Kinematic Analysis of the Collected and Extended Jog and Lope of the Stock Breed Western Pleasure Horse

by

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Abstract

Scientific research concerning stock breed western pleasure horses is limited. Therefore the purposes of this investigation were to determine if stock breed western pleasure horses 1) alter stride length independently of stride duration for the collected and extended jog and lope; 2) perform the extended jog and lope as a gait that more closely follows guidelines set forth by major stock breed associations for western pleasure competition than does the collected jog and lope; 3) maintain a more correct head and topline carriage during the extended jog and lope than during the collected jog and lope, and 4) perform the extended jog and lope with a more natural way of going thereby reducing risk of joint injury and trauma compared to the collected jog and lope.

Reflective markers were placed over seven points on the lateral side of the left and right fore and hindlimbs as well as the medial aspect of the coffin bone; additional markers tracked the temporal bone and vertebral column. Three successful strides of each gait were analyzed using the Peak Motus© 1994-2004 motion analysis system (Peak Performance Technologies, Inc., Englewood,

Colorado, USA). Digitization, transformation, smoothing, and normalization techniques followed standard kinematic techniques.

Results indicate that all gaits were performed as four-beat stepping gaits with diagonal couplets and a lateral footfall sequence with the exception of the right lead collected lope, which exhibited a diagonal footfall sequence. Stock breed western pleasure horses do not alter stride length independently of stride duration during the jog or the lope. Further, the extended jog more closely followed the guidelines set forth by major stock breed associations for western pleasure competition than did the collected jog, however the extended lope did not more closely follow guidelines than did the collected lope. Horses' head carriage and topline did not more closely follow gait performance guidelines during the extended jog or lope as horses maintained a level topline during both the extended and collected jog but did not maintain a level topline during the collected or extended lope. It was concluded that continuing gait definition transformations by more accurately describing the jog and lope as four-beat stepping gaits without visible separation of the diagonal pairs and to encourage even greater forward motion than was seen in the present study should theoretically reduce joint injury and trauma to the stock breed western pleasure horse while maintaining proper performance of the gaits.

Dedication

I would like to dedicate this work to "Nick" who has continued his dam's influence in my life and allows me first hand knowledge of the stock breed performance industry. "Nick" represents all stock breed western pleasure horses, as they are truly the most misunderstood and misjudged athletes of the equine industry. To your trainers, breeders, keepers, riders, and owners who cannot possibly understand the depth of your heart and commitment to their own self edification through recognition and blue ribbons, I offer this slight glimpse into your little understood way of going.

Acknowledgments

The author expresses her sincere gratitude to numerous people for their part in the development of this dissertation. A multitude of thanks is due to Dr. Wendi Weimar for providing direction, mentorship, expertise, and friendship throughout my doctoral program. Appreciation is also due to the other members of my dissertation committee Dr. Robert Gillette, Dr. David Pascoe, and Dr. Betsy Wagner for their guidance and support throughout this project as well as to Dr. Cindy McCall for graciously agreeing to serve as the outside reader. Data collection would not have been possible without the help of my research team including Dr. Wendi Weimar, Dr. Betsy Wagner, Dr. Robert Gillette, Dr. Justin Shroyer, Dr. Josh Bruce, Ande Sumner, Ashley Bruce, Casey Gates, and Oluremi Onifade; your help was indispensable and greatly appreciated. Further thanks are extended to Steve Tidwell and Kimberly Tidwell of Tidwell Training Center, Summer Salter of Summer Salter Show Horses, and Kyle Grant of Kyle Grant Show Horses in Tallassee, Alabama for access to the horses used in this project. Their dedication to improvements in training and showing of western pleasure performance horses is unequalled. Credit is also due to the Auburn University

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List of Abbreviations

APHA	American Paint Horse Association
ApHC	Appaloosa Horse Club
AQHA	American Quarter Horse Association
deg	Degrees
LF	Left fore hoof
LH	Left hind hoof
m	Meters
ms	Milliseconds
m/s	Meters per Second
PBHA	Palomino Breeders Horse Association
RF	Right fore hoof
RH	Right hind hoof
ROM	Range of motion
s	Seconds
stride/s	Strides per Second
TWH	Tennessee Walking Horse
U.S.	United States

Chapter 1

Introduction

Stock Breed Horses

Stock horse breeds were originally developed to run short races, the quarter mile, and due to their disposition and personality, soon became a favorite of cowboys and ranch hands. Dubbed "quarter horses" because of their speed over the quarter mile, these hardy horses with unique cow sense began to excel at ranch work such as driving and cutting cattle (Oelke 1992). In the mid-1900s the focus of horses as work animals changed to horses being promoted more as animals of leisure and sport (Back 1994). As the popularity of equine related sports increased, breed associations were developed to keep track of pedigrees and performance records. Formation of the largest breed registry in the world, the American Quarter Horse Association (AQHA), occurred in 1940 (Oelke 1992). Today, stock type horse breeds make up the majority of registered horses in the United States (U.S.) and are registered through four main breed associations: American Quarter Horse Association (AQHA), American Paint

Horse Association (APHA), Palomino Breeders Horse Association (PBHA), and Appaloosa Horse Club (ApHC).

American Quarter Horse Association is the largest stock breed registry in the U.S. with 2,821,172 registered Quarter Horses in 2008. Total international registrations boast numbers of 129,054 with members in the Bahamas, Czech Republic, Madagascar, and South Africa (AQHA 2008). As the second largest U.S. breed registry, the APHA had approximately 1,000,000 registrations in 2008 (APHA 2008). International memberships include countries such as Canada, Mexico, United Kingdom, and Taiwan. With well over 84,955 APHA members in the United States and abroad, awareness of the Paint is worldwide. Originally founded in California, the PBHA boasts numbers of over 71,000 registered horses and 87,000 members (PHBA 2009). Appaloosa Horse Club horse registrations exceed 630,000 with Texas, Minnesota, Missouri, California, and Oklahoma leading the nation in registration numbers (ApHC 2009a). Appaloosas have received international registrations in countries such as Canada, Germany, Italy, and Belgium. With representation in working cattle, dressage, jumping, western performance, english performance, endurance, trail riding, or track racing, stock horse breeds excel in all disciplines and continue to gain popularity worldwide.

Western Pleasure

While stock type breeds are ridden in various disciplines, the class perceived as the most prestigious and competitive at breed shows is western pleasure (Nice 2006; Noble 2001; Oelke 1992). Western pleasure began as a way to showcase ranch horses with comfortable gaits, attractive appearance, and willing attitudes as well as to prepare the horses for other events such as reining, roping, or cutting. However, the popularity of western pleasure rose in the 1970s to become a separate sport and a way to showcase a well broke horse at a walk, jog, and lope (Meyer 2005). Western pleasure is judged on the horse's ability to be a "pleasure" to ride, and horses are selected for competition based on conformational and locomotive characteristics established by current breed standards. To meet these "pleasurable" standards, stock horses competing in western pleasure should be relaxed, broke, quiet, and responsive to cues while showing no hesitation (AQHA 1994). Stock horses are evaluated on similar standards of gait across breeds with quality of movement and consistency of gait being paramount. Gaits and transitions between the walk, jog, and lope should be smooth and all gaits should be a pleasure to ride (Oelke 1992).

According to AQHA, APHA, PHBA, and ApHC, the jog is defined as a two beat diagonal gait that should be smooth, balanced, and square, with a straightforward movement of the legs and hooves (Figure 1.1). While a properly

performed lope, as defined by breed associations, is an easy, rhythmical, clean three beat gait (Figure 1.2). An excellent jog and lope are characterized by a bright, alert expression and effortless yet efficient motion that results in the horse touching the ground softly. The long axis of the head should remain almost perpendicular to the ground throughout all gaits, and horses should be balanced with a level topline (Figure 1.3). A horse's poll (nuchal crest), or the top of the head located between the ears, should remain level or slightly above the withers (highest point of thoracic vertebrae 3 or 4), or top of the shoulders (Figure 1.3).

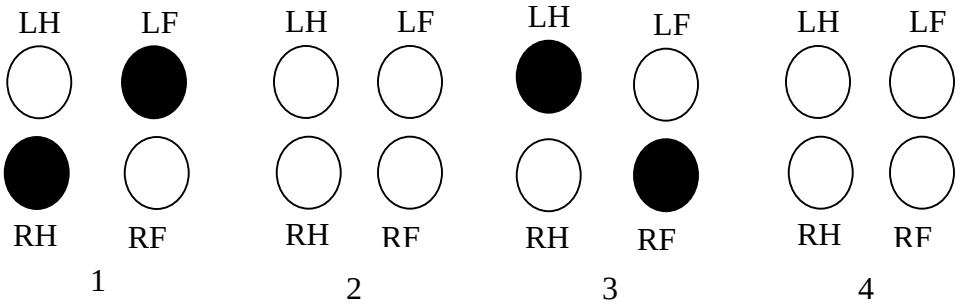

Figure 1.1: Footfall sequence of the jog. Suspension between each ground contact is implied by the breed association definition (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008). Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

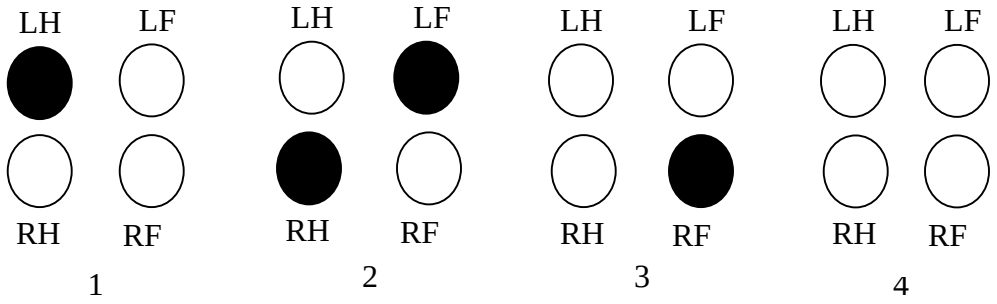

Figure 1.2: Footfall sequence of the right lead lope. Suspension following the third beat is implied by the breed association definition (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008). Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

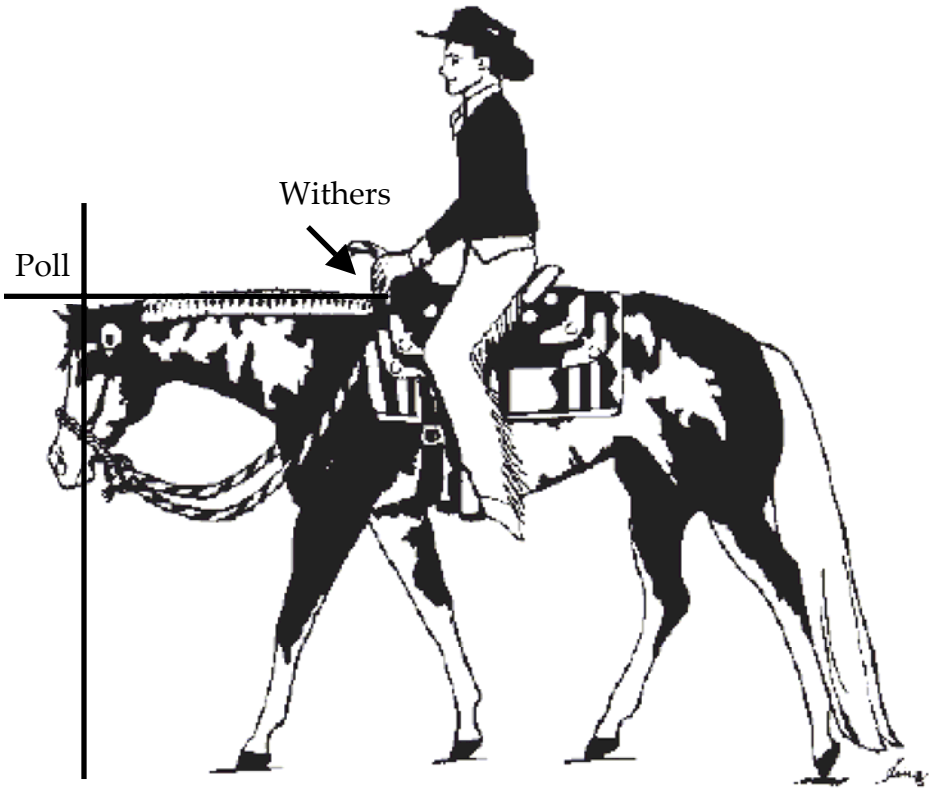

Figure 1.3: Proper headset for a stock breed western pleasure horse. The vertical line depicts proper head carriage about the long axis while the horizontal line indicates proper head and neck carriage (APHA 2009).

Excellent jogging and loping horses are confident, balanced, and under control. The knee and hock joints should remain flat throughout the stride with cushion exhibited at the pastern; horses should have a strong deep stride and never allow the hocks to drift into the tail (Figure 1.4). Horses should be relaxed and lope at a comfortable speed with a free-flowing, ground-covering stride of reasonable length. A straight line from hip to toe and a slightly rounded back is indicative of collection and engagement and are desired in the arena because this self-carriage allows the horse increased reach from behind while the stride is finished through the shoulders with natural flow. Excellent western pleasure horses should display a great degree of lift and self-carriage, and each gait should be performed at a speed that is natural to the horse's way of going (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008).

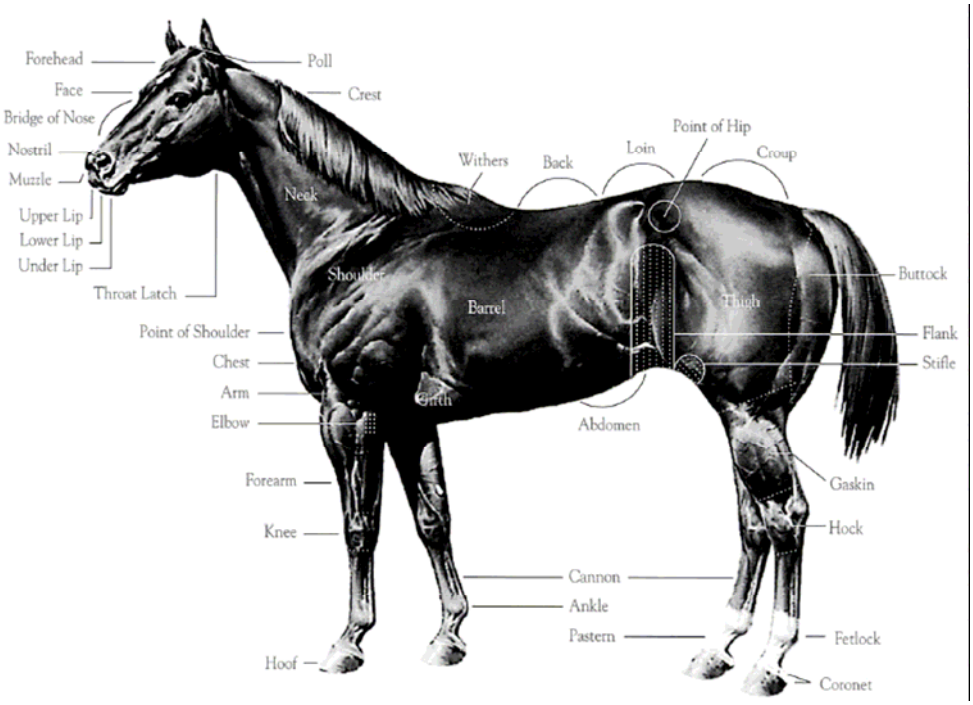

Figure 1.4: External anatomy of the equine (AQHA 2002).

In the 1970s, trainers and exhibitors began decreasing the speed at which the horses moved in order to win; public perception was that the slowest horse in the pen was the most desirable and was often the winner (Nice 2006). The demand for a slower moving, more collected western pleasure horse resulted in undesirable gait characteristics being performed during competition, as determined by the industry and scientists alike (Barakat 2008; Eppers and Hamilton 2008; Kuhlwein 2002; Meyer 2005; Nice 2006; Nicodemus and Booker 2007; Nicodemus and Clayton 2001a). For a horse to achieve collection, the body and back must be rounded thereby lifting the shoulders so that the hindquarters reach as far under the body as possible (Hokana and Hamilton 2010). Collected

gaits put great demand on conformation and function of the hindlimbs (Holmström *et al.* 1994), and as an industry, stock breed western pleasure requires high levels of collection for horses to excel in the show arena. Inability to attain gait collection caused stock breed western pleasure horses to adapt and move so slowly that all suspension, which existence is implied based on breed association gait definitions, has been lost (APHA 2009; ApHC 2009b; AQHA 2009; Barakat 2008; Kuhlwein 2002; Rogers 2004; Williams 2004). Unnatural gait adaptations caused the horse to appear as if it was hopping slowly down the rail with downhill momentum as it pulled itself using its forelimbs. Horses began to be overcanted and were forced to lope unnaturally slow by pitching the hip toward the center of the ring while the head and outside shoulder remained on the rail. In 2001, Nicodemus and Clayton found that neither the jog nor lope had a phase of suspension making the gait a stepping gait instead of a leaping gait, with both gaits having lateral footfalls (Nicodemus and Clayton 2001a). These findings were contradictory to the breed association definitions for the jog and lope.

The year 2005 was monumental for stock breed western pleasure as rule changes dictated by breed associations better defined the jog and lope in order to correct the ultra slow, artificial gaits being performed. Rules now require an extension of the jog in at least one direction of the arena. By definition, the

extended jog should show an increase in speed, be flat, cadenced, and quiet. Extension, does not, however, mean an increase in speed alone; but rather, the emphasis is on engagement from the hindquarters resulting in extension of the horse's leg. Further, the only gait recognizable as a lope will have an increase in forward motion and the horse's hip should not be canted toward the center of the arena. Research conducted by Nicodemus and Booker (2007) after rule changes took effect in stock breed western pleasure competition concluded that horses were still performing the jog and lope as four-beat stepping gaits with lateral footfall sequence and no period of suspension (Figures 1.5 & 1.6). The jog was symmetrical (Figure 1.5) while the lope was an asymmetrical gait with leads (Figure 1.6). Both the jog and lope were performed with diagonal couplets as diagonal limb pairs for each gait moved closely together in time instead of simultaneously (Figure 1.5 & 1.6). However, gait improvements and more detailed guidelines did result in improvements in the gait when compared to the earlier (Nicodemus and Clayton 2001a) four beat jog and lope study. Stock breed western pleasure horses performed the jog with more diagonal limb support than did the horses in the earlier study. Additionally, the inclusion of "forward motion" judging criterion during the lope resulted in no quadrupedal support, which was found in the Nicodemus and Clayton (2001a) study (Nicodemus and Booker 2007).

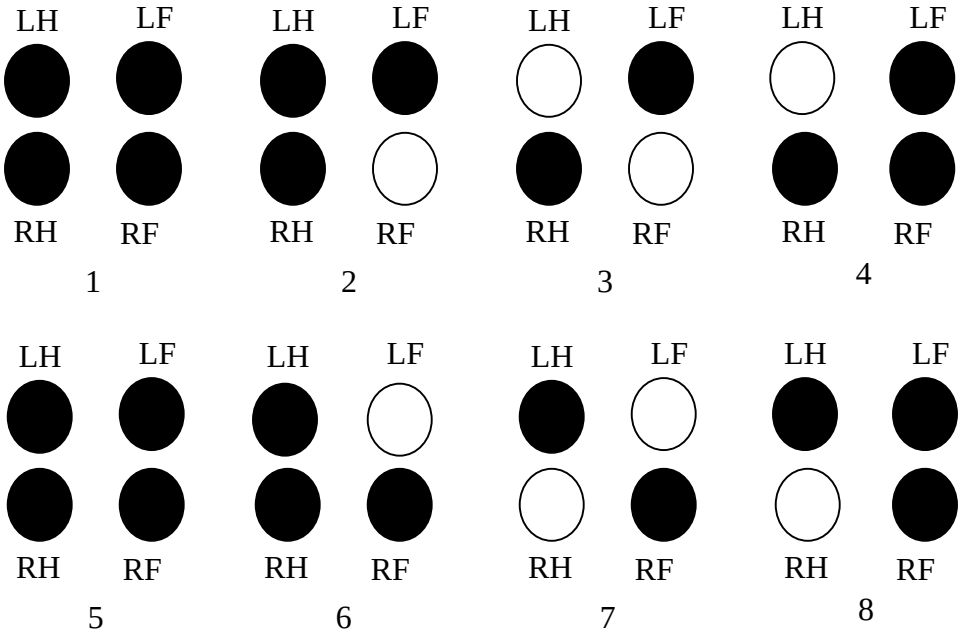

Figure 1.5: Limb support phases of the stock breed western pleasure jog. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore) (Nicodemus and Booker 2007). Filled circles represent stance phase while open circles represent swing phase.

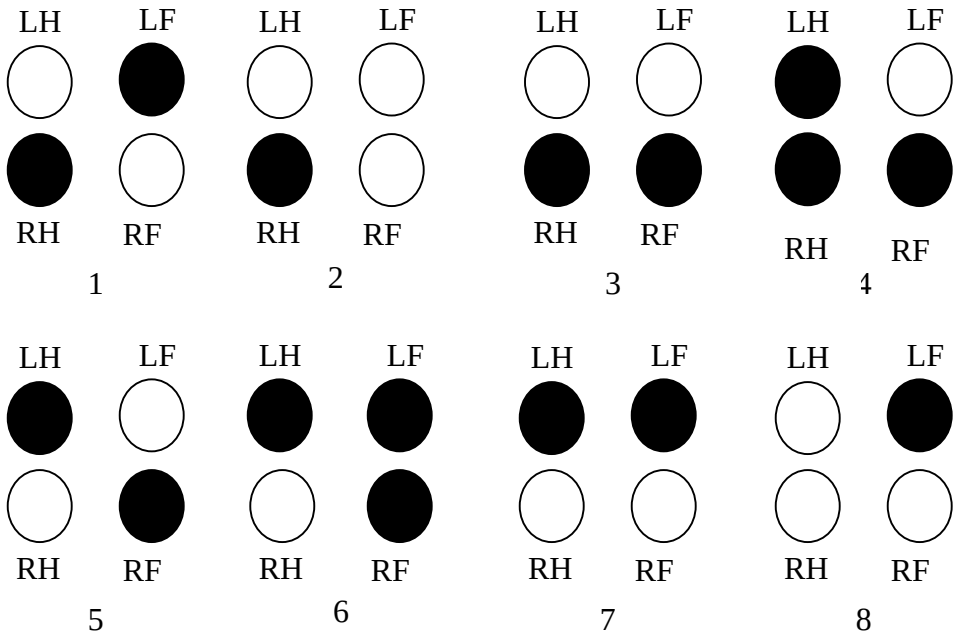

Figure 1.6: Limb support phases of the stock breed western pleasure left lead lope. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore) (Nicodemus and Booker 2007). Filled circles represent stance phase while open circles represent swing phase.

Statement of the Problem

Extensive kinematic research on European horse breeds has assisted in correctly defining gaits including the walk, trot, and canter. As defined by Barrey (2001), the walk is a four beat gait with no period of suspension and an overlap between the stance phases of limbs (Figure 1.7). The trot is described as a two beat, symmetrical, diagonal gait with suspension that has variations including the collected, working, medium, and extended trots (Figure 1.8). The canter is a three beat, asymmetrical gait that is described as having right or left leads and suspension (Figure 1.9 & 1.10) (Barrey 2001).

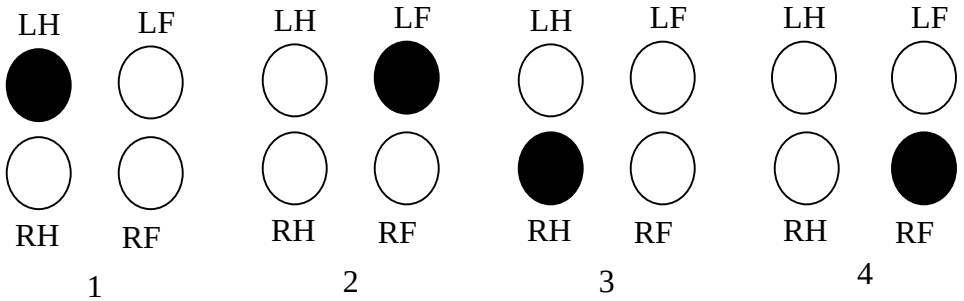

Figure 1.7: Footfall sequence of the walk. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

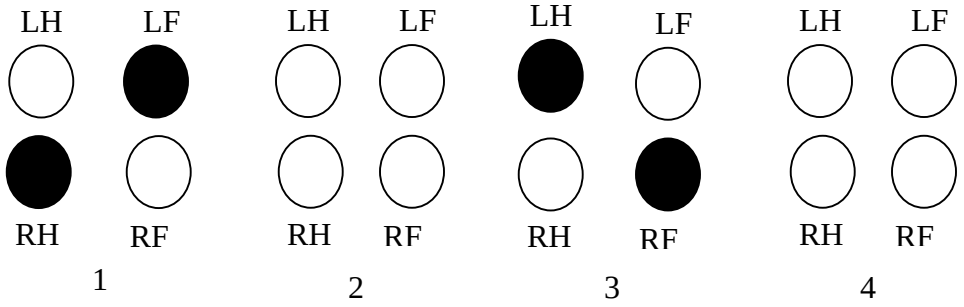

Figure 1.8: Footfall sequence of the trot with suspension between each ground contact. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

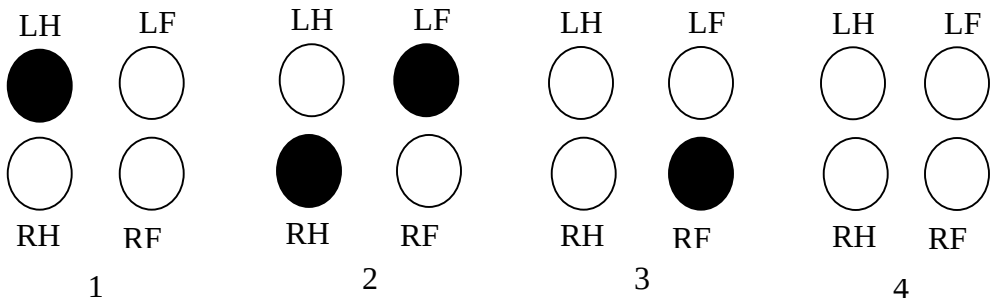

Figure 1.9: Footfall sequence of the right lead canter with suspension following the third beat. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

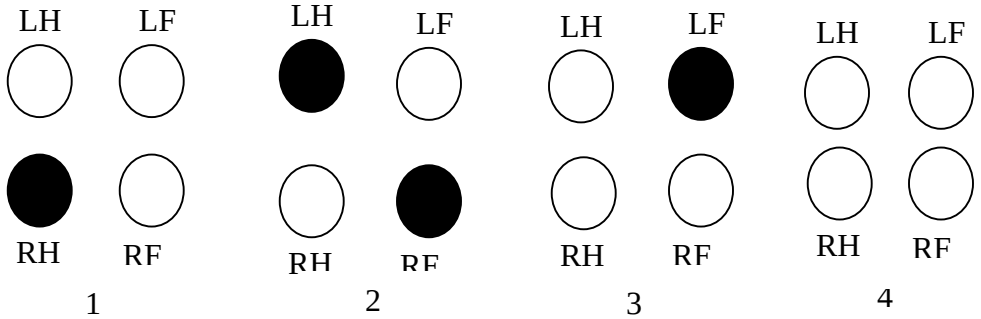

Figure 1.10: Footfall sequence of the left lead canter with suspension following the third beat. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

Furthermore, despite the scientific definitions, the jog and lope are considered to be adaptations of the trot and canter, respectively, performed by the stock breed western pleasure horse. So, while the jog and lope appear to be variations of the trot and canter, they are four-beat stepping gaits similar to the equine walk and non-walking stepping gaits of gaited horses. In an effort to correct these gait "abnormalities" breed associations have introduced new rules;

however, inconsistencies still exist. The current project sought to identify if the extended jog and lope more closely resemble breed association definitions when compared to the collected jog and lope of stock breed western pleasure horses, which incorrectly implies that western pleasure horses are performing a variation of the trot and canter. Further, it is accepted that elite performance horses that have been showing at the national level since the age of two do not often maintain a show career after the age of five. This lack of senior performance horses is anecdotally linked to the intense training these horses receive early in the show career and the ultra slow gait they are expected to achieve. This investigation will lead to insight in the performance of these gaits and may help determine whether the high level of collection required to perform the jog and lope, coupled with the speed of the gait, increases the horse's risk for joint injury and trauma. As this project will provide for the systematic evaluation of these gaits, particular gait mechanics may be identified that could be contributors to articular joint break down of western pleasure horses.

Purpose of the Study

The purpose of this study was to collect temporal, linear, and angular kinematics for each gait in order to compare the variables of the collected and extended jog and the collected and extended lope to determine consistency with

current rule books of the major stock breed associations. Additionally, head position was compared to determine consistency with current rulebooks of the major stock breed associations. Comparisons of these variables answered several questions: 1) Do stock breed western pleasure horses alter their stride length independently of stride duration for the collected and extended jog and lope; 2) Does the performance of the extended jog more closely follow the guidelines set forth by major stock breed associations for western pleasure competition than does the collected jog; 3) Does the performance of the extended lope more closely follow the guidelines set forth by major stock breed registries for western pleasure competition than does the collected lope; 4) Does the head carriage and topline of the western pleasure horse during the extended jog and lope more closely follow the guidelines set forth by major stock breed associations for western pleasure competition than does the collected jog and lope; and 5) Does the performance of the extended jog and lope conform to a more natural way of going for stock breed western pleasure horses thereby reducing risk of joint injury and trauma compared to the collected jog and lope?

Hypotheses

Based on previous research it was hypothesized that stock breed western pleasure horses altered their stride length independently of stride duration when transitioning from the collected jog and lope to the extended jog and lope. It was further hypothesized that the extended jog and lope more closely followed the guidelines set forth by major stock breed associations for western pleasure competition than did the collected jog and lope. Horses' head carriage more closely followed the guidelines for stock breed western pleasure during the extended jog and lope than during the collected jog and lope. Finally, performance of the extended jog and lope conformed to a more natural way of going and reduced the risk of joint injury and trauma than did the collected jog and lope.

Operational Definitions

The following definitions are standard terminology for equine biomechanics and will be used as the operational definitions for the current study.

Advanced lift-off - time between the first visible flexion of the fetlock joint of two specified limbs (Deuel 2001).

Advanced placement - time between ground contact with the heel of two specified limbs.

Breakover - the heel of the hoof rotates about the toe, which is in contact with the ground, in preparation for swing phase (Clayton 2004).

Couplet - two limbs make ground contact relatively close together in time, not simultaneously, and may be diagonal or lateral.

Diagonal limbs - a forelimb and the contralateral hindlimb (Deuel 2001).

Extension - refers to an increase in joint angle and greater extension of the horse's legs rather than just an increase in speed. Proper extension is accomplished through increased engagement or reach of the hindquarters underneath the body of the horse (APHA 2009; ApHC 2009b; AQHA 2009; Deuel 2001; PHBA 2008).

Footfall sequence - order in which the hoofs make contact with the ground, always beginning with the hind hoof.

Gait - the cyclic, repetitive movement associated with each stride distinguished by the sequence and timing of the repetitive movements.

Categories of gait:

Asymmetrical - footfalls are independent from the opposite side of the body including the canter and gallop (Table 1.1).

Leaping or running - one or more suspension phases, where all limbs are off the ground, occur during the gait including the trot, canter, and gallop (Table 1.1).

Stepping or walking - at least one hoof is in contact with the ground throughout the stride as seen in the walk. This gait has no suspension phase (Table 1.1).

Symmetrical - actions on one side of the body are mirrored on the other side of the body as seen in the walk and trot (Table 1.1) (Clayton 2004).

