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Influence of velocity on Weimaraner trotting mechanics

By

Leif Carlisle

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Masters of Science
in Agricultural Life Sciences
in the Department of Animal and Dairy Sciences

Mississippi State, Mississippi

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Influence of velocity on Weimaraner trotting mechanics

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While Weimaraner size may assist in the performing of tasks of a sporting dog, it also makes the breed more susceptible to hip dysplasia. However, this breed has a lower rate of dysplasia. This may be due to selected gait velocity and mechanics specific to the breed, but gait analysis of Weimaraners is lacking. Study objectives were to define normal trotting mechanics and to determine the influence of velocity on gait. Dogs were trotted at a slow and fast trot and at both velocities. The trot had a diagonal footfall sequence with a 2-beat rhythm alternating between diagonal bipedal support and suspension. Velocity increase was achieved with significant increases in stride length and head, withers, fore, and hind paw displacements ($P < 0.05$). Range of motion of the elbow and hip significantly increased with increasing velocity ($P < 0.05$). These parameters will assist in gait evaluation and detection of lameness.

Key Words: Weimaraner, trot, kinematics, velocity

DEDICATION

I would like to dedicate this thesis to my family who has supported me no matter what.

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Molly Nicodemus, for helping me through this process. I would also like to thank Dr. Scott Willard for giving me the opportunity to complete my degree and be successful academically.

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CHAPTER I

REVIEW OF LITERATURE

Background of Gait Analysis

Gait analysis is applied to study the mechanics of the structure and function of biological systems (Kreighbaum and Barthels, 1996). This branch of research is referred to as biomechanics and includes such research areas as kinematics, the description of bodies in motion, and kinetics, the description of the forces creating and changing the motion of the body. While the biological system commonly used in biomechanical studies is the human, other biological systems that are studied using gait analysis include, but are not limited to, horses (Clayton, 2004), dogs (Charteris et al., 1978), cats (Martin et al., 1995), cows (Nicodemus and Chapa, 2003), ewes (Abourachid, 1997), and even pigs (Applegate et al., 1988).

Since the horse is primarily a performance animal that is valued and selected based on their gait performance, gait analysis is a vital tool to the horse industry, and thus, has been more thoroughly applied to horses than other animal species. The application of gait analysis has assisted in defining the numerous gaits performed by various horse breeds (Cano et al., 2001, Galisteo et al., 1997) and has further determined the influence of such factors as training (Back et al., 1995; Cano et al., 2000; Nicodemus and Booker, 2007), breed-type (Back et al., 2007; Cano et al., 2001; Francesca et al., 2007), lameness (Hobbs et al., 2009; Huisheng et al., 2001; Morris and Seeherman, 1987), and shoeing (Keegan et al. 1998; Willemen et al., 1997) on various equine gaits.

Canine and Performance Sports

Dogs are referred to as "man's best friend" so it is no wonder that there are 78.2 million owned dogs in the United States with 39% of United States households owing at least one dog according to the American Pet Products Manufacturers Association 2011-2012 National Pet Survey (Sutherland, 2012). Dog owners spend around $225 per dog for vaccinations and well visits on average each year. This cost does not include the cost of veterinary care associated with health problems, which can vary greatly.

The American Kennel Club (AKC) was founded in 1884 and is the largest registry for purebred dog pedigrees in the United States and strives to promote the breeding of purebred dogs for type and function (AKC, 2014, 2015). Dog breeds registered with the AKC are divided into seven groups: Sporting, Hound, Working, Terrier, Toy, Non-Sporting, and Herding. Sporting breeds of dog have been developed for the hunting of small game. The Sporting group includes two of the most popular dog breeds in the United States, the Labrador Retriever and the Golden Retriever. Thirty breeds are listed under the Sporting group and these breeds include spaniels, setters, retrievers, and pointers.

While dogs are more often considered house pets than performance animals and are often more selected for temperament than gait performance, today many dogs are still expected to perform as hunters, racers, herders, and competitors in dog shows and agility competitions where gait performance is an essential aspect of their success in these activities. In fact, the AKC was established with a focus on dog performance as the first nine dog breeds registered with AKC were hunting breeds (Pointer, Chesapeake Bay Retriever, English Setter, Gordon Setter, Irish Setter, Clumber Spaniel, Cocker Spaniel, Irish Water Spaniel, and Sussex Spaniel), classified as the Sporting Group (AKC, 2009a). Today, the Sporting Group compared to the Hound, Working, Non-Sporting, Terrier, and Toy Groups includes some of the most popular dog breeds registered by the AKC with 30% of the dogs registered in the AKC being classified as Sporting dog breeds (Nyholm, 2007). The Labrador Retriever, listed under the Sporting Group, has been ranked according to the AKC as the most popular United States dog breed for the past 18 years (AKC, 2009b). The Golden Retriever, another dog breed from the Sporting Group, was ranked in both 2007 and 2008 as the 4th largest dog breed in the United States. Both types of retriever are commonly used today for hunting and are the most popular hunting breeds in the United States. Thus, these breeds require dogs that can locomotively perform in an effective manner in all types of environment. To emphasize this need for the dog to perform in a way that meets the primary uses of the breed, AKC recognized shows not only include evaluation of the dog's conformation, but also evaluation of the gait of every dog competing at the show. There are strict guidelines of what judges should look for in each breed (AKC, 2014).

The Labrador and Golden Retrievers are both classified as gun dogs, also known as bird dogs, which are divided into three primary types according to their duties during the hunt; these types include the pointer, flusher, and retriever (Grib, 2010). Both the Labrador and Golden Retrievers are classified as retriever gun dogs as they excel in "marking" and retrieving a "fallen" bird back to the hunter. As for the pointer gun dog, this type includes such breeds as the English Pointer where the dog excels in "freezing" and “pointing” to the hunter the location of the bird. In comparison, the flusher gun dog such as the Cocker Spaniel is known for pushing the bird to flight making it easier for the hunter to successfully hit their target. Some gun dogs such as the Weimaraner and the German Shorthaired Pointer are known as “all purpose” gun dogs as they are bred and trained to do multiple duties such as pointing and flushing.

Along with gun dogs being classified according to type of hunting duty, they are also classified according to the type of birds that they are commonly trained to hunt such as waterfowl (duck) and upland game (pheasant and quail) (Grib, 2010). The Labrador and Golden Retrievers and the German Wirehaired Pointer are more commonly used for waterfowl hunting due to their water-repellent coats and their natural ability to move effectively through water, while gun dog breeds such as the Weimaraner, English Pointer, and Vizsla are more commonly used for upland game due to their excellent ability to travel over terrain where upland game is found. This ability to travel through specific environments quickly and efficiently requires a dog that is bred and selected based on locomotive performance. Gait analysis has assisted in describing the gait parameters of such sporting dogs as the Labrador (Bertram and Todhunter, 2000) and Golden (Marsh et al., 2009) Retrievers; however, it has rarely been used to study gun dog breeds more specific to upland game hunting.

Dog breeds bred to be “all purpose” gundogs include the Weimaraner, Brittany, German Shorthaired Pointer, German Wirehaired Pointer, Vizsla, Italian Spinone, and Large Musterlander (Harper, 2007). The Brittany, German Shorthaired Pointer, and Weimaraner are the three most popular “all purpose” gundog breeds in the United States (AKC, 2009b). Both the Brittany and German Shorthaired Pointers are medium sized dog breeds with bloodlines tracing back to the English Pointer, while the Weimaraner is a larger dog breed tracing back to the Bloodhound, making the conformation and disposition of this breed unique from the other two breeds (Harper, 2007). Along with being larger, with hound-like characteristics, the Weimaraner is unique in that it is a slower gundog with a distinctive short-haired grey coat.

