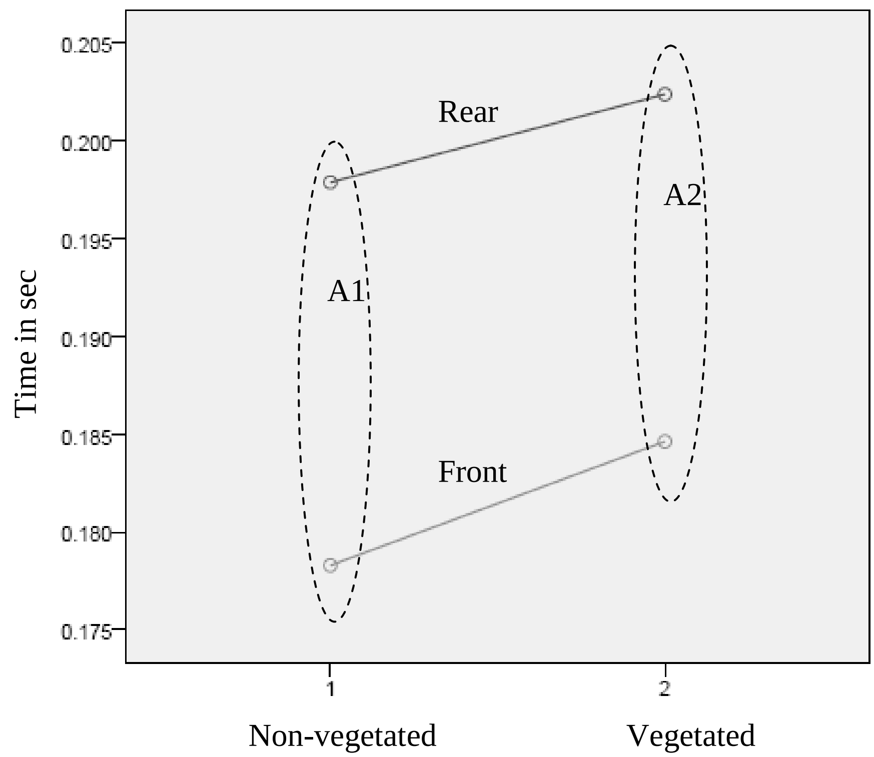

Figure 9. Review of a specialized version of Figure 2 that clearly indicates that the rear and front ends show the same trend even though there was not a significant surface effect. Also, the circles labeled A1 and A2 illustrate that there was a significant difference between the front and rear ends of the dog on the non-vegetated and vegetated surfaces, indicating that the front end and the rear end of the dog behaved differently on the vegetated and non-vegetated surfaces.

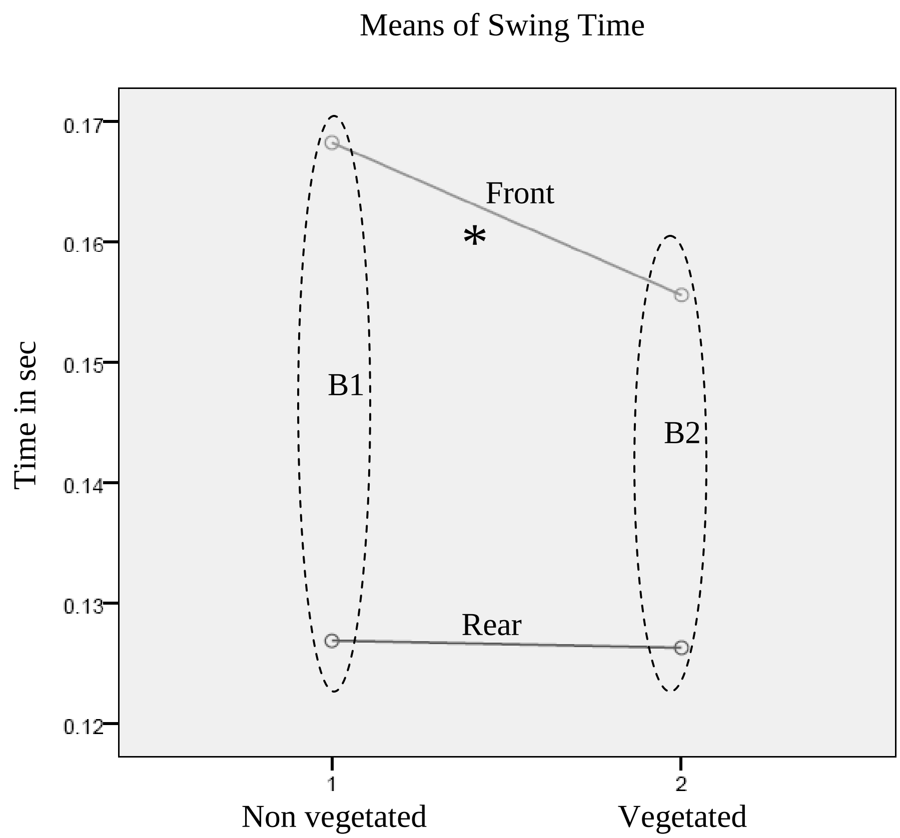

Figure 10. Review of a specialized version of Figure 3 that highlights several statistically significant findings. A) First, the chart clearly indicates the interaction for end, and further identifies that the change in front swing time is most responsible for this interaction. B) The circles labeled B1 and B2 illustrate that there was a significant difference between the front and rear ends of the dog on the non-vegetated and vegetated surfaces, indicating that the front end and the rear end of the dog behaved differently on the vegetated and non-vegetated surfaces. The asterisk denotes a significant difference was present across surface for the front swing time only.

No main effects were observed for rear stance time or front stance time. This indicates that the surface shifting under the paw on a non-vegetated surface did not increase stance time as previously shown in Pinnington and Dawson's (2001) study that compared soft beach sand to a grass surface in humans. However, it must be mentioned that the dynamics of the beach sand compared to our study's loamy sand may differ greatly due to particle size, shape, and distribution. The increase in stance time in humans is thought to be due to the need to gain stability as the surface shifts when loaded by the foot and to counteract foot slippage during propulsion (Pinnington & Dawson, 2001). It is hypothesized that while the non-vegetated surface did shift beneath the dog, the surface did not deform/shift as much as a sand surface when loaded by a human. The present study did observe main effects for foot slippage (i.e., negative paw displacement) however, it did not appear to effect stance time.

Horizontal

The step distance and negative displacement values were normalized for body length of the dog. Over the non-vegetated surface the dogs had a mean rear step distance of 164.2 % of the body length and 190.1 % of the body length for the front step distance. On the vegetated surface the dogs had a mean rear step distance of 164.4 % of the body length and 177.9 % of body length for the front step distance. Negative displacement values of the paw were also measured. The rear paw displaced -6.6 % and the front paw displaced -21.4 % of body length for the non-vegetated surface. The rear paw displaced -5.2 % and the front paw displaced -17.2 % of body length for the vegetated surface.

Main effects were found for stride length and negative displacement for the surface effect, the end effect, and for the surface*end interaction. The significant surface*end interaction illustrates that there is a difference for surface and end and that the difference is accounted for by the front stride length, front negative displacement, and rear negative displacement across surface (refer to Figure 11 and Figure 12). There was a significant end effect indicating that the front and rear limbs moved differently across the surfaces. On the non-vegetated surface the rear and front stride length difference of means was 25.0 % BL and on the vegetated surface the difference of means was 13.5 % BL. This finding indicates that the dogs had substantially different front and rear stride lengths on these 2 surfaces, and that the greatest difference was noted on the non-vegetated surface. At this point, it is not clear whether a greater difference in stride length between the front and rear limbs is valuable to propulsion or safety, but it can be presumed that an exaggerated difference would have an influence on the rhythmic nature of sprinting.

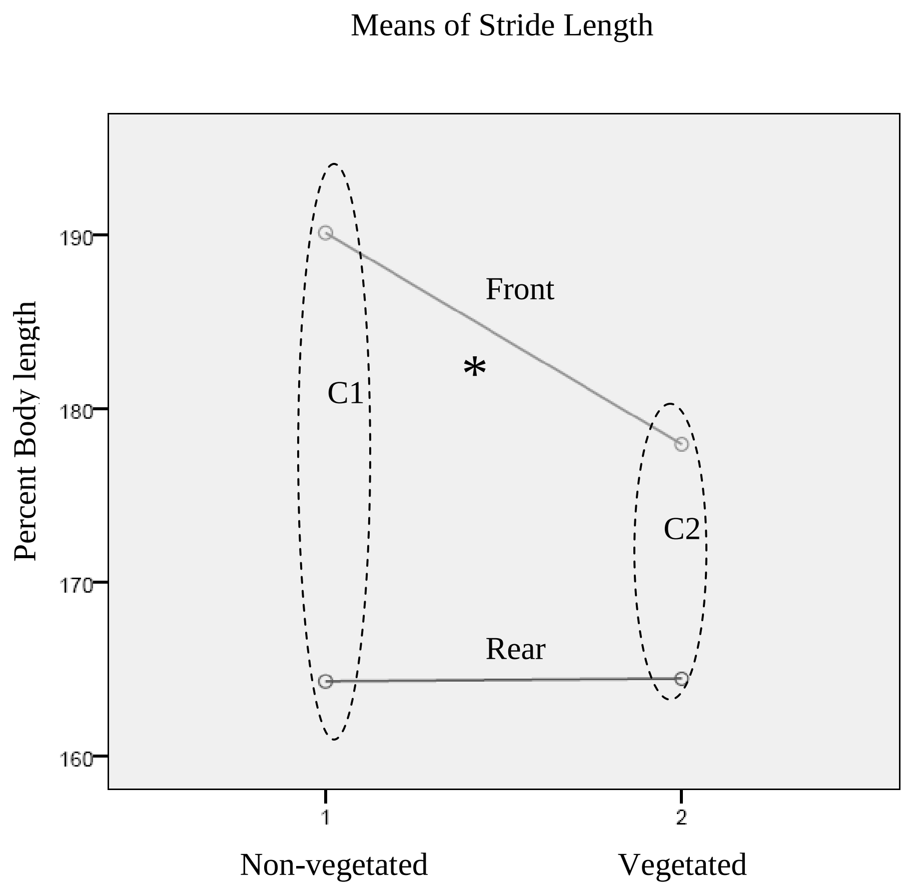

Figure 11. Review of a specialized version of Figure 4 that highlights several statistically significant findings. A) First, the chart clearly indicates the interaction for end, and further identifies that the change in front stride length is responsible for this interaction. B) The circles labeled C1 and C2 illustrate that there was a significant difference between the front and rear ends of the dog on both the non-vegetated and vegetated surfaces, indicating that the front end and the rear end of the dog behaved differently on the vegetated and non-vegetated surfaces. The asterisk denotes a significant difference was present across surface for the front limb only.