Types of gaits:

Walk - four beat, symmetrical, lateral gait with regular rhythm, and overlap between stance phases of limbs, but no suspension (Figure 1.7, Table 1.1).

Trot - two beat, symmetrical, diagonal gait with regular rhythm, diagonal pairs, and suspension. The trot has a footfall sequence of right hindlimb and left forelimb followed by the left hindlimb and right forelimb moving together in time (Figure 1.8). Suspension phases are found between ground contact of each diagonal pair (Table 1.1).

Jog

Breed Association – two-beat gait that is smooth and ground covering. Horses performing the jog should move from one diagonal pair to the other. Suspension is implied in this definition (Figure 1.1) (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008). The equine industry considers the jog to be a variation of the trot.

Scientific - four-beat stepping gait with symmetry, lateral footfall sequence, irregular rhythm, diagonal couplets and no period of suspension (Figure 1.5).

Visual – observers see horses making ground contact with one diagonal couplet as the other diagonal couplet is reaching toe off. No suspension phase is visible (Figure 1.11).

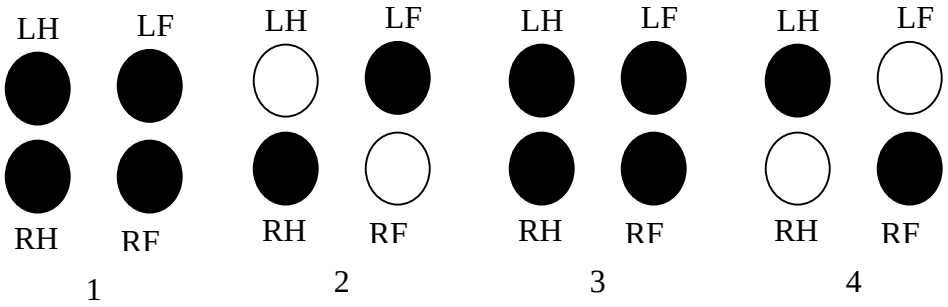

Figure 1.11: Representation of what is seen by observers during the stock breed western pleasure jog. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

Canter - three beat, asymmetrical gait with regular rhythm, suspension, and leads. The canter has a footfall sequence of trailing hindlimb, diagonal pair, and leading forelimb. The leading forelimb dictates the lead; the right lead has a footfall sequence of left hind, right hind and left fore, right forelimb (Figure 1.10) while the left lead has a footfall sequence of right hind, left hind and right fore, and, left forelimb (Figure 1.9). The suspension phase follows beat three (Table 1.1) (Deuel 2001).

Lope

Breed Association - easy, rhythmical, clean three-beat gait. Suspension is implied in this definition. Horses loping to the left should be on the left lead while horses loping to the right should be on the right lead (Figure 1.2) (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008). The equine industry considers the lope to be a variation of the canter.

Scientific - four-beat stepping gait with asymmetry, lateral footfall sequence and irregular rhythm. The lope has leads with the footfalls beginning with the trailing hind, followed by the leading hind and trailing fore working as a diagonal couplet, and finally the leading forelimb (Figure 1.6) (Nicodemus and Booker 2007).

Visual – horses appear to be making ground contact with the leading forelimb as the trailing hindlimb is entering swing phase. No suspension is visible during the lope (Figure 1.12).

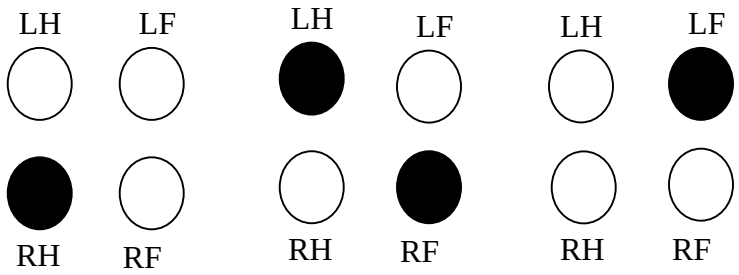

Figure 1.12: Representation of what observers see during the stock breed western pleasure left lead lope. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

Table 1.1: Scientific classification of equine gaits – right hind (RH), right fore (RF), left hind (LH), and left fore (LF) (Barrey 2001).

Classification	Gait	Gait Variations	Footfall Sequence	Beats/stride	Symmetry
Stepping Gaits	Walk	Collected Medium Extended	RH, RF, LH, LF	4	Yes
	Toelt Paso Rack Fox-trot	Medium	RH, RF, LH, LF	4	Yes
	Jog	Collected Extended	RH-LF, LH-RF	2	Yes
	Lope	Collected Extended	Trailing H, Leading H & Trailing F, Leading F	3	No
Leaping Gaits	Trot	Piaffe Passage Collected Medium Extended Flying-trot	RH-LF, Suspension, LH-FR, Suspension	2	Yes
	Pace	Medium Extended	RH-RF, Suspension LH-LF, Suspension	2	Yes
	Canter	Collected Medium Extended Disunited	Trailing H, Leading H & Trailing F, Leading F, Suspension	3	No
	Gallop	Transverse Rotary	Transverse: Trailing H, Leading H, Trailing F, Leading F, Suspension	4	No

Types of horses:

Gaited – horses that perform gaits in addition to or instead of the natural walk, trot, and canter. These horses are classified as three-gaited or five-gaited and perform gaits such as the flat walk, running walk, rack, stepping pace, amble, toelt, paso largo, and paso corto. Some breeds of horses that are classified as gaited include the American Saddlebred, Missouri Fox Trotter, Icelandic, Tennessee Walking Horse, Paso Fino, and Peruvian Paso (Thomas 2005).

Non-gaited – horses that perform natural gaits known as the walk, trot, and canter (Thomas 2005).

Joint Nomenclature: for the purpose of the current study the following common joint names were substituted for anatomical joint names for simplicity and clarity (Table 1.2) (Kainer and McCracken 1998).

Table 1.2: Anatomical and common joint names for all joints analyzed in the current study (Kainer and McCracken 1998). Common joint names will be used in order to promote simplicity and clarity.

Anatomical Joint Names	Common Joint Names
Antebrachiocarpal Midcarpal Carpometacarpal Intercarpal	Carpal/Carpus
Coxofemoral	Hip
Cubital	Elbow
Femoropatellar Femorotibial	Stifle
Humeral	Shoulder
Metacarpophalangeal	Fetlock
Proximal Interphalangeal	Pastern
Proximal Intertarsal Distal Intertarsal Tarsometatarsal Tarsocrural	Hock

Lateral limbs - ipsilateral fore and hindlimbs (Deuel 2001).

Leading limb - the second of two hindlimbs or two forelimbs to touch and leave the ground during an asymmetrical gait.

Limb support sequence - sequence of limb combinations that support the body during stance phase (Clayton 2004).

Bipedal or double limb support - two limbs support the body and may consist of diagonal or lateral limbs or fore or hindlimbs.

Quadrupedal limb support - all four limbs support the body

Tripedal limb support - three limbs support the body and may be comprised of two forelimbs and one hindlimb or two hindlimbs and one forelimb.

Unipedal limb support - one limb is in stance phase.

Overlap - during one or more stride phases two limbs are simultaneously in stance (Deuel 2001).

Overstride - the hind hoof steps over the track of the front hoof as it leaves the ground (Clayton 2004).

Suspension - period during the gait cycle when all limbs are off the ground

Trailing limb - the first of two hindlimbs or two forelimbs to touch and leave the ground during an asymmetrical gait (Deuel 2001).

Chapter II

Literature Review

The purpose of this study was to collect temporal, linear, and angular kinematics for each gait of the stock breed western pleasure horse in order to compare the variables of the collected and extended jog and the collected and extended lope as well as head position to determine consistency with current rulebooks of major stock breed associations. Additionally, this study sought to determine if the extended jog and lope conform to a less restrictive movement pattern for stock breed western pleasure horses, which may reduce the risk of joint injury and trauma than does the collected jog and lope. The current chapter presents the review of literature on the topics of a) defining gaits through kinematics, b) head carriage, and c) injuries.

Equine biomechanics research after 1965 has shown that Hildebrand (1965) was correct when he stated that a horse's "locomotion is more controllable

than that of other animals, and at the hand of man it has learned to be versatile in the selection of gaits and also to use gaits . . . that are unnatural to the species and unique to itself." Modern computerized gait analysis equipment, when used to quantify locomotor performance, improves objectiveness and correctness of selection and assessment when evaluating stock breed western pleasure prospects and has allowed researchers to define various gaits and the variables that influence these gaits. The human eye, even if trained, is not able to see subtle differences in conformation or gait adaptations as precisely as computer analysis. Therefore, as the competitive nature of horse showing increases, it is pertinent that accurate and objective techniques are used to measure conformation and locomotion in order to provide scientific data to be used for defining and classifying gaits as well as for clinical and performance applications.

Defining Gaits Through Kinematics

Gait is a term that is used to encompass the cyclic movements associated with each stride, and it is the sequence and timing of the repetitive movements that help distinguish specific gait patterns (Nicodemus and Clayton 2003) and for the remainder of this project will refer to the gait of horses. Gait may be classified into several categories: (a) symmetrical or asymmetrical, (b) diagonal

or lateral footfall sequences, and (c) stepping or leaping (Grogan 1951). Symmetrical gaits such as the walk, flat walk, classic fino, trot, pace, stepping pace, and fox trot are classified as such due to the mirrored actions occurring on the opposite side of the body (Barrey 1999; Clayton and Bradbury 1995; Hildebrand 1965; Nicodemus and Clayton 2001b; Nicodemus and Holt 2003a). Gaits with footfalls moving independently from the opposite side of the body are classified as asymmetrical and include the canter and gallop. Footfall sequence is determined independently from symmetry; however, both symmetrical and asymmetrical gaits may exhibit a diagonal or lateral footfall sequence. Diagonal footfall is attained when forelimb hoof contact is in sequence with the hoof contact of the diagonal hindlimb, as with the trot. Thus, forelimb and lateral hindlimb synchronization classify a lateral gait as exhibited in the walk and pace. Gaits are also categorized by whether a flight phase exists during the stride. Stepping gaits, such as the walk, are characterized by at least one limb being in contact with the ground throughout the stride, and leaping gaits, such as the trot and canter, have a period of suspension (Grogan 1951). Suspension, or the flight phase, is a period in which all limbs are in flight or off the ground (Table 1.1) (Hildebrand 1965). While not a category for classifying gaits, limb support phases may also be used to further differentiate between gait patterns. Horses employ all combinations of support including, single, bipedal, tripedal and

quadrupedal. In addition, these support phases may be adjacent limbs or diagonal limb combinations (Leach *et al.* 1987).

Walk and walk variations.

While the current study is not evaluating the walk of the stock breed western pleasure horse, its characterization as a stepping gait is important to the evaluation of the jog (Deuel 2001). The jog is defined as a stepping gait (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a) but considered to be a variation of the trot, which is a leaping gait (Deuel 2001), and creates confusion between scientists and industry personnel as to what type of gait the jog may be classified. Hildebrand (1965) developed a gait continuum that distinguished between symmetrical gaits based on the temporal variables of percent (%) stride of advanced placement and hind stance. When plotting the stock breed western pleasure jog (46% lateral advanced placement; 60% hind stance) (Booker 2005; Nicodemus and Booker 2007) on Hildebrand's continuum, it would fall in the region between the Arabian jog (54% lateral advanced placement; 54% hind stance) and Quarter Horse walk (33% lateral advanced placement; 66% hind stance) (Figure 2.1) (Hildebrand 1965; Nicodemus and Booker 2007). This positioning of the jog on Hildebrand's continuum indicates that the jog is more closely related to the walk or animated variation of the slow trot or jog, performed by the Arabian horse, than the trot and places it within the

dotted area where Hildebrand (1965) indicated unusual gaits with no common name (Figure 2.2). Based on this positioning it is reasonable to conclude that stock breed western pleasure horses are not performing the jog/trot or the walk when jogging, but an altogether separate gait that has not been appropriately named. Both the stock breed western pleasure jog and the walk have lateral footfall sequences, and four beats, but the jog has diagonal pairs that work as couplets where the walk does not. Neither the stock breed western pleasure jog nor the walk has a suspension phase, and the jog has an irregular rhythm while the walk has a regular rhythm. Because of the stock breed western pleasure horse's unique gait adaptation, termed "jog" by the equine industry, and its close relationship to the walk, it is important to understand the walk and its variations.

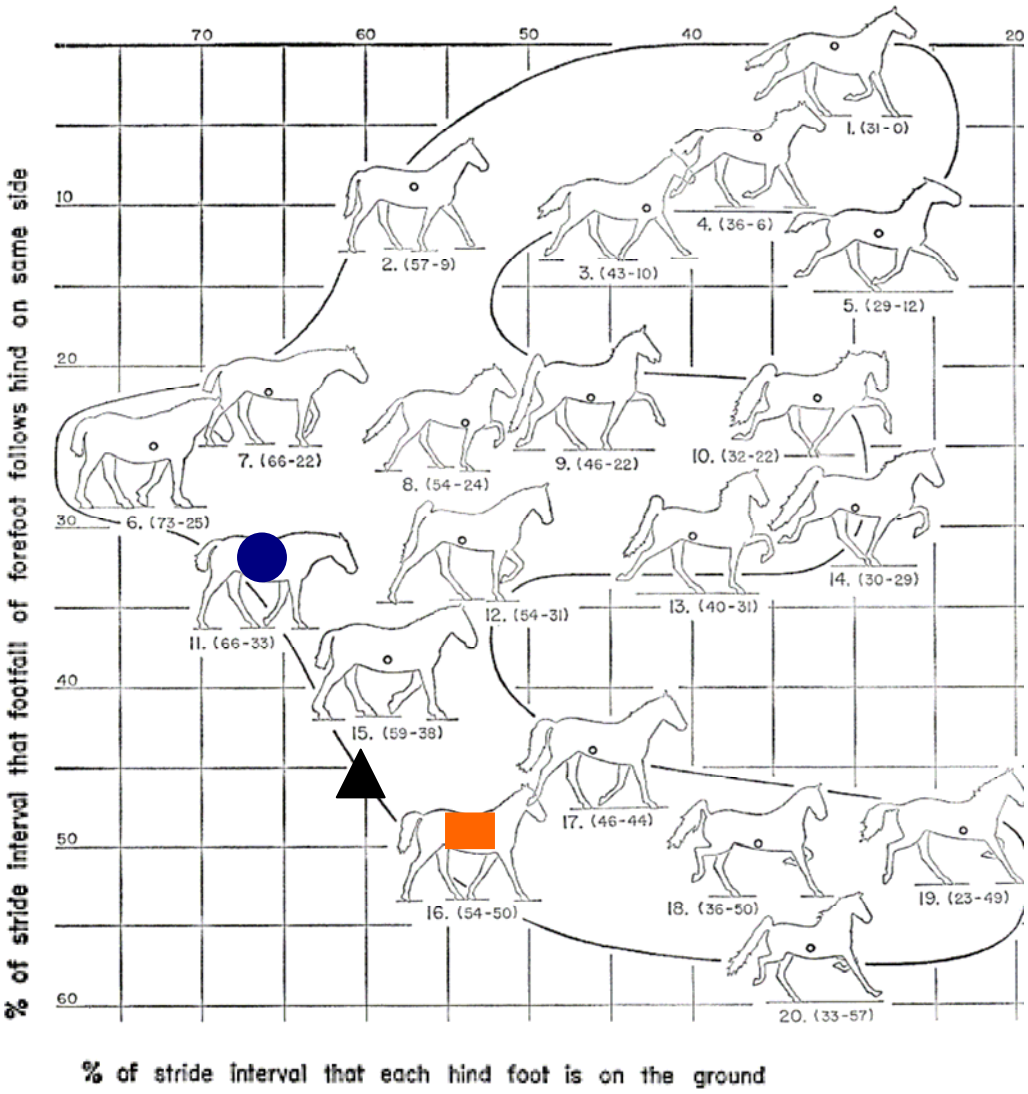

Figure 2.1: The graph in which nearly all symmetrical gaits of horses fall (Hildebrand 1965). The blue filled circle indicates the Quarter Horse walk while the orange filled square indicates the Arabian horse slow trot. The black filled triangle indicates the position where the stock breed western pleasure jog would fit into the continuum.

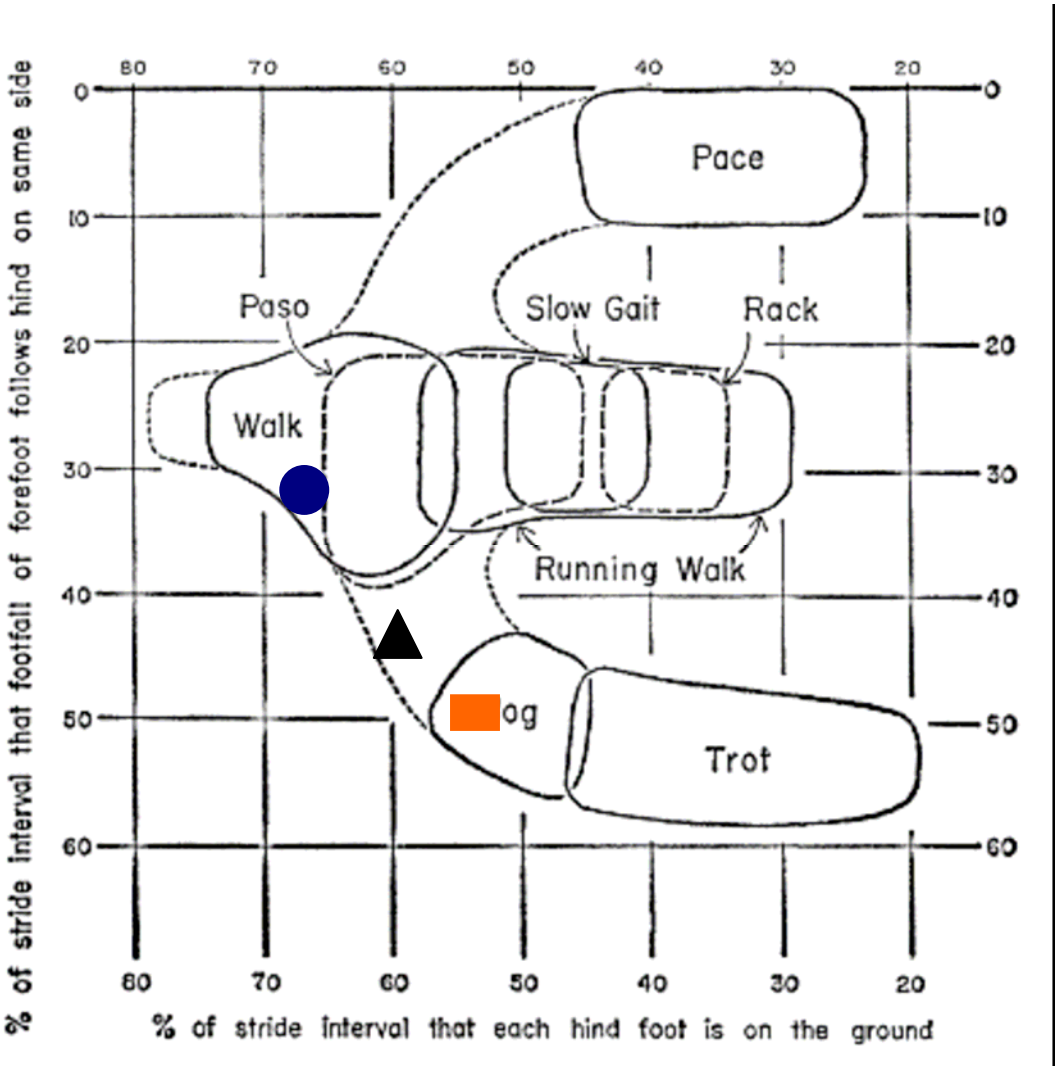

Figure 2.2: The relationship between symmetrical gaits of horses. Gaits that would fall within areas indicated by dotted lines are unusual and have no common name (Hildebrand 1965). The blue filled circle indicates the Quarter Horse walk while the orange filled square indicates the Arabian horse slow trot. The black filled triangle indicates the position where the stock breed western pleasure jog would fit into the continuum.

The foundation of all horse gaits is the walk. Defined as the slowest and most complex of all gaits, the walk is a four-beat stepping gait characterized by no period of suspension and an overlap between stance phases of the limbs (Deuel 2001). Clayton (1995) compared the collected, medium, and extended walks of dressage horses and found that as the gait becomes more extended the rhythm becomes irregular with lateral couplets so that lateral limbs move closely together in time but not synchronously.

Hodson *et al.* (1999) compared the collected and extended walks of competitive dressage horses to the walking half pirouette finding the walking rhythm of the half pirouette becomes irregular with periods of quadrupedal support and limb asymmetries. Asymmetry and quadrupedal support were not present in the collected and extended walks and is most likely due to the increased speed at which the collected and extended walks were performed when compared to the walking half pirouette. It was concluded that the walking half pirouette, a half circle executed on the haunches as the forehand moves around the length of the horse's body, was not performed according to Federation Equestre Internationale (FEI) rules because it did not maintain the same footfall sequence, rhythm, or beats as the walk. Additionally, each horse performed the walking half pirouette slightly different most likely due to different balancing strategies (Hodson *et al.* 1999). While this study is not

considering the stock breed western pleasure walk, neither the jog nor the lope is performed according to breed association definitions similar to the walking half pirouette. Previous studies have found periods of quadrupedal support in the stock breed western pleasure jog (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a) and lope (Nicodemus and Clayton 2001a) just as periods of quadrupedal support were found in the walking half pirouette of the dressage horse (Hodson *et al.* 1999). During a half pirouette, the horse loses forward motion becoming unbalanced (Hodson *et al.* 1999), which explains the presence of quadrupedal support (Clayton 1989; Hodson *et al.* 1999; Nicodemus and Clayton 2003). With this in mind, it can be suggested that the inclusion of quadrupedal support during the stride of stock breed western pleasure horses at the jog or lope indicates a loss of balance, and, therefore, a loss of dynamic stability.

Temporal variables are a separate approach to classifying walk variations of non-gaited and gaited horse breeds. Temporal variables of the slow and fast walks of gaited breeds, (classic fino of the Paso Fino and road gait of the American Single-Footing Horse) indicate all walking gaits have four-beats, regular rhythm, and lateral footfall sequences, but differentiation between gaits is facilitated by limb support and stance durations (Nicodemus *et al.* 2000). Morgan Park Horses were found to demonstrate a variation of the walk called

the park walk which may be performed with two or four beats and has no period of suspension (Nicodemus *et al.* 2001). While temporal variables have assisted in defining the walk of non-gaited horse breeds, gaited horses have been subjected to a greater number of studies that evaluated walking gaits.

Temporal variables, such as footfall sequence and rhythm have been used to evaluate the gaits of gaited horses, whose gaits have been misunderstood and incorrectly defined for years by the equine industry. Specifically, fifteen different four-beat stepping gaits performed as faster variations of the walk by gaited horse breeds were differentiated from each other by examining temporal variables. All gaits had a lateral footfall sequence and at least one hoof on the ground throughout the stride, but it was the rhythm and limb support sequences that assisted in distinguishing between these gaits (Nicodemus and Clayton 2003). While the majority of gaited horse studies have been conducted on the Tennessee Walking Horse (TWH), Nicodemus and Clayton (2001b) conducted a gaited horse study looking at the temporal variables of Paso Fino stepping gaits. All gaits exhibited four beats and were distinguished by the regularity of the rhythm. Motion patterns and stride characteristics of the toelt, a gait performed by Icelandic horses, were evaluated at various speeds and it was determined that the toelt at all speeds was a four-beat, symmetrical gait with alternating single and double support phases (Zips *et al.* 2001). Temporal variable studies of the

TWH have included: 1) yearlings in training at the flat walk (Nicodemus and Holt 2003a); 2) foals at the flat walk (Nicodemus and Holt 2002); 3) 3-gaited, plantation shod horses at the flat walk, running walk, and canter (Nicodemus and Holt 2003b); and 4) the flat shod running walk and the relationship of velocity on the gait (Nicodemus *et al.* 2002). A fifth study evaluating the walk and running walk of the TWH determined that temporal variables of the flat walk were similar to those found in previous studies (Roberson *et al.* 2007). Each of the TWH studies has assisted in defining the specific gaits and determining the effect of variables on gait.

Temporal variables, including the number of beats per stride, rhythm, and footfall sequence, have been used at length to evaluate and define walking gaits for non-gaited and gaited horses. Lateral footfall sequence is the common thread no matter which variation of the walk is performed or by which breed, and while the stock breed western pleasure walk will not be evaluated in this study, there is importance in understanding the walk and its variations in order to understand the relationship between the walk and the jog. Additionally, one of the attempts of the current study is to address some of the discrepancies between the breed definition guidelines and the scientific definitions of the stock breed western pleasure horse jog, so there is value in understanding how temporal variables have been used to appropriately define and evaluate walking gaits.

Trot and trot variations.

As defined by Deuel (2001), a trot is a symmetrical, two-beat leaping gait with diagonal pairs. Holmström *et al*. (1995) documented that elite dressage horses performing the collected trot spent a greater percentage of stride on the forelimb (297.5 ± 17.4 ms) than when performing the working trot (263.5 ± 33.4 ms) or trot in hand (227 ± 24.2 ms). Dressage horses performing the collected trot demonstrate a shorter stride length (2.50 ± 4 m) and reduced stride duration (783 ± 11 ms) when compared to the performance of working (2.73 ± 0.04 m; 755 ± 10 ms), medium (3.26 ± 0.05 m; 733 ± 17 ms), or extended trots (3.55 ± 0.07 m; 722 ± 15 ms) (Clayton 1994b). Parameters indicating the quality of the trot have been used to categorize horses.

Holmström *et al*. (1994), using stride length and duration, detected differences between warmblood riding horses judged as "good" or "poor" trotting horses. Horses classified as "good" had a longer stride duration (794.0 ± 13.4 ms vs. 644.5 ± 40.7 ms) and hind stance duration (216.0 ± 7.4 vs. 198.0 ± 4.5 ms) as well as larger positive diagonal advanced placement (29.8 ± 7.6 vs. 11.5 ± 5.8 ms) than those classified as "poor." Low stride frequency was correlated to longer stride duration and is required for good gait quality (Back *et al.* 1994; Barrey 1999; Holmström *et al.* 1994). Large positive diagonal advanced placements may be an indicator of a horse's balance and ability to carry more

weight on the hindlimbs (Back *et al.* 1994; Holmström *et al.* 1993, 1994, 1995). While warmblood and stock breed horses are physically different, both breeds have the ability to perform a collected adaptation of the trot. Therefore, when comparing the jog of the stock breed western pleasure horse to the warmblood, stock breed western pleasure horses had a longer stride duration (921 ± 34 ms) and hind stance (559 ± 47 ms) than those classified as "good" trotters, which indicates that stock breed western pleasure horses would be classified as "good." However, the jog had a negative diagonal advanced placement, longer fore stance duration (626 ± 40 ms), and a considerable percent of stride was spent in tripedal with two forelimb support (19 ± 9%), which, unlike the "good" trot, indicates that the stock breed western pleasure horse carried more weight on the forelimbs, or forehand, than the hindlimbs during the jog (Booker 2005; Nicodemus and Booker 2007).

Gait parameters for determining the quality of gait as mature adult horses are possibly set as foals (Back *et al.* 1994). Dutch Warmblood foal locomotion at the trot has been quantified finding kinematic parameters such as velocity, stride and stance duration, stride length, and joint ranges of motion for the shoulder (humeral), elbow (cubital), carpus (antebrachiocarpal, midcarpal, carpometacarpal, and intercarpal), and fetlock (metacarpophalangeal) joints are set as early as 4 months of age. Video analysis measured the kinematics of

superior gait in young trotting Warmbloods to identify criteria for determining good or superior gait qualities. Superior gait qualities determined at a young age may reflect future performance in the show ring; results showed that fore and hindlimb stride and swing phases correlated with aspects of a gait score such as length, suppleness, and strength that are judged visually. As well, judging scores correlated strongly with limb durations, protraction/retraction angles, scapular angles, forelimb fetlock angles, stifle angles, and tarsal angles. Horses were judged as well as scored objectively using kinematics, and the ranking given based on kinematics closely simulated subjective rankings by judges. Further research on kinematic response in trotting Warmbloods to a 70-day training period found that limb durations and protraction/retraction angles were significantly different following training (Back *et al.* 1995). Along with kinematic changes due to training, studies have shown kinematic changes including increased stride length and flexion of the shoulder, elbow, and carpus occur with growth in trotting Andalusian foals as they aged up to 24 months (Cano *et al.* 2001). A horse's age influences gait, but the mechanics of gait development as a horse ages has not been kinematically determined (Barrey 1999). Measuring locomotor and physiological parameters could help predict the future performance of young horses.

As with the walk, temporal variables of the trot as performed by different breeds and types of horses has been useful in defining and classifying the trot and its variations. Temporal variables have been used to define the trot of the hunter type Arabian and Quarter Horse (Nicodemus 2007; Nicodemus and Slater 2006). The Arabian hunter trot was defined as a leaping gait (suspension: 16 ± 3% of stride) with symmetry because the limbs moved in diagonal pairs (Nicodemus and Slater 2006); hunter type Quarter Horses also performed the trot as a leaping gait (suspension: 19 ± 1%) with symmetry because the limbs moved as diagonal pairs (Nicodemus 2007). During stance phase Arabian horses used diagonal bipedal limb support (84 ± 3%) but most of the stride was spent in swing phase (fore stance: 40 ± 3%, hind stance: 44 ± 1%) (Nicodemus and Slater 2006); Quarter Horses spent a comparable time to that of the Arabian hunter pleasure horse in diagonal bipedal support (81 ± 1%) (Nicodemus 2007). Arabian horses performed the trot with a velocity of 2.36 ± 0.07 m/s, stride duration of 718 ± 16 ms, and stride length of 1.70 ± 0.04 m while Quarter Horses performed with a velocity of 2.83 ± 0.31 m/s, stride duration of 773 ± 43 ms, and stride length of 2.19 ± 0.25 m. The hunter trot of the Arabian and Quarter Horse was performed as a similar gait when comparing velocity, stride length, and stride duration across breeds. These similarities indicate that the hunter trot has similar gait parameters between the Arabian and Quarter Horse breeds, so whether or not

the horses are the same breed, the hunter trot is similar when performed negating the differences in conformation and gait style between the Arabian and Quarter Horse. Quarter (stock) Horses also perform the western pleasure jog, which is considered to be a variation of the collected trot by the equine industry and science, but by scientific definition, the jog cannot be a variation of the trot because the jog is classified as a stepping gait while the trot is a leaping gait. Performance of the collected trot and other trot variations further solidify the scientific argument that the jog is not a variation of the trot.

Trot variations performed by dressage horses include the piaffe, passage, collected, working, medium, extended, and flying trot (Clayton 1994b, 1997; Weishaupt *et al.* 2009). Clayton (1997) classified the collected trot, passage, and piaffe as symmetrical gaits. The passage and piaffe were determined to have considerable variations in fore and hind stance duration, suspension, and diagonal advanced lift-off between individual horses, and both gaits can be distinguished from the collected trot through stride duration differences. While the collected, medium, working, extended, and flying trots exhibit diagonal pairs, the passage demonstrates diagonal couplets with the hindlimbs always impacting the ground before the diagonal forelimb. The passage is performed at a slower velocity than the trot with an increase in collection and a more vertical movement than forward movement (Clayton 1997; Weishaupt *et al.* 2009).

Diagonal couplets seen in the passage are likely due to the slow velocity in which the gait is performed. If the reduction in speed results in diagonal couplets in the passage of dressage horses it is reasonable to conclude that the diagonal couplets seen in the stock breed western pleasure horse jog are also due to velocity.