The conformation of the "all purpose" gundog breeds such as the Weimaraner is very important in allowing the dog to perform all tasks required in a hunt (WCA, 2015). Conformation of the Weimaraner must allow for activities such as stalking, tracking, swimming, jumping, climbing, sudden turns, sprints, sudden and frequent stops, carrying and retrieving both heavy and light game, and the ability to cover large distances of ground over various terrains at slow and fast speeds. While the large size of the Weimaraner may assist the breed in performing these activities, the size also may make the breed more susceptible to hip dysplasia, an abnormal formation of the hip socket leading to arthritis of the hip joint (Poy et al., 2000; Todhunter et al., 2003; Smith et al., 2001). The Weimaraner, compared to other large dog breeds, demonstrates a lower incidence of dysplasia, which may be due to the preferred slower speed of this breed. Dysplasia, despite the low rates, is a concern as it can lead to crippling lameness if not identified early and treated.

Other health conditions plaguing the Weimaraner breed that influence normal gait mechanics include hypertrophic osteodystrophy (HOD) and hypomyelinogenesis, delayed myelination (Colan, 1998). HOD is common in several large breeds of growing dogs. Weimaraners are 21% more likely to develop HOD than mixed breed dogs. Most puppies that are presented with HOD have acute onset of fever and swelling at growth plates of the long bones. Puppies also have a lack of appetite and lameness. Hypomylinogenesis occurs when puppies are born with improper nerve coverings. This results in tremors and incoordination. Puppies born with hypomyelinogenesis may show improvement over time and may return back to normal health by one year of age. Both conditions influence gait before eighteen months of age, retarding normal gait development, and while puppies surviving these conditions can potentially live normal lives, the age period that these health conditions occur are critical periods for gait development.

Judging Standards

Breed associations and other related governing organizations determine standards for conformation in both the equine and canine industries. These standards are applied for selecting animals used for breeding programs and for judging animals participating in conformation and performance competitions; and yet, these standards can be vague and unclear, making the interpretation subjective at times. AKC is an example of a canine governing organization that, from it's origination in 1884 to today, has grown from governing nine dog breeds to establishing and governing the standards of over 150 breeds (AKC, 2009b, 2014).

The Weimaraner is an example of a dog breed falling under the governing standards of the AKC, being first recognized by the AKC in 1943 (WCA, 2015). With an AKC litter registration ranking of 34^{th} (AKC, 2009b), the breed is less familiar than other dog breeds in the United States; thus, emphasizing a need for clear breed standards for prospective buyers of Weimaraners (Nyholm, 2007). According to current AKC standards, the Weimaraner is a medium sized gun dog designed to hunt upland game with a gait that allows for speed, stamina, and power during the hunt (AKC, 2015). To accomplish this, the gait is smooth, coordinated, and effortless (WCA, 2015). While the AKC recognizes multiple gun dog breeds, the Weimaraner is unique as it is bred to be versatile in it's hunting duties which require a range of activities that are not focused on just one type of movement. These activities can vary from carrying and retrieving both heavy and light game to covering long distances through forestland and fields at varying speeds. Therefore, Weimaraner conformation and movement may differ from the specialized gun dog breeds including the more popular and better-recognized Labrador Retriever, although both breeds fall under the Sporting Group of the AKC. To continue producing dogs that can perform the specialized activities of the Weimaraner breed and ensure that the conformation and performance meets not only the standards of a Sporting dog, but also the standards that are unique to the breed,guidelines established by the AKC and the Weimaraner Club of America (WCA) need to be objective and clear, as well as free of subjective interpretations, for both current dog owners and potential dog owners.

To test the level of objectivity in standards determined by breed associations and other related governing organizations and to determine the application of these standards during judged competitions, research using kinematic analysis has been utilized in the equine show arena. Finding that what the human eye sees and what the horse actually performs may be two different things. Researchers correlating subjective impressions of the judge with kinematic measurements found that a longer stride length and a slower stride rate produced a higher ranking for Warmblood sport horses according to judging officials (Holmstrom et al., 1997). In the Holmstrom et al. (1997) study, horses judged as "good" at the trot had longer stance phase duration in comparison to horses judged as "poor". Holmstrom et al. (1997) also found that horses did not shift their center of gravity toward the hind limbs to achieve balance and collection as most dressage manuals have indicated. Instead, Holmstrom et al. (1997) indicated that collection may have been achieved by carrying the same weight on the hind limbs for a longer period of time.

Hodson et al. (1998) found that horses performing the half pirouette at the canter did not meet Federation Equestre Internationale requirements during the 1995 Olympics dressage competition. The half pirouette strides showed an irregularity in which there was a short interval between footfalls of the outside forelimb and inside hind limb and a long interval between footfalls of the inside hind limb and inside forelimb. This was due to early placement of the inside hind limb. Due to the short intervals between footfalls and increased stance times of both hind limbs, periods of tripedal support in each stride of the pirouette were increased, and thus, not matching the preferred locomotion of the canter of the dressage horse.

In the western pleasure arena, there has been some discrepancy between judging standards and what is actually performed. In studies done on western pleasure stock breed types such as the American Quarter Horse, Nicodemus and Booker (2007) found that these horses performed four beat stepping gaits for both the jog and the lope. Breed associations define the jog as a two beat diagonal gait that is smooth and ground covering, while the lope is described as a three beat gait performed with rhythm, forward motion and ease. These discrepancies have also been observed in other western pleasure breeds such as the Arabian and Morgan western pleasure horse (Nicodemus and Williams, 2009).

While judging standards are important in canine competitions, research is lacking concerning comparisons made between judging standards and kinematics as found in the equine industry. This type of research performed on dogs may assist in more completely and objectively establishing standards that match more correctly the conformation and performance of each dog breed.

Breed Type

Although breed associations and other related governing organizations, both equine and canine, have worked relentlessly in establishing guidelines that are unique to each breed, for many years it was acceptable for kinematic and kinetic research studies to use subjects collected from multiple breed types when performing a study, and thus, ignoring the influence of conformational and performance differences between the breeds. In fact, breed type has been consistently ignored when selecting subjects for kinematic studies with most investigators focusing more on the size of the animal. For example, a canine study may focus on just large dog breeds using breeds like the Labrador and Golden Retrievers, Greyhound, and German Sheppard all in the same study despite differences in breed and in AKC grouping (AKC, 2009b, 2014; Nyholm, 2007). Similarly, equine kinematic research focused more on height for subject selection excluding ponies from studies unless the study was focused exclusively on pony kinematics (Back et al., 2002) with selection criteria more directed towards training background (Tans et al., 2009). Although most horse breeds perform the same basic gaits, the walk, trot, and canter, breed type for those classified as gaited horse breeds has alone defined the gait performed by a horse such as the running walk of the Tennessee Walking Horse and the tolt of the Icelandic Horse (Nicodemus and Clayton, 2003).

As for horse breeds naturally performing the same basic gaits of the walk, trot, and canter, Cano et al. (2001) found differences in conformational characteristics between breeds which accounted for much of the variability seen in kinematic patterns. This study revealed marked differences in the trot of the Andalusian, Arabian, and Anglo Arabian horse. Anglo Arabian horses displayed longer swing duration in both front limbs than the other breeds. The Anglo Arabian also displayed smaller angular range of motion in the scapula and pelvis inclination and in shoulder, hip and forelimb protraction/retraction angles. At lift off, stifle and tarsal joint angles were more flexed. Comfortable trotting speeds were also different for each breed studied. In a comparison study of the Andalusian and the Dutch Warmbloods, there appeared to be more flexion of the elbow and carpus of the Andalusian during the swing phase (Galisteo et al., 1997). This was thought to be due to the Andalusian having a more sloping conformation of the shoulder. This conformation facilitates forward and upward movement of the front limb in late swing phase, and is, therefore, a favorable type of conformation of the breed.

One defining feature of a gait is stride length (Nicodemus and Clayton, 2003). Limb length is a determinant of stride length as longer limbs are associated with longer, more ground covering strides (Khumsap et al., 2002). This is due to the body mass traveling further forward over the grounded hoof or foot during stance, combined with the fact that longer limb bones offer greater leverage (Clayton, 2004). Stride length can also be influenced by the suppleness of the proximal limb, particularly the elbow, shoulder, and hip, which allows the limbs to rotate through a wider arch. In a study comparing Shetland pony foals to Dutch Warmblood foals of the same age, pony foals had significantly larger ranges of protraction and retraction of fore and hind limbs due to the fact that they had to perform a more extended trot at the required velocity due to their size (Back et al., 1999). The Dutch Warmblood foals however, showed considerably more extension in the elbow, stifle and tarsal joints in mid-stance with more flexion in the hip in comparison to the pony foals. These differences are a reflection of the more horizontal position of the femur of the Dutch Warmblood.