Means of Negative Displacement

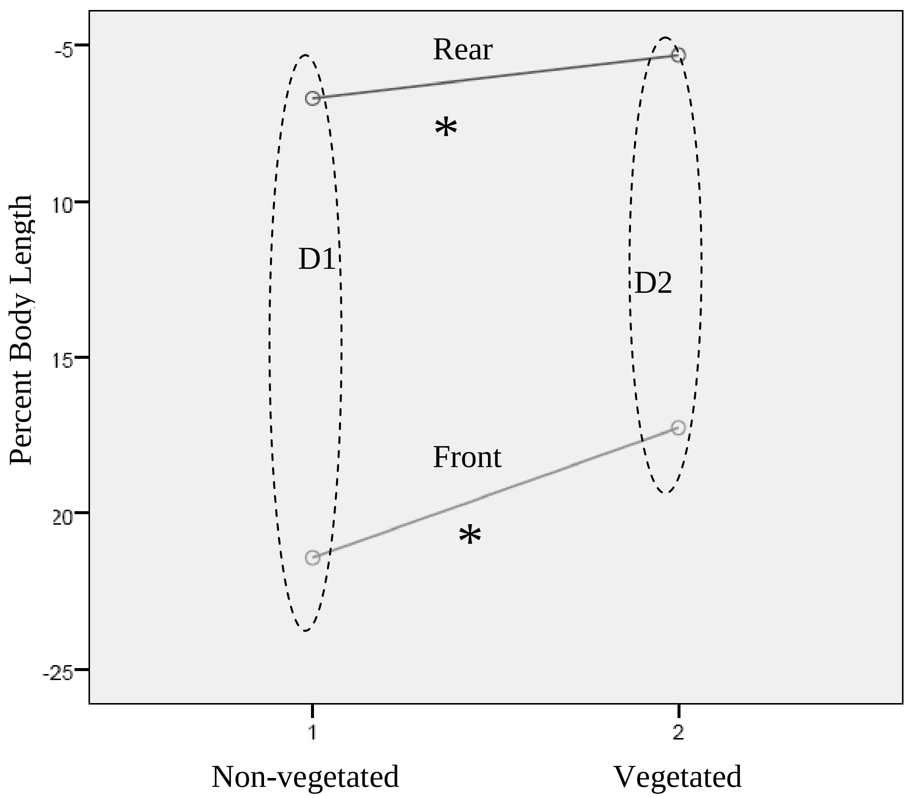

Figure 12. Review of a specialized version of Figure 5 that highlights several statistically significant findings. A) First, the chart clearly indicates the interaction for end, and further identifies that the change in front and rear negative displacement is responsible for this interaction. B) The circles labeled D1 and D2 illustrate that there was a significant difference between the front and rear ends of the dog on the non-vegetated and vegetated surfaces, indicating that both the front end and the rear end of the dog behaved differently on the vegetated and non-vegetated surfaces. The asterisk denotes a significant difference was present across surface.

Rear stride length was not significantly different (difference of means was 0.159 % BL) for the surface effect, yet front limb stride length was significantly different (difference of means was 12.177 % BL) for the surface effect. Rear stride length was not affected by surface even though there was a main effect for rear and front paw negative displacement. During the rear limb action phase the front limbs are in contact with the ground. The rear limbs and the front limbs are applying a horizontal propulsive force. The limbs are in different stages of the action phase because they began out of sync with one another. Therefore, propulsion is a synergistic effort between the front and rear limbs even though they are in separate stages of the action phase. The separate stages may allow the dog to increase propulsion in a stable limb when another limb is sliding in a negative direction. It appears that if the dog could increase propulsion in either the rear or front limbs during or just after the presence of a negative paw displacement, rear step distance would not be affected by the slip. In addition, the first movement initiation stride is relatively short (i.e., approximately 165% of body length) compared to what it is at maximum velocity (i.e., approximately 694 % of body length; Gillette and Zebas 1997). Thus, the negative displacement may not be great enough to affect the relative small magnitude of the initial rear stride length.

Surface did have an effect on front limb stride length which is most likely the result of the negative displacements; as stride length was longer on the surface that allowed for the greatest negative displacement (i.e. non vegetated surface). The larger negative displacements require that the dog cover not only the ground that they had anticipated, but must also make up the negative distance that the paw slipped. Stride length is also a component of rear and front limb propulsion (i.e. vertical and horizontal).

Propulsion can be affected by negative displacement of the paw. However, there was no difference in velocity of the dog between the surfaces, therefore, it is hypothesized that the larger negative displacements did not affect propulsion. Propulsion plays a role in stride length because the higher the velocity of the torso in the positive direction, the larger the distance covered by the torso and the larger the stride length will become. That is, the larger the distance the torso travels during the swing phase, the larger the stride length will be because the swinging limb is attached to the moving torso. Therefore, the stride length is a component of the moving torso and the swinging limb. If the torso remained stationary the limb would travel a shorter distance than if the torso was moving forward. This is because the distance traveled by the paw is a combination of the ROM of the shoulder joint plus the distance covered by the torso while the paw is off the ground, which ultimately determines the stride length. Since the negative displacements did not affect propulsion, the larger stride lengths on the non vegetated surface must be a result of the larger negative displacements. The larger negative displacements caused the limb to travel further because the paw had to make up for the larger negative displacements. In order for the dogs to keep the same velocity and stay balanced they would need to swing the limb forward placing it in the same spot that they would had they not slipped. Thus the negative displacement had to be made up for with a longer stride length.

Main effects were observed for surface and end for rear and front limb negative displacement. On the non-vegetated surface the rear and front negative displacement difference of means was 14.736 % BL and on the vegetated surface the difference of means was 11.995 % BL. This finding indicates that the front paws and rear paws slip differently on the different surfaces. The difference in end effect is due to anatomy and the mechanics of weight distribution. The dog carries 60 % of its weight over the front paws and the head and neck complex rotate about the thoracic complex further influencing front end mechanics. More research is needed to understand this influence. In addition, the rear paw is placed behind the rear limb axis of rotation, whereas, the front paw is placed in front of the front limb axis of rotation. Therefore, the rear paw has less distance to negatively displace than the front paw during the action phases (refer to Figure 13). Rear negative displacement (difference of means 1.389 % BL) and front limb negative displacement (difference of means 4.170 % BL) were significantly different for surface. This finding indicates that the dog slips more on the non-vegetated surface than on the vegetated surface at the front paws as well as the rear paws.

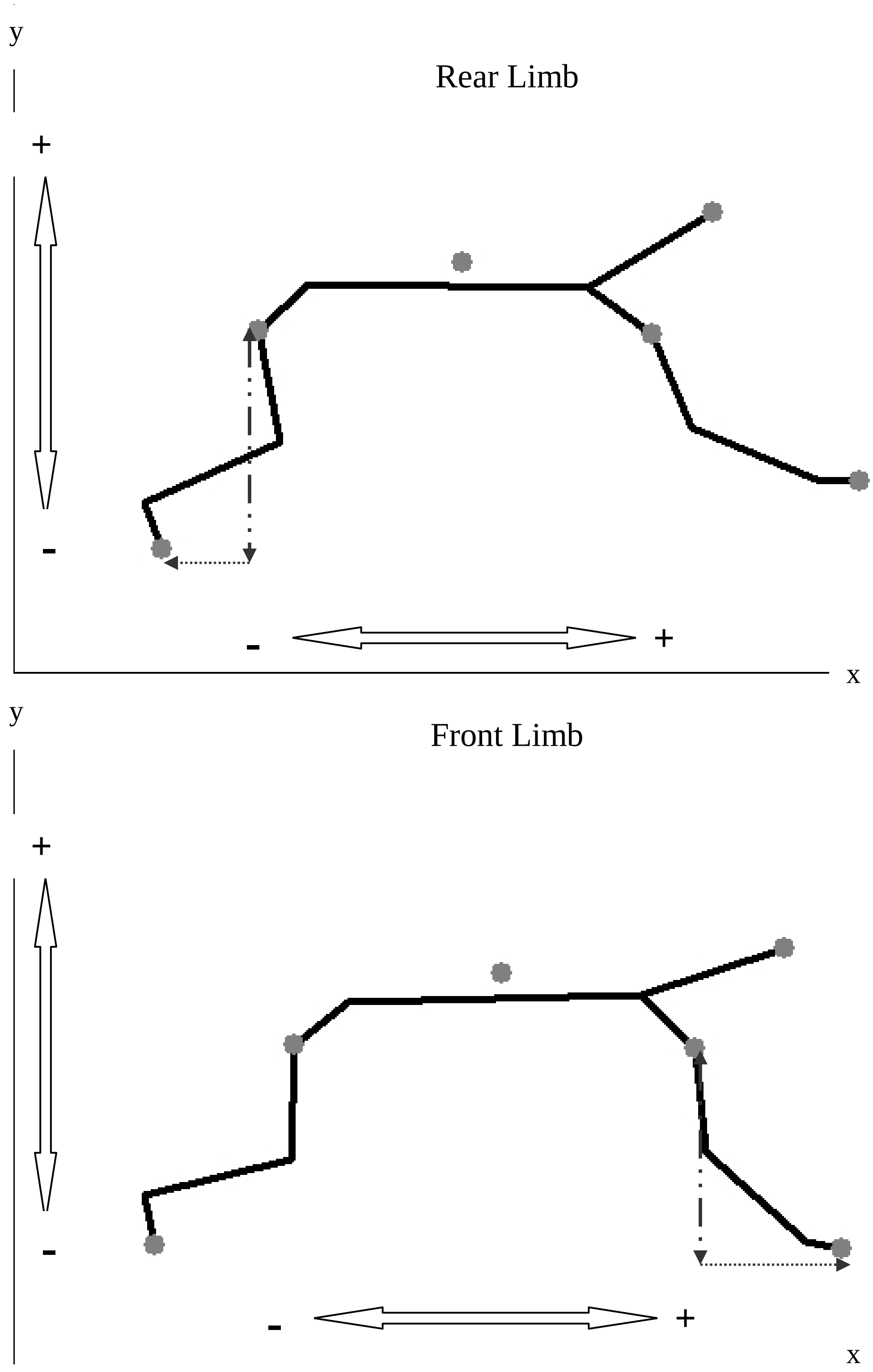

Figure 13. This figure represents the beginning of the action phase for the rear limb and for the front limb.

Once the dog initiates movement the objective becomes to apply vertical and horizontal propulsion forces to the ground in order to obtain maximal sprint velocity. If the horizontal propulsive forces exceed the shear strength of the surface then the foot will displace in the negative direction (Ratzlaff, 1997). The present study found that both the rear and front paws displaced in the negative direction. Main effects were found for negative displacements of the rear and front paws. This data indicates that the horizontal propulsive forces exceeded the shear strength of the non-vegetated surface to a greater degree than the vegetated surface. This can result in a loss of propulsion and abnormal kinematics that could place the dog at risk for injury. As the non-vegetated surface allowed the greatest magnitude of negative displacement this author considers it less safe than the vegetated surface upon which to initiate movement.

Vertical

The vertical displacement variables were normalized for dog body height. From the standing position the dogs displaced vertically in the negative direction to the set position (refer to Figure 8 sequential picture 2). In the set position the dogs displaced to a mean position of 62 % of the body height at the hip, 87.2 % at the head, and 57.3 % at the shoulder on the non-vegetated surface. On the vegetated surface the dogs displaced to a mean position of 61.6 % of the body height at the hip, 89.2 % at the head, and 59.4 % at the shoulder.

There was a main effect for surface, displacement, and the surface*displacement interaction. The surface*displacement interaction illustrates that there is a difference across surface dependent upon part (head, shoulder, and hip) of dog (refer to Figure 14).