A specific trot adaptation includes the jog performed by western pleasure horses. Nicodemus and Clayton (2001a) and Nicodemus and Booker (2007) found that the jog of stock breed western pleasure horses had a four-beat gait with lateral footfall sequence and irregular rhythm with diagonal couplets. Likewise, Arabian and Morgan western pleasure horses performed the jog with four-beats, lateral footfalls, and irregular rhythm (Nicodemus and Luckett 2008). Limbs during the jog rarely had lift-off or contact with the ground at precisely the same time, which gave the gait an irregular rhythm (Hildebrand 1965). Stride duration was found to be similar between jogs (Nicodemus and Clayton: 951 ± 44.9 ms; Nicodemus and Booker: 921 ± 34 ms; Nicodemus and Luckett: Arabian = 921 ± 48 ms, Morgan = 971 ± 42 ms) performed by western pleasure horses no matter their breed. In all previously cited studies, horses demonstrated a period of quadrupedal limb support during the jog. The four-beat rhythm, due to diagonal couplets, and lack of suspension should, by definition, classify the jog as a stepping gait in contrast to the leaping gait classification of the trot (of which the jog is a variation) (Nicodemus and Booker

2007). Diagonal couplets create the illusion of synchronization in diagonal pairs during the jog because the fore and hind limbs on opposite sides of the body moved closely together and strike the ground at nearly the same time.

Other trot-like equine gaits demonstrate diagonal couplets as seen in stock breed western pleasure horses. Early studies by Grogan (1951) and Hildebrand (1965) state that Standardbred trotters and pacers may display diagonal or lateral couplets with the hindlimb striking slightly before the forelimb. Holmström *et. al* (1995) determined that elite dressage horses performing at the collected trot may display couplets and have placement of the fore or hind limb of the diagonal pair slightly before the other limb. Another dressage study found that when high-speed cinematography was used, a slight diagonal pair disassociation was seen at impact with the fore or hindlimb moving in advance (Clayton 1994b). Paso Fino horses perform the paso corto and paso largo as stepping gaits with diagonal couplets similar to the stock breed, Arabian, and Morgan western pleasure jog (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a, b; Nicodemus and Luckett 2008). Diagonal and lateral couplets are also seen in the Icelandic horses performing the toelt, although breed standards require a regular rhythm. Additionally, the toelt is described by the industry as a gait with no suspension (FEIF 2009), but a small percentage of horses showed suspension when performing the toelt with suspension increasing as speed increased

(Biknevicius *et al.* 2006; Zips *et al.* 2001), and may be performed at speeds ranging from 0.89 to 5.98 m/s with a lateral footfall sequence (Biknevicius *et al.* 2006). The Icelandic Horse Association considers suspension during the stride of the toelt a fault; however, some Icelandic horses are performing the toelt with suspension. Similarly, stock breed western pleasure horses are not performing the jog with a period of suspension even though major stock breed association gait definitions for the jog imply that the gait should have suspension. This lack of suspension and diagonal couplets seen in the jog of stock breed, Arabian, and Morgan western pleasure horses likens the gait more to the fox trot performed by the Missouri fox trotting horse.

The fox trot performed by the Missouri Fox Trotter has no period of suspension and is diagonal in rhythm due to diagonal couplets but has a lateral footfall sequence. Limb support phases of the fox trot included tripedal with two hindlimbs and with two forelimbs and diagonal and lateral bipedal supports (Clayton and Bradbury 1995; Nicodemus and Clayton 2003). Stride duration and forelimb stance was longer for the Nicodemus and Clayton (2003) study than that of the Clayton and Bradbury (1995) study (Table 2.1). The difference in stride duration seen in the two previously mentioned studies for the fox trot is most likely due to the velocity of the Missouri Fox Trotters; stride duration decreases as velocity increases, so it is reasonable to conclude that the horses

used in the Clayton and Bradbury (1995) study were traveling at a faster rate than those in the Nicodemus and Clayton (2003) study. The jog performed by the western pleasure horse is closely related to the fox trot of the Missouri Fox Trotter in limb support, footfall sequence, and rhythm because both have diagonal couplets and longer periods of diagonal bipedal support (Clayton and Bradbury 1995; Nicodemus and Booker 2007; Nicodemus and Clayton 2001a). Similar limb support phases between the fox trot and stock breed western pleasure jog included tripedal with two hindlimbs and two forelimbs as well as diagonal and lateral bipedal supports. However, stock breed western pleasure horses had a considerably longer stride duration and forelimb stance time than did the Missouri Fox Trotting horse (Table 2.1). The combination of longer stride duration and forelimb stance time for the stock breed western pleasure horse may be due to the horse's headset being considerably lower than that of the Missouri Fox Trotter. Neither the stock breed western pleasure jog nor the fox trot has a period of suspension. For both the fox trot and the jog, the lack of suspension means there is no "bounce" in the stride and allows for a smoother, more comfortable ride. It is the synthesis of these scientific data that has shown that the jog of the stock breed western pleasure horse, a non-gaited horse breed, is closely related to the fox trot of the Missouri Fox Trotter, a gaited horse breed.

Table 2.1: Means (SD) for stride duration (ms) and forelimb stance (%) of the fox trot as performed by the Missouri Fox Trotter and jog as performed by the stock breed western pleasure horse (Clayton and Bradbury 1995; Nicodemus and Booker 2007; Nicodemus and Clayton 2001a; Nicodemus and Clayton 2003).

	Fox Trot		**Jog**	
	Clayton and Bradbury (1995)	**Nicodemus and Clayton (2003)**	**Nicodemus and Clayton (2001a)**	**Nicodemus and Booker (2007)**
Stride Duration (ms)	593 (17.40)	639 (27)	951 (44.9)	921 (34)
Forelimb Stance (%)	54.7 (1.80)	58 (4)	66 (7)	68 (3)

The Dutch Warmblood trot and stock breed western pleasure jog have also been evaluated using joint kinematics. Dutch Warmbloods at the trot demonstrated peak flexion angles of 146 ± 9.6^{o} for the fetlock, 109.7 ± 5.9^{o}, for the carpus, 110.1 ± 3.4^{o} for the elbow, and 115.5 ± 2.9^{o} for the shoulder with most of the motion occurring during swing phase (Lanovaz *et al.* 1999). Stock breed western pleasure horses at the jog flexed the carpus (116.18 ± 11.2^{o}) and fetlock (181.19 ± 8.3^{o}) less than Dutch Warmbloods, while showing similar shoulder (114.69 ± 3.93^{o}) and greater elbow flexion (104.33 ± 7.44^{o}) (Nicodemus and Booker 2007). Differences seen between trotting Warmbloods and jogging stock breed western pleasure horses indicate the Warmbloods' forelimb range of motion (ROM) may be initiated at the carpus and fetlock joints while the western

pleasure horse's motion may be initiated at the elbow joint. Both breeds utilized the shoulder joint for forelimb ROM. Limited flexion of the carpus and fetlock (Figure 1.4) was found in the stock breed western pleasure horse and is consistent with judging standards because the horse's knees should be flat moving during the jog and fetlocks should minimize spring and lift of the body (Nicodemus and Booker 2007).

The trot and its variations are performed differently when evaluating horses within and between breeds; additionally, the visual image is sometimes deceiving, so it is important to evaluate gait based on scientific parameters. Stride length and duration, velocity, diagonal advanced placements and lift-offs, and limb stance phases may all be utilized to objectively quantify and define the trot and it is variations. While the stock breed western pleasure jog has been subject to scientific analyses (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a), the extended jog has not been evaluated. Accurately differentiating between the collected and extended jog of the stock breed western pleasure horse is important to the equine industry for clinical and performance applications and will assist in understanding gait definitions in order for gaits to be either performed according to breed guidelines or for the gait definitions to be changed to better reflect what horses are performing.

Canter and canter variations.

Stock breed western pleasure horses perform the lope, which is considered by science and the industry to be a variation of the canter and synonymous with the collected canter of the dressage horse. While the similarities of asymmetry as well as leading and trailing limbs exist between performance of the canter and the lope, the lope is a stepping gait because there is not period of suspension (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a) and the canter is considered a leaping gait because there is a period of suspension in the medium and extended canter performed by the dressage horse (Clayton 1994a). However, the lack of suspension found in the collected canter of elite dressage horses and the lope of stock breed western pleasure horses might explain why the western pleasure lope is commonly referred to as a collected canter (Clayton 1994a; Nicodemus and Booker 2007; Nicodemus and Clayton 2001a). Based on the acceptance of stock breed western pleasure lope being a variation of the canter, it is important to understand how the canter and its variations are performed.

The canter is a three-beat asymmetrical gait with a footfall sequence of a trailing hind, diagonal pair, and leading forelimb. The trailing limbs are defined as the first of two fore or hindlimbs to touch and leave the ground during each stride of asymmetrical gaits; whereas, leading limbs are the second of two fore or

hindlimbs to touch and leave the ground (Deuel 2001). Similarities in stance and swing duration have been found between horses cantering on the left lead and those on the right lead (Back *et al.* 1997). Dutch Warmbloods were used in gait studies to quantify and set parameters such as velocity, stride length, stride duration, stance duration, and scapula, elbow, carpus, and fetlock joint angles of the canter (Back *et al.* 1993) and to determine flexion/extension, lateral bending, and axial rotation of the spine during the canter (Faber *et al.* 2001). Further canter studies compared the extended canter in horses trained for dressage to those trained for racing and found differences between velocity, stance durations and overlaps, suspension, and time between impacts of the diagonal pair due to training. Specifically, racehorses had longer suspension phases and shorter stance durations and limb overlaps when performing the extended canter (Clayton 1993). Nicodemus (2007) looked at the hunter canter of the Quarter Horse and found that the trailing fore and leading hindlimb worked as a diagonal pair because each limb spent the same amount of time in stance (fore: 46 ± 5%; hind: 46 ± 5%); the leading forelimb (42 ± 4%) and trailing hindlimb (41 ± 3%) spent less time in stance phase. Limb support phases throughout the stride included suspension, diagonal bipedal, single fore, single hind, and tripedal with two forelimbs (Nicodemus 2007). The canter is performed differently based on breed and type of horse within breed; further, variations of the canter exist.

The canter may be performed as a collected, medium, extended, or disunited gait with all variations having periods of suspension. Advanced placement in the dressage canter was found to be the longest between the leading fore and trailing hindlimb for the medium and extended canters; however, a period of suspension was found during this phase between placement of the leading fore and trailing hindlimb in dressage horses at the canter (Clayton 1994a) that is not present in the plantation shod TWH canter (Nicodemus and Holt 2003b), or stock breed western pleasure lope, which is a canter variation (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a). Advanced placement of the leading fore and trailing hindlimb shortened for the working canter, and at the collected canter no suspension was recorded for advanced dressage horses. Stride length and duration as well as velocity for dressage horses at the canter was 1.98 m, 609 ms, and 3.27 m/s for collected; 2.35 m, 608 ms, and 3.91 m/s for working; 2.93 m, 595 ms, and 4.90 m/s for medium; and 3.46 m, 572 ms, and 5.97 m/s for extended (Clayton 1994a).

Considered to be another variation of the canter is the lope of the western pleasure horse. Research has found that western pleasure horses demonstrated a four-beat lope, lateral footfall sequence, and no periods of suspension (Nicodemus and Williams 2009; Nicodemus and Clayton 2001a). Stock breed western pleasure horses perform the lope as a four-beat stepping gait but a

period of quadrupedal support (2% of stride) was found in the Nicodemus and Clayton (2001a) study unlike the horses in Nicodemus and Booker (2007) where no (0%) quadrupedal support was found. It should be noted that differences seen between the two stock breed western pleasure horse studies may be due to changes in show trends from 2001 to 2007. Interestingly, Arabian and Morgan western pleasure horses also do not show a period of quadrupedal support during the lope (Nicodemus and Williams 2009). The lope was performed with a velocity of 1.74 ± 0.13 m/s and stride duration of 715 ± 38 ms (Nicodemus and Booker, 2007); Nicodemus and Clayton (2001a) found a stride duration of 721.4 ± 26.7 ms, which was longer than the stride duration found by Nicodemus and Booker (2007) and indicates that horses in the Nicodemus and Booker study were traveling at a faster velocity than those in the Nicodemus and Clayton study. Velocity was slower and stance duration was longer for the stock breed western pleasure horse lope than for the collected canter of the dressage horse (velocity = 3.27 m/s; stance duration = 609 ms) (Clayton 1994a) however, the equine industry considers these gaits to be synonymous. Based on the velocity and stance durations it is possible that the stock breed western pleasure lope was misclassified by the equine industry because of its visual similarities to the collected canter of the dressage horse. Limb support throughout the stride of the stock breed western pleasure lope was diagonal and lateral bipedal, unipedal

fore and hind, and tripedal with two fore and two hindlimbs, and horses spent the greatest percentage of this stride in diagonal bipedal support (44 ± 6%), just as observed in the collected canter of the dressage horse, however, the velocity is the telling variable.

Other similarities exist between the Nicodemus and Booker (2007) and Nicodemus and Clayton (2001a) studies for stance durations for the leading hind (2001a = 59 ± 4%, 2007 = 60 ± 3%), leading fore (2001a = 62 ± 1%, 2007 = 57 ± 6%), and trailing forelimb (2001a = 62 ± 1%, 2007 = 59 ± 5%). However, the limb beginning the stride cycle for the lope, the trailing hind, was found to have a longer stance duration during the Nicodemus and Clayton (2001a) lope (69 ± 2%) when compared to the Nicodemus and Booker (2007) (50 ± 4%) study. Similar limb support phases between the lope in Nicodemus and Clayton (2001a) and the Nicodemus and Booker (2007) study include single forelimb, diagonal and lateral bipedal, and tripedal with two fore and two hindlimbs. Advanced placement was found in stock breed western pleasure horses at the lope to be the shortest between the leading fore and trailing hindlimb, the period where suspension usually occurs (Nicodemus and Booker, 2007), instead of being the longest as seen in the Nicodemus and Clayton (2001a) study. Nicodemus and Clayton (2001a) completed the temporal variable study of the stock breed western pleasure lope before stock breed associations attempted to improve performance

of the gait by including the "forward motion" clause in the gait definition. The Nicodemus and Booker (2007) evaluation of the stock breed western pleasure lope occurred after the definition change by breed associations. Comparisons between the two western pleasure studies indicate that while there was some improvement in the lope, such as no quadrupedal support, after the rule changes the lope was still not being performed according to breed association guidelines. The disassociation of the diagonal pair gives the gait four-beats rather than three and likens the gait to the canter of the plantation shod TWH.

The canter of the plantation shod TWH was found to be a four-beat stepping gait (Nicodemus and Holt, 2003a) and performed at a velocity of 3.8 ± 0.7 m/s and a stride duration of 679 ± 58 ms; stock breed western pleasure horses perform the lope at a slower velocity (1.74 ± 0.13 m/s) and a longer stride duration (715 ± 38 ms) than the TWH performs the canter (Nicodemus and Booker 2007). Both the TWH canter and stock breed western pleasure lope exhibited diagonal and lateral bipedal, unipedal fore and hind, and tripedal with two fore and two hindlimb limb support phases. The TWH spent the greatest percentage of stride in lateral bipedal support (34%), while the stock breed western pleasure horses performed with diagonal bipedal support (44 ± 6%) as the greatest percentage of stride. Splan and Hunter (2003) continued TWH gait studies by comparing the canter of horses trained for performance classes to

those trained for light shod classes. Stock breed western pleasure horses perform the lope with a stride duration between that of the performance (879 ± 0.183 ms) and light (654 ±0.006 ms) shod TWH canter. Performance (38.25 ± 1.67%) and light (22.73 ± 2.01%) shod horses spent a great percent of stride in diagonal bipedal support just as the stock breed western pleasure horse. Limb stance durations for the lope (trailing fore = 59 ± 5%, leading fore = 57 ± 6%, trailing hind = 50 ± 4%, leading hind = 60 ± 3%) were longer than the limb stance durations for the performance trained (trailing fore = 41.32 ± 0.54%, leading fore = 38.07 ± 0.80%, trailing hind = 48.86 ± 1.15%, leading hind = 49.03 ± 0.43%) and light shod trained TWH (trailing fore = 37.89 ± 0.79, leading fore = 26.38 ± 1.20%, trailing hind = 48.07 ± 1.20%, trailing fore = 37.89 ± 0.79%) performing the canter. The low, flat line of motion required in stock breed western pleasure necessitates a lower, shorter limb swing phase. In the TWH canter studies, light shod horses exhibited suspension, but plantation and performance shod horses, similar to the stock breed western pleasure horse at the lope, performed the canter with no period of suspension (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a; Splan and Hunter 2004). In short, the stock breed western pleasure horse performs the lope with similarities and differences between the plantation, performance, and light shod TWH. The velocity of the stock breed western pleasure horse is slower than that of the plantation shod TWH, but performed

with a stride duration between that of the performance and light shod TWH. Limb support phases between the stock breed western pleasure lope and the plantation, performance, and light shod TWH are similar with the greatest similarities to the stock breed western pleasure lope found in the amount of diagonal bipedal support seen in the performance and light shod TWH. However, the stock breed western pleasure horse had longer limb stance durations than either the performance or light shod TWH.

In addition to temporal variables, kinematic measures have been used to evaluate Dutch Warmbloods at the canter and stock breed western pleasure horses at the lope. Leading forelimb joints of Warmbloods at the canter had greater ROM with more distinctive flexion peaks for the shoulder and fetlock; more gradual flexion peaks of the elbow, carpus, and fetlock; and more gradual extension peaks for the elbow than did the stock breed western pleasure horse's leading forelimb. Both the elbow and carpus demonstrated close pattern similarities, while the fetlock of the stock breed western pleasure horse demonstrated a double peak of extension during stance that was not present in the canter. In stock breed western pleasure horse's leading hindlimb, the stifle (femoropatellar and femorotibial), hock (proximal intertarsal, distal intertarsal, tarsometatarsal, and tarsocrural), and fetlock joints demonstrated less ROM than the Warmblood canter, while the hip (coxofemoral) showed similar ROM. The

hip and stifle flexed and extended more gradually throughout the lope stride, similar to the patterns demonstrated during the Dutch Warmblood canter for the hip and stifle joints. Less distinction was seen during flexion peaks of stance and swing for the hock joint at the lope, which demonstrated a similar motion pattern to the canter of the Dutch Warmblood. Fetlock flexion peaks were less distinctive at the lope, and the fetlock lacked a double peak of flexion during the loping swing phase that was present in the Warmblood canter (Back *et al.* 1997; Nicodemus and Booker 2007). Both the canter and lope were performed with a high degree of engagement from the hindquarters, which may explain the similarity in joint motion of the leading hindlimbs of the Dutch Warmblood and the stock breed western pleasure horse. Slower velocity of the lope and lack of suspension, when compared to the canter, may explain the decrease in joint ROM and more gradual and less distinctive flexion and extension peaks.

The canter and its variations are performed differently when evaluating horses within and between breeds; however, asymmetry and leading limbs are always present no matter the variation. Stride length and duration, velocity, advanced placements and lift-offs, and limb stance phases are all utilized to objectively quantify and define the canter and the variations. While the stock breed western pleasure lope has been subjected to scientific analysis (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a), the extended lope has not been

evaluated. Based on previous research (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a) that indicates that stock breed western pleasure horses do not exhibit a period of suspension further analysis is warranted to accurately differentiate between the collected and extended lope of the stock breed western pleasure horse. The importance of correctly identifying loping gaits of stock breed western pleasure horses has clinical and performance applications; correct gait identification will assist in understanding gait definitions so that the lope may either be performed according to breed guidelines or for the gait definition to be changed to better reflect how horses are performing the lope.

In summary, by defining gaits using temporal variables and kinematic analysis, researchers have created an objective basis for comparison of gaits and horses between and within breeds. Gait analysis defines footfall sequence, limb support, rhythm, stride durations, displacements, and joint angles of the gait. Stock breed western pleasure horses have been the subject of several studies (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a); however, discrepancies still exist between the industry and scientific definitions and classifications of the stock breed western pleasure jog and lope. Because change takes time, gait classifications are not likely to be affected in the near future; however, through the presentation of research and dissemination of information

regarding these inconsistencies, perhaps change can be enacted that will provide more consistent gait definitions. Further, the extended jog and lope have yet to be evaluated scientifically. Kinematic research associated with stock breed western pleasure is important to the equine industry for clinical and performance applications and will assist in understanding gait definitions in order for gaits to be either performed according to breed guidelines or for the gait definitions to be changed to better reflect what horses are performing.

Head Carriage

Reins are used to modify head placement during locomotion; and in turn, has a direct impact on limb activity (Biau *et al.* 2002). Roepstorff *et al.* (2002) determined that forelimb activity was influenced significantly more than hindlimb activity with rein adjustment. Specifically, when using draw reins to lower headset and increase collection, horses performed the trot with longer forelimb (87.25 ± 3.25 ms) than hindlimb (78.93 ± 3.21 ms) stance durations (Roepstorff *et al.* 2002). A low headset, characteristic of stock breed western pleasure horses, may have similar effects to those of draw reins on gait since the jog exhibited a longer forelimb stance (626 ± 40 ms) duration than hindlimb (559 ± 47 ms) stance duration (Booker 2005). Although no scientific literature exists that links the stock breed western pleasure horse to a shift in weight, stock breed

western pleasure horses at the jog have been found to spend a considerable amount of time in fore stance (626 ± 40 ms) when compared to the hind (559 ± 47 ms) and implies a greater amount of weight being carried on the forelimbs, or forehand (Booker 2005). Increased weight on the forelimbs would result in a heavier gait than is acceptable according to stock breed western pleasure standards and may be linked to the injuries seen in the forelimbs of western pleasure horses. Contrastingly, head and neck positions that have been found to induce a weight shift from the forehand to the hindquarters in unridden dressage horses at the walk and trot include positions where: (a) the neck is moderately elevated and the poll is flexed or extended slightly and (b) a low, flexed head and neck with the poll extremely flexed behind vertical (Waldern *et al.* 2009). At first glance these findings seem counterintuitive since it has been hypothesized that the increased forelimb stance seen in stock breed western pleasure horses when compared to hindlimb stance is due to the horse's head set; however, a dressage horse's "low" headset is going to be higher than a stock breed western pleasure horse's "normal" headset. Further studies by Rhodin *et al.* (2005) used side reins to determine head and neck positions, range of motion for flexion-extension, lateral bending, and axial rotation of the back during the walk and trot.

Rhodin *et al.* (2005) evaluated back kinematics at the walk and trot using side reins and determined that horses that were forced to work in a low headset, like the stock breed western pleasure horse, had decreased lateral bending in the lumbar region and decreased flexion-extension of the back when compared to a free position. Decreased back movement is evident in the minimal vertical ROM for the withers (9.06 ± 2.84 cm), loin (9.10 ± 2.41 cm), and croup (8.97 ± 2.63 cm) of the stock breed western pleasure horse (Booker 2005); however, the headset of horses in the Rhodin *et al.* (2005) study had the head and neck fixed in the low position, while stock breed western pleasure horses naturally carry their head in a low position without restraint. Decreased back movements seen in stock breed western pleasure horses may be a direct result of this collected frame required to execute the jog and lope correctly, according to stock breed association guidelines. The collected frame is a result of restriction by the horse of vertical displacement of the head, spine, and hip. It is possible that the collected frame of the stock breed western pleasure horse also has implications to balance. As horses begin traveling at slower velocities, as seen in the walking half pirouette and passage of dressage horses (Clayton 1989; Hodson *et al.* 1999) and western pleasure jog and lope (Nicodemus 2007; Nicodemus and Booker 2007), there is a loss of forward motion that causes the horse to become unbalanced. This unbalanced posture results in a loss of dynamic stability and has been linked to

the presence of quadrupedal support during gaits with slow velocities (Clayton 1989; Hodson *et al.* 1999; Nicodemus and Booker 2007). Ultimately, judging standards that allow for a less collected frame and higher headset in stock breed western pleasure horses may produce differences in gait.

Injuries

Modern stock breed western pleasure horses are being bred specifically for western pleasure competition and thus have a different body type than other stock horses, which may predispose them to skeletal injuries. This modern western pleasure horse is taller and has less muscle mass over the shoulders and hindquarters with steeper shoulder (scapular) and pastern (proximal phalanx, P1) angles than typical stock horses (Figure 1.4) (Black 1999). Western pleasure horses tend to be shod at steep hoof angles with aluminum shoes, which further increases hoof angle and decreases breakover time for carpus flexion to allow for the "flat kneed" appearance of the stock breed western pleasure horse. Stock breed horses also have a smaller foot size, when compared to body size, which increases the propensity for hoof lameness including inflammation of the distal coffin (interphalangeal) joint, which is the articulation of the distal end of the middle phalanx, proximal end of distal phalanx, and the distal sesamoid bone and may have implications for balance. Other injury locations that are common

due to the combination of conformational aspects, fatigue, early training, and shoeing techniques are the proximal origin of the suspensory ligament as well as the pastern (proximal interphalangeal) joint and hock (tarsus) of the hindlimb (Figure 1.4). Back soreness due to inflammation of the hock or pastern joint, inexperienced or overweight riders, and improper saddle fit are also major contributors to injuries in stock breed western pleasure horses; however, osteoarthritis due to trauma is the most common cause of stifle (femoropatellar and femorotibial) joint lameness in the stock breed western pleasure horse (Noble 2001).

Osteoarthritis or degenerative joint disease (DJD) makes up 33% of all equine lameness and is the inflammation of moveable weight bearing joints due to the degeneration of articular cartilage and the subsequent exposure and formation of subchondral bone in the weak areas (Alwan *et al.* 1991; Clyne 1987). Primary causes of DJD include normal wear and tear, ageing, or heredity; secondary causes include trauma, joint overload and instability, acute inflammatory joint disease, infection, or other bone disease. Young horses are susceptible to DJD in highly moveable joints such as the carpus and fetlock (metacarpophalangeal) joints (Figure 1.4) while older horses are more susceptible to injury at the hock (intertarsal and interphalangeal) joint (Auer and Fackelman 1981; Clyne 1987). Some predispositions to developing DJD are fatigue, chronic

joint overuse, early training, conformation defects, and shoeing techniques; stock breed western pleasure horses fall into each predisposition category (Auer and Fackelman 1981).

While no scientific literature exists directly linking western pleasure to osteoarthritis, it is accepted in the equine industry that elite performance horses that have been showing at the national level since the age of two do not often maintain a show career after the age of five. This lack of senior aged performance horses is anecdotally linked to osteoarthritis induced by the intense training these horses receive early in the show career and the ultra slow gait they are expected to achieve. This investigation will lead to insight in the performance of these gaits and help determine whether the high level of collection required to perform the jog and lope, coupled with the speed of the gait, increases the horse's risk for joint injury and trauma.

Summary

In light of the limited previous scientific work evaluating stock breed western pleasure horses the need for further research is evident. The jog and lope of the stock breed western pleasure horse are highly specialized gaits performed by an elite sector of the equine industry. Identifying, defining, and contrasting the collected and extended jog and lope as well as evaluating the role

of head position may have implications for mechanisms of injury in stock breed western pleasure horses. There are apparent contradictions in classification of the jog and lope by the industry as well as breed association definitions. The equine industry views the stock breed western pleasure jog and lope as collected versions of the dressage horse trot and canter, respectively. Based on kinematic evidence, this classification is accurate; however, when compared to temporal variables, the jog and lope are not just slower more collected versions of the trot and canter; the trot and canter are classified as leaping gaits while the jog and lope are stepping gaits. Further, the breed association definitions imply suspension in these gaits because the jog should be a two-beat gait and the lope should be a three-beat gait. In order to perform the jog and lope correctly, the gaits would have to exhibit a period of suspension between each beat of the trot and after the third beat of the lope. The extended jog and lope of the stock breed western pleasure horse have not been previously evaluated and may more closely follow the breed association definitions for performance and head position. Additionally, the performance of the extended jog and lope should conform to a more natural way of going for the horse, have more forward motion and range of motion, thereby reducing the risk of joint injury.

Chapter III

Materials and Methods

The purpose of this study was to collect temporal, linear, and angular kinematics for each gait of the stock breed western pleasure horse in order to compare the variables of the collected and extended jog and the collected and extended lope as well as head position to determine consistency with current rulebooks of major stock breed associations. Additionally, this study sought to determine if the extended jog and lope conform to a more natural way of going for stock breed western pleasure horses, which may reduce the risk of joint injury and trauma than does the collected jog and lope. The current chapter presents the materials and methods and includes sections a) animals, b) recording techniques, c) data collection, d) data analysis, and e) statistics.

Animals

Six stock breed western pleasure horses, four geldings and two mares, (5.50 ± 1.87 years; 1.54 ± 0.02 m; 417.98 ± 20.13 kg) were used for this study based on the horse's current status as a western pleasure horse in training or competition (Table 3.1). Three strides from each horse for each gait, collected and extended jog and lope (right and left leads), were analyzed. Horses selected for this study 1) were located at a nationally known stock breed western pleasure trainer's facility, 2) demonstrated desirable jogging and loping qualities according to what is currently being seen in stock breed western pleasure competition, 3) determined to be "healthy" for the purpose of this research project on data collection day by a licensed veterinarian, 4) are actively training for or competing in stock breed western pleasure competition, and 5) demonstrated visual soundness. The research team included individuals who are actively involved in the equine industry and are qualified to render judgments concerning gait quality and acceptability in stock breed western pleasure as well as soundness. To insure consistency, the same person affixed the markers on the horses, and the same rider rode all horses.

An owner/agent consent form was signed for each equine subject (Appendix A.1), and information regarding age, breed, sex, show history, height,

and weight was gathered and documented by the research team before each horse was analyzed (Table 3.1, Appendix A.2). Weight was estimated prior to videotaping using a commercially available standard equine measure tape while height was determined using a standard equine height stick; the same researcher recorded each measurement. All horses wore aluminum wedge shoes on the fore hooves; four of the six horses wore light steel racing plates on the hind hooves while the remaining two did not wear hind shoes at all. No intra-articular joint injections of any kind were noted for the stifle, hock, fetlock, or coffin joints within the last year.

Table 3.1: Subject information and means (± s.d.) on research animals including randomly assigned horse number, age (years), gender (M = mare, G = gelding), height (meters), weight (kilograms), and breed registry (AQHA = American Quarter Horse Association, PHBA = Palomino Horse Breeders Association; APHA = American Paint Horse Association).

Horse #	**Age (yrs)**	**Gender (M/G)**	**Height (m)**	**Weight (kg)**	**Breed Registry**
1	5	M	1.53	441.80	AQHA
2	4	G	1.54	428.64	AQHA
3	8	G	1.53	396.43	AQHA/PHBA
4	6	G	1.51	390.54	APHA
5	7	M	1.57	428.64	APHA/PHBA
6	3	G	1.57	421.84	AQHA
Means (± s.d.)	**5.50 (1.87)**		**1.54 (0.02)**	**417.98 (20.13)**	

Recording Techniques

Flat retroreflective markers comprised of Polyken (Tyco Adhesives, Norwood MA) and Johnson & Johnson Athletic tape (Johnson & Johnson Services, New Brunswick, NJ) were placed over seven points on the lateral side of the left and right forelimb following the recommendations of Back *et al.* (1995) and were used to calculate angles between the proximal and distal segments of the joints tracked: the proximal end of the spine of the scapula, posterior aspect of the tuberculum majus of the humerus (shoulder joint), transition between the proximal and the middle thirds of the lateral collateral ligament (LCL) of the cubital joint (elbow joint), midway between the site of attachment of the LCL of the carpal joint and the styloid process (carpal joint), site of attachment of the LCL of the metacarpophalangeal joint (fore fetlock joint), estimated center of the rotation of the distal interphalangeal joint (coffin joint), and proximal aspect of the lateral hoof wall (fore hoof) (Figures 3.1 - 3.3). Seven markers of the same materials were placed on the lateral side of the left and right hindlimb: the ventral aspect of the tuber coxae (point of the hip), lateral aspect of the greater trochanter (hip joint), lateral condyle of the femur (stifle joint), talus (hock joint), metatarsal attachment of the LCL of the metacarpophalangeal joint (hind fetlock joint), over the estimated center of rotation of the distal interphalangeal joint (coffin joint), and proximal aspect of the lateral hoof wall (hind hoof) (Figures 3.1

- 3.3) (Back *et al.* 1995). Additional markers tracked the medial aspect of the coffin bone on the right and left fore and hindlimbs (Figure 3.1 & 3.2). A marker was placed on the right and left side of the temporal bone, along the zygomatic process to determine head position (Figure 3.1 & 3.2). Markers comprised of one-half of a styrofoam ball covered with Scotchlite 8850 retroreflective tape (Motion Lab Systems, Inc., Baton Rouge, LA) and mounted on black foam were used along the vertebral column at the withers, lumbar-sacral junction, and point of the croup (Figure 3.3).