As for the canine species, most of the biomechanical research associated with dogs classified under the AKC Sporting Group was done on the popular Labrador Retriever. Research associated with this breed included comparing the trot of the Labrador Retriever to the Greyhound (Betram and Todhunter, 2000; Colburne et al., 2005). The Greyhound, a tall, lean, fast breed bred to hunt rabbit, is classified under the AKC Hound Group (AKC, 2009b; Nyholm, 2007). Betram and Todhunter (2000) found that Greyhounds used fewer, longer strides than the Labrador Retrievers to travel at the same absolute speed while performing the trot. Analysis of the absolute values for stride period and stride length suggested these two breeds moved in distinctly different manners. Differences between the Labrador Retriever and the Greyhound, found in these studies, assist in supporting why these breeds are classified under different AKC groups.

Comparisons between the Rottweiler, a medium-large, robust, powerful dog classified in the Working Group of the AKC (AKC, 2009b; Nyholm, 2007), and the Labrador Retriever further emphasized this point (Molsa et al., 2010). In a force plate study comparing ground reaction forces of healthy Rottweilers with healthy Labrador Retrievers, Molsa et al. (2010) found differences between the breeds in thoracic limb peak vertical forces and in pelvic limb vertical impulses. The size difference between the two breeds also produced differences in relative velocity. The differences were large enough to cause significant differences in force platform values between the two breeds. To date, research comparing different dog breeds classified under the same AKC group has not been performed.

Training

In the horse industry, the breed of the horse will often dictate what type of sport a horse will be trained for. However, many horse breeds are now promoted as versatile performers because they are able to compete in such diverse sports as western pleasure, jumping, cutting, barrels, dressage, and driving. The same can be said for some dog breeds such as the Weimaraner that can be trained for multiple hunting duties such as pointing, flushing, and retrieving. With these more versatile breeds the type and quality of training becomes an important part in understanding how an animal performs their gaits.

While breed type has been found to influence gait, the performance type determined by the type of training the animal has been subjected to, has also been shown to influence gait. Clayton (1993) compared the canter of the dressage horse and the racehorse, finding that there were no significant differences between the two groups in terms of speed, stride length, distances between limb placements, or stride duration. There were, however, differences in stance durations, overlaps, and suspension. The dressage horse had significantly longer overlaps and much shorter suspension times in comparison to the racehorse.

Although both the hunter pleasure and country English pleasure horse perform the same gaits and appear similar to those persons unfamiliar to the industry, research comparing these two performing types found that the Arabian breed demonstrated different trotting temporal variables (Nicodemus and Slater, 2007) and cantering temporal variables (Slater and Nicodemus, 2008) unique to the performance type. At the trot, Nicodemus and Slater (2007) found that stride length was the distinguishing factor between the Arabian hunter pleasure horse and the Arabian country English pleasure horse. At the canter, Slater and Nicodemus (2008) noted significant differences between the two performance types in terms of stride length, diagonal bipedal support, and advanced placement between the trailing fore and leading hind limb.

With conditioning and training, a horse or dog will fine-tune their performance, leading to an animal that can perform a gait or a maneuver efficiently, with ease, and fluidity. These conditioned animals will also be able to repeat the flawless performance consistently and effortlessly. In a study by Tans et al. (2009) researchers found that horses with training in dressage had more efficient and precise transitions between trotting and a halt than horses with less or no dressage training. The longer the horse had been in training, the fewer steps were used to go from a trot to a halt and from a halt to a trot. In studies on Dutch Warmbloods, after 70 days of training, horses had a shorter stance phase while maintaining the same total stride duration as observed prior to training (Back et al., 1995). These horses also showed less limb flexion after training. Standardbred horses after five months of pre-race training had greater flexion of the elbow and fore fetlock and greater extension of the carpus and hind fetlock. When comparing Andalusian horses before and after training, Cano et al. (2000) found that after training, horses displayed shorter stride lengths and a greater stride frequency at the trot as compared to kinematic analysis done prior to training. Similarly, with training, Tennessee Walking Horses perform a running walk that is much faster and more animated in the show ring than the natural, untrained gait found on the trail ride (Nicodemus et al., 2002).

Velocity

Velocity is defined as the rate of movement determined as the displacement divided by the time taken and is dependent on direction of movement (Clayton, 2004). In gait analysis, velocity is measured linearly and angularly. Speed is defined as the rate of movement determined as the distance covered divided by the time taken. If movement and displacement are measured in the same direction, then speed and velocity are the same.

The gaits of different breeds of horses have been analyzed and defined by temporal variables and velocities, and it has been shown that velocity can influence the type of gait performed and the way the gait is performed (Clayton, 2004). Stride length and stride rate both increase with increasing linear speed in the equine walk (Rubin and Lanyon, 1982). The walk is a four beat stepping gait with a regular footfall sequence, but with increasing velocity, the regularity of the rhythm of the walk can be lost (Nicodemus, 2005). The walk is considered the least tiring and most efficient of the gaits utilized by the dog (Nunamaker and Blauner, 1985). During the walk the principal support phases occur between either diagonally opposite or ipsilateral fore and hind limbs (Rubin and Lanyon, 1982). This support phase is referred to as bipedal support consisting of one front limb and one hind limb and alternating between diagonal and lateral pairs (Clayton, 2004). Other support phases of the walk include tripedal or quadrupedal limb support and the presence and duration of this support depends on the velocity (Rubin and Lanyon, 1982).

As the speed of the walk increases, limbs of quadrupeds move faster until the animal changes from a walk to a trot (Rubin and Lanyon, 1982). Due to shortening of stance durations, periods of tripedal and quadrupedal support decrease and periods of bipedal support increase (Clayton, 2004). The horse relies on forward momentum at faster speeds to remain balanced on fewer supporting limbs. The same is true for the dog. Roush and McLaughlin (1994) found that stance times in the fore and hind limbs of Greyhounds decreased as velocity increased at the walk.

Gaited equine breeds perform variations of the walk that are described as “faster” while still maintaining a symmetrical, four-beat stepping footfall pattern with a lateral hoof placement sequence (Biknevicius et al., 2004). Speed has also been shown to affect limb support in various equine gaits including those of the gaited horse breeds (Nicodemus, 2005; Nicodemus et al., 2002). Gaited breeds, such as the Tennessee Walking horse, perform what is often referred to as a type of ‘running walk’ because the lateral-sequence single foot is also the footfall pattern of the flat-footed walk, but performed at speeds typical of the trot (Biknevicius et al., 2004).

As these gaited breeds are asked to perform their gaits at even faster speeds, they are still able to perform the gait without the inclusion of the suspension phase (Nicodemus et al., 2002). When performing the tolt, the Icelandic Horse increases periods of unipedal support and decreases periods of tripedal support with increasing velocity (Nicodemus, 2005). The running walk of the Tennessee Walking Horse has an increase in diagonal advanced placement, lateral advanced lift-off, and diagonal and lateral bipedal support with an increase in velocity (Nicodemus et al., 2002).

The trot is defined as a symmetrical, two-beat leaping gait where the diagonal limb pairs move more or less synchronously and the diagonal support phases are separated by aerial or suspension phases (Clayton, 2004). In the equine trot, increasing speed has been shown to decrease stride duration (Robert et al., 2002) and increase stride length and rate (Vilar et al., 2008). In equine gaits, speed and velocity impact the type of trot a horse performs (Holmstrom and Drevemo, 1997; Clayton, 2004), just as they similarly affect the walk. Slower speeds produce a more collected trot with a shorter stride length, while faster speeds produce a more extended trot with a longer stride length (Robert et al., 2002).