Further inspection of the interaction indicates that the difference across surface is accounted for by the changes in head and the shoulder position (refer to Figure 15). The head and shoulder behave in a like manner across surfaces, with mean vertical displacements yielding larger values over the vegetated than over the non-vegetated surface, however, the hip mean vertical displacement was not different across surfaces. The difference for the vertical displacement (i.e. part of dog) effect is accounted for by the relationship of the shoulder to head and hip to head within surface. There was not a displacement effect for the relationship of the shoulder to hip vertical displacement within surface for vegetation, however, there was for the non-vegetated surface. The shoulder was lower than the hip on the non-vegetated surface (difference of means = 4.6 % BH) but not on the vegetated surface (difference of means = 2.2 % BH). These findings indicate that the head was at a significantly higher position than both the hip and shoulder and that the hip and shoulder vertical positions were significantly different from one another on the vegetated surface. This illustrates that the dogs are altering the mechanics of the body to prepare to counteract the effects of a potential negative displacement.

Means of Vertical Displacement

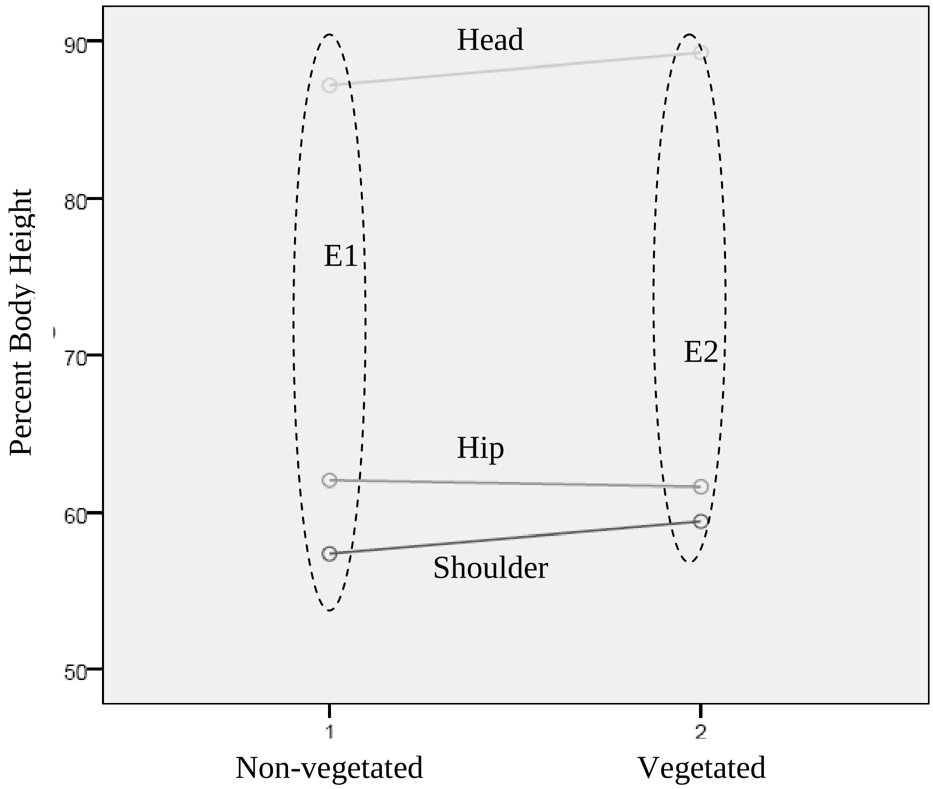

Figure 14. Review of a specialized version of Figure 6 that highlights several statistically significant findings. A) First, the chart clearly indicates the interaction for displacement, and further identifies that the effect is accounted for by the relationship of the shoulder to head and hip to head within surface. B) The circles labeled E1 and E2 illustrate that there was a significant difference between the part of dog but no difference was present between hip and shoulder on the vegetated surface.

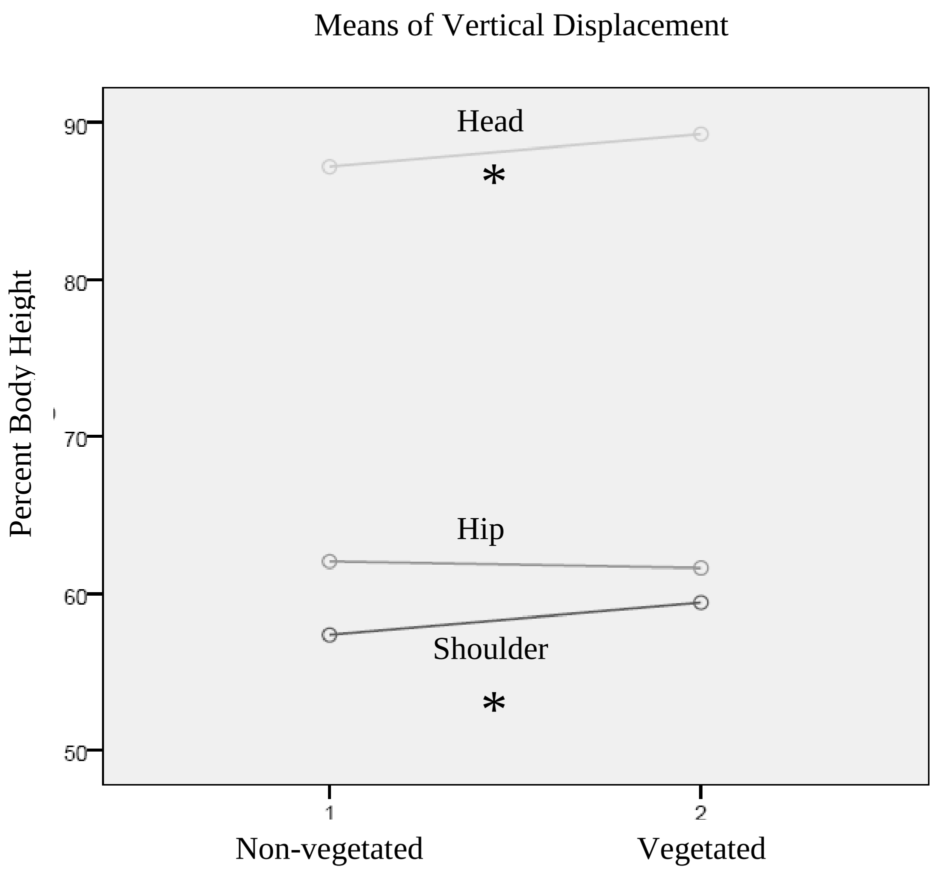

Figure 15. Review of a specialized version of Figure 6 that highlights statistically significant findings for surface. The asterisk denotes a significant difference was present across surface for the head and shoulder only.

No main effects were found for vertical displacement of the hip (difference of means = 0*.41 %*) in the set position for surface. This indicates that the surface did not affect preparatory movement strategies for hip vertical displacement in the set position. A main effect was found for vertical displacement of the shoulder (difference of means = *2.06 %*) and head (difference of means = *2.09 %*) in the set position for surface. The shoulder and head were significantly lower on the non-vegetated surface. In addition, the shoulder was lower than the hip on the non-vegetated surface but not on the vegetated surface. This suggests that the dogs were adopting a preparatory movement strategy that was surface specific prior to movement initiation. A recurring trend through out the data is that the surface had a greater affect on the front end of the dog than the back end. The significant surface and displacement affects accounted for by the shoulder and head further support this trend.

Due to the rear (difference of means = *1.38 %*) and front paw (difference of means = *4.16 %*) negative displacements yielding significantly larger distances on the non-vegetated surface, the dogs may be anticipating the larger negative displacement and employing a movement compensation strategy to counter the effects of the negative displacement. The dogs may have increased the flexion of the shoulder and extension of the elbow to reach further out to try and grab more of the loose non-vegetated surface as they tried to propel themselves. This reaching out would allow placement of the paws further in front of the center of gravity and to grab/build up more surface behind the paw as it slides in the negative direction along the surface. The more surface that builds behind the paw, the larger the pile of soil behind the paw will become and the harder it will be to negatively displace the pile (acting as a starting block). Also the more surface that builds behind the paw, the further down into the surface the paw will sink. The pile of accumulated surface and the sinking of the paw into the surface will allow the surface to place a greater reactive force in the positive direction against the force of the paw in the negative direction. Based on onsite subjective observations of the damage to the non-vegetated surface by the paw and review of high speed video it appears that the paw did sink deeper into the surface. In addition, more material built up behind the paw as the paw was further negatively displaced (see Figure 9). Therefore, reaching out further to rake the paw over a greater distance is a logical explanation for why the dog would increase the reach. However, what does reaching out further have to do with lowering of the point of the shoulder and head? Reaching out further increases the mass moment of inertia of the torso about the hip by distributing the effective mass (i.e., torso + front limbs) further from the axis of rotation (i.e., increasing the radius of gyration). The increased mass moment of inertia causes the torso to rotate more and lower the point of the shoulder and head. In the set position, the rear limb point of ground contact is behind the rear limb axis of rotation and the lumbar and thoracic spine extends. The combination of these positions makes it difficult for the dog to increase the vertical lift of the torso when the increase in mass moment of inertia is present due to increased shoulder flexion and elbow extension. The end result is a lowering of the cranial aspect of the torso.

Human athletes can manipulate their body positions to influence the GRF. This is accomplished by lowering or raising the hips and by leaning forward or backwards to change the position of the CG. The dogs may be manipulating the GRF just like the humans since the hips are higher than the shoulder and the head is lowered on the non-vegetated surface. This position may increase the load on the front paws helping the front paws to penetrate further into the surface and also to increase the normal force thus increasing the friction.