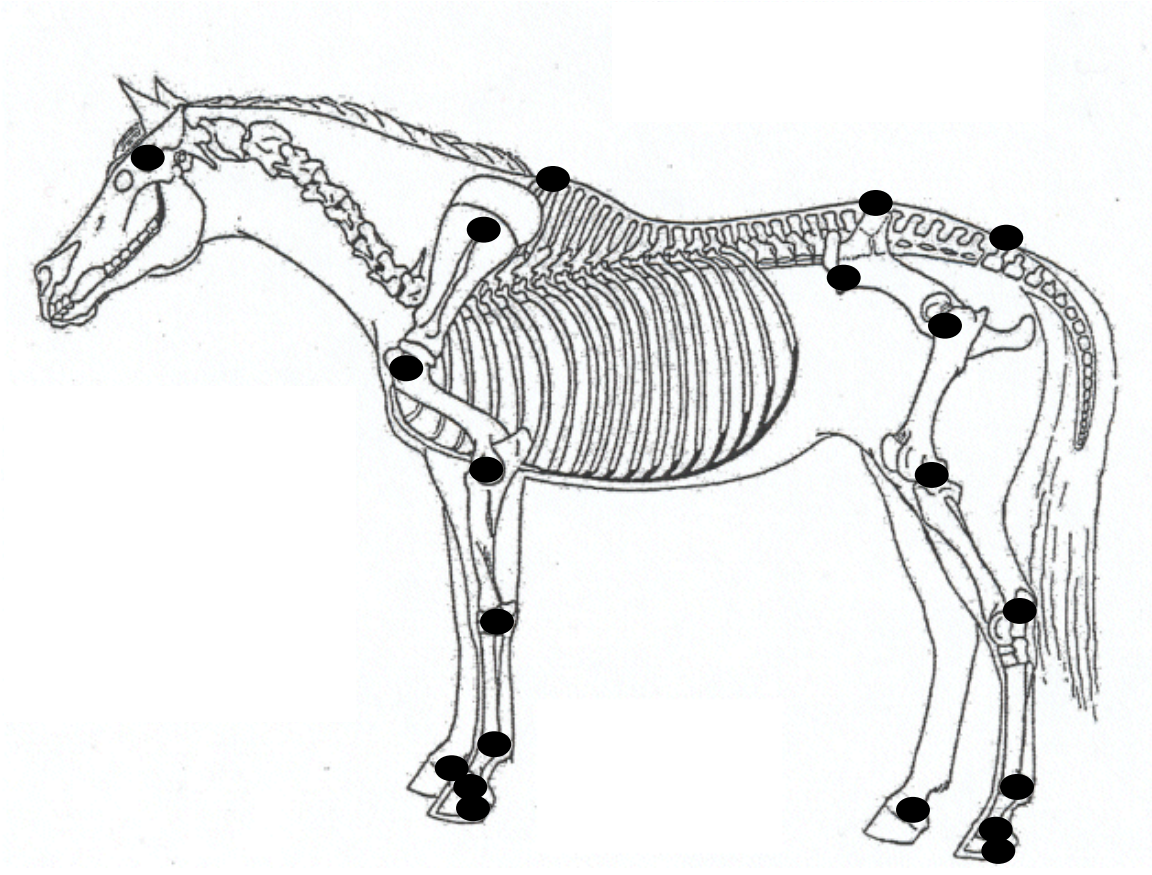

Figure 3.1: Retroreflective marker locations for data collection. Marker placement was the same for each side of the horse.

Figure 3.2: Horse 1 during data collection demonstrating placement of the reflective markers on the lateral side fore and hindlimbs, along the vertebral column, and at the zygomatic process. Flat retroreflective markers were comprised of polyken (Tyco Adhesives, Norwood MA) and Johnson & Johnson Athletic tape (Johnson & Johnson Services, New Brunswick, NJ).

Figure 3.3: Three dimensional markers comprised of one-half of a styrofoam ball covered with Scotchlite 8850 retroreflective tape (Motion Lab Systems, Inc., Baton Rouge, LA) and mounted on black foam were used along the vertebral column at the withers, lumbar-sacral junction, and point of the croup.

Data Collection

In order to obtain video footage of each horse performing at an optimal level, the same rider who trains the horse rode each horse at the collected and extended jog and lope through the capture volume. All equine subjects wore the same saddle and saddle pad (20.41 kg) as well as bridle and correction bit (1.36 kg) during data collection. The capture volume was created using four orange cones set in a 3.05 m x 3.35 m rectangle (Figure 3.4). Horses were videotaped using two 30 Hz Canon 3CCD digital video camcorders (GL2 NTSC, Canon, Lake Success, New York, USA). Camcorders were set perpendicular to the plane of motion at 7.16 m from the edge of the capture volume to the center of the tripod, one on either side of the horse (Figure 3.4). Cameras were set to capture two full strides at a height of 1.37 m, and videotaped the horses performing the collected and extended jog and lope through the capture volume (Figure 3.4). The capture volume was calibrated using a 1 m x 1 m calibration frame that was placed in the center of the capture volume before each trial. The runway (5 cm deep when packed and 6 cm deep when unpacked) was raked and packed between each trial to ensure noticeable hoof placement and lift-off. For each gait considered, horses were allowed a practice trial to acclimate the horse to the capture volume. A successful trial was determined visually by the research team and required consistency of the collected and extended jog and lope using

noticeable hoof contact and lift-off, correctness of gait, and sustained marker attachment. Three successful trials of the collected and extended jog and lope were captured for each horse.

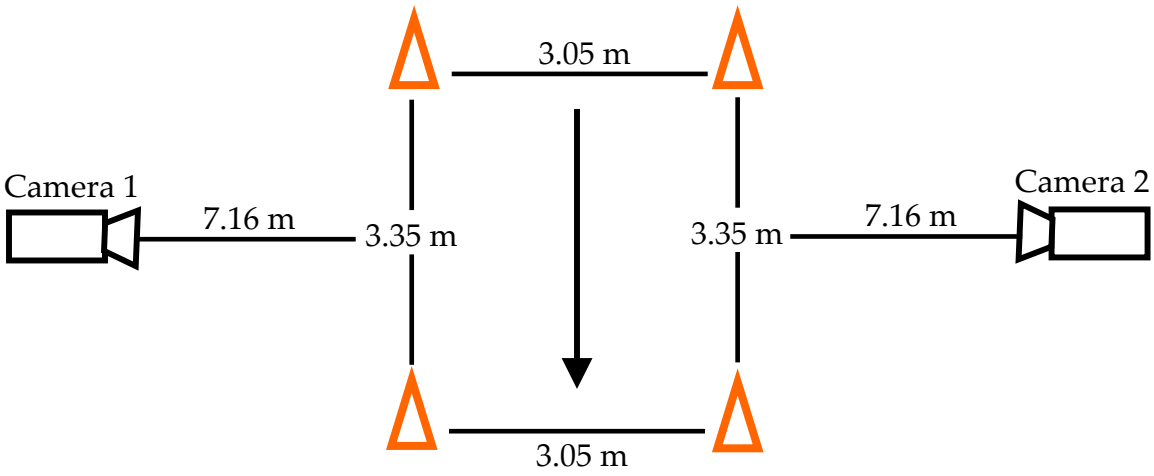

Figure 3.4: Depiction of the capture volume with orange cones set at a 3.05 m x 3.35 m rectangle, and cameras set 7.16 m from the edge of the capture volume for data collection of the collected and extended jog and lope of stock breed western pleasure horses. Center arrow indicates direction of travel; drawing is not to scale.

Data Analysis

Three successful strides of the collected (n = 18) and extended (n = 18) jog and the collected lope right lead (n = 18) and left lead (n = 18) and extended lope right lead (n = 18) and left lead (n = 18) were analyzed using the Peak Motus© 1994-2004 motion analysis system (Peak Performance Technologies, Inc., Englewood, Colorado, USA). Digitization, transformation, smoothing, and

normalization techniques followed standard kinematic techniques when using the Peak Motus system (Schamhardt *et al.* 1993).

Temporal variables were visually determined for all strides of the collected and extended jog and lope using frame-by-frame analysis of video frames to document hoof placement and lift-off for calculation of stride duration, fore and hindlimb stance and swing durations, diagonal advanced placement and lift-off, lateral advanced placement and lift-off, and limb support phases. The gait cycle was considered to be hind hoof contact to the next contact of the ipsilateral hind hoof. Hoof placement was determined to take place during the frame where any part of the hoof visually made contact with the ground, and lift-off was documented as the frame where all parts of the hoof were visually not in contact with the ground. Stride duration was calculated as the time it takes to make one full stride cycle and was measured in seconds (s). Forelimb and hindlimb stance was determined as the time from hoof placement to lift-off. Diagonal advanced placement was calculated as the time between placement of the forelimb and the placement of the diagonal hindlimb; whereas, lateral advanced placement was calculated as the time between placement of the hindlimb and the placement of the lateral forelimb. Diagonal advanced lift-off was determined as the time between lift-off of the forelimb and diagonal hindlimb. Lateral advanced lift-off was determined as the time between lift-off

of the hindlimb and lateral forelimb. The number of limbs supporting the body sequentially through the stride determined limb support sequence (Clayton 2004).

The shoulder joint was calculated using the markers at spine of the scapula, shoulder, and elbow, and the elbow joint was calculated using markers at the shoulder, elbow, and carpus (Figure 3.5). Markers at the elbow, carpus, and fetlock were used to calculate the carpal joint while the fore fetlock joint was calculated using the markers at the carpus, fore fetlock, and fore coffin (Figure 3.5). The hip joint was calculated using the markers at the point of the hip, hip, and stifle, and the stifle joint was calculated using the markers at the hip, stifle, and hock (Figure 3.6). Markers at the stifle, hock, and hind fetlock were used to calculate the hock joint while the markers at hock, fetlock, and hind coffin were used to calculate the hind fetlock joint (Figure 3.6).

Graphical depictions of the joint motion were used to create models of limb coordination. Joint angles were measured on the flexor side of the joint and upward curves indicate flexion while downward curves indicate extension of the joint. Displacements of the limbs, spine, and head were tracked with horizontal displacement taken from the most caudal to the most cranial location of the tracked marker. Vertical displacement was taken from the most proximal to the most distal location of the tracked marker.

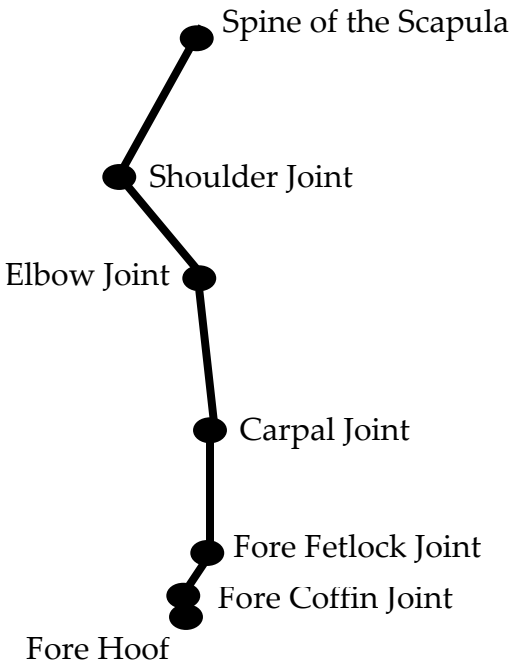

Figure 3.5: Depiction of forelimb joint angles for calculation of joint kinematics of the stock breed western pleasure horse: the proximal end of the spine of the scapula, shoulder joint, elbow joint, carpal joint, forelimb fetlock joint, forelimb coffin joint, and lateral fore hoof.

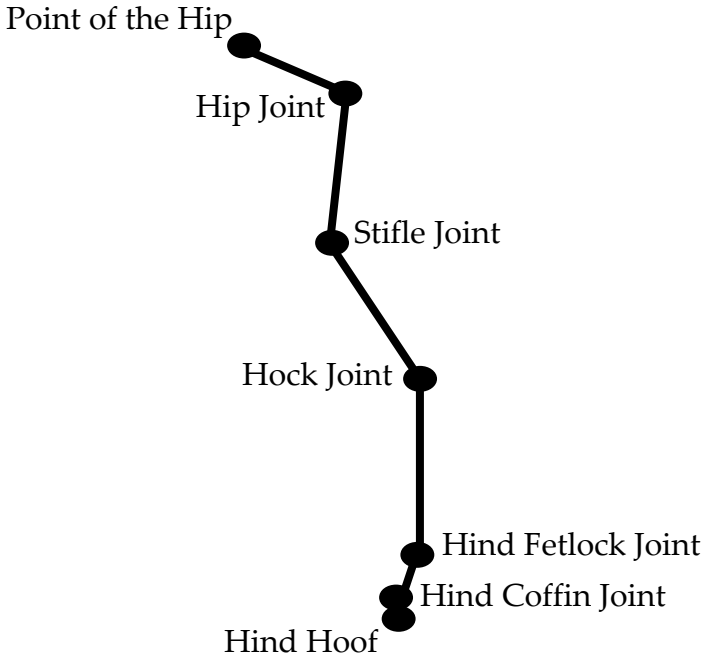

Figure 3.6: Depiction of hindlimb joint angles for calculation of joint kinematics of the stock breed western pleasure horse: point of the hip, hip joint, stifle joint, hock joint, hindlimb fetlock joint, hindlimb coffin joint, and lateral hind hoof.

Statistics

Means and standard deviations of the temporal, linear, and angular kinematic variables of the jog (collected and extended) and lope (collected and extended) were calculated. A paired-samples T test was used to determine symmetry of the collected and extended jog by comparing the stance and swing durations of the right and left fore and hindlimbs. Since gait symmetry was determined, the left and right variables of the collected and extended jog were collapsed. Paired-samples T test were used to compare the collapsed variables of fore to hindlimb stance and swing durations, diagonal advanced placement to lateral advanced placement, as well as diagonal advanced lift-off to lateral advanced lift-off to assist in defining the collected and extended jog. Vertical excursions of the head, withers, and hip were examined via paired-samples T tests to determine topline variability within the collected and extended jog. Temporal variables of the collected and extended jog were differentiated using a multivariate repeated measures ANOVA to examine stride duration; diagonal and lateral advanced placements and lift-offs; and bipedal, quadrupedal, tripedal with two fore, and tripedal with two hindlimb support. Linear variables of the collected and extended jog were differentiated using a multivariate repeated measures ANOVA to examine stride length, velocity, and vertical excursions for the head, withers, hip, and fore and hind coffin. One multivariate repeated

measures ANOVA was conducted to determine the angular kinematic differences between the collected and extended jog for the shoulder, carpus, hip, stifle, and hock joint angles.

A paired-samples T test was used to determine asymmetry of the collected and extended lope by comparing the stance and swing durations of the right and left fore and hindlimbs. Paired-samples T test were used to compare fore to hindlimb stance and swing durations, diagonal advanced placement to lateral advanced placement, as well as diagonal advanced lift-off to lateral advanced lift-off to assist in defining the collected and extended lope. Vertical excursions of the head, withers, and hip were examined via paired-samples T tests to determine topline variability within the collected and extended lope. Temporal variables of the collected and extended lope were differentiated using a multivariate repeated measures ANOVA to examine stride duration; diagonal and lateral advanced placements and lift-offs; and bipedal, tripedal with two fore, tripedal with two hindlimb, and unipedal support. Linear variables of the collected and extended lope were differentiated using a multivariate repeated measures ANOVA to examine stride length, velocity, and vertical excursions for the head, withers, hip, and fore and hind coffin. Two multivariate repeated measures ANOVAs were conducted to determine the angular kinematic differences between the collected and extended lope, one for leading limbs and

one for trailing limbs. For the forelimb, shoulder and carpus angles were evaluated, and for the hindlimb, hip, stifle, and hock angles were evaluated.

Due to the large number of variables analyzed and the relatively small sample size, there were insufficient residual degrees of freedom to perform a multivariate ANOVA for the temporal, linear, or angular variables of the collected and extended jog and lope. Therefore, the univariate results are presented cautiously and with the understanding of the risk of type 1 errors being increased due to the number of comparisons being performed. A significance level of 95% was chosen for statistical comparisons, all variables that were deemed significant had a univariate P value less than or equal to 0.04. Therefore, the risk of type 1 errors is rather small, even considering the number of comparisons being performed. All statistical procedures were calculated by PASW software (Version 18.0; SPSS Inc., Chicago, Illinois, USA), and statistical significance will be determined by a P value less than 0.05 ($P \leq 0.05$).

Chapter IV

Results

The purpose of this study was to collect temporal, linear, and angular kinematics for each gait of the stock breed western pleasure horse in order to compare the variables of the collected and extended jog and the collected and extended lope as well as head position to determine consistency with current rulebooks of major stock breed associations. Additionally, this study sought to determine if the extended jog and lope conform to a more natural way of going for stock breed western pleasure horses, which may reduce the risk of joint injury and trauma than does the collected jog and lope. The current chapter presents the results and includes sections a) collected jog, b) extended jog, c) collected versus extended jog, d) collected lope, e) extended lope, and f) collected versus extended lope.

Collected Jog

Temporal and linear kinematics.

In accordance with past stock breed western pleasure research (Nicodemus and Booker 2007; Nicodemus and Clayton 2003), the collected jog (*n*=6) in the present study had a lateral footfall sequence due to hind limb touchdown followed by the touchdown of the front limb on the ipsilateral side (Figure 4.1). Horses performed the collected jog with a mean stride length of 1.28 ± 0.17 m, duration of 1.91 ± 0.12 s, and frequency of 0.53 ± 0.03 stride/s. Velocity of the collected jog was 0.67 ± 0.01 m/s. Hind step length was 0.55 ± 0.20 m and fore step length was 0.58 ± 0.10 m, each consisting of approximately one half of the total stride length. Consistent with a symmetrical gait, no statistical significance was found between the stance or swing durations of the left and right fore (stance P=0.41; swing P=0.22) or left and right hind (stance P=0.41; swing P=0.50) limbs (Table 4.2 & 4.3). Since the gait is determined to be symmetrical, temporal variables were collapsed for the left and right variables. A significant difference was found between the collapsed variables for fore and hind limb stance (P≤0.05) and swing (P≤0.05) durations (Table 4.2).

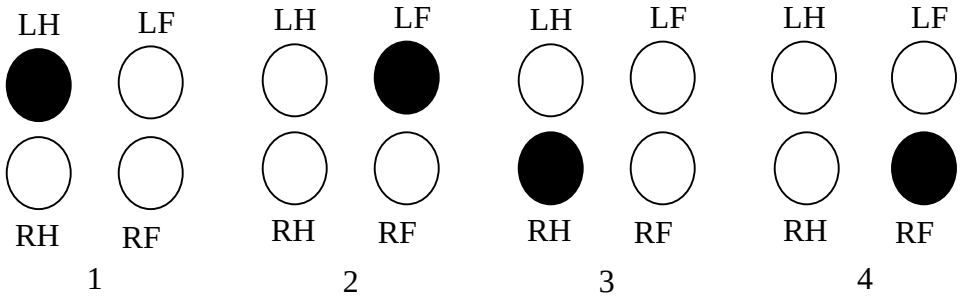

Figure 4.1: Lateral footfall sequence of the collected jog as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Table 4.1: Means (± s.d.) for stance durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the collected jog: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	**RH (s)**	**LH (s)**	**RF (s)**	**LF (s)**
1	1.12 (0.02)[a]	1.10 (0.03)[a]	1.17 (0.06)[b]	1.18 (0.05)[b]
2	1.29 (0.04)[a]	1.31 (0.11)[a]	1.28 (0.02)[b]	1.27 (0.07)[b]
3	1.22 (0.05)[a]	1.20 (0.09)[a]	1.34 (0.17)[b]	1.49 (0.20)[b]
4	1.17 (0.03)[a]	1.19 (0.02)[a]	1.42 (0.05)[b]	1.38 (0.05)[b]
5	1.22 (0.04)[a]	1.24 (0.07)[a]	1.30 (0.09)[b]	1.34 (0.14)[b]
6	1.11 (0.15)[a]	0.78 (0.50)[a]	1.22 (0.12)[b]	1.22 (0.04)[b]
Mean (± s.d.)	1.18 (0.07)[a]	1.14 (0.19)[a]	1.29 (0.09)[b]	1.31 (0.11)[b]
	1.16 (0.12)[a]		1.30 (0.20)[b]	

Means within the same row followed by different letters are significantly different at P≤0.05.

Table 4.2: Means (± s.d.) for swing durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the collected jog: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	RH (s)	LH (s)	RF (s)	LF (s)
1	0.59 (0.02)[a]	0.59 (0.07)[a]	0.52 (0.02)[b]	0.54 (0.04)[b]
2	0.65 (0.02)[a]	0.63 (0.03)[a]	0.64 (0.02)[b]	0.61 (0.04)[b]
3	0.68 (0.05)[a]	0.70 (0.03)[a]	0.64 (0.05)[b]	0.64 (0.05)[b]
4	0.90 (0.06)[a]	0.84 (0.04)[a]	0.63 (0.00)[b]	0.67 (0.03)[b]
5	0.74 (0.04)[a]	0.72 (0.02)[a]	0.65 (0.05)[b]	0.69 (0.05)[b]
6	0.74 (0.07)[a]	1.10 (0.58)[a]	0.63 (0.00)[b]	0.68 (0.07)[b]
Mean (± s.d.)	0.72 (0.11)[a]	0.76 (0.19)[a]	0.62 (0.10)[b]	0.64 (0.10)[b]
	0.74 (0.13)[a]		0.63 (0.05)[b]	

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Lateral advanced placement was 0.88 ± 0.14 s and showed statistical significance (P≤0.05) from diagonal advanced placement, 0.13 ± 0.05 s. Lateral advanced lift-off (0.90 ± 0.12 s) and diagonal advanced lift-off (0.09 ± 0.05 s) also showed statistical significance (P≤0.05). Advanced placements and lift-offs indicate that footfalls of the collected jog occurred as diagonal couplets, instead of diagonal pairs that are dictated by the breed standard, so the gait had a four beat rhythm instead of a two beat rhythm. Only 16.67% of strides showed a diagonal pair during hoof placement and 16.67% during lift-off. The longest limb support phase during the collected jog was diagonal bipedal (57.78 ± 10.48%) followed by quadrupedal (19.26 ± 4.35%), tripedal with two forelimbs (16.72 ± 12.71%), and tripedal with two hindlimbs (6.24 ± 7.28%) (Figure 4.2). As expected, there was no period of suspension found in the collected jog.

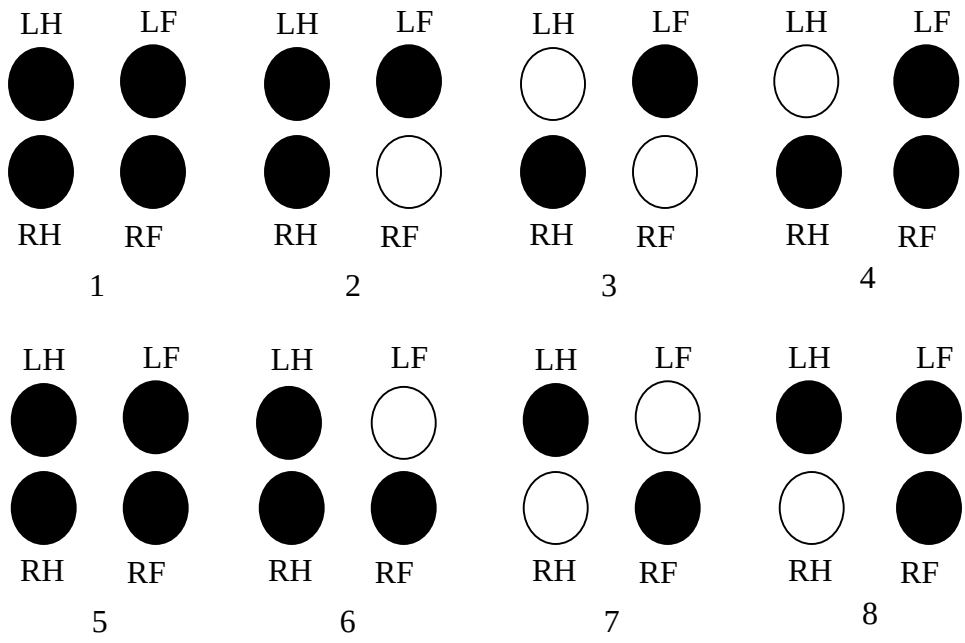

Figure 4.2: Limb support phases of the stock breed western pleasure collected jog. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore). Filled circles represent stance phase while open circles represent swing phase.

Vertical excursion was greatest for the head (0.12 ± 0.05 m) followed by the hind coffin (0.11 ± 0.01 m), fore coffin (0.09 ± 0.01 m), croup (0.08 ± 0.01 m), and withers (0.07 ± 0.01 m) during the collected jog. A statistical difference was not found when comparing the vertical excursions of the withers to croup ($P=0.45$), withers to head ($P=0.94$), or croup to head ($P=0.18$), which indicates that horses exhibited a balanced topline when performing the collected jog and, therefore, conform to breed standards concerning gait performance.

Angular kinematics.

Peak flexion and extension as well as joint range of motion (ROM) for the shoulder, elbow, carpus, fore fetlock, hip, stifle, hock, and hind fetlock joints for collected jog are shown in Table 4.3. The greatest ROM was seen for the hind fetlock followed by the fore fetlock, carpus, and elbow joints; the shoulder joint exhibited the least ROM. Representative fore and hindlimb joint kinematics for horses at the collected jog are presented graphically in Figures 4.3 and 4.4. Graphs were plotted from hoof contact to the next contact of the same hoof as a percent of stride and represent joint flexion or extension during a complete stride. The black vertical line indicates the initiation of stance phase for forelimb graphs and the initiation of swing phase for hindlimb graphs. Upward inclinations in graphs indicate extension of the joint while downward inclinations indicate flexion. Forelimb joint motion graphs indicate that swing phase occurred from 0 – 33% of the stride while the shoulder gradually extended and the elbow, carpus, and fetlock gradually flexed (Figure 4.3). Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints. Stance phase occurred from 34 – 100% of the stride with the fore hoof making contact with the ground at around 33% of stride. Gradual extension of the elbow and carpus and flexion of the shoulder continued throughout stance; peak extension of the fetlock occurred at mid stance.

Hindlimb joint motion graphs indicate that the first 61% of stride was spent in stance phase; the hip gradually extended throughout stance to reach peak extension at late stance (Figure 4.4). The hock reached peak extension at 40% of stride and then gradually flexed to reach peak flexion at mid swing phase. Swing phase occurred from 62 – 100% of the stride while the hip, stifle, and hock gradually flexed. Peak extension of the fetlock occurred during mid stance, and peak flexion occurred during early swing phase.

Table 4.3: Means (± s.d.) for peak flexion and extension joint angles (deg) measured on the flexor side of the joint and range of motion (ROM) (deg) for fore and hindlimbs at the collected jog.

Joint	Peak Flexion (deg)	Peak Extension (deg)	Joint ROM (deg)
Forelimb			
Shoulder	110.04 (7.93)	118.63 (7.54)	8.60 (1.77)
Elbow	93.97 (8.60)	148.67 (6.78)	54.70 (4.87)
Carpus	116.73 (4.75)	181.63 (2.26)	64.90 (4.94)
Fetlock	149.58 (4.34)	228.18 (8.94)	78.61 (7.04)
Hindlimb			
Hip	100.16 (3.82)	115.48 (3.46)	15.32 (1.42)
Stifle	136.81 (7.93)	168.81 (6.90)	32.00 (4.48)
Hock	133.43 (4.98)	167.53 (3.85)	34.10 (4.29)
Fetlock	145.60 (5.32)	226.66 (8.02)	81.06 (8.80)

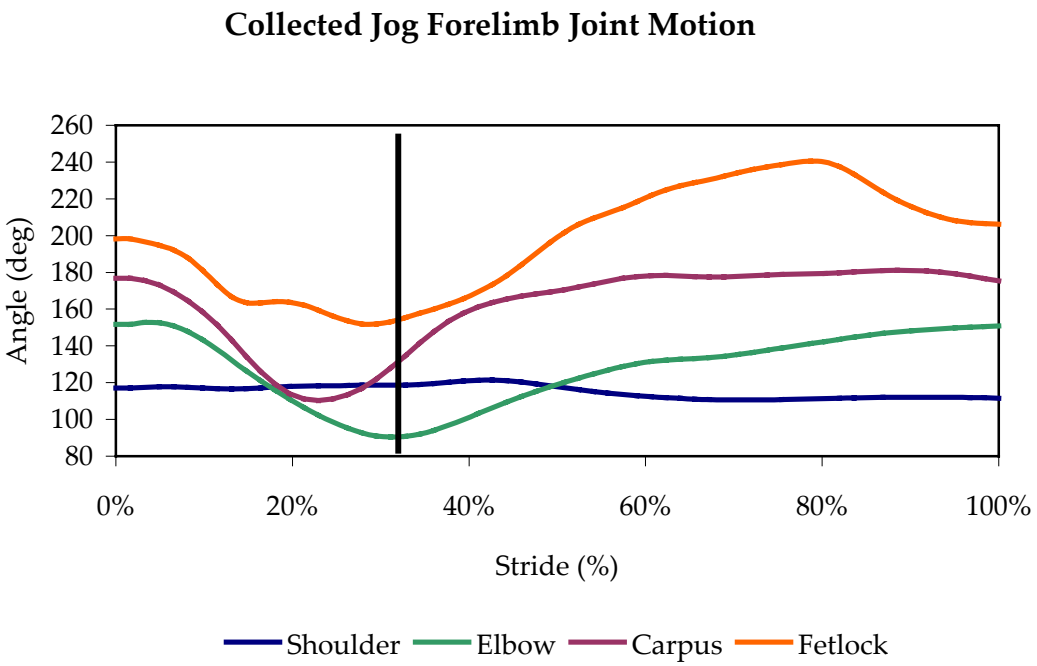

Figure 4.3: Representative forelimb motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the collected jog of the stock breed western pleasure horse. The gait cycle was right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of stance phase.