Horses are often trained at varying speeds to develop their musculature (Robert et al., 2002). Robert et al. (2002) found that changes in velocity as small as 0.5 m/s resulted in significant changes in equine locomotion. According to Robert et al. (2002), at faster speeds, there is increased eccentric activity of the triceps brachii muscle, which limits the flexion of the elbow, and the tensor fasciae latae muscle is needed to stabilize the stifle. This increase in axial muscle activity provides additional trunk stability and changes the spine into a rigid platform from which the limbs can swing faster.

Similar to horses, in a study done on Greyhounds, increasing velocity caused a decrease in stance durations for both front and hind limbs at the trot (Roush and McLaughlin, 1994). As durations decreased, vertical ground reaction forces increased with increasing trotting velocity. Additional research using Greyhounds reported similar influences on other measurements of ground reaction forces with changes in velocity (McLaughlin and Roush, 1995; Riggs et al., 1993). As for studies measuring power across the joints, hip extension power was determined to become significantly greater at faster velocities compared to slower velocities in trotting Greyhounds (Colborne et al., 2006). An increase in trotting velocity of Greyhounds leads to increases in positive power from the extensors of the hip joint and flexors of the stifle joint during the first half of the stance phase and an increase in tarsal power during the second half of the stance phase. Colborne et al. (2006) found that changes in velocity resulted in changes in timing and local amplitudes of the angular displacement, moment, and power curves without changing their overall patterns.

The pace is a preferred leaping gait for long legged dogs, although research concerning this gait is lacking (Nunamaker and Blauner, 1985). The pace is described as a symmetrical, two-beat, leaping gait (Clayton, 2004). Legs on the same side of the body move forward in unison (Nunamaker and Blauner, 1985). Most long legged dogs with close-coupled bodies are thought to pace due to foot interference between the hind foot and front leg during transitions between the walk and the trot.

The gallop is an asymmetrical, four-beat, leaping gait with usually one aerial phase in each stride (Clayton, 2004). The footfall sequence can be a transverse sequence of limb placements or a rotary sequence, and in both cases, the sequence depends on which set of limbs are leading and which are trailing as the gait is asymmetrical. The transverse sequence involves the sequence moving across the body axis, alternately moving from left to right limbs so that a left lead transverse footfall sequence would be right or trailing hind limb, left or leading hind limb, right or trailing forelimb, followed by left or leading forelimb. The rotary sequence of limb placement involves the order of footfalls following a circular pattern in that a left lead rotary placement would be left or leading hind limb, right or trailing hind limb, right or trailing forelimb, followed by left or leading forelimb.

Horses primarily employ the transverse gallop (Clayton, 2004) and can perform it at various speeds (Bertram and Gutmann, 2008). The rotary gallop is the gallop sequence generally used by the cheetah, and in dogs, speed and velocity dictate which sequence of limb placement is used (Nunamaker and Blauner, 1985). The slow gallop or transverse gallop of the dog is used to sustain a speed over a long period of time, while the rotary gallop is used to achieve maximum speed, as in pursuit of prey.

At slower speeds the transverse footfall sequence of the equine gallop is adapted so that the leading hind and trailing forelimb move as a diagonal pair, and thus, recreating the gait from a four-beat to a three-beat gait referred to as the canter (Clayton, 2004). As the horse decreases speed from the transverse gallop to the canter, stride and stance durations increase. At extremely slow speeds, such as that performed by the western pleasure horse, the suspension of the canter can become completely absent and the diagonal limb pair can disassociate creating a four-beat gait with a lateral footfall sequence similar to the walk (Nicodemus and Booker, 2007). This gait is referred to as the lope, and while both the lope and gallop are four-beat gaits, the lope is produced with a period of quadrupedal limb support that is not found in the gallop or in the canter. Nicodemus and Booker (2007) found horses performing the lope had greater than 0% of the stride in diagonal advanced placements and lift-offs indicating that limbs were not moving as pairs during the loping stride, creating a four-beat rhythm.

The canter footfall pattern has the legs of one diagonally opposite pair moving out of phase with each other, while those of the other pair remain ‘in phase’ (Rubin and

Lanyon, 1982). A single stride of the canter starting with the lead or ‘out of phase’ forelimbs followed by an aerial phase with the animal landing on the diagonally opposite or ‘out of phase’ hind limb. Next in the line sequence, the contralateral hind limb and it’s diagonally opposite (in phase) forelimb make ground contact simultaneously, similar to the trot. As these limbs leave the ground, the out of phase lead forelimb is placed on the ground, providing the animal with unipedal support before push off and the next aerial phase.

Lameness

Pain has been defined as suffering, either physical or mental, as an impression on the sensory nerves causing distress (Anil and Deen, 2002). One physical sign of pain in animals is lameness. Quadrupeds, such as dogs and horses, have the ability to distribute weight off of an injured limb, making limping or lameness detection difficult (Nunamaker and Blauner, 1985). The natural symmetry of a gait must be taken into account when evaluating asymmetries associated with lameness (Clayton, 2004). In both the dog and horse, the walk and trot are commonly used to evaluate lameness (Nunamaker and Blauner, 1985). The walk will show which leg is involved only if the lameness is more severe. The trot is necessary in lameness evaluation because it increases the vertical forces on all limbs by two fold, increasing the chance of observation of lameness that is more subtle.

A dog using the pace in place of a trot can be a sign of lameness (Nunamaker and Blauner, 1985). The pace is a symmetrical two-beat leaping gait similar to the trot, but with a lateral footfall sequence (Clayton, 2004). For both the dog and horse, certain breeds will naturally perform the pace, and thus, the production of the gait will not always be evidence of lameness, but any sign of asymmetry while performing the gait could be an indication of pain.

While observing for lameness in the quadruped, rising of the head and neck marks lameness of the front limbs when the injured limb is placed on the ground (Nunamaker and Blauner, 1985). For hind leg lameness in dogs, the front limbs will be carried further underneath the body and the head will be lowered to shift more weight toward the front end. Like wise, the horse will show similar lowering of the head with hind limb lameness. Tail movement of the dog can be a sign of hind limb lameness as it will rise when the injured leg is on the ground and lower when the injured leg is in the air. Instead of the tail, the hip of the horse will be lifted on the side of the lame hind limb as the limb is placed on the ground (Stashak, 1987).

Lameness in the quadruped such as the horse can be categorized as support limb lameness, swinging limb lameness, mixed lameness, or complementary lameness (Stashak, 1987). Supporting limb lameness is seen when the quadruped is supporting weight on the affected foot or when the animal lands on the foot. Injuries to bones, joints, collateral ligaments, motor nerves, or injury to the foot are classified as supporting lameness. Swinging limb lameness is observed when the limb is in motion. Causes of swinging limb lameness are thought to be pathologic changes that involve joint capsules, muscles, tendons, tendon sheaths, and bursas. Mixed lameness is the combination of supporting limb and swinging limb lameness. Complementary lameness is lameness resulting from uneven distribution of weight on a limb or limbs due to pain in another limb. When discussing lameness in the quadruped, one should be able to distinguish between lameness resulting from pain and non-painful alterations in gait often referred to as mechanical lameness.

Lameness in dogs can occur for a variety of different reasons making the detection of lameness and the determination of the cause difficult until the health condition has become quite severe. In a growing dog, potential causes of lameness in the hind limbs include hip dysplasia, avascular necrosis, avulsion of the long digital extensor, osteochondritis dissecans in the stifle or hock, and luxating patellas; and in the forelimb lameness can be due to osteochondritis dissecans of the shoulder, luxation/subluxation of the shoulder, osteochondritis of the elbow, and elbow incongruity (Brinker et al., 1990), among others. In an adult dog, hind limb lameness can be due to such conditions as arthritis, luxating patella complex, cruciate/meniscal syndrome, inflammatory joint disease, and neoplasia; and forelimb lameness can be due to such conditions as arthritis, calcification of supraspinatus tendon, bone or soft tissue neoplasia, luxation/subluxation of the shoulder, and inflammatory joint disease. While examining a dog for lameness, shortened stride, dragging of toenails, toeing in or toeing out, “bunny hopping”, stumbling, ataxia, criss-crossing of the rear legs, asymmetry of gait or stance, and abnormal sounds upon ambulation should be noted by examiner.