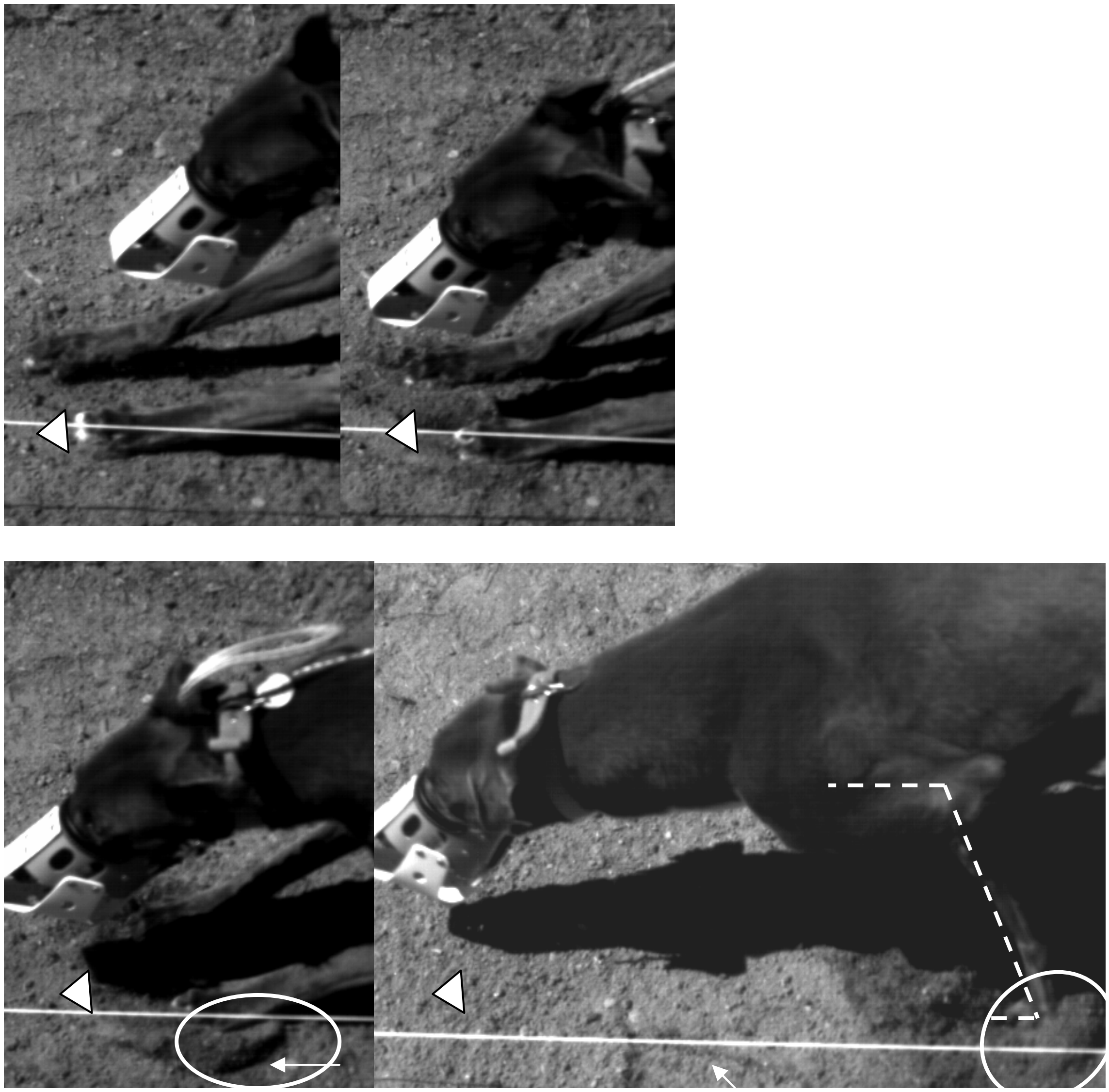

Figure 16. Sequential pictures of the dog paw digging into non-vegetated surface and building material up behind the paw. The triangle in each picture denotes where the nails of the paw entered the ground at initial contact. The circle shows the soil building behind the paw and the arrow points to the edge of the building soil. The doted line illustrates the position of the lower limb as it is hard to see.

Velocity

No main effects were found for average velocity. Average velocity over the non-vegetated surface was 3.37 m/s while the average velocity over the vegetated surface was 3.4 m/s. The average velocity is not affected because the dog can apply the appropriate forces to obtain the same average velocity on both surfaces.

Surface Safety

According to the subjective and quantitative findings of this study there are multiple reasons why the non-vegetated surface is not as safe as the vegetated surface upon which to initiate movement. One reason has to do with the negative acceleration of the front limb during negative paw displacement. Subjective high speed video analysis shows that as the front limb negatively accelerates (i.e., in the negative x direction) during the negative displacement of the paw, the head and neck positively accelerate (i.e., in the y direction) causing an eventual tensile force (i.e., because the segments are moving away from each other) on the soft tissues of the cranial forearm, shoulder, and neck muscles. The faster and further these masses accelerate away from each other the higher the force and rate of force application will be on the associated tissues. On the non-vegetated surface the paws negatively displaced further than on the vegetated surface. According to the Ratzlaff et. al. (1997) study the non-vegetated surface has a lower shear strength than the vegetated surface. It can reasonably be hypothesized that a lower shear strength would allow for greater negative displacement and acceleration of the paw and front limb. Greater negative acceleration of the paw and front limb would produce higher injurious forces on the cranial forearm, shoulder, and neck soft tissues.

Another reason why the non-vegetated surface is not as safe as the vegetated surface is because the greater negative paw displacements place injurious forces on the lumbar vertebral and paravetebral structures. Subjective video analysis shows that the larger the negative slip the more the elbow extends. The elbow joint is partially responsible for applying vertical forces to the torso. As the center of gravity passes over the elbow, the elbow extends lifting the shoulder complex and thus applying a vertical force to the torso. The most efficient position for positive vertical force from elbow extension is when the front limb is perpendicular to the ground (i.e., 90˚ horizontal) in a fixed closed chain position. In the negatively displaced paw situation, the front limb angle is less than 90˚ and the paw may not be in a fixed closed chain position (i.e., the paw may be sliding along the surface). In this case the paw is in an open chain position in a closed chain situation. The body approaches the limb as closed chain but the limb slides along the ground in an open chain. The outcome is a resultant force vector that is more horizontal than vertical. Also if the paw is negatively displacing as the center of gravity passes over the base of front limb support, the elbow will extend in an open chain position. This will reduce its ability to produce a vertical force. Since the ability of the front limb to produce vertical lift of the torso is reduced by the negative displacement, more force is placed on the lumbar vertebral/paravetebral, pelvic, and rear limb structures to maintain optimal kinematics. These structures would have a relatively long lever arm to the head and upper torso and would be placed in a position that would require a large moment to counteract the falling of the head and upper torso as a result of the elimination of support from the front limbs. In order to maintain optimal kinematics the dog will have to rapidly increase force production of the associated muscle groups. The increase in load and rate at which the load is increased could result in injury to these structures.

Overall Conclusions

The primary objective of this study was to determine if surface has an effect on the kinematics of the canine sprint start. The data from this study shows that two like textural surfaces, one with vegetation and one without vegetation has an effect (see Table 17) on the kinematics of the canine sprint start. Main effects were found for the temporal, horizontal, and vertical kinematic variables. In addition, main effects were found for end of dog indicating that the front end moved significantly different than the rear end and that the front end was affected more by the surface than the rear end. Since the two surfaces where texturally classified as the same, the assumption can be made that the effect on movement came from the lack of or presence of vegetation.

Table 17. Significant findings of the study for surface.

	Non-vegetated Surface		Vegetated Surface	
	M	*SD*	*M*	*SD*
FtSwingTime	.168	.010	.155	.013
Front Stride length	190.110	10.446	177.933	11.330
Rear Negative Displacement	-6.687	2.554	-5.298	1.921
Front Negative Displacement	-21.423	2.628	-17.253	3.828
Shoulder	57.335	2.635	59.403	2.594
Head	87.201	8.691	89.292	7.957

The second objective of this study was to determine which surface provided a safer sprint start. The data from this study revealed that the dogs have a greater degree of negative displacement of the paws over the non-vegetated surface. Negative displacement of the base of support has been shown in humans and equine athletes to be associated with injuries (Nigg & Yeadon, 1987; Peterson et. al. 2008). The data from the present study suggests that a vegetated surface is safer for movement initiation than a non-vegetated surface. This finding is troubling as a majority of canine sprint starts occur on the non-vegetated surface type. No research currently exists on injury occurrence or injury mechanisms, therefore this data contributes to current literature by identifying possible injury mechanisms.

This study aims to contribute to the field of Veterinary Sports Medicine by providing subjective and quantifiable data of movement initiation in the dog. In addition, this study quantifies the major properties of the surface to aid in a further understanding of what properties of a surface effect movement. Prior to this study no data existed to assist the veterinary community in determining what kinematic parameters were necessary in order to successfully conduct a sprint start. With this information, veterinarians, physical therapists, trainers, and others can establish kinematic criteria for successful completion of a sprint start for healthy dogs, and dogs with biomechanical disorders. Furthermore, criteria can be established for return to activity after injuries. In addition, trainers and conditioning specialists can use the information to develop conditioning programs that aid or enhance the kinematic parameters of the canine sprint start. The information can also be used by owners, trainers, event officials, and event governing organizations to make decisions about surface issues such as safety, winning records, training techniques, and surface management. In the future, this study's findings may lead to changes in starting surfaces that optimize and equalize performance during events that employ the canine sprint start.

Future Research

Future research should evaluate other kinematic factors of the sprint start. The study of joint kinematics will give rise to an understanding of joint actions during movement initiation. Understanding the counter movement will help determine its implications on sprint start performance, specifically its plyometric components. It will also be necessary to evaluate kinematic factors that determine optimal sprint performance and then develop training and conditioning protocols that exploit these kinematic parameters. In addition, studies should be conducted that utilize the tool of electromyography to determine the muscular contributions to these kinematic parameters. Further studies should seek to determine kinetic parameters associated with canine sprint starts. Other studies should evaluate surface textural properties, surface vegetative properties, and how individual surface properties influence movement initiation and overall performance. In addition, future projects should develop synthetic movement initiation surfaces or an apparatus to increase performance and make performances safer.