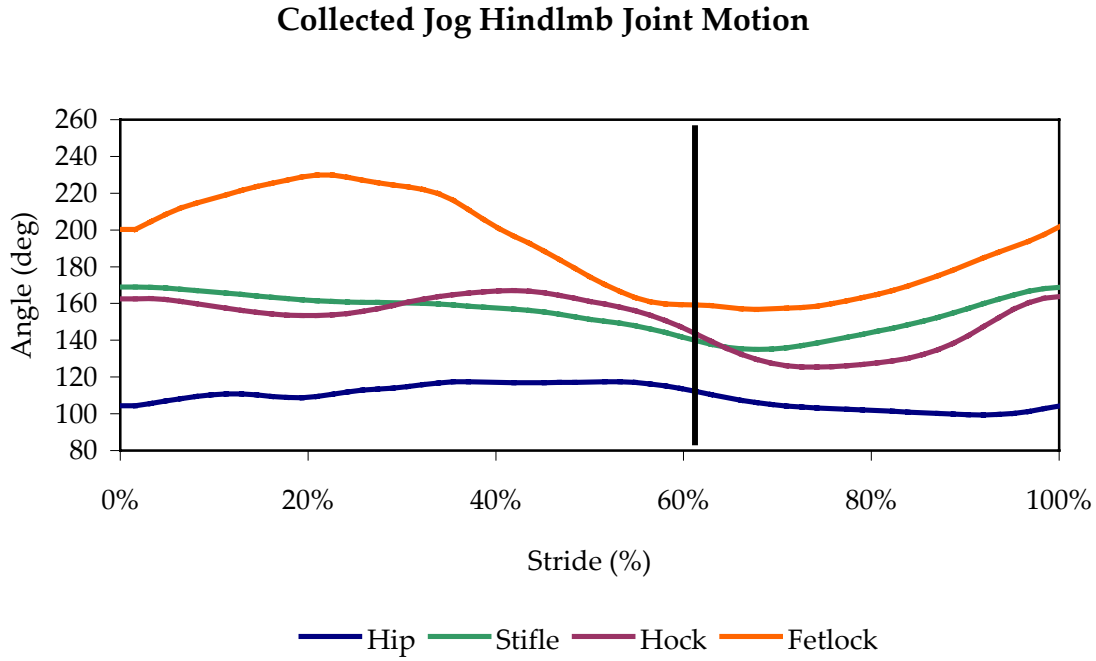

Figure 4.4: Representative hindlimb motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the collected jog of the stock breed western pleasure horse. The gait cycle was right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of swing phase.

Extended Jog

Temporal and linear kinematics.

The extended jog (*n*=6) had a lateral footfall sequence due to hind limb touchdown followed by the touchdown of the front limb on the ipsilateral side (Figure 4.1). Horses performed the extended jog with a mean stride length of 1.42 ± 0.16 m, duration of 1.75 ± 0.08 s, and frequency of 0.57 ± 0.03 stride/s. Velocity of the extended jog was 0.82 ± 0.01 m/s. Hind step length was 0.75 ± 0.13 m and fore step length was 0.65 ± 0.13 m, with hind step length not being

statistically different from fore step length (P=0.28). Consistent with a symmetrical gait, no statistical significance was found between the stance or swing durations of the left and right fore (stance - P=0.36; swing – P=0.52) or left and right hind (stance - P=0.85; swing – P=0.60) limbs (Table 4.4 & 4.5). Since the gait was determined to be symmetrical, temporal variables were collapsed for the left and right variables. A significant difference was found between the collapsed variables for fore and hind limb stance (P≤0.05) and swing (P≤0.05) durations (Table 4.4 & 4.5).

Table 4.4: Means (± s.d.) for stance durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the extended jog: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	RH (s)	LH (s)	RF (s)	LF (s)
1	1.01 (0.05)[a]	1.01 (0.04)[a]	1.07 (0.07)[b]	1.03 (0.00)[b]
2	1.11 (0.04)[a]	1.18 (0.05)[a]	1.11 (0.05)[b]	1.55 (0.02)[b]
3	0.99 (0.05)[a]	1.03 (0.00)[a]	1.11 (0.04)[b]	1.07 (0.00)[b]
4	1.05 (0.05)[a]	1.05 (0.07)[a]	1.19 (0.08)[b]	1.22 (0.10)[b]
5	0.98 (0.02)[a]	0.92 (0.02)[a]	1.08 (0.07)[b]	1.09 (0.15)[b]
6	1.00 (0.00)[a]	0.97 (0.03)[a]	1.03 (0.00)[b]	1.08 (0.04)[b]
Mean (± s.d.)	1.02 (0.05)[a]	1.03 (0.09)[a]	1.10 (0.05)[b]	1.12 (0.20)[b]
	1.02 (0.07)[a]		1.13 (0.11)[b]	

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.5: Means (± s.d.) for swing durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the extended jog: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	RH (s)	LH (s)	RF (s)	LF (s)
1	0.62 (0.02)[a]	0.61 (0.04)[a]	0.57 (0.03)[b]	0.54 (0.02)[b]
2	0.64 (0.05)[a]	0.68 (0.04)[a]	0.67 (0.06)[b]	0.69 (0.04)[b]
3	0.73 (0.03)[a]	0.69 (0.02)[a]	0.64 (0.04)[b]	0.63 (0.00)[b]
4	0.82 (0.04)[a]	0.83 (0.00)[a]	0.68 (0.02)[b]	0.67 (0.03)[b]
5	0.75 (0.02)[a]	0.77 (0.00)[a]	0.62 (0.02)[b]	0.69 (0.02)[b]
6	0.77 (0.03)[a]	0.81 (0.05)[a]	0.69 (0.02)[b]	0.70 (0.00)[b]
Mean (± s.d.)	0.72 (0.08)[a]	0.73 (0.09)[a]	0.64 (0.05)[b]	0.65 (0.06)[b]
	0.73 (0.08)[a]		0.65 (0.05)[b]	

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Lateral advanced placement was 0.89 ± 0.06 s and showed statistical significance (P≤0.05) from diagonal advanced placement, 0.06 ± 0.03 s. Lateral advanced lift-off (0.88 ± 0.05 s) and diagonal advanced lift-off (0.07 ± 0.05 s) also showed statistical significance (P≤0.05). Advanced placements and lift-offs indicate that footfalls of the extended jog occurred as diagonal couplets, instead of diagonal pairs as dictated by the breed standard. This footfall sequence yielded a gait with a four beat rhythm. Only 33.33% of strides showed a diagonal pair during hoof placement and 33.33% during lift-off, which again indicates that the extended jog was not performed with diagonal pairs and does not conform to the breed standard. The longest limb support phase during the extended jog was diagonal bipedal (70.20 ± 7.37%) followed by quadrupedal (14.07 ± 5.47%), tripedal with two forelimbs (13.31 ± 12.68%), and tripedal with

two hindlimbs (2.41 ± 4.80%) (Figure 4.2). As expected, there was no period of suspension found in the extended jog.

Vertical excursion was greatest for the withers (0.16 ± 0.20 m) followed by the head (0.12 ± 0.05 m), hind coffin (0.11 ± 0.01 m), fore coffin (0.10 ± 0.02 m), and the croup (0.10 ± 0.01 m) during the extended jog. A statistical difference was not found when comparing the vertical excursions of the withers to croup (P=0.99), withers to head (P=0.25), or croup to head (P=0.31), which indicates that horses exhibited a balanced topline when performing the extended jog and, therefore, conform to breed standards concerning gait performance.

Angular kinematics.

Peak flexion and extension as well as joint range of motion for the shoulder, elbow, carpus, fore fetlock, hip, stifle, hock, and hind fetlock joints for extended jog are shown in Table 4.6. The greatest ROM was seen for the hind fetlock followed by the fore fetlock, carpus, and elbow joints; the shoulder joint exhibited the least ROM. Representative fore and hindlimb joint kinematics for horses at the extended jog are graphically presented in Figures 4.5 and 4.6. Graphs were plotted from consecutive right hind touchdowns as a percent of stride and represent joint flexion or extension during a complete stride. Upward inclinations in graphs indicate extension of the joint while downward

inclinations indicate flexion. The black vertical line indicates the initiation of stance phase for forelimb graphs and the initiation of swing phase for hindlimb graphs. Forelimb joint motion graphs indicate that swing phase occurred from 0 – 37% of the stride while the shoulder gradually extended and the elbow, carpus, and fetlock gradually flexed (Figure 4.5). Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints. Stance phase occurred from 38 – 100% of the stride with the fore hoof making contact with the ground at around 37% of stride. Gradual extension of the elbow and carpus and flexion of the shoulder continued throughout stance; peak extension of the fetlock occurred at mid stance.

Hindlimb joint motion graphs indicate that the first 59% of stride was spent in stance phase; the hip gradually extended throughout stance to reach peak extension at late stance (Figure 4.6). The hock reached peak extension at 45% of stride and then gradually flexed to reach peak flexion at early swing phase. Swing phase occurred from 60 – 100% of the stride while the shoulder, stifle, and hock gradually flexed. Peak extension of the fetlock occurred during mid stance, and peak flexion occurred during early swing phase just prior to peak flexion of the stifle and hock.

Table 4.6: Means (± s.d.) for peak flexion and extension joint angles (deg) measured on the flexor side of the joint and range of motion (ROM) (deg) for fore and hindlimbs at the extended jog.

Joint	Peak Flexion (deg)	Peak Extension (deg)	Joint ROM (deg)
Forelimb			
Shoulder	110.32 (7.15)	118.48 (7.14)	8.16 (1.59)
Elbow	93.12 (8.09)	148.48 (6.59)	55.37 (4.07)
Carpus	117.15 (4.50)	181.84(2.71)	64.70 (4.68)
Fetlock	151.07 (5.18)	231.27 (9.45)	80.20 (6.77)
Hindlimb			
Hip	99.99 (4.29)	116.21 (3.56)	16.22 (1.55)
Stifle	135.44 (7.88)	172.60 (6.54)	37.16 (4.53)
Hock	131.35 (6.13)	167.36 (4.35)	36.01 (4.38)
Fetlock	144.62 (4.96)	232.49 (10.11)	87.87 (9.77)

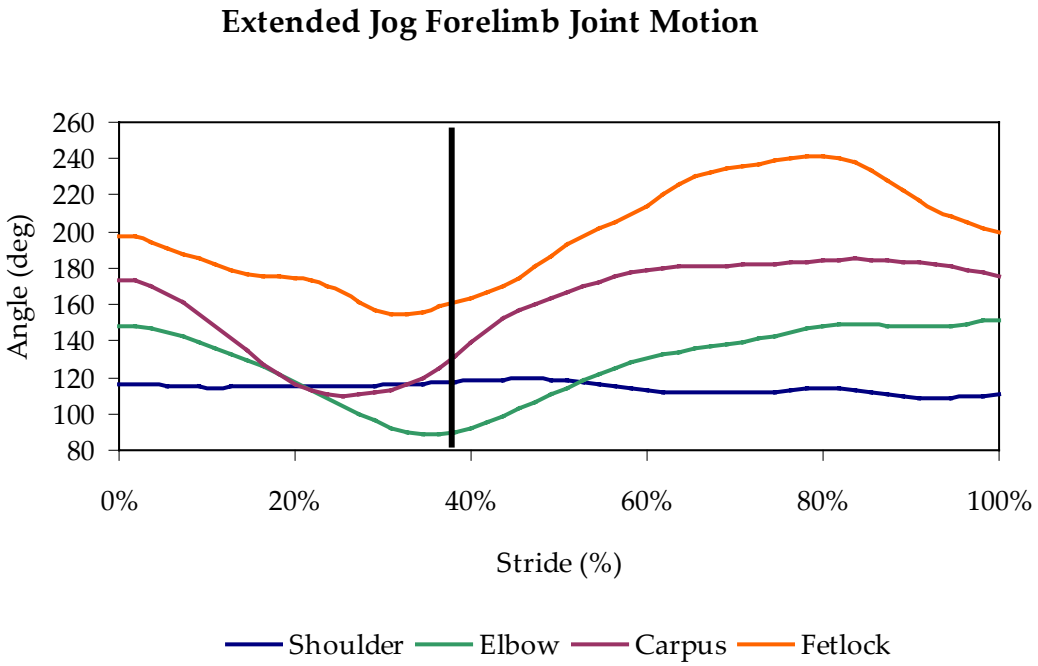

Figure 4.5: Representative forelimb motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the extended jog of the stock breed western pleasure horse. The gait cycle was right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of stance phase.

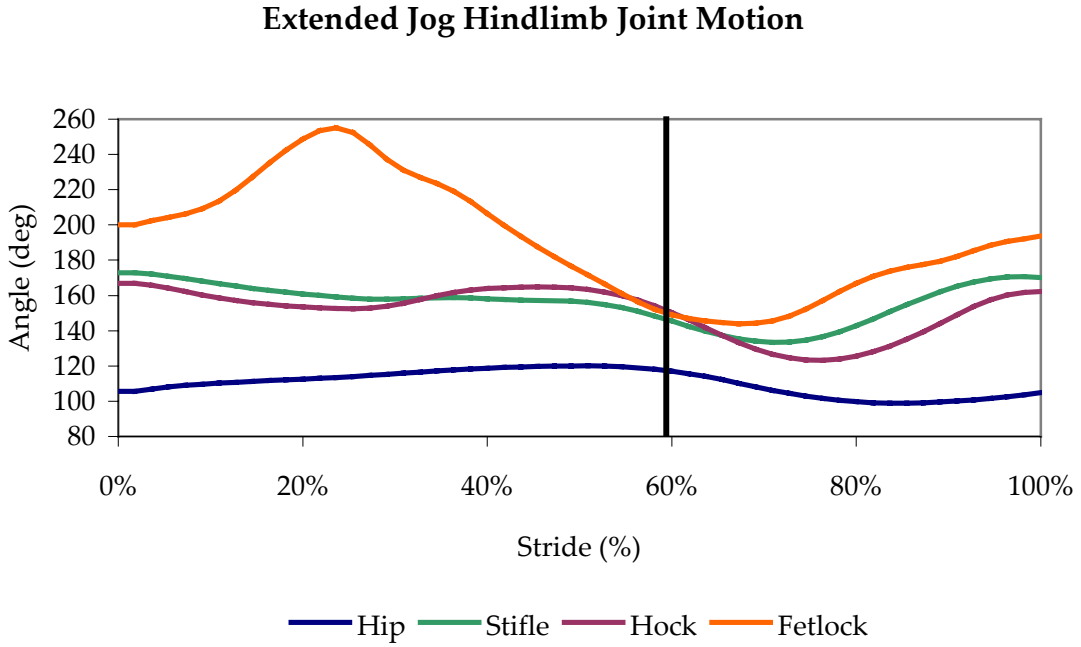

Figure 4.6: Representative hindlimb motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the extended jog of the stock breed western pleasure horse. The gait cycle was right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of stance phase.

Collected versus Extended Jog

Temporal and linear kinematics.

Both the collected and extended jog exhibited a lateral footfall sequence (Figure 4.1); however, due to the large number of variables analyzed and the relatively small sample size, there were insufficient residual degrees of freedom to perform a multivariate ANOVA for either the temporal or linear variables. Therefore, the univariate results are presented cautiously and with the

understanding of the risk of type 1 errors being increased due to the number of comparisons being performed. Although a significance level of 95% was chosen for statistical comparisons, all variables that were deemed significant had a univariate P value less than or equal to 0.009. Therefore, the risk of type 1 errors is acceptably small, even considering the number of comparisons being performed.

Stride length was longer for the extended jog and indicated significant statistical significance ($P \leq 0.05$) from the collected jog (Table 4.7). Horses also performed the extended jog with a velocity that was statistically significant ($P \leq 0.05$) from the velocity of the collected jog. As well, vertical excursion of the hip indicated statistical significance ($P \leq 0.05$). The display of greater vertical excursion at the hip when at the extended jog than when performing the collected jog indicates that the extended jog exhibited greater lift in the hindlimbs than did the collected jog. Stride duration, diagonal advanced placement and bipedal limb support indicated temporal statistical significance ($P \leq 0.05$) when compared between the collected and extended jog. The shorter time seen for diagonal advanced placement when performing the extended than when performing the collected jog indicates that diagonal pairs moved more closely together in time during the extended jog than in the collected jog. Additionally, the increase in percentage of stride spent in diagonal bipedal limb

support at extended jog infers that horses were exhibiting a "more diagonal" gait than seen in the collected jog. No statistical significance was found between the collected and extended jogs for the linear variables of vertical excursions for the head (P=0.61), withers (P=0.33), fore coffin (P=0.38), or hind coffin (P=0.68); no statistical significance was found for the temporal variables of diagonal advanced lift-off (P=0.34), lateral advanced placement (P=0.15), lateral advanced lift-off (P=0.07), or limb support phases of tripedal with two hindlimbs (P=0.31), tripedal with two forelimbs (P=0.46), or quadrupedal (P=0.10). Similarities and differences in temporal and linear kinematics between the collected and extended jog were congruent with the scientific, breed association, and visual interpretation of the gait due to the collected jog being a slower, less forward moving gait than the extended jog.

Table 4.7: Statistically significant different (P≤0.05) means (± s.d.) for temporal and linear variables of stride length (m), stride duration (s), velocity (m/s), vertical excursion of the hip (m), diagonal advanced placement (s), and diagonal bipedal limb support for stock breed western pleasure horses at the collected and extended jog (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

	Collected Jog	**Extended Jog**
Stride Length (m)	1.28 (0.17)	1.42 (0.16)
Stride Duration (s)	1.91 (0.12)	1.75 (0.08)
Velocity (m/s)	0.67 (0.01)	0.82 (0.01)
Vertical Excursion of the Hip (m)	0.08 (0.01)	0.10 (0.01)
Diagonal Advanced Placement (s)	0.13 (0.05)	0.06 (0.03)
Diagonal Bipedal Limb Support (%)	57.78 (10.48)	70.20 (7.37)

Angular kinematics.

Due to the large number of variables analyzed and the relatively small sample size, there were insufficient residual degrees of freedom to perform a multivariate ANOVA for the angular variables. Therefore, the univariate results are presented cautiously and with the understanding of the risk of type 1 errors being increased due to the number of comparisons being performed. Although a significance level of 95% was chosen for statistical comparisons, all variables that were deemed significant had a univariate P value less than or equal to 0.02. Therefore, the risk of type 1 errors is acceptably small, even considering the number of comparisons being performed.

Angular variables indicating statistical significance (P≤0.05) between the collected and extended jog include peak hip extension and peak stifle flexion,

extension, and ROM (Table 4.8). Differences in these joints seem to indicate that the distinction between the collected and extended jog are most likely due to variation in hindlimb kinematics. No statistical significance was seen for peak extension of the shoulder (P=0.69), carpus (P=0.36), or hock (P=0.38); peak flexion of the shoulder (P=0.42), carpus (P=0.27), hip (P=0.72), or hock (P=0.22); or ROM of the shoulder (P=0.20), carpus (P=0.60), hip (P=0.07), or hock (P=0.07) joints when compared between the collected and extended jogs. Motion graphs indicated the same trends in joint motion between the collected and extended jogs (Figures 4.3 – 4.6).

Table 4.8: Statistically significant (P≤0.05) means (± s.d.) for angular variables (deg) of peak flexion, peak extension, and range of motion (ROM) for stock breed western pleasure horses at the collected and extended jog.

	Collected Jog	**Extended Jog**
Hip		
Peak Extension	115.48 (3.46)	116.21 (3.56)
Stifle		
Peak Flexion	136.81 (7.93)	135.44 (7.88)
Peak Extension	168.81 (6.90)	172.60 (6.54)
ROM	32.00 (4.48)	37.16 (4.53)

Collected Lope

Right lead temporal and linear kinematics.

Horses performed the right lead collected lope with right limbs on the leading side of the body and left limbs on the trailing side; the right lead collected lope (n=6) had a diagonal footfall sequence of trailing hind (left hind) followed by leading hind (right hind) and trailing fore (left fore), working as a diagonal pair, followed by the leading forelimb (right fore) (Figure 4.7). Disuniting of the diagonal pair was seen in 72.22% of strides with 61.54% of those strides showing a diagonal footfall sequence as the leading hindlimb (right hind) made contact with the ground an instant before the trailing fore (left fore). Disuniting of the diagonal pair gave the lope a four beat rhythm, which does not conform to the breed standard for gait performance.

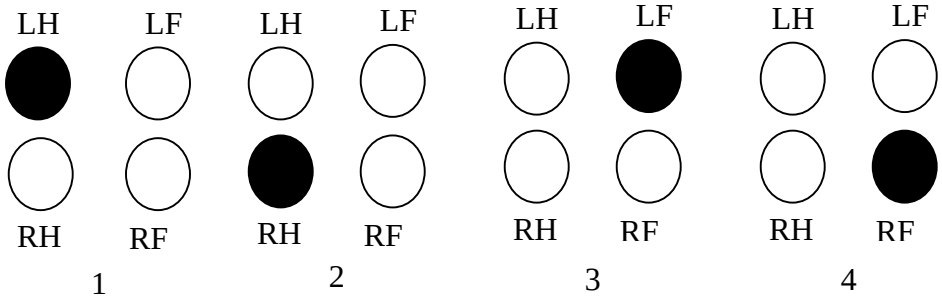

Figure 4.7: Diagonal footfall sequence of the right lead collected lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Mean stride length was 1.57 ± 0.18 m when calculated from consecutive right hind down placements and 1.44 ± 0.11 m when calculated from consecutive left hind down placements and approached statistical significance when compared (P=0.05). This longer stride length seen for the right hind when compared to the left hind seems visually counterintuitive because the left hind, as the trailing hind, appears to have the longer stride length. Stride duration indicated a significant statistical difference (P≤0.05) when calculated from consecutive right hind down placements (1.35 ± 0.07 s) than when calculated from consecutive left hind down placements (1.37 ± 0.06 s). These measures indicate that while the stride length was longer when calculated from right hind to right hind than left hind to left hind, stride duration was shorter when calculated from right hind to right hind than left hind to left hind and indicates that the lope is performed according to breed and scientific standards as an asymmetrical gait. Stride frequency also showed statistical significance (P≤0.05) when calculated from consecutive right hind down placements (0.74 ± 0.04 stride/s) than when calculated from consecutive left hind down placements (0.73 ± 0.03 stride/s). Horses performed the right lead collected lope with a velocity of 1.16 ± 0.15 m/s. Hind step length was 0.60 ± 0.19 m and fore step length was 0.59 ± 0.15 m, each consisting of approximately one half of the total stride length.

Statistical significance was found between the stance and swing durations of the left and right hind (P≤0.05), and interestingly, the only swing duration comparison not yielding statistical significance (P=0.14) was between the right and left fore limbs (Table 4.9 & 4.10). Statistical significance was found between left and right lateral advanced placement, diagonal advanced placement, and diagonal advanced lift-off (P≤0.05) (Table 4.11). Significant differences observed between left and right variables of hind stance and swing durations as well as the differences between lateral and diagonal advanced placement and lift-off indicated that the lope was asymmetrical as dictated by both scientific and breed definitions.

Table 4.9: Means (± s.d.) for stance durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the right lead collected lope: right hind (RH) and left hind (LH).

Subject	RH (s)	LH (s)
1	0.83 (0.03)[a]	0.72 (0.02)[b]
2	0.89 (0.02)[a]	0.83 (0.03)[b]
3	0.81 (0.05)[a]	0.75 (0.02)[b]
4	0.73 (0.03)[a]	0.69 (0.04)[b]
5	0.81 (0.02)[a]	0.72 (0.07)[b]
6	0.81 (0.04)[a]	0.75 (0.05)[b]
Mean (± s.d.)	0.81 (0.05)[a]	0.75 (0.05)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.10: Means (± s.d.) for swing durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the right lead collected lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	RH (s)	LH (s)	RF (s)	LF (s)
1	0.54 (0.02)[a]	0.69 (0.04)[b]	0.82 (0.04)[c]	0.81 (0.02)[c]
2	0.56 (0.04)[a]	0.63 (0.06)[b]	0.84 (0.04)[c]	0.82 (0.02)[c]
3	0.49 (0.02)[a]	0.56 (0.04)[b]	0.67 (0.15)[c]	0.83 (0.00)[c]
4	0.52 (0.02)[a]	0.61 (0.02)[b]	0.72 (0.02)[c]	0.77 (0.00)[c]
5	0.57 (0.00)[a]	0.65 (0.02)[b]	0.74 (0.02)[c]	0.81 (0.02)[c]
6	0.57 (0.03)[a]	0.63 (0.03)[b]	0.83 (0.00[c]	0.88 (0.02)[c]
Mean (± s.d.)	0.54 (0.03)[a]	0.62 (0.04)[b]	0.77 (0.07)[c]	0.82 (0.04)[c]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.11: Means (± s.d.) for left and right lateral and diagonal advanced placements and lift-offs (s) for stock breed western pleasure horses at the right lead collected lope: left lateral = LF-LH, right lateral = RF-RH, left diagonal = RF-LH, and right diagonal = LF-RH.

	Left	Right
Lateral Advanced Placement (s)	0.40 (0.05)[a]	0.49 (0.04)[b]
Diagonal Advanced Placement (s)	0.82 (0.15)[a]	0.19 (0.39)[b]
Lateral Advanced Lift-off (s)	0.49 (0.04)[a]	0.49 (0.06)[a]
Diagonal Advanced Lift-off (s)	0.85 (0.18)[a]	0.09 (0.12)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

During the right lead collected lope, horses exhibited eight different limb support phases: 1) diagonal bipedal (RF-LH), 2) unipedal hind (LH), 3) bipedal hind (RH-LH), 4) tripedal with two hindlimbs (LF-RH-LH), 5) diagonal bipedal (LF-RH), 6) tripedal with two forelimbs (RF-LF-RH), 7) lateral bipedal (RF-RH), and 8) unipedal fore (RF) (Figure 4.8). However, some horses displayed alternate limb support strategies in place of phases three and seven. Two horses

exchanged phase three, one stride each, with lateral bipedal (LF-LH) support; four horses exchanged phase seven, 2.25 ± 0.96 strides each, with bipedal forelimb (RF-LF) support. Tripedal with two hindlimb (LF-RH-LH) support occupied the greatest percent of stride followed closely by diagonal bipedal (RF-LH), tripedal with two forelimbs (RF-LF-RH), diagonal bipedal (LF-RH), unipedal fore (RF), unipedal hind (LH), bipedal hind (RH-LH), and lateral bipedal (RF-RH) (Table 4.12). There was no period of suspension or quadrupedal limb support during the right lead collected lope.

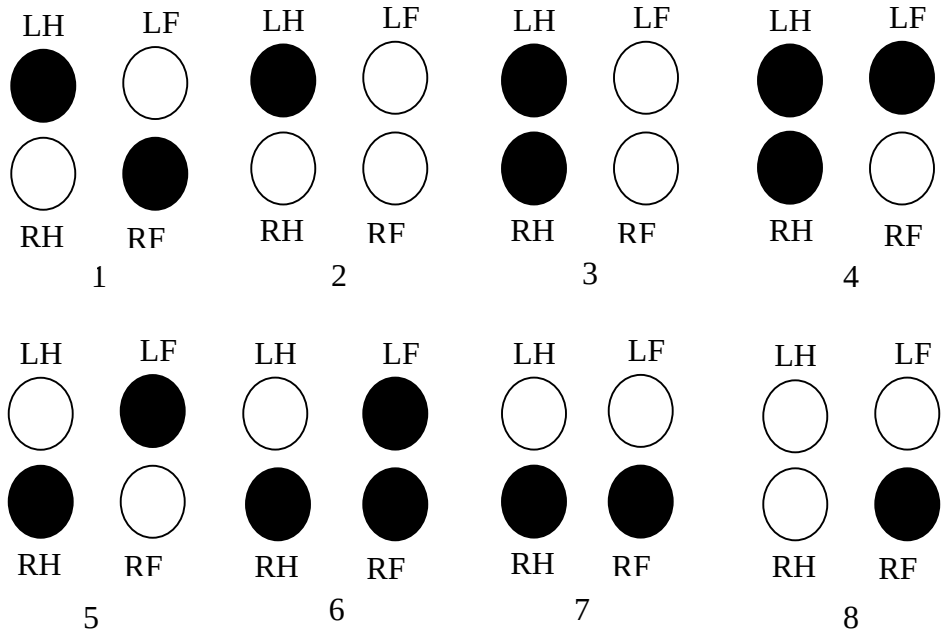

Figure 4.8: Limb support phases of the right lead collected lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Table 4.12: Means (± s.d.) for limb support phases as a percent (%) of stride for stock breed western pleasure horses at the right lead collected lope.

Limb Support Phase	**Percent of Stride (%)**
Tripedal with two Hindlimbs (LF-RH-LH)	22.54 (3.26)
Diagonal Bipedal (RF-LH)	22.35 (3.41)
Tripedal with two Forelimbs (RF-LF-RH)	22.14 (2.04)
Diagonal Bipedal (LF-RH)	11.74 (4.87)
Unipedal Fore (RF)	9.20 (2.16)
Unipedal Hind (LH)	5.74 (2.71)
Bipedal Fore (LF-RF)*	2.76 (2.69)
Bipedal Hind (LH-RH)	2.05 (1.36)
Lateral Bipedal (RF-RH)	1.18 (1.81)
Lateral Bipedal (LF-LH)*	0.30 (0.46)

* indicates alternate limb support strategies utilized by some horses.

Vertical excursion was greatest for the head (0.41 ± 0.09 m) followed by the croup (0.40 ± 0.08 m), trailing hind (LH) coffin (0.15 ± 0.05 m), leading fore (RF) coffin (0.15 ± 0.02 m), trailing fore (LF) coffin (0.15 ± 0.03 m), leading hind (RH) coffin (0.13 ± 0.02 m), and the withers (0.12 ± 0.01 m) during the right lead collected lope. A statistical difference was found when comparing the vertical excursions of the head to withers and withers to croup ($P \leq 0.05$) but not when comparing the croup to head ($P = 0.73$), which indicates that horses did not exhibit a balanced topline when performing the right lead collected lope and do not conform to the breed standard concerning gait performance.

Right lead angular kinematics.

Peak flexion and extension as well as joint range of motion (ROM) for shoulder, elbow, carpus, fore fetlock, hip, stifle, hock, and hind fetlock joints for the right lead collected lope are shown in Table 4.13. The greatest ROM was seen for the fetlock joint of all four limbs followed by the right and left carpus joints; the shoulder joints exhibited the least ROM.

Table 4.13: Means (± s.d.) for peak flexion and extension joint angles (deg) measured on the flexor side of the joint and range of motion (ROM) (deg) for fore and hindlimbs at the right lead collected lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Joint	Peak Flexion (deg)	Peak Extension (deg)	Joint ROM (deg)
Leading Forelimb (RF)			
Shoulder	113.26 (10.05)	123.46 (8.92)	10.21 (1.61)
Elbow	87.45 (10.61)	148.23 (9.53)	60.78 (3.59
Carpus	109.77 (6.76)	181.98 (2.97)	72.21 (5.02)
Fetlock	143.51 (5.93)	229.28 (11.19)	85.76 (9.44)
Trailing Forelimb (LF)			
Shoulder	108.09 (7.89)	117.87 (6.66)	9.78 (2.59)
Elbow	100.28 (9.43)	144.89 (6.00)	44.62 (4.73)
Carpus	121.82 (5.83)	182.75 (2.81)	60.93 (5.87)
Fetlock	144.97 (10.51)	233.44 (10.34)	88.47 (10.48)
Leading Hindlimb (RH)			
Hip	100.44 (3.25)	116.60 (5.64)	16.16 (2.49)
Stifle	139.94 (8.42)	176.53 (5.07)	36.59 (6.52)
Hock	134.38 (4.19)	167.25 (3.67)	32.87 (3.14)
Fetlock	149.26 (7.72)	233.80 (13.37)	84.53 (17.73)
Trailing Hindlimb (LH)			
Hip	102.95 (3.82)	121.41 (3.39)	18.45 (3.70)
Stifle	136.35 (7.78)	167.88 (10.05)	31.54 (4.69)
Hock	137.74 (6.24)	168.37 (4.25)	30.62 (6.75)
Fetlock	150.03 (11.88)	233.38 (8.52)	83.35 (17.76)

Representative fore and hindlimb joint kinematics for horses at the right lead collected lope are graphically presented in Figures 4.9 through 4.12. Graphs were plotted from hoof contact to the next contact of the same hoof as a percent of stride and represent joint flexion or extension during a complete stride; the black vertical line indicates the initiation of swing phase. Upward inclinations in graphs indicate extension of the joint while downward inclinations indicate flexion. Leading forelimb (right fore) joint motion graphs indicate that stance phase occurred from 0 – 50% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.9). Swing phase occurred from 51 – 100% of the stride while the elbow, carpus, and fetlock gradually flexed. The shoulder reached peak flexion at mid swing; peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints.