Lameness in dogs is often assigned a subjective score using either a visual analog scale (VAS) or a numeric rating score (NRS) that is based on individual assessment of gait with clinicians relying on changes in limb carriage, duration of weight bearing, stride length, and joint range of motion to assess the degree of lameness (Waxman et al., 2008). With the VAS system, limb function is assigned by marking a line with one end of the line representing clinically normal or sound and the other end representing a non-weight bearing lameness. Owners of dogs are often asked to assess the pain or degree of lameness their dog has experienced or is experiencing using VAS questionnaires (Hudson et al., 2004), but the owner's empathy for their pet produces more subjective, rather than objective, answers to the questionnaire. While the VAS scoring ranges from 0 to 100 making the system fairly sensitive, the NRS describes various types of limb lameness with a more restrictive scale using values only ranging from "0" for clinically sound to "5" for being unable to show any additional signs of lameness (Impellizeri et al., 2000). NRS is also used for defining hip function as the clinician manipulates the hip, but the range again stays limited to "0" indicating no changes in hip movement to "4" indicating significant reduction in range of hip motion. These observed limitations in the scaling systems are supported by early reports in horses describing the relationship between observers using subjective scoring methods when interpreting lameness. The reports indicate that inter- and intra-observer agreement are highly dependent upon lameness severity (Miqueleto et al., 2013). In addition, there have been large discrepancies between visual observation of lameness and force plate data in past dog studies (Waxman et al., 2008). In the Waxman et al. (2008) study, surgeons assessing lameness agreed 100% of the time when dogs were non-weight bearing on the injured limb and 0% of the time when dogs bore 50% to 74% of normal weight on the injured limb, according to force plate data.

While clinicians have consistently utilized visual observation to assist in the diagnosis of lameness, kinematic and kinetic analyses have been recently applied to more accurately measure how the quadruped adapts locomotion to different medical conditions that cause lameness. Such analysis are also being used to determine the success of treatments commonly used to address these conditions. The use of force platforms in kinetic analysis has seen the greatest application in researching gait parameters associated with canine lameness. Force platforms have been used to measure differences between the ground reaction forces, both vertical and horizontal, of lame and sound dogs as the dogs walk and trot over the platform. Force platform measurements have shown more reliability than measurements taken from the NRS and VAS (Quinn et al., 2007), and have been successfully applied in detecting gait abnormalities in experimentally induced lamenesses (Waxman et al., 2008; Madore et al., 2007; Cross et al., 1997). Force platforms have also been used to determine the effectiveness of various treatment methods for chronic lamenesses (Quinn et al., 2007; Beraud et al., 2010; Budsberg et al., 1996; Lister et al., 2009; Li et al., 2008). While less prevalent, kinematic anlaysis, measuring canine joint angles using both two-dimensional, and, more recently, three-dimensionaltechniques, has been a useful tool for assessing canine lameness (de Medeiros et al., 2011; Bockstahler et al., 2011; Tashman et al., 2004). Research measuring the kinematics of normal joint motion in healthy dogs should facilitate a more thorough understanding of abnormalities identified during kinematic analysis of lame dogs.

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CHAPTER II

INFLUENCE OF VELOCITY ON TEMPORAL VARIABLES AND KINEMATICS OF THE WEIMARANER AT THE TROT

Introduction

Gait research analyzing the kinematics of quadrupeds has become a valuable tool in understanding of normal locomotion and in the early detection of lameness. To date, studies utilizing gait analysis of healthy dogs performing the gait that is characteristic to their specific breed are limited, with descriptions only available for those breeds most commonly found in the dog industry. As the most popular dog breed in the United States, the Labrador Retriever is one of the few dog breeds that has been utilized in multiple gait studies measuring healthy locomotion (Bertram and Todhunter, 2000; Colborne et al., 2005; Gustas et al., 2013; Molsa et al., 2010). Furthermore, it is the only dog breed in the American Kennel Club (AKC) sporting group to be studied using gait analysis prior to 2010 when Marsh et al. conducted kinematic gait analysis of Golden Retrievers. However, the Marsh et al. study focused on dogs suffering from Muscular Dystrophy. In sporting types such as the Labrador Retriever, where gait is a direct influence on functionality of the animal, a clear definition of the correct, most desirable gait is needed to determine which animals obtain the superior traits to be used as breeding stock (Evans and Christensen, 1979), and while AKC supplies gait standards for judging that are specific to these breeds, the descriptions are often vague and unclear (AKC, 2015c).

Normal gait is essential for dogs in the sporting group to excel in their hunting duties; thus, changes in gait due to health conditions can significantly influence their ability to perform. Early detection of changes in gait that deviate from normal gait parameters established by kinematic analysis may help sporting dogs perform at maximum capacity and recover quickly from health conditions that are detected early.

One of the most common health conditions influencing normal gait in the dog is hip dysplasia. Kinematic research concerning hip dysplasia has assisted in detecting gait abnormalities at the trot associated with the condition (Bennett et al., 1996; Poy et al., 2000); however, the research only included a few breeds. Thus, kinematic studies documenting the influence of breed type on gait parameters in dogs with hip dysplasia has been limited to only those few breeds (Bertram and Todhunter, 2000; Agostinho et al., 2011). As in the evaluation of lameness in horses, there have been discrepancies in the lameness evaluation and scoring of dogs among clinicians (Hudson et al., 2004; Quinn et al., 2007; Waxman et al., 2008). This limitation may impact sporting dog breeds that were not researched, as those breeds may also suffer from this condition.

Hip dysplasia is most common in fast growing dogs of medium to large breed (Smith et al., 2001). The incidence is high in sporting dog breeds and affected animals can be useless as hunting dogs, while less severe cases can go undetected for years (Harper, 2007). Hip dysplasia is most commonly diagnosed using radiography. Some dogs will show symptoms as early as two years of age, where others may not display clinical signs for years (Smith et al., 2001). This is critical for large sporting dog breeds where the size of the animal makes the breed more prone to hip dysplasia. Unfortunately, without established normal gait parameters for larger sporting dog breeds, such as the Weimaraner, that are known for suffering from hip dysplasia, early detection of lameness is limited (Harper, 2007). In addition to studies documenting the influence of breed type on gait parameters, similar supporting research is available documenting the influence of velocity on gait parameters (Colborne et al., 2006; Maes et al., 2008; McLaughlin and Roush, 1995; Riggs et al., 1993; Roush and McLaughlin, 1994). Therefore, the objectives of this study are to measure the kinematics of the Weimaraner at the slow and fast trot in order to objectively define the trotting gait of this larger sporting dog breed and to determine the influence of velocity on the normal parameters of the trot.

Materials and Methods

The Institutional Animal Care and Use Committee of Mississippi State University approved all procedures in this study. Owner consent was required for study participation with client consent forms being signed prior to data collection (Appendix A).

Research subjects

Six AKC registered Weimaraner dogs that had been determined, by a veterinarian, to be free of any health conditions that would alter gait, were selected for the study. All dogs were regularly exercised prior to data collection by being actively used for upland game hunting. Information concerning the dogs is located in Appendix B.

Data collection

Dogs were led by the same handler at a slow (st) (velocity: 1.2-1.7 m/s) and fast (ft) (velocity: 1.9-2.3 m/s) trot on even, natural footing. Trotting velocities were selected based on previous kinematic studies (Charteris et al., 1979; DeCamp et al., 1993). Strides (n=10) were selected for each dog for each trot based on soundness of the animal, through veterinarian evaluation, consistency and correctness of velocity, noticeable foot placement and lift-off, correctness of gait as described by breed standards (AKC, 2015c; WCA, 2015), and complete marker visibility throughout the stride cycle.

Equipment and kinematic measurement procedure

Circular retro-reflective adhesive tape was used for markers on the subjects for kinematic tracking. Markers (Figure 2.1) were placed via palpation on points used for two-dimensional gait analysis of dogs (Charteris et al., 1979; DeCamp et al., 1993).