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APPENDICES

Appendix A—Equations

Velocity

$$\vec{v} = \frac{X_{n+1} - X_{n-1}}{2\Delta t}$$

$$\vec{v}_{avg} = \frac{v_f - v_i}{\Delta t}$$

Vertical Displacements

$$SPE_y = E_y - RP_y$$

$$SPS_y = S_y - RP_y$$

$$SPH_y = H_y - RP_y$$

Stance Times and Swing Times

$$RST_t = \left| SP_n - RTO_n \right| \; x \; 0.008s$$

$$FST_t = \left| FTD1_n - FTO_n \right| \; x \; 0.008s$$

$$RSW_t = \left| RTO_n - RTD2_n \right| \; x \; 0.008s$$

$$FSW_t = \left| FTO1_n - FTD2_n \right| \; x \; 0.008s$$

Positive and Negative Horizontal Distances

$$FSD_x = FTD2_x - FTD1_x$$

$$RSD_x = RTD2_x - RTD1_x$$

$$FPND_x = FNEP_x - FTD1_x$$

$$RPND_x = RNEP_x - SP_x$$

Normalized Vertical and Horizontal Distances for Body Height and Weight

$SPE_y \%BH = SPE_y / BH$

$SPS_y \%BH = SPS_y / BH$

$SPH_y \%BH = SPH_y / BH$

$FSD_x \%BL = FSD_x / BL$

$RSD_x \%BL = RSD_x / BL$

$FPND_x \%BL = FPND_x / BL$

$RPND_x \%BL = RPND_x / BL$

Definitions

SP = Set Position

E = Ear

RP = Rear Paw

FP = Front Paw

S = Shoulder

H = Hip

BL = Body Length

BH = Body Height

RST = Rear Limb Stance

FST = Front Limb Stance

RSW = Rear Limb Swing

FSW = Front Limb Swing

RTO = Rear Paw Take Off

FTO1 = First Front Paw Take Off

FTD1 = First Front Paw Touch Down

FTD2 = Second Front Paw Touch Down

RTD1 = Rear Paw Touch Down

FSD = Front Step Distance

RSD = Rear Step Distance

FPND = Front Paw Negative Displacement

RPND = Rear Paw Negative Displacement

FNEP = Front Negative End Point

RNEP = Rear Negative End Point

y = Vertical Position

s = Seconds

t = Time

x = Horizontal Position

% = Percent

n = Frame Number

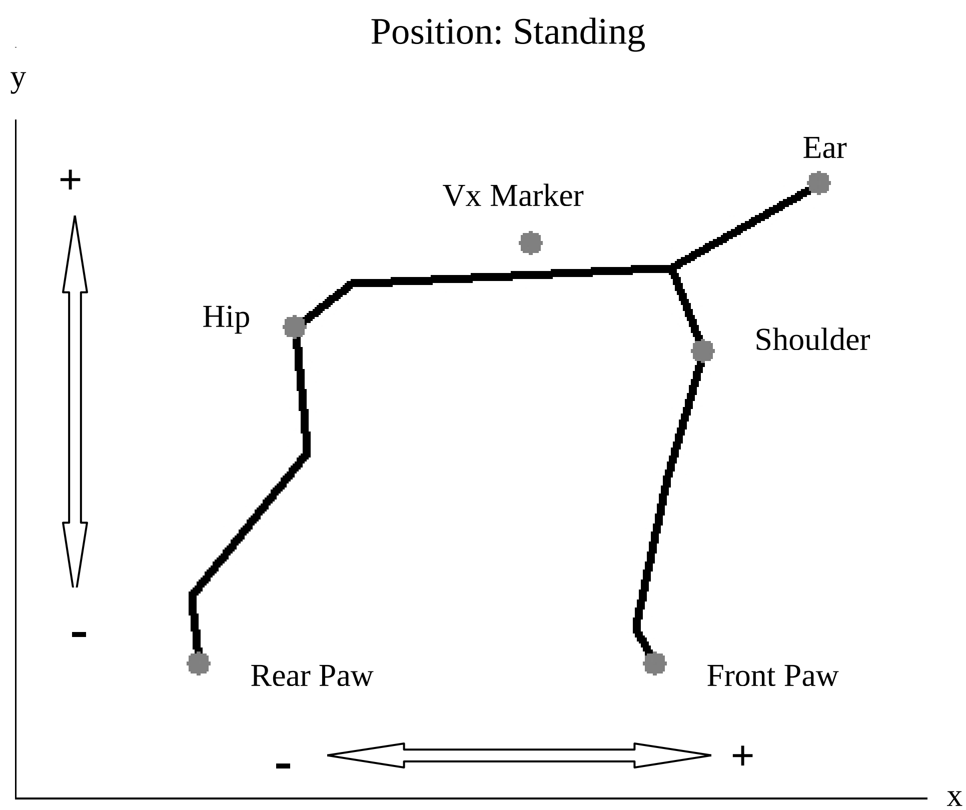

Figure 17. Position: Standing. This figure represents the standing position of the dog prior to the counter movement. From the standing position the dog will employ the counter movement to move to the next position which will be the set position.

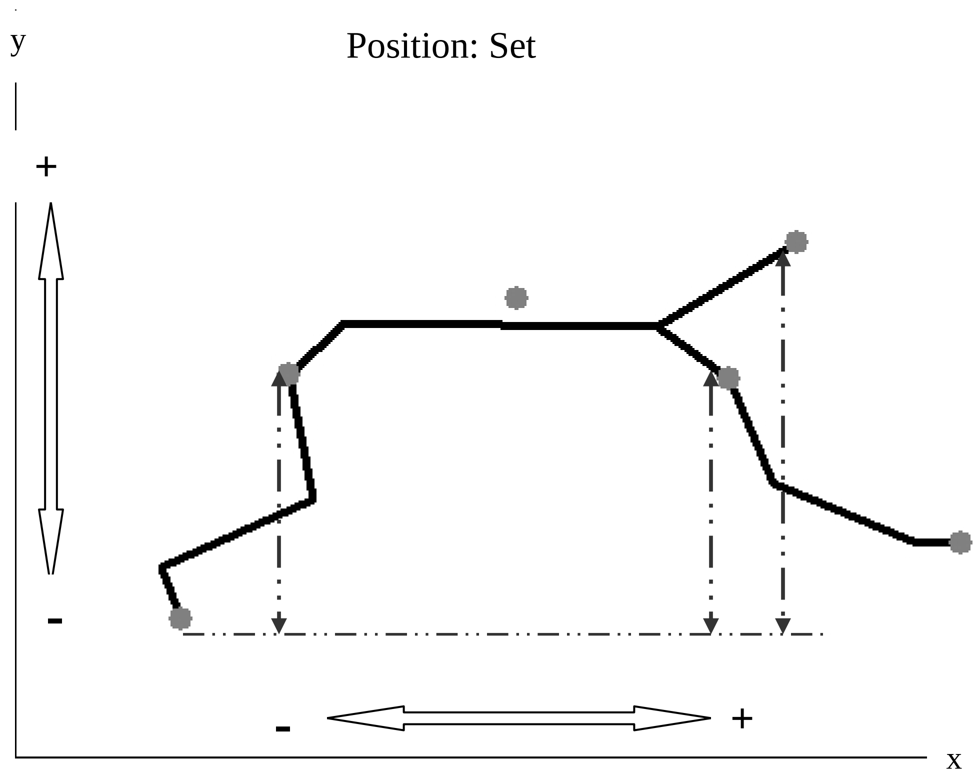

Figure 18. Position: Set. This figure represents the set position which is referenced by a lowering of the center of gravity and refers to the frame before the dog starts movement initiation. This figure also represents the beginning of the action phase for the rear legs. The vertical position of the hip, shoulder, and ear markers from the ground are illustrated by the dashed lines.

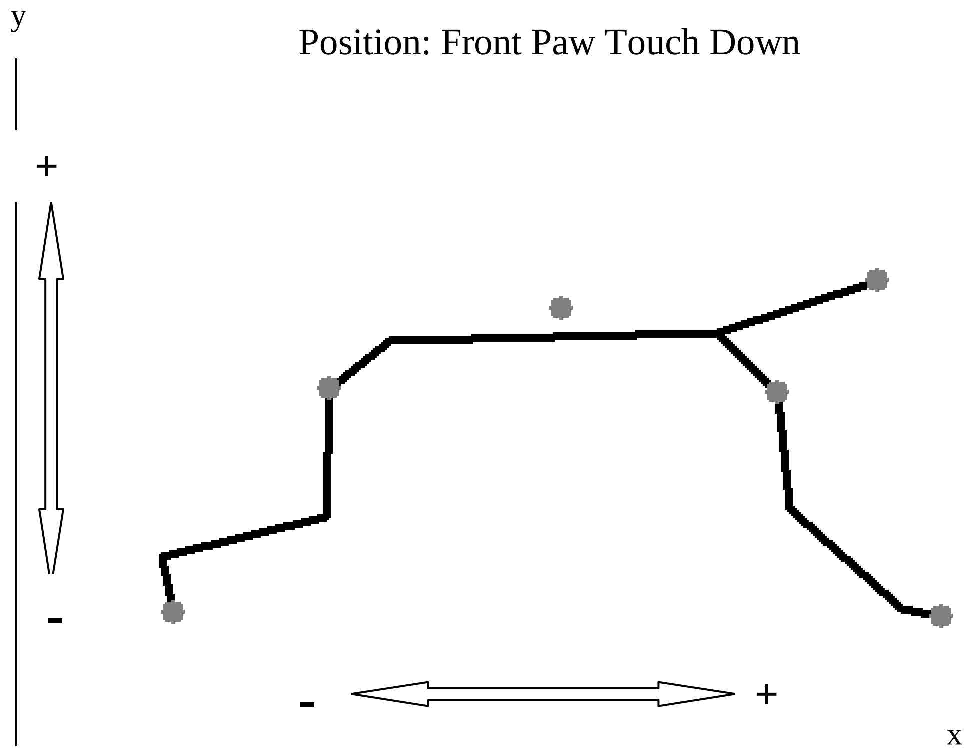

Figure 19. Position: Front Paw Touch Down. This figure represents the position of the body at front paw touch down.

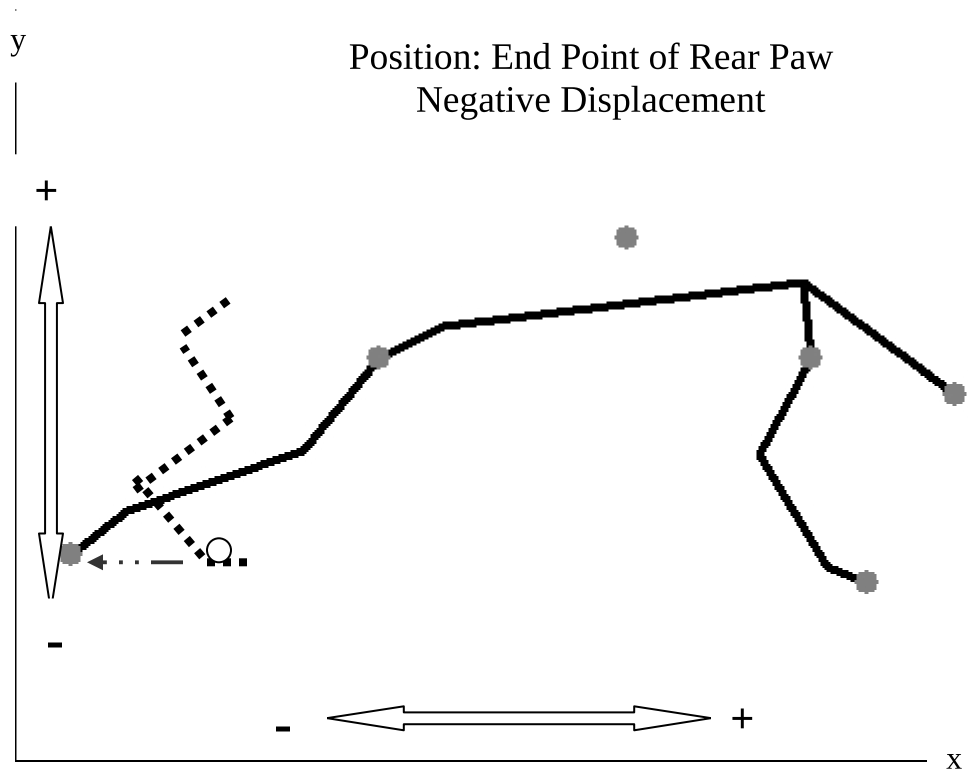

Figure 20. Position: End Point of Rear Paw Negative Displacement. The dotted line indicates the limb placement of the rear limb at the set position. The dotted arrow shows the displacement and direction that the limb travels to its end point or point at which the paw does not negatively displace any further. The displacement is considered the rear paw negative displacement.