Trailing forelimb (left fore) joint motion graphs indicate that stance phase occurred from 0 – 47% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.10). The shoulder reached peak flexion at mid stance and then gradually extended throughout the remainder of the stride. Swing phase occurred from 48 – 100% of the stride during which time the elbow, carpus, and fetlock gradually flexed. Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints.

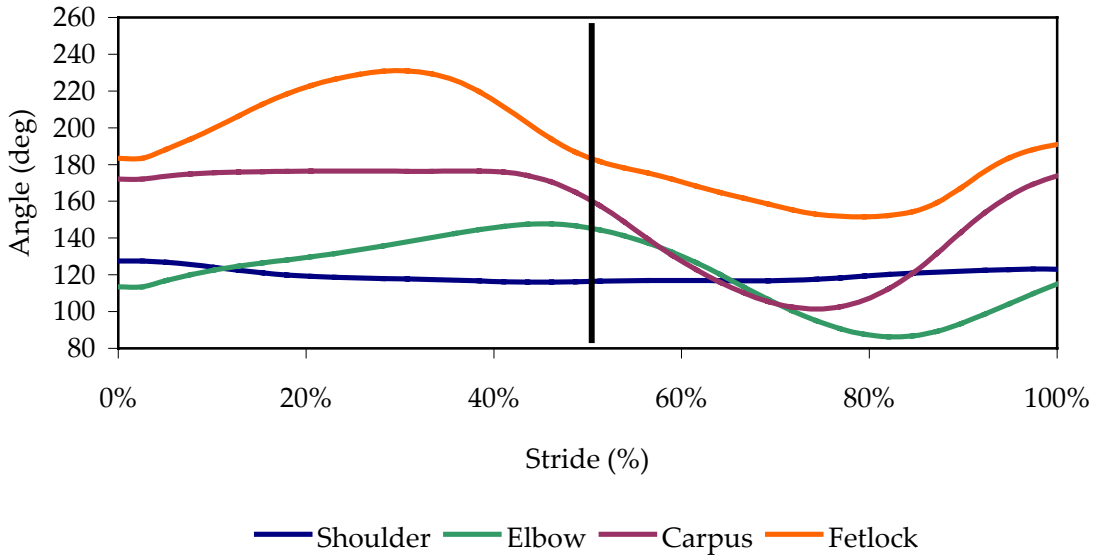

Figure 4.9: Representative leading forelimb (right fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead collected lope of the stock breed western pleasure horse. The gait cycle was right fore hoof contact to the next contact of the right fore hoof, and the black vertical line indicates the initiation of swing phase.

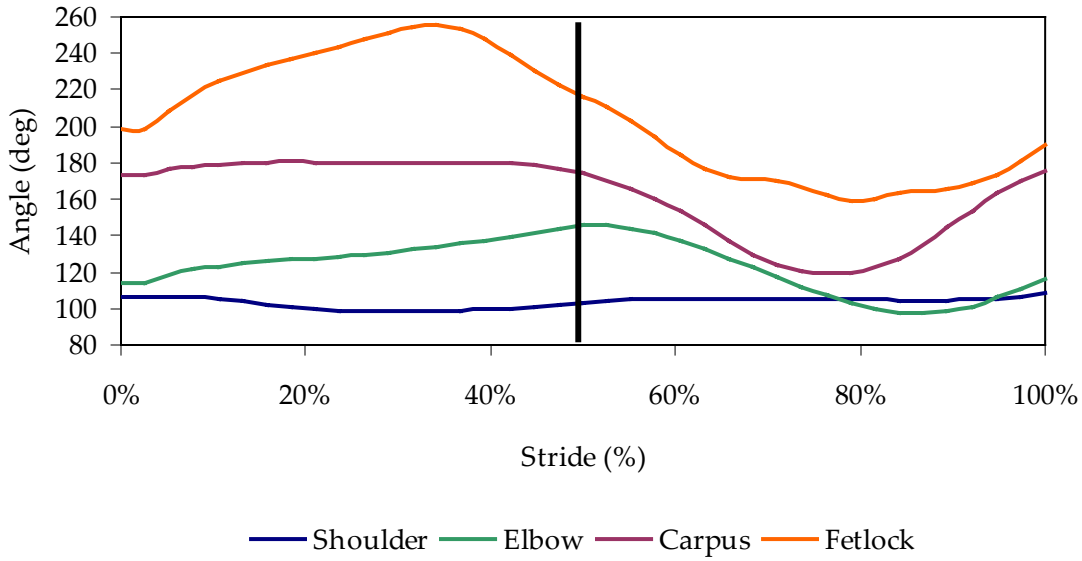

Figure 4.10: Representative trailing forelimb (left fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead collected lope of the stock breed western pleasure horse. The gait cycle was left fore hoof contact to the next contact of the left fore hoof, and the black vertical line indicates the initiation of swing phase.

Leading hindlimb (right hind) joint motion graphs indicate that stance phase occurred from 0 – 53% of stride during which the stifle, and hock gradually flexed (Figure 4.11). The hip reached peak extension at late stance and then gradually flexed throughout the stride; the fetlock reached peak flexion in mid stance and then gradually extended throughout the stride. Swing phase occurred from 54 – 100% of the stride with the stifle and hock indicating double

peaks of extension one in early swing and one in late swing. The fetlock reached peak flexion in early swing.

Trailing hindlimb (left hind) joint motion graphs indicate that stance phase occurred from 0 – 48% of stride during which the stifle and hock gradually flexed and then extended to reach peak extension at late stance (Figure 4.12). The fetlock reached peak extension during early stance. The hip reached peak extension at 25% of stride and then gradually flexed throughout the stride. Swing phase occurred from 49 – 100% of the stride while the stifle, hock, and fetlock gradually flexed with peak flexion of the fetlock occurring prior to peak flexion of the stifle and hock joints.

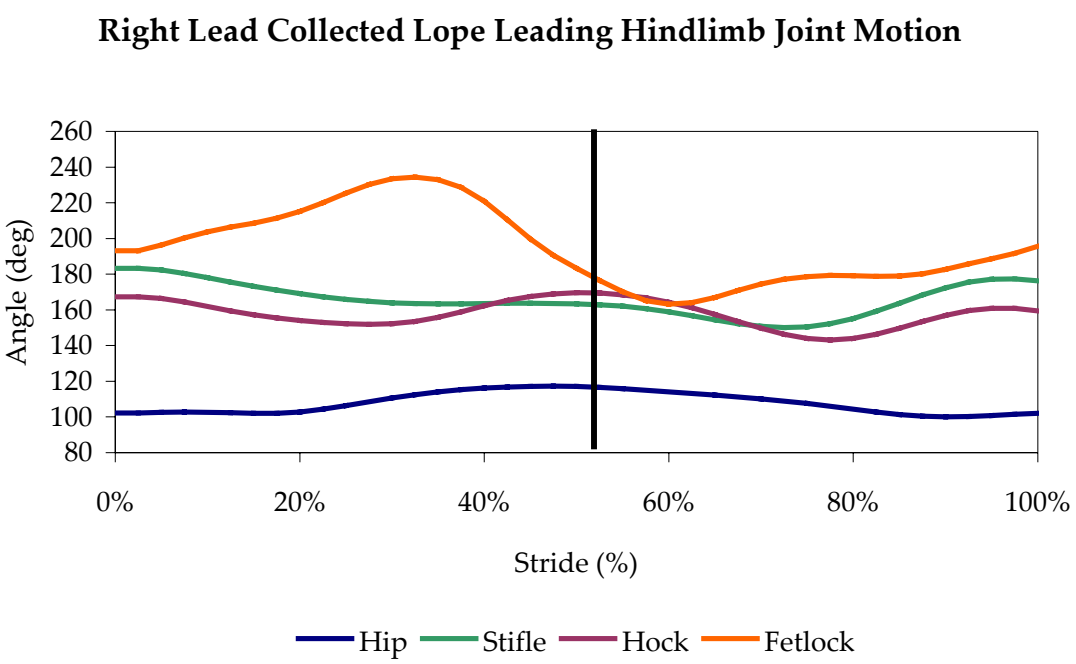

Figure 4.11: Representative leading hindlimb (right hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead collected lope of the stock breed western pleasure horse. The gait cycle was right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of swing phase.

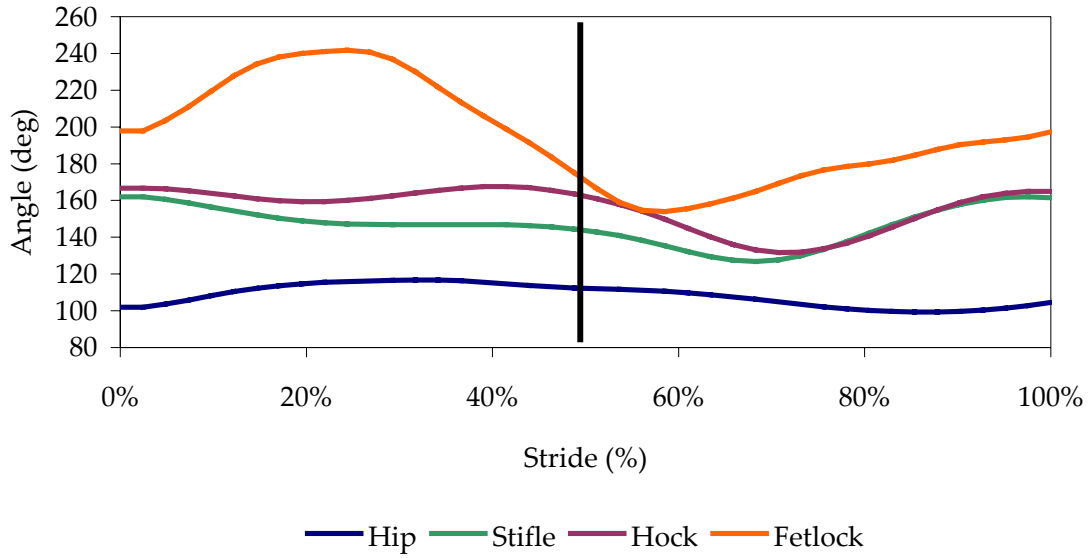

Figure 4.12: Representative trailing hindlimb (left hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead collected lope of the stock breed western pleasure horse. The gait cycle was left hind hoof contact to the next contact of the left hind hoof, and the black vertical line indicates the initiation of swing phase.

Left lead temporal and linear kinematics.

Horses performed the left lead collected lope with left limbs on the leading side of the body and right limbs on the trailing side; in accordance with past stock breed western pleasure research (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a), the left lead collected lope (n=6) had a lateral footfall sequence of trailing hind (right hind) followed by trailing fore (right fore) and leading hind (left hind), working as a diagonal pair, followed by the leading forelimb (left fore) (Figure 4.13). Disuniting of the diagonal pair was seen in

77.78% of strides with 71.43% of those strides showing a lateral footfall sequence as the trailing forelimb (right fore) made contact with the ground an instant before the leading hindlimb (left hind). Disuniting of the diagonal pair gave the lope a four beat rhythm, which does not conform to the breed standard for gait performance. Horses performed the left lead collected lope with a mean stride length of 1.50 ± 0.17 m, stride duration of 1.39 ± 0.08 s, stride frequency of 0.72 ± 0.04 stride/s, and velocity of 1.09 ± 0.13 m/s. No statistically significant difference was found between stride length (P=0.35), duration (P=0.61), or frequency (P=0.64) when calculated from consecutive right hind placements than when calculated from consecutive left hind placements. Hind step length was 0.82 ± 0.29 m and fore step length was 0.60 ± 0.35 m, with hind step length making up a greater percent of the stride.

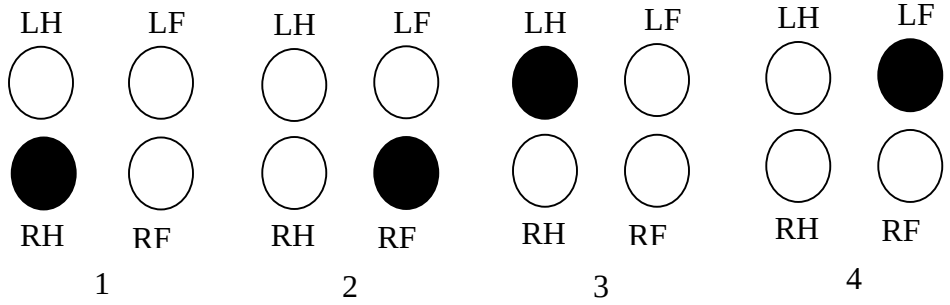

Figure 4.13: Lateral footfall sequence of the left lead collected lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Statistical significance was found between the stance and swing durations of the left and right hind (P≤0.05), swing duration of the left fore and left hind, and swing duration of the right fore and left hind, indicating that the diagonal pair exhibited significantly different swing times (Table 4.14 & 4.15). Statistical significance was found between left and right diagonal advanced placements and lift-offs (P≤0.05) (Table 4.16). Significant differences observed between left and right variables of hind stance and swing durations and diagonal advanced placements and lift-offs indicated that the lope was asymmetrical as dictated by both scientific and breed definitions.

Table 4.14: Means (± s.d.) for stance durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the left lead collected lope: right hind (RH) and left hind (LH).

Subject	RH (s)	LH (s)
1	0.64 (0.02)[a]	0.90 (0.06)[b]
2	0.81 (0.02)[a]	0.96 (0.05)[b]
3	0.74 (0.02)[a]	0.81 (0.02)[b]
4	0.70 (0.03)[a]	0.77 (0.03)[b]
5	0.71 (0.04)[a]	0.84 (0.04)[b]
6	0.80 (0.00)[a]	0.81 (0.10)[b]
Mean (± s.d.)	0.73 (0.06)[a]	0.85 (0.07)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.15: Means (± s.d.) for swing durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the left lead collected lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	RH (s)	LH (s)	RF (s)	LF (s)
1	0.77 (0.00)[a]	0.52 (0.05)[b]	0.67 (0.15)[b]	0.62 (0.18)[ac]
2	0.66 (0.07)[a]	0.62 (0.07)[b]	0.83 (0.06)[b]	0.90 (0.03)[ac]
3	0.53 (0.00)[a]	0.48 (0.02)[b]	0.80 (0.03)[b]	0.76 (0.05)[ac]
4	0.61 (0.02)[a]	0.57 (0.03)[b]	0.69 (0.20)[b]	0.69 (0.14)[ac]
5	0.70 (0.06)[a]	0.56 (0.05)[b]	0.81 (0.05)[b]	0.79 (0.02)[ac]
6	0.66 (0.08)[a]	0.58 (0.02)[b]	0.90 (0.12)[b]	0.83 (0.09)[ac]
Mean (± s.d.)	0.65 (0.08)[a]	0.55 (0.05)[b]	0.78 (0.09)[b]	0.76 (0.20)[ac]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.16: Means (± s.d.) for left and right lateral and diagonal advanced placements and lift-offs (s) for stock breed western pleasure horses at the left lead collected lope: left lateral = LF-LH, right lateral = RF-RH, left diagonal = RF-LH, and right diagonal = LF-RH.

	Left	Right
Lateral Advanced Placement (s)	0.58 (0.17)[a]	0.47 (0.14)[a]
Diagonal Advanced Placement (s)	0.16 (0.19)[a]	0.80 (0.14)[b]
Lateral Advanced Lift-off (s)	0.47 (0.03)[a]	0.55 (0.12)[a]
Diagonal Advanced Lift-off (s)	0.17 (0.21)[a]	0.76 (0.23)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

During the left lead collected lope, horses exhibited eight different limb support phases: 1) diagonal bipedal (LF-RH), 2) unipedal hind (RH), 3) lateral bipedal (RF-RH), 4) tripedal with two hindlimbs (RF-RH-LH), 5) diagonal bipedal (RF-LH), 6) tripedal with two forelimbs (RF-LF-LH), 7) lateral bipedal (LF-LH), and 8) unipedal fore (LF) (Figure 4.14). However, some horses displayed alternate limb support strategies in place of phases three and seven.

Two horses exchanged phase three (1.5 ± 0.71 strides each) with bipedal hind (RH-LH) support; two horses exchanged phase seven, two strides each, with bipedal forelimb (RF-LF) support. Diagonal bipedal (LF-RH) limb support occupied the greatest percent of stride followed closely by tripedal with two hindlimbs (RF-RH-LH), tripedal with two forelimbs (LF-RF-LH), diagonal bipedal (RF-LH), unipedal fore (LF), unipedal hind (RH), left lateral bipedal (LF-LH), and right lateral bipedal (RF-RH) (Table 4.17). There was no period of suspension or quadrupedal limb support during the left lead collected lope.

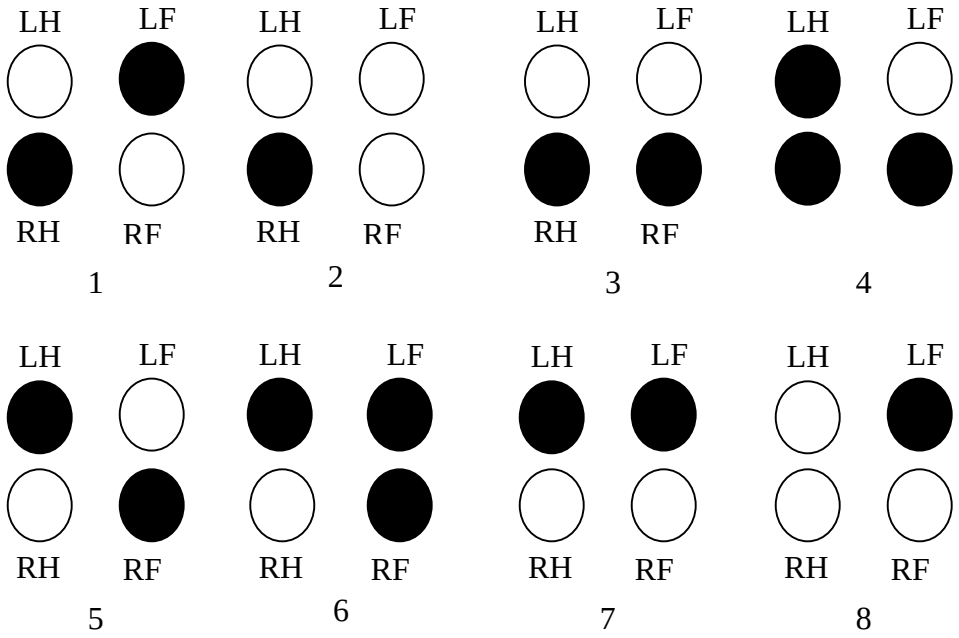

Figure 4.14: Limb support phases of the left lead collected lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Table 4.17: Means (± s.d.) for limb support phases as a percent (%) of stride for stock breed western pleasure horses at the left lead collected lope.

Limb Support Phase	**Percent of Stride (%)**
Diagonal Bipedal (LF-RH)	22.29 (4.94)
Tripedal with two Hindlimbs (RF-RH-LH)	20.85 (4.04)
Tripedal with two Forelimbs (RF-LF-LH)	20.70 (3.50)
Diagonal Bipedal (RF-LH)	14.12 (4.44)
Unipedal Fore (LF)	10.00 (3.78)
Unipedal Hind (RH)	5.52 (3.96)
Lateral Bipedal (LF-LH)	2.66 (2.72)
Lateral Bipedal (RF-RH)	2.06 (1.56)
Bipedal Fore (LF-RF)*	1.39 (2.67)
Bipedal Hind (LH-RH)*	0.40 (0.67)

* indicates alternate limb support strategies utilized by some horses

Vertical excursion was greatest for the croup (0.51 ± 0.13 m) followed by the head (0.42 ± 0.11 m), trailing fore (RF) coffin (0.17 ± 0.02 m), leading hind (LH) (0.16 ± 0.04 m), trailing hind (RH) coffin (0.14 ± 0.02 m), withers (0.12 ± 0.01 m), and the leading fore (LF) coffin (0.12 ± 0.02 m) during the left lead collected lope. A statistical difference was found when comparing the vertical excursions of the head to withers and withers to croup ($P \leq 0.05$) but not when comparing the croup to head ($P = 0.72$), which indicates that horses did not exhibit a balanced topline when performing the left lead collected lope and do not conform to the breed standard.

Left lead angular kinematics.

Peak flexion and extension as well as joint range of motion (ROM) for shoulder, elbow, carpus, fore fetlock, hip, stifle, hock, and hind fetlock joints for the left lead collected lope are shown in Table 4.18. The greatest ROM was seen for the fetlock joint of all four limbs followed by the right and left carpus joints; the shoulder joints exhibited the least ROM.

Table 4.18: Means (± s.d.) for peak flexion and extension joint angles (deg) measured on the flexor side of the joint and range of motion (ROM) (deg) for fore and hindlimbs at the left lead collected lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Joint	Peak Flexion (deg)	Peak Extension (deg)	Joint ROM (deg)
Leading Forelimb (LF)			
Shoulder	110.07 (5.81)	119.62 (5.93)	9.53 (1.10)
Elbow	88.27 (8.30)	147.97 (9.75)	59.70 (2.97)
Carpus	112.89 (6.40)	182.56 (3.83)	69.67 (4.66)
Fetlock	143.47 (7.73)	227.60 (7.74)	84.13 (6.74)
Trailing Forelimb (RF)			
Shoulder	109.82 (9.61)	119.86 (8.73)	10.04 (2.69)
Elbow	95.19 (11.64)	145.44 (8.24)	50.25 (6.08)
Carpus	118.63 (3.67)	181.69 (2.75)	63.06 (3.92)
Fetlock	142.65 (8.53)	234.02 (10.85)	91.37 (6.39)
Leading Hindlimb (LH)			
Hip	99.78 (3.16)	113.55 (3.43)	13.77 (2.01)
Stifle	141.51 (7.19)	177.65 (10.45)	36.15 (3.99)
Hock	139.34 (4.68)	168.57 (4.27)	29.23 (3.72)
Fetlock	147.53 (8.98)	232.57 (7.56)	85.04 (10.83)
Trailing Hindlimb (RH)			
Hip	103.84 (3.86)	122.80 (4.96)	18.96 (2.86)
Stifle	133.34 (5.50)	166.46 (3.60)	33.12 (3.43)
Hock	131.80 (6.38)	167.23 (5.31)	35.43 (5.46)
Fetlock	153.95 (8.29)	234.33 (13.88)	80.38 (16.02)

Representative fore and hindlimb joint kinematics for horses at the left lead collected lope are graphically presented in Figures 4.15 through 4.18. Graphs were plotted from hoof contact to the next contact of the same hoof as a percent of stride and represent joint flexion or extension during a complete stride; the black vertical line indicates the initiation of swing phase. Upward inclinations in graphs indicate extension of the joint while downward inclinations indicate flexion. Leading forelimb (left fore) joint motion graphs indicate that stance phase occurred from 0 – 49% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.15). The shoulder gradually flexed throughout stance. Swing phase occurred from 51 – 100% of the stride while the elbow, carpus, and fetlock gradually flexed. Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints; peak extension of the shoulder occurred in early swing.

Trailing forelimb (right fore) joint motion graphs indicate that stance phase occurred from 0 – 47% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.16). The shoulder reached peak flexion at 19% of stride and then extended throughout the stride. Swing phase occurred from 48 – 100% of the stride while the elbow, carpus, and fetlock gradually flexed. Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints.

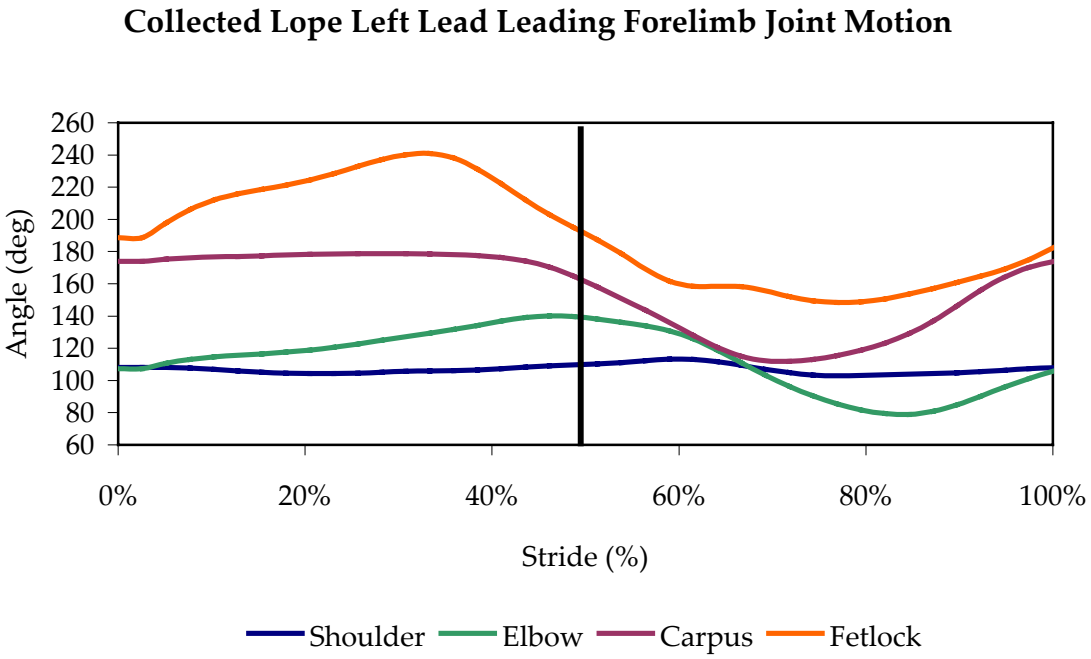

Figure 4.15: Representative leading forelimb (left fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead collected lope of the stock breed western pleasure horse. The gait cycle was left fore hoof contact to the next contact of the left fore hoof, and the black vertical line indicates the initiation of swing phase.

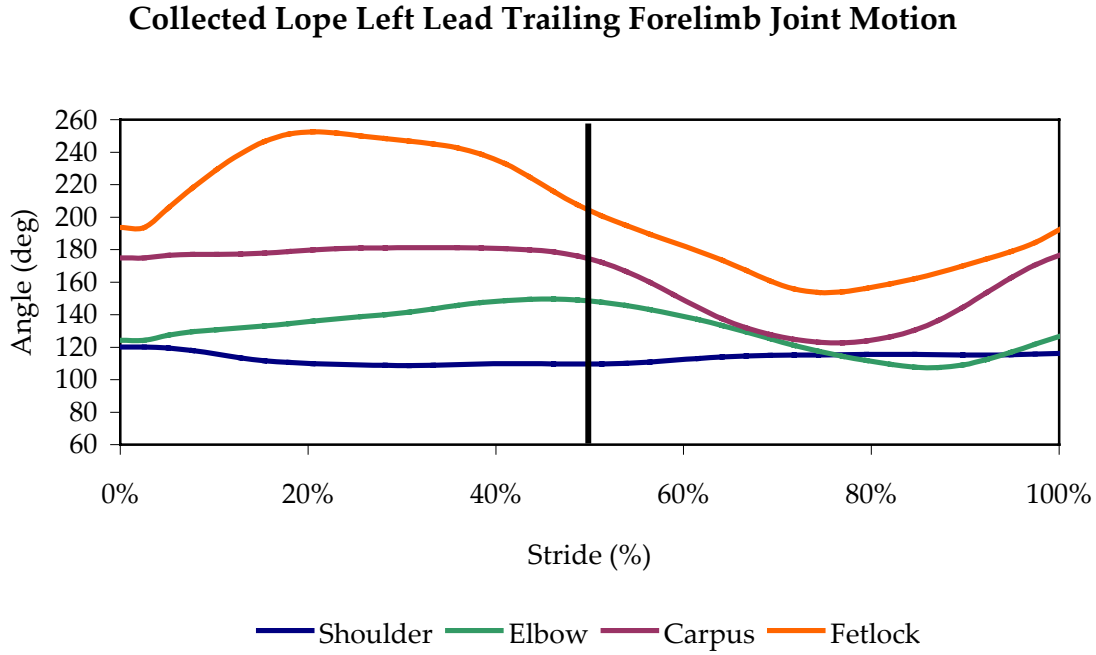

Figure 4.16: Representative trailing forelimb (right fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead collected lope of the stock breed western pleasure horse. The gait cycle was right fore hoof contact to the next contact of the right fore hoof, and the black vertical line indicates the initiation of swing phase.

Leading hindlimb (left hind) joint motion graphs indicate that stance phase occurred from 0 – 57% of stride during which the hip, stifle, and hock gradually flexed and then extended (Figure 4.17). The hip reached peak extension in late stance and then gradually flexed throughout swing phase; the fetlock reached peak extension at late stance and then gradually flexed throughout swing phase. Swing phase occurred from 58 – 100% of the stride with the stifle and hock reaching peak flexion at mid swing, and the fetlock reaching peak flexion in early swing.

Trailing hindlimb (right hind) joint motion graphs indicate that stance phase occurred from 0 – 49% of stride during which the stifle and hock gradually flexed and then extended, and the fetlock reached peak extension at 20% of stride (Figure 4.18). The hip reached peak extension at 30% of stride and then gradually flexed throughout the stride. Swing phase occurred from 50 – 100% of the stride while the stifle, hock, and fetlock gradually flexed. Peak flexion of the fetlock occurred prior to peak flexion of the stifle and hock joints.

Collected Lope Left Lead Leading Hindlimb Joint Motion

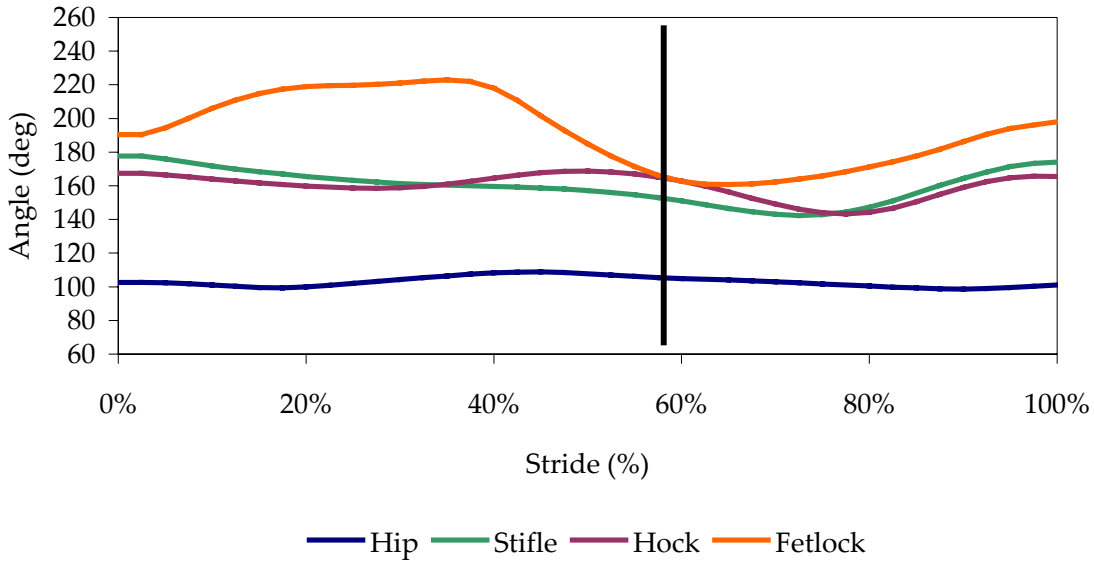

Figure 4.17: Representative leading hindlimb (left hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead collected lope of the stock breed western pleasure horse. The gait cycle was left hind hoof contact to the next contact of the left hind hoof, and the black vertical line indicates the initiation of swing phase.