Two posts placed at each end of the runway marked runway borders. The runway measured 4.9 m in length. A single JVC GR-DVL 9500 camcorder was placed perpendicular to the runway, 11 m from the middle of the line of motion, to film the dogs in the sagittal plane during tracking. At a height of 1.2 m, the zoom lens was positioned to allow a 6-m field of view.

Temporal variables were determined by frame-by-frame analysis including documentation of the video frames of foot placement and lift-off for each stride. Temporal variables measured were stride duration (ms), stride length (m), and stride frequency (strides/s) with the following measured variables given as percent of stride duration: fore and hind limb stance, diagonal advanced placement, diagonal advanced lift-off, single limb support, bipedal limb support, tripedal limb support, quadrupedal limb support, and suspension. Velocity was measured by dividing the stride length by the stride duration. Stride length was the difference between x-coordinates (horizontal displacement) of the distal limb markers in two consecutive contacts of a limb with the ground.

Kinematic analysis

Kinematic variables were analyzed using the Ariel Performance Analysis System (APAS). Joint angles were measured on the flexor aspect of the joint to determine minimum and maximum values during the stride and calculate angular displacement. Horizontal displacement of markers was taken from the most caudal to the most cranial location of the tracked marker during one full stride, including both the stance and swing phases. Vertical displacement of markers was taken from the most proximal to the most distal location of the tracked marker during one full stride including both the stance and swing phases.

Statistical analysis

Means and standard deviations (SD) were calculated for the temporal variables and linear and angular displacements for both the slow and fast trot. Paired Student's t-tests were performed within gaits and between velocity types. All statistical procedures were calculated using the SAS package software 9.4 (SAS Inc., 1982). A significance level of 0.05 was chosen for all tests.

Results

Temporal variables

Both trots were produced with a diagonal footfall sequence and a similar stride duration (st-0.53±0.10 sec, ft-0.47±0.07 sec) and frequency (st-1.94±0.13 str/sec, ft-2.12±0.09 str/sec), alternating between periods of diagonal bipedal support (st-88±2%, ft-75±5%) and suspension (st-12±1%, ft-25±3%) with less than half of the stride cycle of each limb spent in stance (Fore: st-44±4%, ft-38±2%; Hind: st-44±5%, ft-38±4%). Although stride length significantly increased with speed (st-0.90±0.02 m, ft-0.99±0.04 m; P=0.041), the diagonal limbs remained paired on contact (diagonal advanced placement: st-0±0%, ft-0±0%). Despite the small period of suspension, both trots were classified as basic or supported trots as the diagonal limbs stayed paired throughout the stride and were the primary supporters during the stride cycle.

Linear and angular displacements

As the Weimaraner leapt back and forth between flight phase and periods of diagonal bipedal support, the vertical displacement of the top-line of the Weimaraner was not significantly different between the head and the withers (P=0.77) and the withers and the pelvis (P=0.51) at the slow trot (Table 2.1). Although fast trotting head and withers displacements were not significantly different (P=0.62), significant difference in the vertical displacement was observed between the withers and the pelvis (P=0.048). As the Weimaraner transitioned from the slow to fast trot, the vertical displacements of the head (P=0.034) and withers (P=0.042) significantly increased. When tracking horizontal displacements of the fore (P=0.03) and hind (P=0.021) paws, significant differences were observed between velocity types with the horizontal displacements greater at the fast trot.

Both the slow (P=0.53) and fast trots (P=0.63) demonstrated greater horizontal displacement in the hind paws compared to the fore paws, but the differences were insignificant. Vertical displacement between fore and hind paws were similar in the slow trot, and although a larger displacement was seen in the forepaw compared to the hind paw in the fast trot, the difference was insignificant (P=0.16). Comparisons between the slow and fast vertical displacements of the paws demonstrated a significant difference in the forepaw between velocity types (P=0.04). While all joint angles demonstrated an increase in range of motion as the Weimaraner transitioned from the slow to fast trot, only the angular displacement seen in the elbow (P=0.03) and hip (P=0.041) were significantly different between velocity types (Table 2.2).

Discussion

Temporal variables

Detecting lameness and treating conditions affecting gait requires the complete understanding of the normal locomotion of the animal, particularly for gaits that are symmetrical where, when asymmetry is found in these gaits, it can be used as an indicator of lameness. The walk, pace, and trot are symmetrical gaits commonly used by dogs and the trot is the most common ground covering gait over long distances utilized by dogs and other quadrupeds (Nunamaker and Blauner, 1985). In canine locomotion, the trot has the largest range of speed (Maes et al., 2008). A dog can conduct the trot at the same speed as the lateral walk, pace, transverse gallop, and in some cases, as the slow rotary gallop.

Unlike the horse that has been identified as an animal with the ability to perform various forms of the trot with distinct kinematic parameters due to training (Back et al., 1995; Cano et al., 2000) and breed type (Cano et al., 2001), the dog has only been documented to perform two types of trot called the basic trot, also referred to as the "supported trot", and the flying or running trot (Nunamaker and Blauner, 1985). During the basic trot, the dog usually places two feet on the ground at all times with a limited, if any, aerial phase and limbs that typically stay in diagonal pairs (Clayton, 2004). The flying trot has a distinctive aerial phase with an extended stride length and an overreach of the hind limbs. The flying trot may become a four-beat gait as the diagonal limbs dissociate creating a period of unipedal support. Larger breeds are described to be less likely to perform a true flying trot as the aerial phase is described to require more effort for the larger animal (Clayton, 2004). Classifying the Weimaraner, trot is complicated. Their use of suspension at all trotting velocities makes the trot of the breed a flying trot, and yet, the consistency of the pairing of the diagonal limbs creates a true 2-beat gait that lacks unipedal, or single-limb, support which could also justify classifying this trot as a basic trot.

The uniqueness in the limb support is due to the Weimaraner's long fame and leg length. In the flying trot, interference can become an issue when the hind paw hits the ipsilateral forelimb, so, avoiding interference requires the fore paw to be lifted before the ipsilateral hind paw makes ground contact, thus creating a period of unipedal support (Leach et al., 1977). In long-bodied dogs this interference is less of an issue. Maes et al. (2008) found that temporal and spatial coordination between a pair of limbs was strongly linked to trunk length. Other breeds demonstrating similar support phase characteristics as the Weimaraner include those that have been bred for endurance, such as the Dalmatian. Like the Weimaraner, the Dalmatian body length from chest to hindquarters is approximately ten percent longer than the height of the dog at the withers and the foreleg is the same length as the chest is deep (AKC, 2015b). Conformation, and therefore movement, is different between dogs designed for endurance and those built for speed, such as sight hounds, including the Greyhound (AKC, 2015a). Betram and Todhunter (2000) found Greyhounds move in a distinctly different manner than Labrador Retrievers. In the Betram and Todhunter (2000) study, Greyhounds, at a moderate or natural trot speed, had a forward velocity that was similar to that of Labradors, but with longer stride lengths than those displayed by the Labrador Retrievers. Significant differences in the kinetic patterns of the hind limb joints were noted between the Greyhound and Labrador Retrievers in a study by Colborne et al. (2005).

The trot is an important gait for assessing lameness because the aerial phase produces more limb concussion than the other gaits (Clayton, 2004). Lame dogs generally have noticeable asymmetry present in the trot and they are commonly less willing to move at a normal trotting velocity (Brinker et al., 1990). Changes in velocity of a gait have been found to produce changes in gait kinematics for both the dog (McLaughlin and Roush, 1995) and horse (Hobbs et al., 2009). These studies were done at both the walk and he trot, but were limited to specific breeds of dog and horse. Breed type has been shown to influence gait kinematics in the dog (Betram and Todhunter, 2000; Colborne et al., 2005; Melsa et al., 2010) and horse (Cano et al., 2001; Galisteo et al., 1997), suggesting that the findings related to changes in gait velocity may only be applicable to the breeds studied.