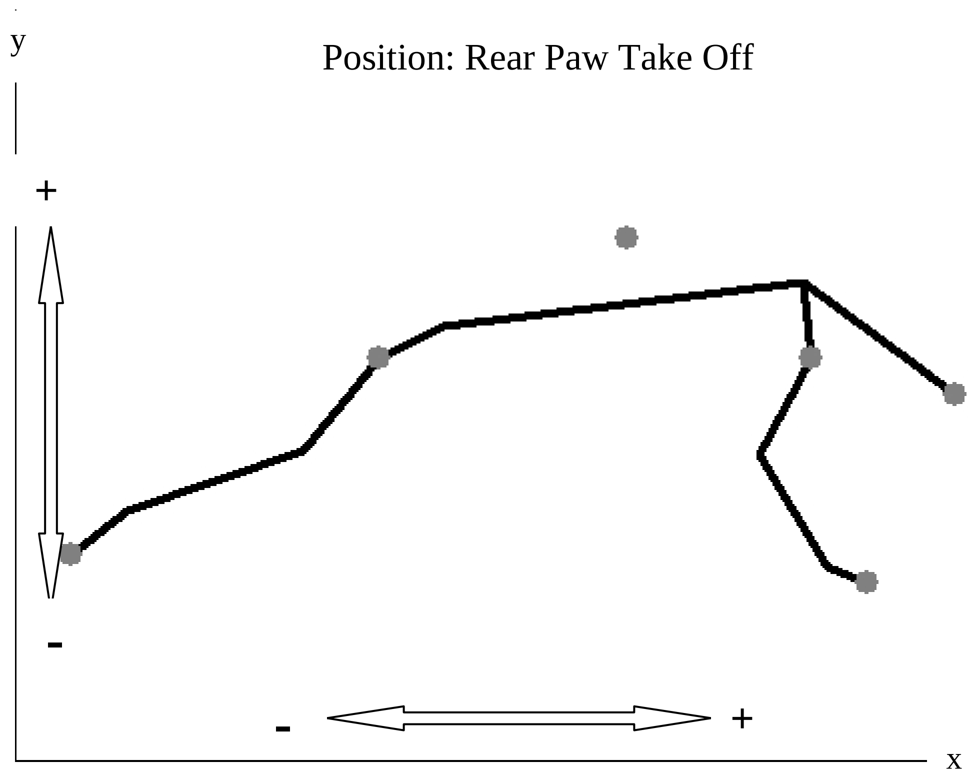

Figure 21. Position: Rear Paw Take Off. This figure represents the end of the action phase for the rear legs. After the rear paw leaves the ground, the limb will enter the rear flight phase.

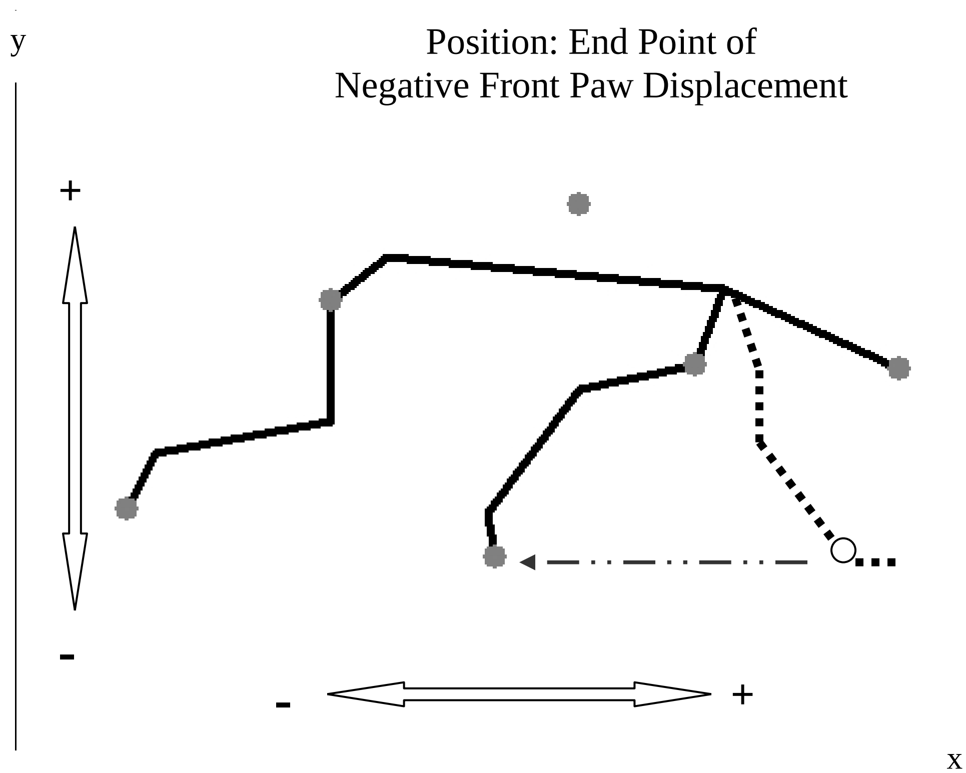

Figure 22. Position: End Point of Front Paw Negative Displacement. The dotted line indicates the limb placement at front paw touch down. The solid and dotted limbs are the same limb at different times in the front stance phase. The dotted arrow shows the displacement and direction that the limb travels to its end point or point at which the paw does not negatively displace any further. The displacement is considered the front paw negative displacement.

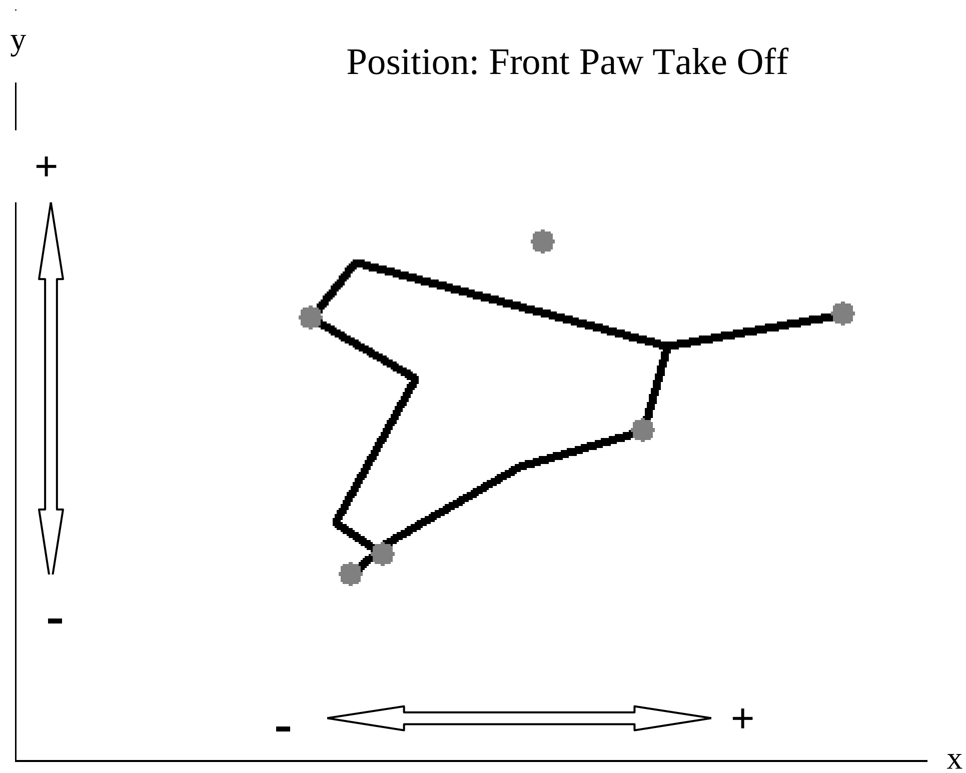

Figure 23. Position: Front Paw Take Off. This figure represents the position of the body at front paw take off.

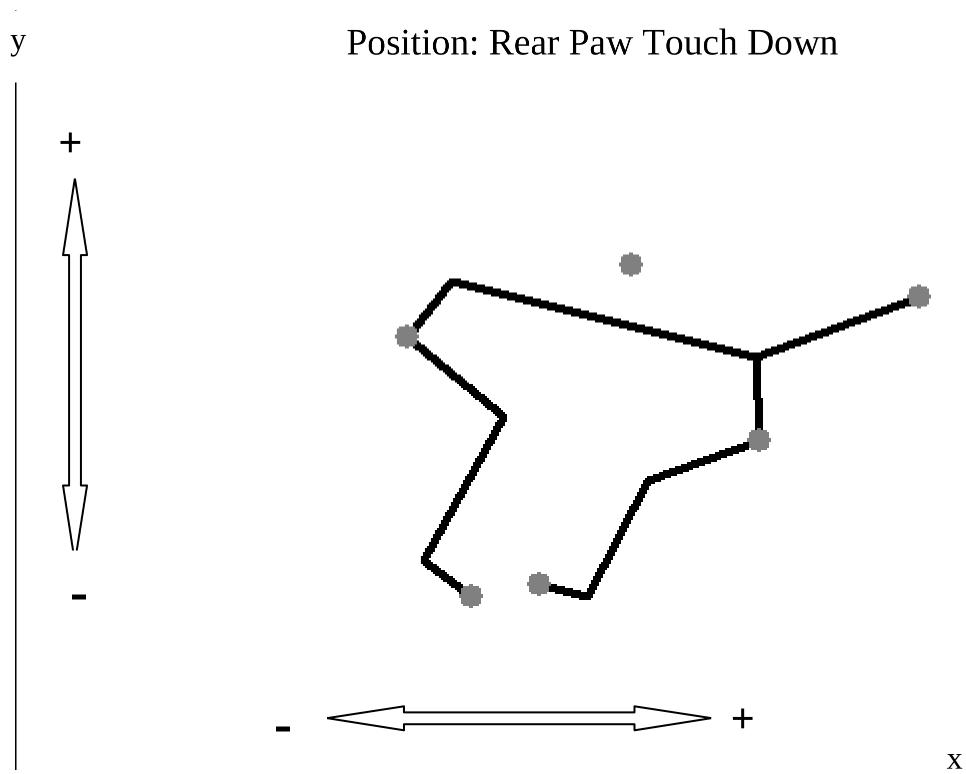

Figure 24. Position: Rear Paw Touch Down. This figure represents the position of the body at rear paw touch down.

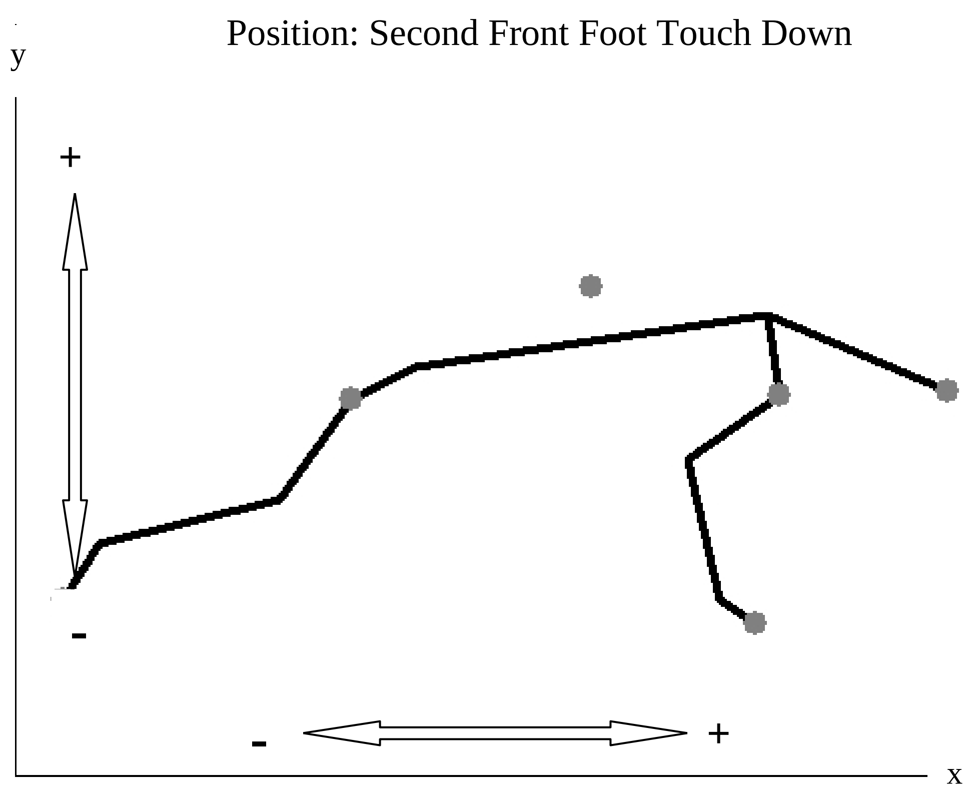

Figure 25. Position: Front Paw Touch Down. This figure represents the position of the body at the second front paw touch down. At this point in the stride the front limbs are moving in an asynchronous manner and the dog has established a lead and non lead leg.