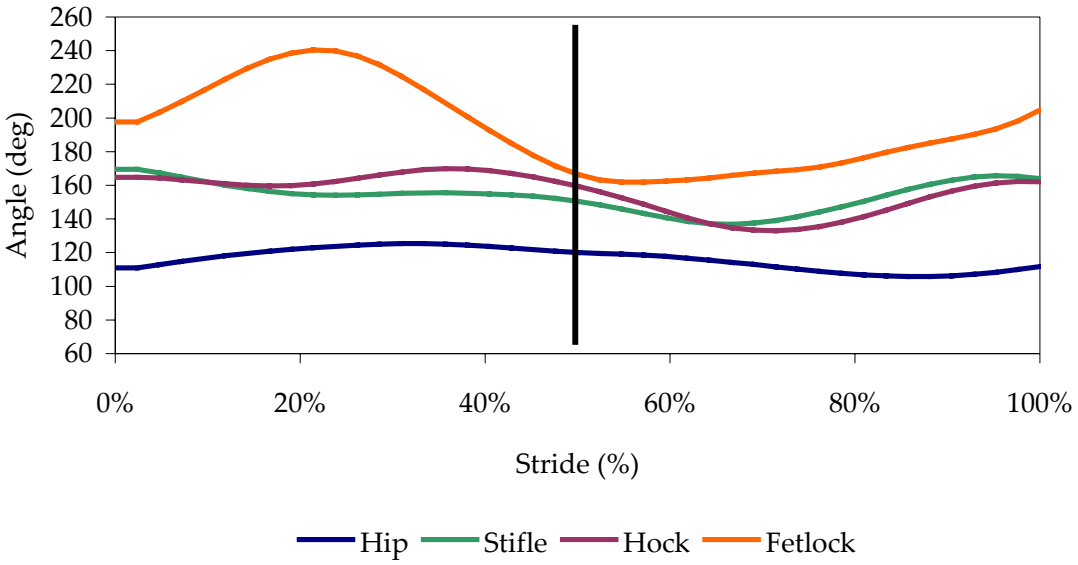

Figure 4.18: Representative trailing hindlimb (right hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead collected lope of the stock breed western pleasure horse. The gait cycle was right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of swing phase.

Extended Lope

Right lead temporal and linear kinematics.

Horses performed the right lead extended lope with right limbs on the leading side of the body and left limbs on the trailing side; the right lead collected lope (n=6) had a lateral footfall sequence of trailing hind (left hind) followed by trailing fore (left fore) and leading hind (right hind), working as a diagonal pair, followed by the leading forelimb (right fore) (Figure 4.19).

Disuniting of the diagonal pair was seen in 77.78% of strides with 57.14% of those strides showing a lateral footfall sequence as the trailing fore (left fore) made contact with the ground an instant before the leading hindlimb (right hind). Disuniting of the diagonal pair gave the lope a four beat rhythm, which does not conform to the breed standard for gait performance. Horses performed the right lead extended lope with a mean stride length of 1.68 ± 0.15 m, stride duration of 1.32 ± 0.08 s, stride frequency of 0.76 ± 0.05 stride/s, and velocity of 1.28 ± 0.12 m/s. No statistically significant difference was found between stride length (P=0.07), duration (P=0.18), or frequency (P=0.18) when calculated from consecutive right hind placements than when calculated from consecutive left hind placements. Hind step length was 0.80 ± 0.26 m and fore step length was 0.76 ± 0.19 m, with hind step length making up a greater percent of the stride.

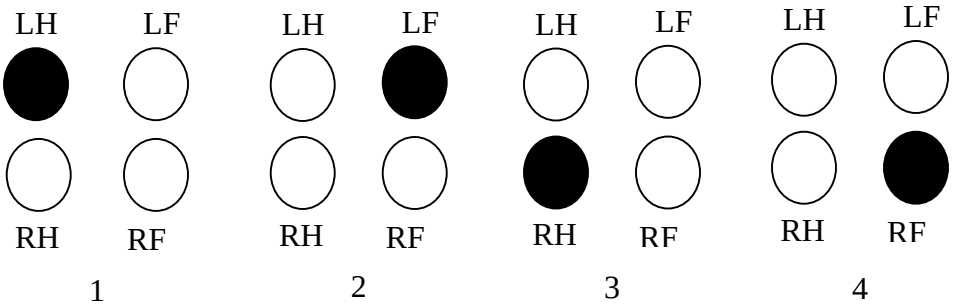

Figure 4.19: Lateral footfall sequence of the right lead extended lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Statistical significance was found between the stance and swing durations of the left and right hind (P≤0.05), and interestingly, the only swing duration comparison not yielding statistical significance (P=0.28) was between the right and left fore limbs (Table 4.19 & 4.20). Statistical significance was found between left and right lateral advanced placement and diagonal advanced lift-off (P≤0.05) (Table 4.21). Significant differences observed between left and right variables of hind stance and swing durations and lateral and diagonal advanced placement and lift-off indicated that the lope was asymmetrical as dictated by both scientific and breed definitions.

Table 4.19: Means (± s.d.) for stance durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the right lead extended lope: right hind (RH) and left hind (LH).

Subject	RH (s)	LH (s)
1	0.81 (0.05)[a]	0.64 (0.02)[b]
2	0.84 (0.04)[a]	0.72 (0.02)[b]
3	0.71 (0.02)[a]	0.63 (0.03)[b]
4	0.67 (0.03)[a]	0.60 (0.03)[b]
5	0.74 (0.07)[a]	0.68 (0.02)[b]
6	0.76 (0.05)[a]	0.68 (0.04)[b]
Mean (± s.d.)	0.75 (0.06)[a]	0.66 (0.04)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.20: Means (± s.d.) for swing durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the right lead extended lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	RH (s)	LH (s)	RF (s)	LF (s)
1	0.58 (0.02)[a]	0.70 (0.03)[b]	0.86 (0.07)[c]	0.74 (0.02)[c]
2	0.57 (0.00)[a]	0.67 (0.03)[b]	0.77 (0.67)[c]	0.80 (0.03)[c]
3	0.50 (0.03)[a]	0.56 (0.04)[b]	0.67 (0.03)[c]	0.74 (0.04)[c]
4	0.58 (0.02)[a]	0.62 (0.02)[b]	0.67 (0.03)[c]	0.74 (0.02)[c]
5	0.56 (0.02)[a]	0.64 (0.05)[b]	0.69 (0.04)[c]	0.77 (0.03)[c]
6	0.60 (0.06)[a]	0.68 (0.02)[b]	0.77 (0.03)[c]	0.83 (0.03)[c]
Mean (± s.d.)	0.56 (0.03)[a]	0.64 (0.05)[b]	0.73 (0.07)[c]	0.77 (0.04)[c]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.21: Means (± s.d.) for left and right lateral and diagonal advanced placements and lift-offs (s) for stock breed western pleasure horses at the right lead extended lope: left lateral = LF-LH, right lateral = RF-RH, left diagonal = RF-LH, and right diagonal = LF-RH.

	Left	Right
Lateral Advanced Placement (s)	0.35 (0.07)[a]	0.48 (0.05)[b]
Diagonal Advanced Placement (s)	0.71 (0.19)[a]	0.38 (0.51)[a]
Lateral Advanced Lift-off (s)	0.58 (0.15)[a]	0.46 (0.05)[a]
Diagonal Advanced Lift-off (s)	0.78 (0.26)[a]	0.04 (0.03)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

During the right lead extended lope, horses exhibited eight different limb support phases: 1) diagonal bipedal (RF-LH), 2) unipedal hind (LH), 3) lateral bipedal hind (LF-LH), 4) tripedal with two hindlimbs (LF-RH-LH), 5) diagonal bipedal (LF-RH), 6) tripedal with two forelimbs (RF-LF-RH), 7) bipedal fore (RF-LF), and 8) unipedal fore (RF) (Figure 4.20). However, some horses displayed alternate limb support strategies in place of phases three and seven. Three horses exchanged phase three, 1.67 ± 0.58 strides each, with bipedal hind (RH-LH) support; two horses exchanged phase seven, 2.50 ± 0.0.71 strides each, with lateral bipedal (RF-RH) support. Tripedal with two hindlimb (LF-RH-LH) support occupied the greatest percent of stride followed closely by tripedal with two forelimbs (RF-LF-RH), diagonal bipedal (RF-LH), diagonal bipedal (LF-RH), unipedal fore (RF), unipedal hind (LH), bipedal fore (RF-LF), and lateral bipedal (RF-RH) (Table 4.22). There was no period of suspension or quadrupedal limb support during the right lead extended lope.

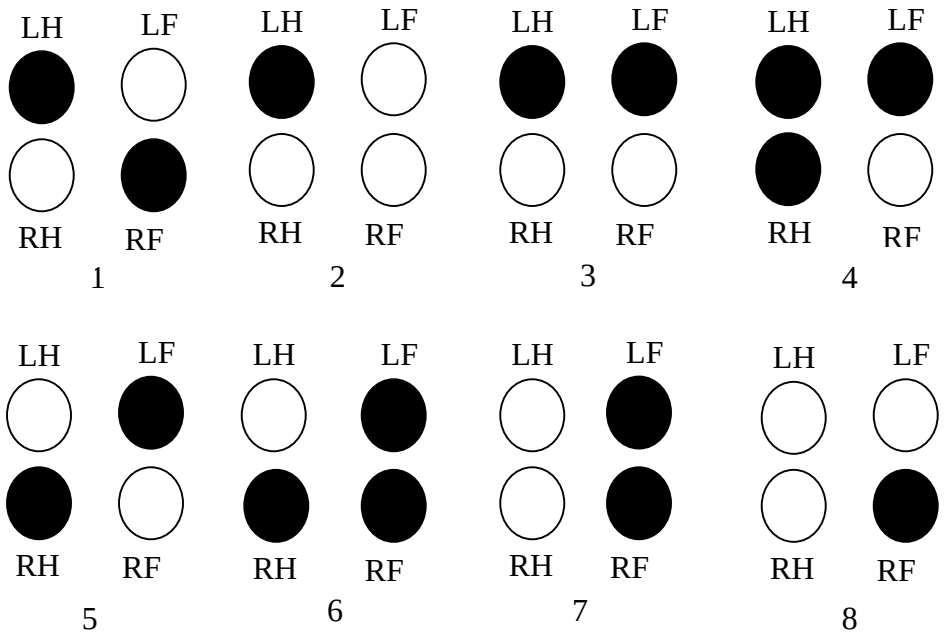

Figure 4.20: Limb support phases of the right lead extended lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Table 4.22: Means (± s.d.) for limb support phases as a percent (%) of stride for stock breed western pleasure horses at the right lead extended lope.

Limb Support Phase	**Percent of Stride (%)**
Tripedal with two Hindlimbs (LF-RH-LH)	20.52 (3.62)
Tripedal with two Forelimbs (RF-LF-RH)	19.59 (2.81)
Diagonal Bipedal (RF-LH)	18.79 (3.72
Diagonal Bipedal (LF-RH)	14.77 (5.01)
Unipedal Fore (RF)	14.37 (2.45)
Unipedal Hind (LH)	7.20 (2.87)
Bipedal Fore (LF-RF)	1.68 (2.01)
Lateral Bipedal (RF-RH)*	1.23 (2.23)
Lateral Bipedal (LF-LH)	1.18 (0.93)
Bipedal Hind (LH-RH)*	0.66 (0.78)

* indicates alternate limb support strategies utilized by some horses

Vertical excursion was greatest for the head (0.40 ± 0.05 m) followed by the croup (0.32 ± 0.20 m), trailing hind (LH) coffin (0.15 ± 0.04 m), trailing fore (LF) coffin (0.15 ± 0.02 m), leading fore (RF) coffin (0.15 ± 0.03 m), leading hind (RH) coffin (0.13 ± 0.03 m), and the withers (0.12 ± 0.01 m) during the right lead extended lope. A statistical difference was found when comparing the vertical excursions of the head to withers ($P \leq 0.05$) but not when comparing the croup to head ($P=0.46$) or withers to croup ($P=0.54$). These significant differences in vertical excursions indicate that horses did not exhibit a balanced topline when performing the right lead extended lope and do not conform to the breed standard concerning gait performance.

Right lead angular kinematics.

Peak flexion and extension as well as joint range of motion (ROM) for shoulder, elbow, carpus, fore fetlock, hip, stifle, hock, and hind fetlock joints for the right lead extended lope are shown in Table 4.23. The greatest ROM was seen for the fetlock joint of all four limbs followed by the right and left carpus joints; the shoulder joints exhibited the least ROM.

Table 4.23: Means (± s.d.) for peak flexion and extension joint angles (deg) measured on the flexor side of the joint and range of motion (ROM) (deg) for fore and hindlimbs at the right lead extended lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Joint	Peak Flexion (deg)	Peak Extension (deg)	Joint ROM (deg)
Leading Forelimb (RF)			
Shoulder	112.60 (9.92)	122.22 (8.36)	9.61 (2.07)
Elbow	85.58 (11.18)	147.82 (8.66)	62.24 (3.58)
Carpus	109.45 (5.32)	182.38 (2.62)	72.93 (4.68)
Fetlock	142.37 (5.69)	230.50 (10.99)	88.13 (9.11)
Trailing Forelimb (LF)			
Shoulder	106.71 (6.37)	117.84 (5.83)	11.13 (1.83)
Elbow	97.97 (8.087)	144.23 (7.54)	46.26 (4.23)
Carpus	120.00 (4.39)	183.06 (2.61)	63.05 (5.41)
Fetlock	142.69 (7.16)	235.89 (9.57)	93.20 (9.89)
Leading Hindlimb (RH)			
Hip	100.12 (3.3.6)	115.73 (4.38)	15.62 (1.86)
Stifle	138.70 (7.45)	178.89 (6.55)	40.18 (8.28)
Hock	135.21 (6.00)	167.51 (3.75)	32.30 (6.45)
Fetlock	147.35 (9.88)	238.63 (9.71)	91.28 (15.86)
Trailing Hindlimb (LH)			
Hip	101.55 (4.22)	121.20 (2.46)	19.65 (4.83)
Stifle	135.25 (4.62)	168.45 (8.93)	33.20 (4.61)
Hock	138.05 (4.78)	169.04 (4.01)	30.99 (7.74)
Fetlock	149.37 (10.16)	232.06 (8.60)	82.69 (12.44)

Representative fore and hindlimb joint kinematics for horses at the right lead extended lope are graphically presented in Figures 4.21 through 4.24. Graphs were plotted from hoof contact to the next contact of the same hoof as a percent of stride and represent joint flexion or extension during a complete stride; the black vertical line indicates the initiation of swing phase. Upward

inclinations in graphs indicate extension of the joint while downward inclinations indicate flexion. Leading forelimb (right fore) joint motion graphs indicate that stance phase occurred from 0 – 56% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.21). Swing phase occurred from 57 – 100% of the stride while the elbow, carpus, and fetlock gradually flexed. The shoulder reached peak flexion at mid swing; peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints.

Trailing forelimb (left fore) joint motion graphs indicate that stance phase occurred from 0 – 54% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.22). The shoulder reached peak flexion at mid stance and then gradually extended throughout the remainder of the stride. Swing phase occurred from 55 – 100% of the stride while the elbow, carpus, and fetlock gradually flexed. Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints.

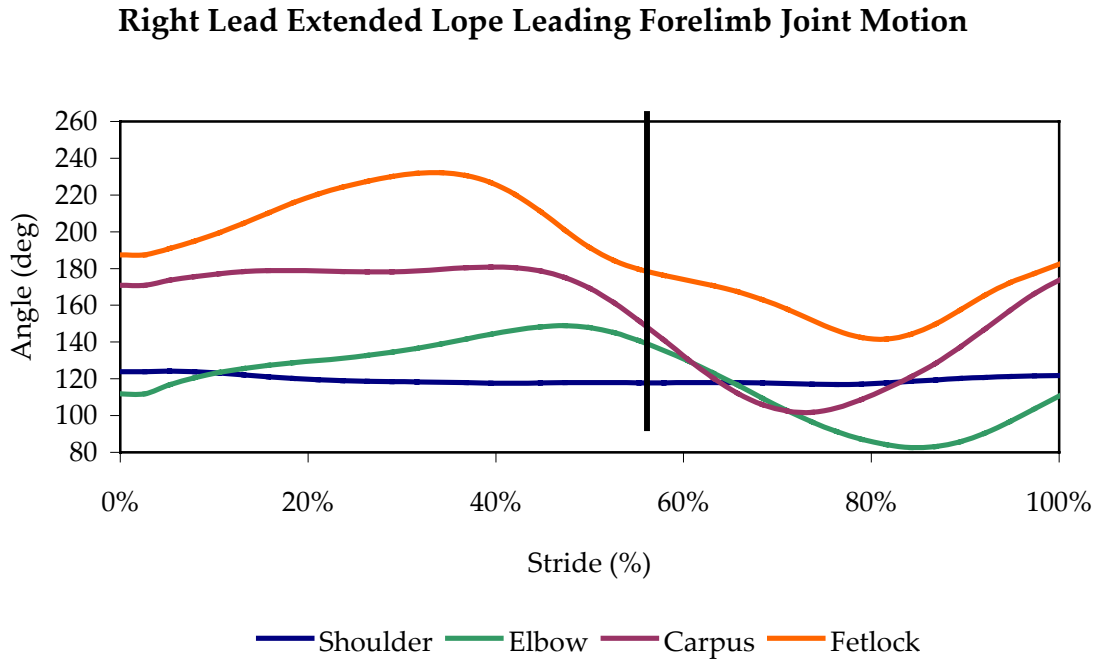

Figure 4.21: Representative leading forelimb (right fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead extended lope of the stock breed western pleasure horse. The gait cycle was right fore hoof contact to the next contact of the right fore hoof, and the black vertical line indicates the initiation of swing phase.

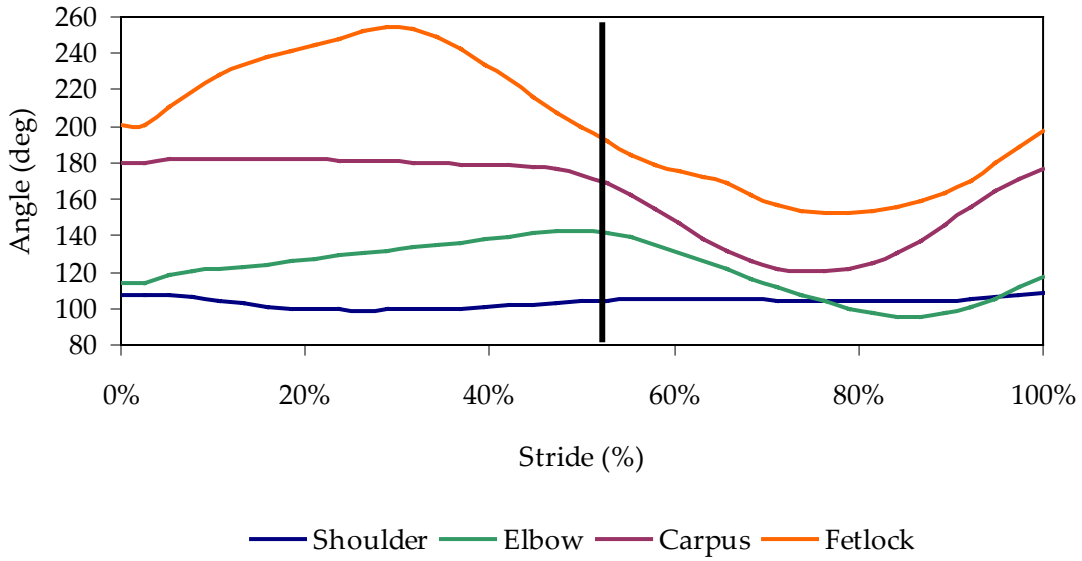

Figure 4.22: Representative trailing forelimb (left fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead extended lope of the stock breed western pleasure horse. The gait cycle left fore hoof contact to the next contact of the left fore hoof, and the black vertical line indicates the initiation of swing phase.

Leading hindlimb (right hind) joint motion graphs indicate that stance phase occurred from 0 – 45% of stride during which the hip, stifle, and hock gradually flexed (Figure 4.23). The hip reached peak flexion at mid stance and then extended to reach peak extension at late stance; the fetlock reached peak extension at mid stance and then flexed to reach peak flexion just after the initiation of swing phase. Swing phase occurred from 46 – 100% of the stride with the stifle and hock reaching peak extension in late swing and the fetlock gradually extending throughout the stride.

Trailing hindlimb (left hind) joint motion graphs indicate that stance phase occurred from 0 – 39% of stride during which the stifle and hock gradually flexed and the hip gradually extended (Figure 4.24). Peak flexion during stance phase of the stifle and hock occurred in early stance; the fetlock reached peak extension during mid stance phase. Swing phase occurred from 40 – 100% of the stride while the stifle, hock, and fetlock gradually flexed. Peak flexion of the fetlock occurred prior to peak flexion of the stifle and hock joints.

Right Lead Extended Lope Leading Hindlimb Joint Motion

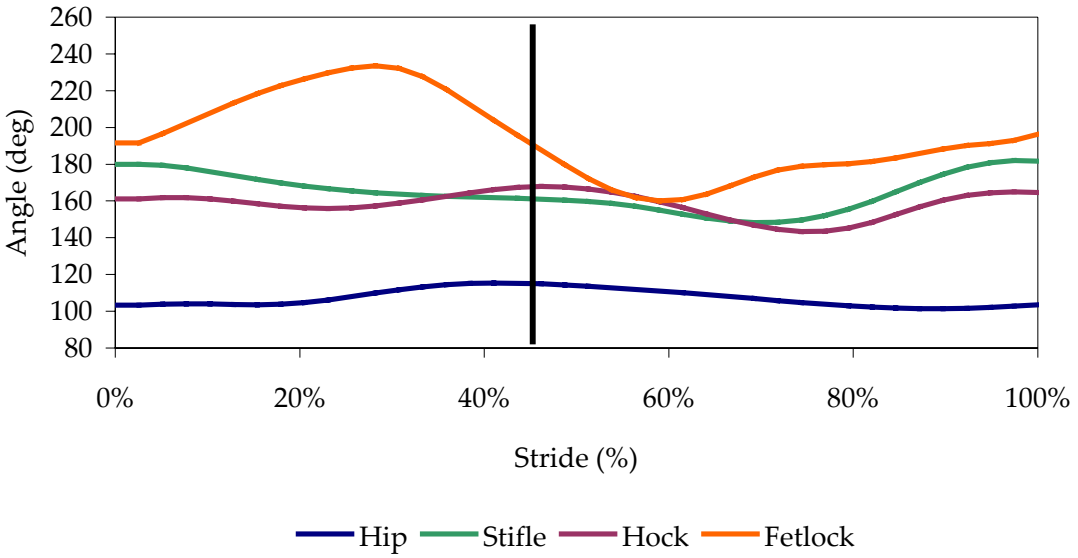

Figure 4.23: Representative leading hindlimb (right hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead extended lope of the stock breed western pleasure horse. The gait cycle right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of swing phase.

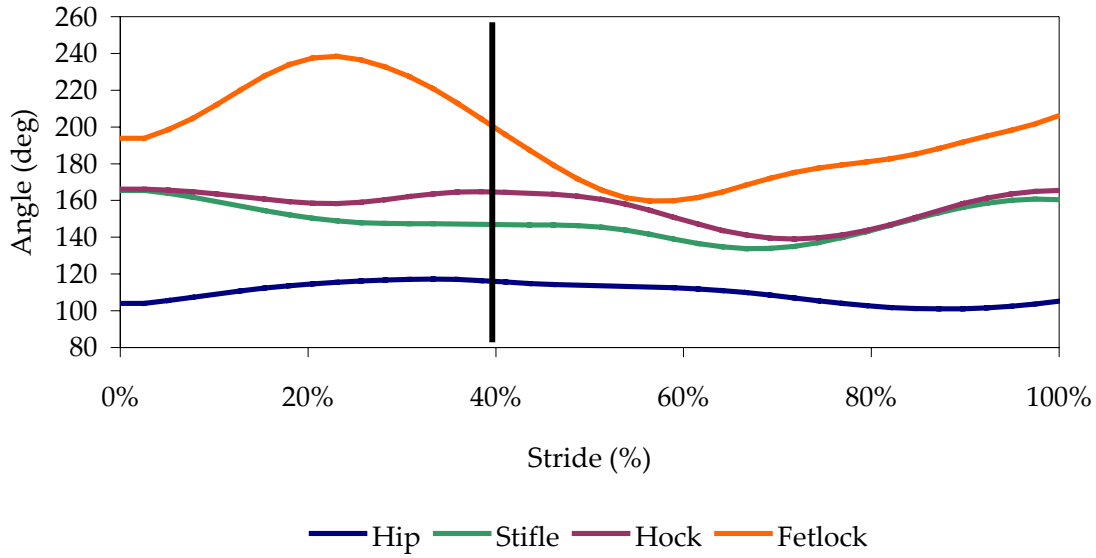

Figure 4.24: Representative trailing hindlimb (left hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the right lead extended lope of the stock breed western pleasure horse. The gait cycle was left hind hoof contact to the next contact of the left hind hoof, and the black vertical line indicates the initiation of swing phase.

Left lead temporal and linear kinematics.

Horses performed the left lead extended lope with left limbs on the leading side of the body and right limbs on the trailing side; in accordance with past stock breed western pleasure research (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a), the left lead collected lope (n=6) had a lateral footfall sequence of trailing hind (right hind) followed by trailing fore (right fore) and leading hind (left hind), working as a diagonal pair, followed by the leading forelimb (left fore) (Figure 4.25). Disuniting of the diagonal pair was seen in

72.22% of strides with 84.62% of those strides showing a lateral footfall sequence as the trailing forelimb (right fore) made contact with the ground an instant before the leading hindlimb (left hind). Disuniting of the diagonal pair gave the lope a four beat rhythm, which does not conform to the breed standard for gait performance. Horses performed the left lead extended lope with a mean stride length of 1.70 ± 0.21 m, stride duration of 1.33 ± 0.08 s, stride frequency of 0.76 ± 0.05 stride/s, and velocity of 1.28 ± 0.19 m/s. No statistically significant difference was found between stride length (P=0.07), duration (P=0.40), or frequency (P=0.45) when calculated from consecutive right hind placements than when calculated from consecutive left hind placements. Hind step length was 0.96 ± 0.18 m and fore step length was 0.91 ± 0.29 m, with hind step length making up only a slightly greater percent of the stride than fore step length.

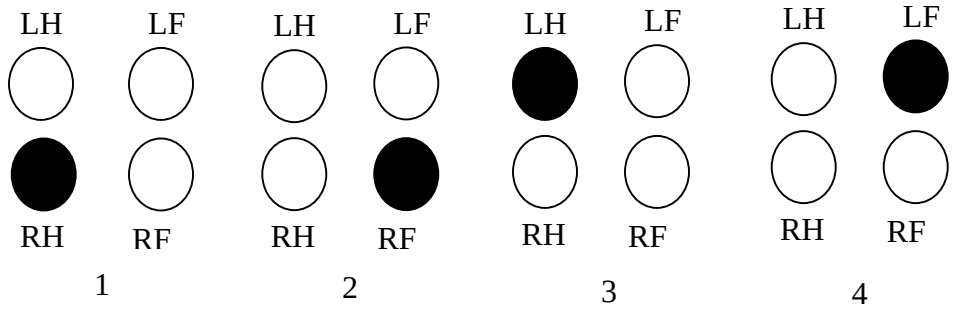

Figure 4.25: Lateral footfall sequence of the left lead extended lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Statistical significance was found between the stance and swing durations of the left and right hind (P≤0.05), and interestingly, the only swing duration comparison not yielding statistical significance (P=0.09) was between the right and left fore limbs (Table 4.24 & 4.25). Statistical significance was found between left and right diagonal advanced placements and lift-offs (P≤0.05) (Table 4.26). Significant differences observed between left and right variables of hind stance and swing durations and diagonal advanced placements and lift-offs indicated that the lope was asymmetrical as dictated by both scientific and breed definitions.

Table 4.24: Means (± s.d.) for stance durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the left lead extended lope: right hind (RH) and left hind (LH).

Subject	RH (s)	LH (s)
1	0.63 (0.03)[a]	0.78 (0.20)[b]
2	0.78 (0.05)[a]	0.83 (0.06)[b]
3	0.68 (0.02)[a]	0.74 (0.02)[b]
4	0.63 (0.03)[a]	0.67 (0.00)[b]
5	0.63 (0.00)[a]	0.72 (0.02)[b]
6	0.74 (0.04)[a]	0.77 (0.00)[b]
Mean (± s.d.)	0.68 (0.06)[a]	0.75 (0.06)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.25: Means (± s.d.) for swing durations (s) for the following limbs of each stock breed western pleasure horse (Subject 1-6) at the left lead extended lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Subject	RH (s)	LH (s)	RF (s)	LF (s)
1	0.77 (0.00)[a]	0.58 (0.08)[b]	0.79 (0.02)[c]	0.79 (0.05)[ac]
2	0.68 (0.04)[a]	0.60 (0.00)[b]	0.77 (0.12)[c]	0.79 (0.02)[ac]
3	0.58 (0.05)[a]	0.49 (0.02)[b]	0.77 (0.03)[c]	0.72 (0.04)[ac]
4	0.62 (0.02)[a]	0.61 (0.02)[b]	0.74 (0.02)[c]	0.71 (0.02)[ac]
5	0.64 (0.02)[a]	0.57 (0.00)[b]	0.73 (0.00)[c]	0.67 (0.03)[ac]
6	0.59 (0.02)[a]	0.57 (0.00)[b]	0.82 (0.02)[c]	0.78 (0.02)[ac]
Mean (± s.d.)	0.65 (0.07)[a]	0.57 (0.04)[b]	0.77 (0.03)[c]	0.74 (0.05)[ac]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

Table 4.26: Means (± s.d.) for left and right lateral and diagonal advanced placements and lift-offs (s) for stock breed western pleasure horses at the left lead extended lope: left lateral = LF-LH, right lateral = RF-RH, left diagonal = RF-LH, and right diagonal = LF-RH.

	Left	Right
Lateral Advanced Placement (s)	0.47 (0.05)[a]	0.43 (0.26)[a]
Diagonal Advanced Placement (s)	0.12 (0.20)[a]	0.85 (0.12)[b]
Lateral Advanced Lift-off (s)	0.48 (0.08)[a]	0.45 (0.06)[a]
Diagonal Advanced Lift-off (s)	0.03 (0.01)[a]	0.87 (0.10)[b]

Means (± s.d.) within the same row followed by different letters are significantly different at P≤0.05.

During the left lead extended lope, horses exhibited eight different limb support phases: 1) diagonal bipedal (LF-RH), 2) unipedal hind (RH), 3) lateral bipedal (RF-RH), 4) tripedal with two hindlimbs (RF-RH-LH), 5) diagonal bipedal (RF-LH), 6) tripedal with two forelimbs (RF-LF-LH), 7) bipedal fore (LF-RF), and 8) unipedal fore (LF) (Figure 4.26). However, some horses chose to display alternate limb support strategies in place of phases three and seven. Two horses exchanged phase three (1.5 ± 0.71 strides each) with bipedal hind (RH-LH) support; three horses exchanged phase seven, 1.67 ± 0.58 strides each, with lateral bipedal (LF-LH) support. Tripedal with two hindlimbs (RF-RH-LH) support occupied the greatest percent of stride followed closely by tripedal with two forelimbs (LF-RF-LH), diagonal bipedal (LF-RH), unipedal fore (LF), diagonal bipedal (RF-LH), unipedal hind (RH), right lateral bipedal (RF-RH), and bipedal fore (RF-LF) (Table 4.27). There was no period of suspension or quadrupedal limb support during the left lead extended lope.