As for the Weimaraner, the mechanics of the flying trot is seen at both velocities, and yet, the production of the flying trot is described as a function of increasing speed in the dog, as in racing Standardbred horses (Clayton, 2004). The use of suspension at all trotting velocities in the Weimaraner may be more due to the size of the breed, rather than the speed of the gait. In gait production, the importance of the suspension phase is that it allows for energy conservation, so the presence of suspension at all velocities may assist the Weimaraner in producing a more energy efficient gait. Without the suspension phase, dogs tend to move with their body at an angle to the line of forward progress, making the gait less efficient (Leach et al., 1977), which is important for sporting dogs. Further research in energy expenditure at the trot in the Weimaraner is needed. An additional gait characteristic that distinguishes the Weimaraner from other large breeds previously studied, including the Laborador Retriever (Clements et al., 2005, Gustas et al., 2013) and German Shepard (Miqueleto et al., 2013) is the Weimaraner's dependence on increasing stride length to increase velocity, and this, along with the consistent use of suspension, can aid in lameness evaluation.

Linear and angular displacements

Completing the picture of gait production in an animal includes not only the temporal variables, but also the linear and angular displacements of the body throughout the stride. As discovered in temporal variable research, velocity and breed type can influence gait. In dog breeds that produce a stepping trot that lacks an aerial phase, the angulation of the topline becomes less level to the ground as the velocity increases (Leach et al., 1977). This drop in the hindquarters allows for the dog to increase overstride in the hind limbs, promoting more reach and distance covered at the faster gait. This type of gait production is also evident in horse breeds such as the Tennessee Walking Horse Breed (Nicodemus et al., 2002). This horse breed performs a faster variation of the walk, referred to as the running walk. What distinguishes the running walk from the flat walk is the occurrence of overstride of the hind limbs. The hindquarters lowering as the forequarters are elevated accomplish this.

The Weimaraner displays suspension in all velocities of the intermediate gait. At the faster velocity, the pelvis is dropped below the line of the head and withers, allowing for hind limb overstride. While timing of the limbs did not significantly change, it was through an increase in range of motion of the hip joint that allowed for this overstride, and to avoid interference with the forelimbs, the range of motion of the elbow joint increased to elevate the limb during the swing phase as the hind limb stepped well under the body. Relationships between velocity and range of motion of the elbow and hip joints have been noted in other canine studies (McLaughlin and Roush, 1994; Brady et al., 2013).

The production of gait is dependent on the body conformation of the animal. Body conformation is strongly influenced by breed type, as a particular breed is bred to do a specific purpose, hence the term 'form to function.' Judging standards of the dog are specific to the breed type. These standards are observed in both a standing dog and a dog in motion (AKC, 2014). Research has assisted in supporting the relationship between conformation and gait mechanics that make each breed unique. The focus of research concerning differences in canine breeds has stayed exclusive to large breed dogs and in finding differences in conformation and gait mechanics (Agostinho et al., 2011; Bertram and Todhunter, 2000; Colborne et al., 2005). Joints identified as demonstrating breed differences in large breed dogs included the elbow, stifle, and tarsus. These studies did not identify the type of trot performed during the study, and thus, these breed differences may be based more off of the type of trot performed, rather than the breed itself. Equine research has indicated trot type does influence gait mechanics, although the type of intermediate gait performed has been found to be dependent on the type of breed (Barrey et al., 2002; Clayton, 2004). When comparing the data collected from the Weimaraner to other large dog breeds studied, joint angles were comparable, but with slightly less range of motion than other breeds measured (Agostinho et al., 2011). This could be related to breed structural differences or could be attributed to weight differences, as the other study was conducted on heavier bodied breeds in which the focus was on range of motion of obese dogs. This study found that the range of motion increased with the increase in weight, thus assisting in absorbing the extra concussion associated with increased weight (Brady et al., 2013). These studies were also performed on a treadmill in which previous research has reported the influence of the treadmill on trotting mechanics in large dog breeds (Gustas et al., 2013).

The health of the animal impacts the gait that is performed, and thus, understanding normal gait mechanics can aid in the early detection of health issues. Even obesity has been determined to impact range of motion in the joint (Brady et al., 2013). While the hip and elbow joints were impacted by velocity in this study, obesity had the same relationship with theses joints during the swing phase. Hip dysplasia, a common disorder found in large breed dogs including the Weimaraner, was also found to impact hip joint mechanics according to Miqueleto et al. (2013). In the Miqueleto et al. (2013) study, German Shepherd dogs diagnosed with hip dysplasia had a higher angular velocity and higher maximum angle of the hip joint than clinically normal German Shepherd dogs. Additional diseases such as muscular dystrophy and medial coronoid process disease have been found to influence joint motion in large breed dogs (Marsh et al., 2010; Caron et al., 2014). Along with detection of lameness, kinematic analysis can assist in evaluation of the effectiveness of treatment approaches and procedures for chronic lameness issues. Significant biomechanical adaptation seen after amputations in dogs indicates the concern for potential lameness issues associated with this procedure (Jarvis et al., 2013). Through such analysis, clinicians can decide if the benefit of such invasive procedures outweighs the potential lameness issues associated with the gait adaptations made after the procedures. Tracking progression of a disease and treatment approaches through gait analysis will assist clinicians in better treating canine disorders. This potential application of technology can only be done after normal locomotion specific to each breed has been documented, as was done for the Weimaraner breed in this study.

Summary

Through gait analysis, the trot of the Weimaraner was defined as a basic or supported trot with a 2-beat diagonal rhythm. Velocity did not change these trotting characteristics, but did influence stride length and linear and angular displacements of both the fore and hind limbs, and thus, should be a controlled variable in future kinematic studies of the Weimaraner. A better understanding of canine locomotion through the analysis of the kinematics, as was done in this study, can be further applied to the clinical examination of gait and the veterinary assessment of locomotive rehabilitation, which is important for large dog breeds such as the Weimaraner that are more susceptible to orthopedic disorders than smaller breeds.

Figure 2.1 Weimaraner with retroflective markers affixed to the skin at boney landmarks over the joint centers of rotation along the forelimbs, hind limbs, and at the head.

Table 2.1 Means ± standard deviations of the linear displacements of the Weimaraner at the slow and fast trots.

Displacement Type	Slow Trot	Fast Trot
Head Vertical Displacement (cm)	5.2+2.3a	9.3+3.4a
Withers Vertical Displacement (cm)	4.7+1.5b	7.2+2.8b,c
Pelvic Vertical Displacement (cm)	4.8+2.0	2.8+0.7c
Fore Paw Horizontal Displacement (cm)	89.5+8.9d	115.6+11.4d
Fore Paw Vertical Displacement (cm)	7.8+3.2e	12.5+4.0e
Hind Paw Horizontal Displacement (cm)	97.2+7.3f	118.2+10.1f
Hind Paw Vertical Displacement (cm)	6.6+1.9	9.7+2.1

Similar superscripts between columns indicate significant difference between velocity types and similar superscripts between rows indicate significant difference within velocity types ($P < 0.05$).

Table 2.2 Means ± standard deviations of the angular displacements of the Weimaraner at the slow and fast trots

Angular Displacement	Slow Trot	Fast Trot
Tarsal (o)	30.5+4.2	36.1+3.7
Stifle(o)	41.9+5.0	46.8+5.6
Hip(o)	20.4+1.1a	29.8+1.0a
Carpal(o)	47.9+7.4	55.6+9.1
Elbow(o)	33.1+3.0b	47.3+4.2b
Shoulder(o)	22.3+4.1	25.6+3.9

Similar superscripts between columns indicate significant difference between velocity types ($P < 0.05$).

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CHAPTER III

CONCLUSION AND FUTURE CANINE BREED STUDIES

Gait analysis allows us to understand the mechanics of an animal and determine what influences the mechanics. Research such as what was done in this study can be applied in the selection of a dog for sporting purposes, breeding purposes, or in the evaluation of the gait for clinical purposes. While canine kinematic research is not new, research specific to a breed of dog is relatively new.