Appendix C—Institution Animal Care and Use Committee approval form.

ANIMAL SUBJECTS REVIEW FORM

PRINCIPAL INVESTIGATOR: Robert Gillette DVM, MSE
RANK/TITLE: **Director**
DEPARTMENT: **Veterinary Sports Medicine Program**
COLLEGE/SCHOOL: **College of Veterinary Medicine**
CAMPUS ADDRESS: **100 McAdory Hall** E-MAIL ADDRESS: **gillerl@vetmed.auburn.edu**
CAMPUS PHONE #: **334.844.5646** FAX #: **334.844.6084**
_______ Check if PI will serve as faculty advisor to the Lead Graduate Student or Resident associated with this activity.

LEAD GRADUATE STUDENT/RESIDENT: Craig Angle M.Ed, M.Ed, ATC, CSCS
RANK/TITLE: **Research Associate I/ Biomechanics Ph.D Candidate**
DEPARTMENT: **Veterinary Sports Medicine Program** E-MAIL ADDRESS: **angletc@vetmed.auburn.edu**
CAMPUS PHONE #:**334.844.5646** FAX #:**334.844.6084**

CO-INVESTIGATOR:
RANK/TITLE:
DEPARTMENT: E-MAIL ADDRESS:
CAMPUS PHONE #: FAX #:

PROJECT TITLE: A kinematic evaluation of greyhound starting surfaces.

STARTING DATE: Day after IACUC approval **EXPIRATION DATE: Will end 2 years from day approved.**
(Must not be prior to IACUC approval) (Must not exceed three years)

Is any part of the funding from a U.S. Public Health Service Agency: Yes _____ No ___X__

REQUIRED SIGNATURES

The information contained on this form provides an accurate description of the animal care and use protocol which will be followed. I agree to abide by governmental regulations and university policies concerning the use of animals. I will allow veterinary oversight to be provided to animals showing evidence of pain or illness. If the information provided for this project concerning animal use should be revised, or procedures changed, I will so notify the committee of those changes in writing, and no proposed changes will be implemented until full IACUC approval has been granted.

Principal Investigator **Date**

Medical care for animals will be available and provided as indicated by a qualified veterinarian. By accepting this responsibility, the veterinarian is providing assurance that any personal interest he/she might have in the project will not conflict with his/her responsibility for the provision of adequate veterinary care for the animals. Furthermore, the veterinarian provides assurance of review and consultation on the proper use of anesthetics and pain relieving medications for any painful procedures.

Project Veterinarian **Date** **Project Veterinarian** (Please type or print)

Departmental Chairperson **Date**

Lead Graduate Student/Resident **Date**

***IACUC Chair** **Date**

*IACUC Chair signs the protocol after IACUC approval has been granted.

PLEASE TYPE IN BOLD FONT AND COMPLETE THE FOLLOWING FORM IN FULL.

1. Will the animals be used in:

Teaching ____________
Research ____**X**____
Demonstration ____________
Production ____________

If Teaching, give the course number:

2.

Species Common Name	**Total Number**	**Source**	**Housing Location**
Canine	8	Robert L. Gillette's personal dogs	Lab Animal Health kennels at the College of Veterinary Medicine

3. Will animals be maintained for a period of 12 or more consecutive hours in a location other than the housing location mentioned in Item 2? (*See Item 3 of Additional Information at the end of this form.*)
Yes _____ No __**X**__
If Yes, specify the location and reason.

4. PERSONNEL QUALIFICATIONS (*See Item 4 of Additional Information at the end of this form.*)

A. Indicate who will provide daily care and maintenance of the animal(s). Indicate name(s) or identify the particular unit staff.

Dr. Bobby Brown and the department of Lab Animal Health Staff

B. List the names of all individuals who will conduct procedures involving animals on this protocol. If all individuals are not currently known, please indicate as such.

Robert L. Gillette, Craig Angle, and the Sports Medicine Staff

C. Principal Investigator Certifications

My signature on page 1 of this form certifies that:

1) Individuals performing animal procedures on this protocol are or will be qualified to perform their particular animal related duties through training and/or experience (individuals will be supervised until adequate training has occurred). Training and/or experience must encompass the following: *biology, handling, and care of the species; aseptic surgical methods and techniques (if applicable); the concept, availability, and use of research or testing methods that limit the use of animals or minimize distress; the proper use of anesthetics, analgesics, and tranquilizers (if applicable); and procedures for reporting animal welfare concerns. Informative links regarding training resources have been provided for assistance as needed at http://www.auburn.edu/research/vpr/animals.
2) All individuals working with animals, animal tissues, or animal products on this protocol will be informed of relevant *occupational health and safety issues prior to performing their duties. * Informative links have been provided for assistance in this and other areas as needed at http://www.auburn.edu/research/vpr/animals.

5. State how or why you selected the species to be used in this project.

The study is based on dogs and no other species would be anatomically correct.

6. STUDY/ACTIVITY JUSTIFICATION AND OBJECTIVES:

A. Justification:

The ability to develop large horizontal propulsive forces during movement initiation is imperative to success in a sprint start. In humans the horizontal propulsive forces during sprint movement initiation have been reported to be 46% higher than the same force generated during ground contact at maximum velocity (Mero, 1988). All athletic dogs such as agility dogs, greyhounds, and retrievers initiate movement prior to their racing or other performance event. As with humans, the horizontal forces are high during movement initiation for the dog. A dog's performance will be optimized when the surface to which the dog is interfaced provides adequate traction and energy transfer from the legs to the ground.

B. Objectives:

The objective of this study is to conduct a kinematic (motion) analysis of eight greyhounds initiating movement over 4 different surfaces and determine which surface is optimal for greyhound racing.

7. SUMMARY OF PROPOSED ACTIVITY: USE LAY TERMS to give a description of the proposed activity. *From reading this section it should be possible for a non-scientist to determine exactly how animals will be used in the context of the proposed activity.*

Eight Greyhounds will be selected upon passing a medical examine to rule out any underlying orthopedic conditions that may interfere with project objectives and outcomes. The medical examinations will be conducted in the manner of a physical orthopedic assessment. The Greyhounds will execute three movement initiation sprint trials on each of the four different surfaces (astro turf, sand, natural turf, and rubber mat). The dogs will be divided into four groups (G1-G4). Each test day a group will be assigned to a specified surface and each dog will complete 3 trials on the specified surface (refer to table 1). The six trials per group conducted over the four day test period (i.e. total of 24 trials) will be averaged. This will reduce increases in performance due to training effects. In addition, to minimize fatigue, there will be a minimum of 15 minutes rest in between trials and at least three days rest in between testing days for the dogs.

Table 1.

Surface	Day 1	Day 2	Day 3	Day 4
Dry Astro Turf	G1	G2	G3	G4
Sand	G2	G3	G4	G1
Natural Turf (grass)	G3	G4	G1	G2
Rubber Mat	G4	G1	G2	G3

Subjects will be "hand slipped" (i.e. a technique used to release track trained greyhounds without a starting box) on one of the four surfaces. The hand slip technique is when the handler places one hand on the collar and one arm under the belly of the dog. Then the handler in one quick motion lets go of the collar and brings his arm out from under the belly of the dog. At this point the dog is free of the restraint of the handler and is able to run freely. This method is preferred so that the dog is not tethered and can quickly be released to run. It is a widely used technique in canine sports when a dog needs to be released at a certain period in time. The same experienced handler (Dr. Robert Gillette) will be used to hand slip the dogs throughout the data collection process. The dogs have been previously trained to go after a lure (coon skin hat tied on a string) that is placed in front of them. The lure will be accelerated by a lure operator. The lure operator will keep the lure in front of the dog for approximately 30 meters. At this point the lure will be stopped and the dog will be allowed to play with the lure. The dogs will be released by the handler upon notification that the lure operator is about to accelerate the lure. This process will be repeated for at least three sequences and kinematic data (quantified motion) will be collected.

Surface Construction

Astro turf and a rubber mat will be fastened to four individual sheets of 6x4x ¾ inch plywood. The starting surfaces will be fastened to the plywood with glue. The plywood for each surface will be fastened to the ground by driving eight 12 inch spikes through the plywood and into the ground. This will lock the plywood in place and not allow it to slip beneath the greyhound. A level will be placed over the

plywood to insure that the starting surface is level. This set up will be used to mimic two of the surfaces that athletic dogs usually start on. For the other two surfaces we will have the dogs start over grass and start over sand.

Kinematics

The starting kinematics will be filmed by two synchronized Troubleshooter High Speed Cameras. The cameras will be placed perpendicular to the test surface. One camera will be placed on each side of the dog relative to the sagital plane. Reflective markers (white porous tape) will be placed on the dogs and used by the motion analysis software in locating the specified anatomical locations. The coordinates of the markers will be used to define kinematic parameters of the sprint start. Reflective markers will be fitted at the joints of defined body segments on each dog prior to filming. Axial markers will be placed caudal to the ear on the lateral aspect of the atlantal wing, on the point of the cranial angle of the scapula, and on the dorsal point of the iliac crest. Front limb appendicular markers will be placed on the acromion/greater tubercle of the scapulohumeral joint, on the lateral epicondyle of the humerus, on the ulnar styloid process/ulnar carpal bone of the carpus, and on the distal lateral aspect of the fifth metacarpal bone. The hind-limb appendicular markers will be placed on the eminence of the greater trochanter of the femur, on the lateral epicondyle of the femur, on the lateral prominence of the malleolus of the distal tibia, and on the distal lateral aspect of the fifth metatarsus.

The protocol designated that the dogs be of good health prior to being in the study. Dr. Gillette will be present to monitor the test subjects as they are filmed and handled. He will attend to any incidental health problems that may arise.

This study requires eight dogs to complete the project.

This section should include a clear description of the experimental design (research protocols) or activities involving animals (teaching, demonstration, or production/maintenance protocols). This section should also include a brief description of each phase of activities involving animals and should make it possible to account for all animals requested in Item 2. Justification for animal numbers is required to assure that only the necessary number of animals is being used. (*See Item 7 of Additional Information at the end of this form for guidance in providing the appropriate information.)*

8. A. Select pain/distress category relevant to the use of animals in this study. (*See Item 8A of Additional Information at the end of this form.)*

C ___**X**___ D ________ E ________

B. If category D or E was chosen in 8A, please complete the following. (*See Item 8B of Additional Information at the end of this form.)*

1) Database(s) searched or other sources consulted to determine the

availability of alternatives.

Database Searched Date of Search Years Covered

Medline
Agricola
CABA
Altweb
Other (describe)

2) Keywords and search strategy used when considering alternatives to the painful or distressful procedure(s).
N/A

3) A succinct written narrative based on results of the database search, that will permit the IACUC to readily assess whether the search topics were appropriate and whether the search was sufficiently thorough. This narrative must address the following:

Reduction: **N/A**

Replacement: **N/A**

Refinement: **N/A**

4) If alternatives are available but will not be used, please provide a justification.

N/A
5) If pain/distress category E is to be employed, please provide a justification for withholding pain and/or distress relieving drugs.

N/A

Will surgery be performed?
Yes _____ No **__X__**
If yes, please address the following, as applicable:

A. Non-survival surgery - Describe all surgical procedures, including surgical preparation. Indicate where surgery will be performed (building and rooms). Identify the person(s) and describe their qualifications for performing the particular surgical procedure(s).

B. Survival surgery - Describe all surgical procedures, including surgical preparation and post-surgical care. Please indicate that aseptic technique will be followed if the procedure is a survival surgical procedure. Indicate where surgery will be performed and what postoperative care will be provided (building and rooms). Identify the person(s) and describe their qualifications for performing the particular surgical procedure(s).

10. Administration of analgesics, anesthetics, tranquilizing drugs, and/or neuromuscular blocking agents (Indicate generic name, dose, route of administration and frequency; if by inhalation, method of scavenging waste anesthetic gases.)
N/A

11. Administration of reagents, cells, drugs (other than anesthetics or analgesics), infectious agents, carcinogens, recombinant DNA, etc. (Indicate generic name, dose, route of administration and frequency, anticipated side effects, monitoring protocol.)

N/A

12. ASSURANCES:

A. Provide a brief statement to confirm that proposed activities involving animals do not duplicate previous experiments unnecessarily.

The investigator has performed an intensive and up-to-date literature search to identify similar projects. This study does not duplicate any previous experiments.

B. My signature on page 1 of this form certifies that exercise of caged dogs will be accomplished according to the Animal Welfare Act (AWA) or cage size provides adequate space for exercise to meet AWA requirements. Alternatively, explain why an exception should be approved by the IACUC.

N/A

C. Will wild caught or endangered animals be utilized?
Yes ________ No ____**X**__

If Yes, the investigator is responsible for obtaining and maintaining valid permits (if required) for collecting, purchasing, transporting, and holding of these animals. List applicable federal and/or state permit numbers and expiration dates.

13. HAZARDOUS AGENTS

Use of hazardous agents in animals may require approval of the appropriate institutional committee. Contact the Department of Risk Management and Safety (844-4870) for specific information.

Hazardous Agent	**Yes**	**No**	**Agent**	**Date of Committee Approval and BUA #**
Radioisotopes		**X**		
Biological Agents		**X**		
Hazardous Chemicals or Drugs		**X**		
Recombinant DNA		**X**		

Describe the practices and procedures required for the safe handling and disposal of contaminated animals and material associated with this study. Also describe methods for removal of radioactive waste and, if applicable, the monitoring of radioactivity.

N/A

14. What will be the disposition of the animals at the termination of the project? If euthanasia is to be performed, what will be the method of carcass disposal?

They will be returned to Robert Gillette as healthy as when they entered the study as approved by Dr. Bobby Brown. If euthanasia is to be performed, with Robert Gillette's authorized permission the carcass will be cremated at the College of Veterinary.

15 All protocols must include the method of euthanasia that will be used during the normal course of the protocol or in the event of unforeseen circumstances resulting from illness or injury. Please specify the method, agent, dose, and route of administration. The euthanasia method must be consistent with the AVMA Panel on Euthanasia or justification for deviation should be indicated. This document is available on the Animal Resources website, http://www.auburn.edu/research/vpr/animals/resources/res_index.htm and in the Journal of the American Veterinary Medical Association (Vol. 218, No. 5, Pages 669-696, 2001).

If needed, the method of euthanasia will be IV Beuthanasia at 1 cc per 10 lbs.

ADDITIONAL INFORMATION

THIS PAGE NEED NOT BE INCLUDED WHEN SUBMITTING FORM FOR REVIEW

3. The IACUC is required to inspect animal housing areas and laboratories (at least twice per year) where animals are kept for 12 or more hours.

Federal regulations require institutions to ensure that people caring for or using animals are qualified to do so through documented training or experience. This training is to include investigators, technical personnel, trainees, visiting investigators, and any other individuals who may perform animal husbandry, anesthesia, surgery, or other experimental manipulations involving animals.

7. Please use this procedure list for guidance in providing the necessary information. Please note that this is not meant to be an exhaustive list, but only a guide.

$ **Body fluid sampling** (e.g. blood, cerebrospinal fluid, ascites, urine —describe method of collection, amount, frequency).
$ **Antibody production** (indicate route of administration, volume administered per site, number of sites, adjuvant use and frequency, consideration of alternatives to Freund's adjuvant, anticipated side effects, monitoring protocol).
$ **Ascites method for monoclonal antibody production**. Auburn University requires adherence to the Office for Protection from Research Risks (OPRR) policies concerning the production of monoclonal antibodies using the mouse ascites method. Please refer to the OPRR document http://oacu.od.nih.gov/ARAC/ascites.htm. Use of the ascites method requires justification as to why in vitro systems cannot be used.
$ **Special diets** (describe any anticipated nutritional deficit or other health concerns).
$ **Indwelling catheters or implants** (describe type, maintenance/monitoring protocol).
$ **Restraint of an unanesthetized animal** other than that associated with brief routine procedures such as for the collection of blood (describe method, duration, frequency).
$ **Tumor transplantation** (describe any anticipated functional deficit to the animal, monitoring protocol, endpoint).
$ **Food or fluid restriction** (e.g. greater than that associated with pre-anesthetic procedures — describe, include justification and monitoring protocol.)
$ **Special housing, equipment, animal care** (e.g. describe special caging, water, feed, waste disposal, etc.)
$ **Experimental endpoint criteria** (list the criteria to be used to determine when euthanasia is to be performed. Death as an endpoint must always be scientifically justified.)

8A. USDA promulgated PAIN/DISTRESS CATEGORIES - Please use the following categories when categorizing the pain/distress level.

C Pain or Distress - None or Minor

These include studies that DO NOT involve surgery; induction of painful or stressful disease conditions, or pain or distress in excess of that associated with routine injections or blood collection. Included are induction or transplantation of tumors in animals (as long as the tumors do not cause pain and the animals are terminated prior to becoming ill), administration of mildly toxic substances or pathogenic agents that cause no significant disease or distress, polyclonal antibody production (antigen inoculations and blood collection) as long as significant disease does not result, mild food restriction, and, typically, the collection of animals from the wild or from experimental units (i.e. fish in earthen ponds) for minor procedures. NOTE: If blood is to be collected via the retro-orbital or intracardiac methods, then anesthesia is required and Pain/Distress D must be selected. Also, if *in vivo* monoclonal antibody production is to be performed, the pain category D must be selected.

D Pain or Distress Relieved by Appropriate Measures

A major concern of the reviewers of these protocols is the degree of pain and/or distress imposed on the animals in the studies, and the methods the investigators will use to prevent, relieve, or minimize such pain or distress.

Following is a partial list of procedures known to involve significant pain and/or distress:

1. Surgical procedures such as biopsies, gonadectomy, exposure of blood vessels, chronic catheter implementation, laparotomy, or laparoscopy
2. Administration of any chemical or organism that would be expected to produce pains or distress but which will be alleviated by analgesics
3. Intracardiac or retro-orbital blood collections
4. Monoclonal antibody production (ascites method)
5. Other procedures which would be painful or distressful to the animal if performed without the benefit of anesthesia, analgesic, and/or tranquilization (e.g., exsanguination).

E Pain or Distress without Anesthesia, Analgesia or Tranquilizers

If the nature of the study prohibits the use of pain and/or distress relieving drugs, or if unavoidable and unalleviable pain or distress will be produced, you must provide a written justification. (Include this in your response to Item 8, B, 5.) Such procedures include: direct stimulation of central nervous system pain tracts, nociceptor stimulation by physical or chemical means that cause severe pain (e.g., corneal abrasions), or any potentially painful procedure if performed without chemical relief of pain.

8B. The Animal Welfare Act (AWA) requires that the Principal Investigator (PI) consider alternatives and provide a written narrative of the sources consulted to determine whether or not alternatives exist to procedures which may cause pain or distress.

According to the Animal Welfare Information Center (AWIC) of the U.S. Department of Agriculture (USDA), an alternative to procedures that may cause more than momentary pain or distress to animals is any procedure which results in REDUCTION in number of animals used, REFINEMENT of techniques to alleviate such pain or distress, or REPLACEMENT of animals (e.g. with an insentient model such as might be accomplished through use of cell culture or computer simulation). For assistance in conducting database/network searches, as required by the AWA when procedures may cause more than momentary pain or distress to animals, investigators may contact the AU Library On-Line Services (844-1748). Alternatively, to explore a variety of resources for evaluating alternatives investigators may consult the following website: http://www.aaalac.org/alts.htm

PI Checklist for Animal Subjects Review Form

General:

❒ Did you use the newest version of the Animal Subjects Review Form?

❒ Did you spell out all acronyms the first time they were used?

❒ Did you verify the spelling of all drugs used?

❒ Did you include a copy of any referenced Standard Operating Procedures (SOPs) and/or existing protocols?

❒ Did you omit all irrelevant information when using a previous protocol file to create a new Animal Subjects Review Form?

All Protocols:

❒ Did you check yes or no to Public Health Service funding source?

❒ #2- Did you clarify animal numbers as “per year” or “project total”?

❒ #2 and #7- Did you make sure animal numbers in these two sections agree?

❒ #2- Did you name the commercial sources?

❒ #2- Did you provide the specific housing facility?

❒ #4 - Did you list all individuals involved in study by their names (if known)?

❒ #7- Did you address how the animal numbers were **determined** and/or **justify** these numbers?

❒ #7- Could the study design be presented more clearly using a table?

❒ #7 and #11- Did you, if applicable, include the route of administration and/or dosage for all drugs used?

❒ #7- Did you, if applicable, include the technique, location, and/or volume of blood drawn?

❒ #7- Did you, if applicable, provide the method of transportation and/ or the method of restraint?

❒ #8.B.3. - Did you specify reduction, replacement, and/or refinement as they pertain to this study?

❒ #10 and #11- Did you, if not applicable, put None or N/A?

❒ #12 – Did you provide, if applicable, permit numbers and expiration dates?

❒ #13 – Did you include, if applicable, the Biological Use Authorization (BUA) number and date of approval or indicate that it is pending?

❒ #14 - Did you address method of carcass disposal and/or the location in the event that euthanasia becomes necessary?

❒ #15 - Did you indicate the method of euthanasia should it become necessary?

Teaching Protocols:

❒ #7- Did you include, if applicable, the number of students per animal, the number of animals per lab, and the number of labs per year.