As stated by Nunamaker and Blauner (1985), the gait of an animal is influenced by the function of all organ systems of the body, and nearly all boney structures of the body. Just as was documented in other studies comparing breed differences, the same assumption can be made that the Weimaraner would demonstrate differences in gait from that of other breeds (Carr et al., 2015; Bertram and Todhunter; 2000; Colborne et al., 2005; Molsa et al., 2000). Nevertheless, to truly know if there are differences between the Weimaraner and other breeds, further research is needed specifically comparing the Weimaraner breed with other breeds in the same research setting using the same research protocol. While velocity of the Weimaraners in this study matched that of previous large dog studies, and thus avoided velocity-related changes in kinematic variables, previous kinematic studies have also documented differences associated with handlers and footing (Carr and Dycus, 2016; Gillette and Angle, 2008; Keebaugh et al., 2015). Therefore, even greater consistency in the research protocols between studies would assist in making more conclusive statements concerning breed differences between the Weimaraner and other large dog breeds.

We know that pure bred sporting dogs, such as the Weimaraner, have been bred for a specific purpose, and so, their conformation and gait should be closely linked to the tasks that they were originally bred to do (AKC, 2015; WCA, 2015). Breed and judging standards for Weimaraner movement have been founded on ideals of optimum function and conformation. Dogs in this study were all working hunting dogs, but had not been evaluated by American Kennel Club judges using breed standards (AKC, 2014). Nevertheless, the same can be said for other canine kinematic studies, and thus, further research is recommended using accomplished show dogs that are compared to their working counterparts to determine if differences are seen between performance types, both in this breed and in other breeds. Although this type of kinematic research is lacking in dogs, it has been done in equine athletes, and performance type within the same breed has been shown to influence gait mechanics (Clayton, 1993; Hobbs et al., 2009; Nicodemus and Slater, 2007; Slater and Nicodemus, 2008), and thus, the same may be true for canine athletes.

Realistically, although performance type studies have been valuable for the equine industry, the majority of dog owners are less interested in performance and sport and more interested in improving quality and length of life for their companion. This is what makes the Weimaraner so valuable to study, because, similar to most large dog breeds, they are susceptible to hip dysplasia, but not to the extent seen in those other breeds (Smith et al., 2001). Hip dysplasia is among the most important orthopedic health issues found in large dog breeds and can be costly for dog owners as well as reduce length of life of the dog. Kinematic research has been applied to the study of hip dysplasia in large dog breeds (Bennett et al., 1996; Poy et al., 2000), but the research hasn't included the Weimaraner. While such studies are valuable to help understand this health condition, determining attributes that make the Weimaraner unique from other large dog breeds is important to better understand how to select for sounder animals.

Documentation of the normal gait mechanics of sound animals is fundamental to more objective clinical evaluations. Evaluation of lameness in dogs can be difficult, so lamenesses are commonly not detected until dogs are non-weight bearing, with such delays in detection resulting in prolonged recoveries (Hudson et al., 2004; Waxman et al., 2008). This study lays a foundation for understanding the normal parameters of the gait of the Weimaraner, facilitating early detection of abnormal gait associated with unsoundness. Nevertheless, further research investigating Weimaraners suffering from hip dysplasia and being treated for the condition, as compared to other large dog breeds, will assist in further understanding of how hip dysplasia relates to the Weimaraner breed.

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APPENDIX A

MISSISSIPPI STATE UNIVERSITY CLIENT CONSENT FORM

Study:
Influence of Performance Type on the Kinematics of the Walk and Trot of the Canine

Purpose of Study:
Understanding of the normal locomotion of a healthy animal will help to detect abnormal locomotion associated with lameness. Kinematics measures the timing, displacements, and joint angles of the limbs of the animal to better describe the gait. Kinematics is measured by filming the animal performing the gait and inputting the video into a computer program that tracks the limbs during the animal's locomotion. Reflective stickers are placed along the limbs of the animal to assist the computer program in tracking the limbs. While kinematic research has been done on canines, kinematic research has not been performed in comparing the gaits (walk and trot) of the different American Kennel Club (AKC) groups (sporting, non-sporting, working, herding, and hound) to determine if there are differences in gait kinematics between the different AKC groups. AKC groups breeds according to what performance activity they are bred and trained for, whether their activity is hunting, herding, or guarding. Equine research has determined performance type does influence gait kinematics, but this research is unavailable for the canine. Therefore, canines representing breeds found in these AKC groups will be filmed performing a walk and trot while being led by their handler.

Researchers:
Dr. Molly C Nicodemus, Mississippi State University
Leif Carlisle, Mississippi State University

Description of Study:
75 canines (15 canines for each of the 5 AKC groups to be studied) will be led by the canine's owner in front of a video camera using a collar and leash performing both a walk and trot. The 5 AKC groups to be studied include the Sporting, Working, Hound, Non-Sporting, and Herding groups. Filming to take place at the home of the canine's owner or at an AKC sanctioned event. Selection of filming site will be determined by the owner. Prior to data collection, the owner and researcher will meet with the canine's veterinarian to discuss the health of the canine and determine the canine's suitability for the study. The canine's veterinarian will be consulted throughout the project and will be invited to attend the data collection. During the data collection, reflective stickers will be placed by the researcher as the owner handles the canine along the fore and limbs at palpation points of each joint center and on the distal and proximal aspect of each limb. Additional sticker will be placed on the head above the eye. A total of 15 passes in front of the video camera at each gait will be performed. Throughout the data collection canines will be given time to rest between each pass and will be monitored for any sign of fatigue. After the last pass reflective stickers will be removed by the researcher as the owner handles the canine. Data collection will be performed for each subject within a day. Video will be downloaded into the computer and will be analyzed using Ariel Performance Analysis System to determine limb timing, displacements, and joint angles.

Risks:
While no risks are anticipated for any canine participating in the data collection, the veterinarians of each canine will be consulted with prior to data collection to ensure the canine is in good enough health to perform the required gaits for the filming. Veterinarians will be invited to attend the data collection and those veterinarians unavailable for the data collection will be placed on call in case any injuries occur during the data collection. Canines may become fatigued during the data collection or may take a misstep while performing their gaits causing limb strain or other unforeseen injuries. Owners will be responsible for handling and leading canines and consulting researchers if any concern comes up related to fatigue of the canine. Canines will be allowed a short resting period between each pass in front of the camera to assist in preventing fatigue. For those data collections taking place at an AKC sanctioned event, the event veterinarian will be consulted prior to the filming and will be present during the filming to monitor any potential injuries.

Voluntary Participation:
Participation in this study is voluntary. You will not be penalized in any way if you elect not to participate and you may discontinue participation at any time.

Confidentiality of Records:
Although information gained from this investigation may be published and used for educational or regulatory purposes, your identity and your animal's identity will remain confidential to the extent provided by law.

Financial Obligation:
There are no financial obligations to be incurred by the client to participate in the study.

Contact Information:
If you have questions about these specific research procedures, contact Dr. Molly C Nicodemus at 662-325-9271. If you have questions about the use of animals in association with Mississippi State University, you may contact the MSU Institutional Animal Care and Use Committee at 662-325-0994. If you wish to submit an anonymous report about activities you feel are inappropriate, you may do so through the MSU Ethics Line at 877-310-0424.

I agree to the previously listed guidelines, and want to enter my animal into this study. I accept all risks associated with this study. I understand that there will be no extra cost to me, and that all samples and information derived from the study will belong to Mississippi State University. I also understand that the investigators may terminate my animal's participation in the study if continuation is not in the best interest of my animal.

Owner Name______________________________ Animal Name____________________

Owner Signature____
Date

Researcher Signature____
Date

Thank you for agreeing to enter your animal into this study.

APPENDIX B

DOG INFORMATION

Table B.1 Dog information

Subject Identification Number for Study	Age (yrs)	Gender	Weight (lbs)	Yrs Worked for Annual Hunting Activities	Healthcare Activities Requiring Veterinarian
1	10	Female	75	2005-Present	Annual Vaccinations and Wellness Exam; Spay
2	8	Female	60	2006-2010	Annual Vaccinations and Wellness Exam
3	8	Male	60	2006-2010	Annual Vaccinations and Wellness Exam
4	7	Male	65	2008-Present	Annual Vaccinations and Wellness Exam
5	5	Male	85	2010-Present	Annual Vaccinations and Wellness Exam
6	7	Female	70	2009-Present	Annual Vaccinations and Wellness Exam