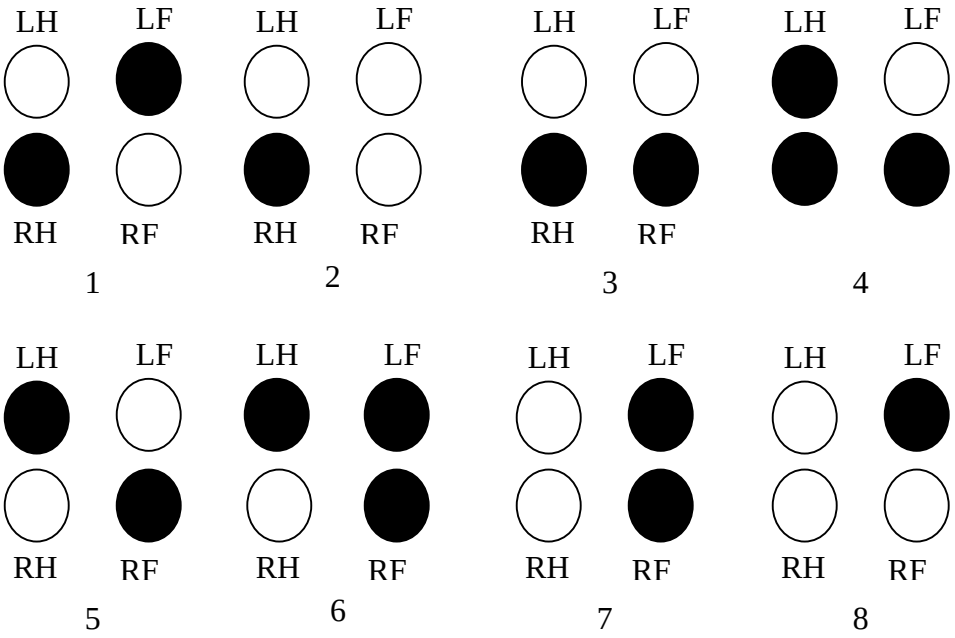

Figure 4.26: Limb support phases of the left lead extended lope as performed by the stock breed western pleasure horse. Each circle is representative of a horse's hoof (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

Table 4.27: Means (± s.d.) for limb support phases as a percent (%) of stride for stock breed western pleasure horses at the left lead extended lope.

Limb Support Phase	**Percent of Stride (%)**
Tripedal with two Hindlimbs (RF-RH-LH)	22.69 (3.49)
Tripedal with two Forelimbs (RF-LF-LH)	20.33 (3.09)
Diagonal Bipedal (LF-RH)	19.60 (4.94)
Unipedal Fore (LF)	13.80 (4.56)
Diagonal Bipedal (RF-LH)	12.40 (4.77)
Unipedal Hind (RH)	6.32 (3.31)
Lateral Bipedal (RF-RH)	2.12 (1.36)
Bipedal Fore (LF-RF)	1.14 (1.48)
Lateral Bipedal (LF-LH)*	0.92 (1.14)
Bipedal Hind (LH-RH)*	0.68 (0.07)

* indicates alternate limb support strategies utilized by some horses

Vertical excursion was greatest for the croup (0.45 ± 0.06 m) followed by the head (0.38 ± 0.09 m), trailing fore (RF) coffin (0.18 ± 0.03 m), leading hind (LH) (0.18 ± 0.04 m), leading fore (LF) coffin (0.13 ± 0.02 m), withers (0.13 ± 0.01 m), and trailing hind (RH) coffin (0.13 ± 0.02 m) during the left lead extended lope. A statistical difference ($P \leq 0.05$) was found when comparing the vertical excursions of the head to withers and withers to croup; a statistical difference was not found when comparing the head to croup ($P = 0.06$). These significant differences in vertical excursions indicate that horses did not exhibit a balanced topline when performing the left lead extended lope and do not conform to the breed standard concerning gait performance.

Left lead angular kinematics.

Peak flexion and extension as well as joint ROM for shoulder, elbow, carpus, fore fetlock, hip, stifle, hock, and hind fetlock joints for the left lead extended lope are shown in Table 4.28. The greatest ROM was seen for the fetlock joint of all four limbs followed by the right and left carpus joints; the shoulder joints exhibited the least ROM.

Table 4.28: Means (± s.d.) for peak flexion and extension joint angles (deg) measured on the flexor side of the joint and range of motion (ROM) (deg) for fore and hindlimbs at the left lead extended lope: right hind (RH), left hind (LH), right fore (RF), and left fore (LF).

Joint	Peak Flexion (deg)	Peak Extension (deg)	Joint ROM (deg)
Leading Forelimb (LF)			
Shoulder	110.04 (5.00)	118.94 (5.70)	8.90 (1.63)
Elbow	87.50 (9.49)	145.89 (6.45)	58.38 (4.47)
Carpus	112.23 (5.07)	182.70 (2.89)	70.48 (4.17)
Fetlock	142.89 (4.58)	227.60 (9.92)	84.71 (9.12)
Trailing Forelimb (RF)			
Shoulder	108.29 (8.50)	119.17 (9.64)	10.87 (3.67)
Elbow	97.12 (8.59)	145.24 (9.53)	48.12 (6.15)
Carpus	119.39 (4.27)	182.15 (3.36)	62.76 (5.49)
Fetlock	143.33 (5.78)	235.02 (10.56)	91.69 (9.84)
Leading Hindlimb (LH)			
Hip	99.98 (2.87)	113.71 (3.63)	13.73 (1.86)
Stifle	141.65 (6.27)	177.63 (9.95)	35.98 (4.58)
Hock	141.41 (3.32)	168.78 (3.57)	27.37 (4.21)
Fetlock	149.17 (7.45)	234.01 (6.41)	84.84 (10.70)
Trailing Hindlimb (RH)			
Hip	103.61 (4.28)	124.47 (5.74)	20.86 (2.27)
Stifle	134.49 (6.09)	164.90 (4.98)	30.41 (4.19)
Hock	136.47 (5.03)	167.06 (5.53)	30.59 (5.77)
Fetlock	156.98 (7.09)	237.12 (11.92)	80.14 (14.36)

Representative fore and hindlimb joint kinematics for horses during the left lead extended lope are graphically presented in Figures 4.27 through 4.30. Graphs were plotted from hoof contact to the next contact of the same hoof as a percent of stride and represent joint flexion or extension during a complete stride; the black vertical line indicates the initiation of swing phase. Upward inclinations in graphs indicate extension of the joint while downward

inclinations indicate flexion. Leading forelimb (left fore) joint motion graphs indicate that stance phase occurred from 0 – 55% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.27). The shoulder gradually flexed throughout the stance phase. Swing phase occurred from 56 – 100% of the stride while the elbow, carpus, and fetlock gradually flexed. Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints; peak extension of the shoulder occurred in early swing.

Trailing forelimb (right fore) joint motion graphs indicate that stance phase occurred from 0 – 54% of stride during which the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.28). The shoulder reached peak flexion at 20% of stride and then extended throughout the stride. Swing phase occurred from 55 – 100% of the stride while the elbow, carpus, and fetlock gradually flexed. Peak flexion of the carpus occurred prior to peak flexion of the elbow and fetlock joints.

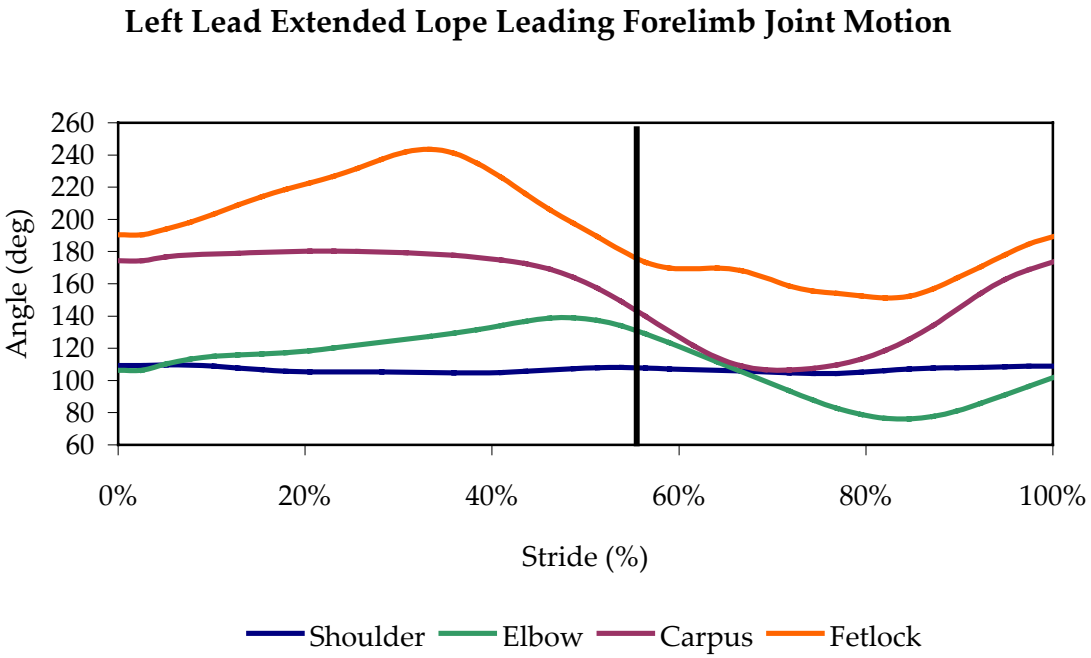

Figure 4.27: Representative leading forelimb (left fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead extended lope of the stock breed western pleasure horse. The gait cycle was left fore hoof contact to the next contact of the left fore hoof, and the black vertical line indicates the initiation of swing phase.

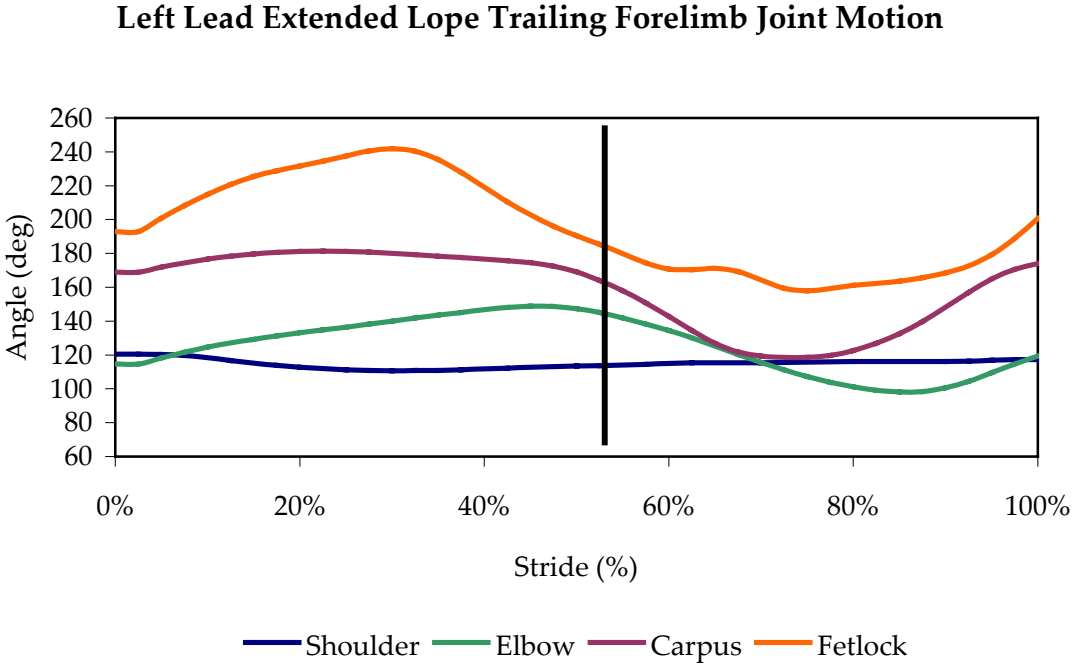

Figure 4.28: Representative trailing forelimb (right fore) motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead extended lope of the stock breed western pleasure horse. The gait cycle was right fore hoof contact to the next contact of the right fore hoof, and the black vertical line indicates the initiation of swing phase.

Leading hindlimb (left hind) joint motion graphs indicate that stance phase occurred from 0 – 45% of stride during which the hip, stifle, and hock gradually flexed and then extended (Figure 4.29). The hip reached peak extension in late stance and then gradually flexed throughout swing phase; the fetlock reached peak extension at mid stance and then flexed to reach peak flexion at early swing. Swing phase occurred from 46 – 100% of the stride with the stifle and hock reaching peak flexion at mid swing and then gradually extending throughout the stride.

Trailing hindlimb (right hind) joint motion graphs indicate that stance phase occurred from 0 – 41% of stride during which the stifle and hock gradually flexed and then extended, and the fetlock reached peak extension (Figure 4.30). The hip reached peak extension at 23% of stride and then gradually flexed throughout the stride. Swing phase occurred from 42 – 100% of the stride while the stifle, hock, and fetlock gradually flexed. Peak flexion of the fetlock occurred prior to peak flexion of the stifle and hock joints.

Left Lead Extended Lope Leading Hindlimb Joint Motion

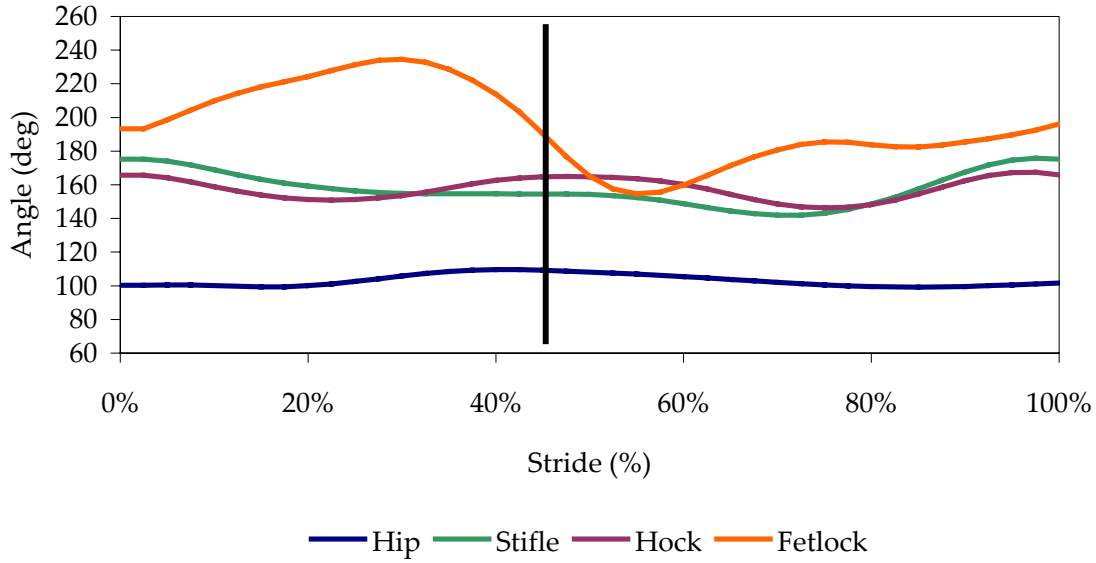

Figure 4.29: Representative leading hindlimb (left hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead extended lope of the stock breed western pleasure horse. The gait cycle was left hind hoof contact to the next contact of the left hind hoof, and the black vertical line indicates the initiation of swing phase.

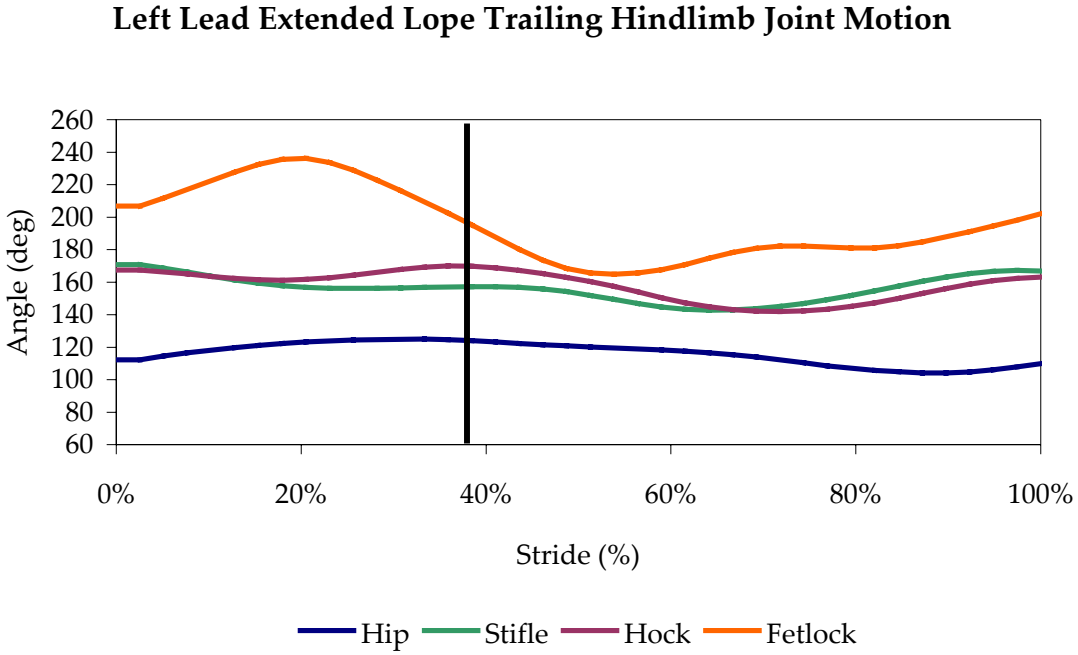

Figure 4.30: Representative trailing hindlimb (right hind) motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the left lead extended lope of the stock breed western pleasure horse. The gait cycle was right hind hoof contact to the next contact of the right hind hoof, and the black vertical line indicates the initiation of swing phase.

Collected versus Extended Lope

Right lead temporal and linear kinematics.

Horses performed the right lead collected lope with a diagonal footfall sequence and the right lead extended lope with a lateral footfall sequence (Figure 4.7 & 4.19). The diagonal footfall sequence found in the collected lope was due to 61.54% of the disunited strides yielding a right hind contact prior to left fore contact; the lateral footfall sequence found in the extended lope was due to

57.14% of the disunited strides yielding a left fore contact prior to right hind contact. These differences in footfalls were related to variations in limb support strategies for phases three and seven between the collected and extended right lead lope (Figure 4.8 & 4.20). Limb support phase three consisted of bipedal hind (RH-LH) during the collected lope and of left lateral bipedal (LF-LH) during the extended lope while phase seven consisted of right lateral bipedal (RF-RH) during the collected lope and bipedal fore (LF-RF) during the extended lope. Due to the large number of variables analyzed and the relatively small sample size, there were insufficient residual degrees of freedom to perform a multivariate ANOVA for either the temporal or linear variables of the right lead collected and extended lope. Therefore, the univariate results are presented cautiously and with the understanding of the risk of type 1 errors being increased due to the number of comparisons being performed. Although a significance level of 95% was chosen for statistical comparisons, all variables that were deemed significant had a univariate P value less than or equal to 0.04. Therefore, the risk of type 1 errors is acceptably small, even considering the number of comparisons being performed.

Stride length was longer for the right lead extended lope and indicated statistical significance ($P \leq 0.05$) from the right lead collected lope (Table 4.29). Horses also performed the right lead extended lope with a velocity that was

statistically significant (P≤0.05) from the velocity of the right lead collected lope. As well, vertical excursion of the withers indicated statistical significance (P≤0.05). The display of greater vertical excursion at the withers when at the extended lope than when performing the collected lope indicates that the extended lope exhibited greater lift in the forelimbs than did the collected lope. Diagonal advanced placement as well as several limb support phases indicated temporal statistical significance (P≤0.05) when compared between the collected and extended lope. Interestingly, the shorter time seen for diagonal advanced placement between the right fore and left hind limbs when performing the extended than when performing the collected lope indicates that leading forelimb and trailing hindlimb moved more closely together in time during the extended lope than in the collected lope.

Table 4.29: Statistically significant (P≤0.05) means (± s.d.) for stride length (m), velocity (m/s), vertical excursion of the withers (m), diagonal advanced placement of the right fore to left hind (s), and limb support phases of tripedal with two forelimbs, diagonal bipedal, and unipedal fore for stock breed western pleasure horses at the right lead collected and extended lope (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

	Collected Lope	**Extended Lope**
Stride Length (m)	1.57 (0.08)	1.68 (0.06)
Velocity (m/s)	1.16 (0.06)	1.28 (0.05)
Vertical Excursion of the Withers (m)	0.12 (0.01)	0.13 (0.01)
Diagonal Advanced Placement (RF-LH) (s)	0.82 (0.06)	0.71 (0.08)
Limb Support Phases (%)		
Tripedal with two Forelimbs (RF-LF-RH)	22.14 (0.84)	19.59 (1.15)
Diagonal Bipedal (LF-RH)	22.35 (1.39)	18.79 (1.52)
Diagonal Bipedal (RF-LH)	11.74 (1.99)	14.77 (2.05)
Unipedal Fore (RF)	9.20 (0.89)	14.37 (1.00)

Right lead angular kinematics.

Due to the large number of variables analyzed and the relatively small sample size, there were insufficient residual degrees of freedom to perform a multivariate ANOVA for the angular variables. Therefore, the univariate results are presented cautiously and with the understanding of the risk of type 1 errors being increased due to the number of comparisons being performed. A significance level of 95% was chosen for statistical comparisons; however, no angular variables indicated statistical significance when compared between the collected and extended right lead lope. Motion graphs indicated the same trends

in joint motion between the collected and extended right lead lope (Figures 4.9 – 4.12 and 4.21 – 4.24).

Left lead temporal and linear kinematics.

Horses performed the left lead collected and extended lope with a lateral footfall sequence (Figures 4.13 & 4.25); however, horses approached the two gaits with variations in limb support strategies for phase seven, but not with phase three, between the collected and extended left lead lope (Figure 4.14 & 4.26). Phase seven consisted of left lateral bipedal (LF-LH) during the collected lope and bipedal fore (LF-RF) during the extended lope. Due to the large number of variables analyzed and the relatively small sample size, there were insufficient residual degrees of freedom to perform a multivariate ANOVA for either the temporal or linear variables of the left lead collected and extended lope. Therefore, the univariate results are presented cautiously and with the understanding of the risk of type 1 errors being increased due to the number of comparisons being performed. Although a significance level of 95% was chosen for statistical comparisons, all variables that were deemed significant had a univariate P value less than or equal to 0.04. Therefore, the risk of type 1 errors is acceptably small, even considering the number of comparisons being performed.

Stride length was longer for the left lead extended lope and indicated significant statistical significance ($P \leq 0.05$) from the left lead collected lope (Table

4.30). Horses also performed the left lead extended lope with a velocity that was statistically significant (P≤0.05) from the velocity of the left lead collected lope. Stride duration as well as diagonal advanced lift-offs, lateral advanced lift-offs, and unipedal left fore limb support phase indicated temporal statistical significance (P≤0.05) when compared between the collected and extended lope. Interestingly, the shorter time seen for diagonal and lateral advanced lift-offs between the fore and hindlimbs when performing the extended than when performing the collected lope indicates that they moved more closely together in time during the extended lope than in the collected lope.

Table 4.30: Statistically significant (P≤0.05) means (± s.d.) for stride length (m), velocity (m/s), stride duration (s), diagonal advanced lift-offs (s), lateral advanced lift-off (s), and unipedal fore limb support for stock breed western pleasure horses at the left lead collected and extended lope (LH – left hind, LF – left fore, RH – right hind, RF – right fore).

	Collected Lope	**Extended Lope**
Stride Length (m)	1.50 (0.07)	1.69 (0.08)
Velocity (m/s)	1.09 (0.05)	1.28 (0.08)
Stride Duration (s)	1.39 (0.03)	1.33 (0.03)
Diagonal Advanced Lift-off (RF-LH) (s)	0.76 (0.09)	0.03 (0.01)
Diagonal Advanced Lift-off (LF-RH) (s)	0.17 (0.09)	0.87 (0.04)
Lateral Advanced Lift-off (RF-RH) (s)	0.55 (0.05)	0.45 (0.03)
Unipedal Fore Limb Support (LF)	10.00 (1.54)	13.80 (1.86)

Left lead angular kinematics.

Due to the large number of variables analyzed and the relatively small sample size, there were insufficient residual degrees of freedom to perform a multivariate ANOVA for the angular variables. Therefore, the univariate results are presented cautiously and with the understanding of the risk of type 1 errors being increased due to the number of comparisons being performed. A significance level of 95% was chosen for statistical comparisons, all variables that were deemed significant had a univariate P value less than or equal to 0.04. Therefore, the risk of type 1 errors is rather small, even considering the number of comparisons being performed. Angular variables indicating statistical significance ($P \leq 0.05$) between the collected and extended left lead lope include hip ROM, stifle ROM, peak hock flexion, and hock ROM (Table 4.31). Differences in these joints seem to indicate that the distinction between the collected and extended left lead lope are most likely due to variation in hindlimb kinematics. Motion graphs indicated the same trends in joint motion between the collected and extended left lead lope (Figures 4.15 – 4.18 and 4.27 – 4.30).

Table 4.31: Statistically significant (P≤0.05) means (± s.d.) for angular variables (deg) of peak flexion, peak extension, and range of motion (ROM) for stock breed western pleasure horses at the collected and extended left lead lope.

	Collected Lope	**Extended Lope**
Hip ROM	18.96 (1.17)	20.86 (0.93)
Stifle ROM	33.12 (1.40)	30.41 (1.71)
Hock		
Peak Flexion	131.80 (2.61)	136.47 (2.01)
ROM	35.43 (2.23)	30.59 (2.35)

Chapter V

Discussion

The purpose of this study was to collect temporal, linear, and angular kinematics of the stock breed western pleasure horse in order to compare the variables of the collected and extended jog and the collected and extended lope to determine consistency with current rulebooks of major stock breed associations. Additionally, this study sought to determine if the extended jog and lope conform to a more natural way of going for stock breed western pleasure horses, which may reduce the risk of joint injury and trauma more than does the collected jog and lope. The current chapter presents the discussion on the topics of a) collected and extended jog, b) collected and extended lope, c) injuries, and d) summary.

After numerous locomotive studies, Hildebrand (1965) concluded that a horse's locomotion is not only more controllable than that of other animals but is more adaptable and opportunistic with regards to limb support and footfall

sequences. Equids have the innate ability to adapt, and in turn, exhibit gait performance variations; this adaptability, whether through training or breeding, has resulted in the stock breed western pleasure horse's performance of the jog and lope, which are viewed (perhaps erroneously) as gait variations of the dressage horse's trot and canter, respectively.

Collected and Extended Jog

Hildebrand (1965) developed a gait continuum that distinguished between symmetrical gaits based on the temporal variables of percent (%) stride of advanced placement and hind stance. When plotting the previously studied stock breed western pleasure jog (lateral advanced placement – 46%; hind stance – 60%) (Booker 2005; Nicodemus and Booker 2007) on Hildebrand's continuum, it fell in the region between the Arabian jog (lateral advanced placement – 50%; hind stance – 54%) and Quarter Horse walk (lateral advanced placement – 33%; hind stance – 66%) (Figure 5.1) (Hildebrand 1965; Nicodemus and Booker 2007). The current study plots the collected jog at 45.20 ± 5.52% lateral advanced placement and 61.02 ± 5.97% hind stance while the extended jog is plotted at 50.35 ± 1.39% lateral advanced placement and 58.75 ± 4.07% hind stance (Figure 5.1). Hildebrand's two charts can be overlaid to indicate the breed of horse and gait performed. In considering these charts, the data from the present study

indicates that the position of the collected jog is still more closely related to the walk or an animated variation of the slow trot, performed by the Arabian horse, than the trot and places it within the dotted area where Hildebrand (1965) indicated unusual gaits with no common name (Figure 5.2). Additionally, while the extended jog is plotted bordering the region that indicates unusual gaits, it is closer to the Arabian at the trot with regards to lateral advanced placement than the collected jog (Figure 5.2). Based on positioning it is reasonable to conclude that stock breed western pleasure horses are not simply performing a variation of the trot when executing the collected and extended jog, but altogether separate gaits that have not been appropriately named or classified (Figure 5.2).

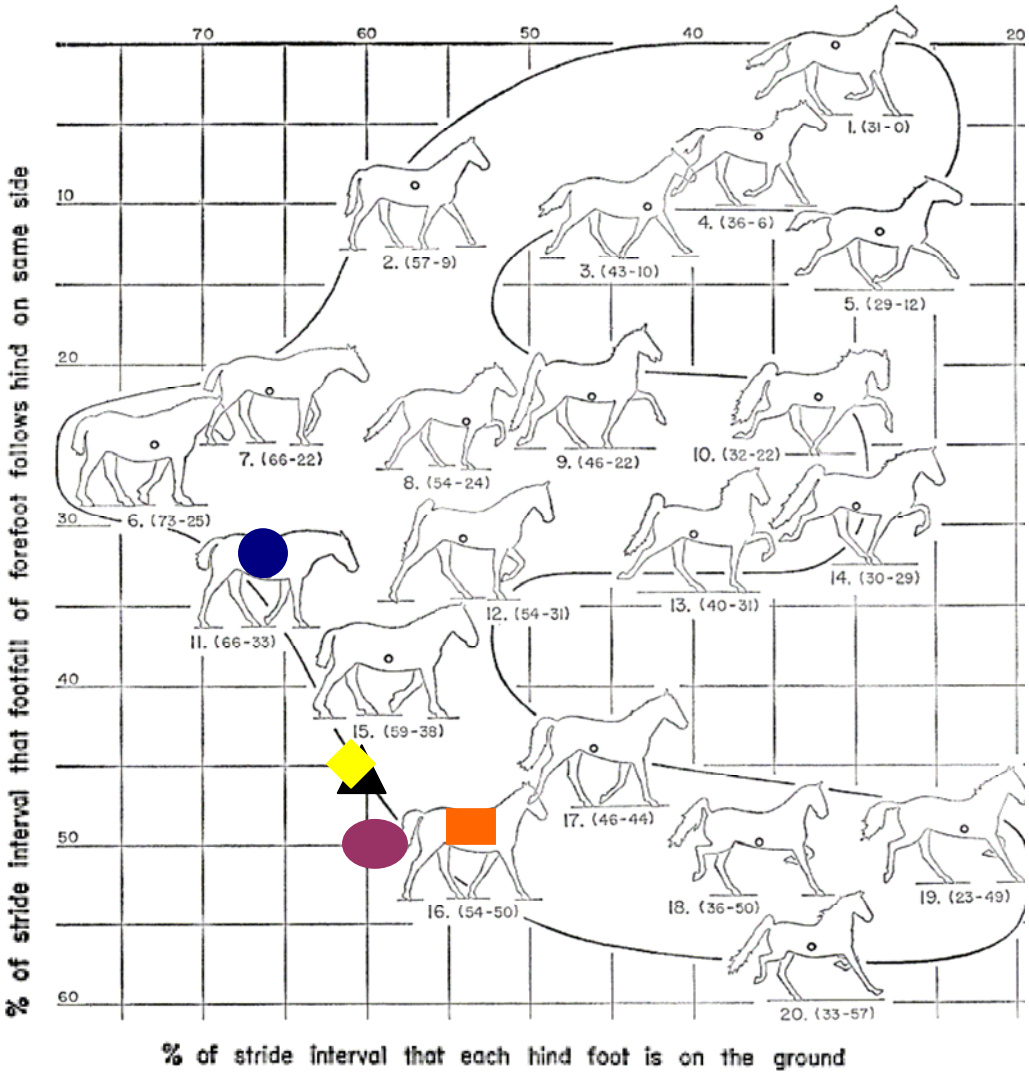

Figure 5.1: The graph in which nearly all symmetrical gaits of horses fall (Hildebrand 1965). The blue filled circle indicates the Quarter Horse while the orange filled square indicates the Arabian horse. The black filled triangle (partially hidden) indicates the stock breed western pleasure jog as determined by Nicodemus and Booker (2007). The yellow filled diamond indicates the position where the collected jog would fit into the continuum while the purple filled oval indicates the position where the extended jog would fit into the continuum.

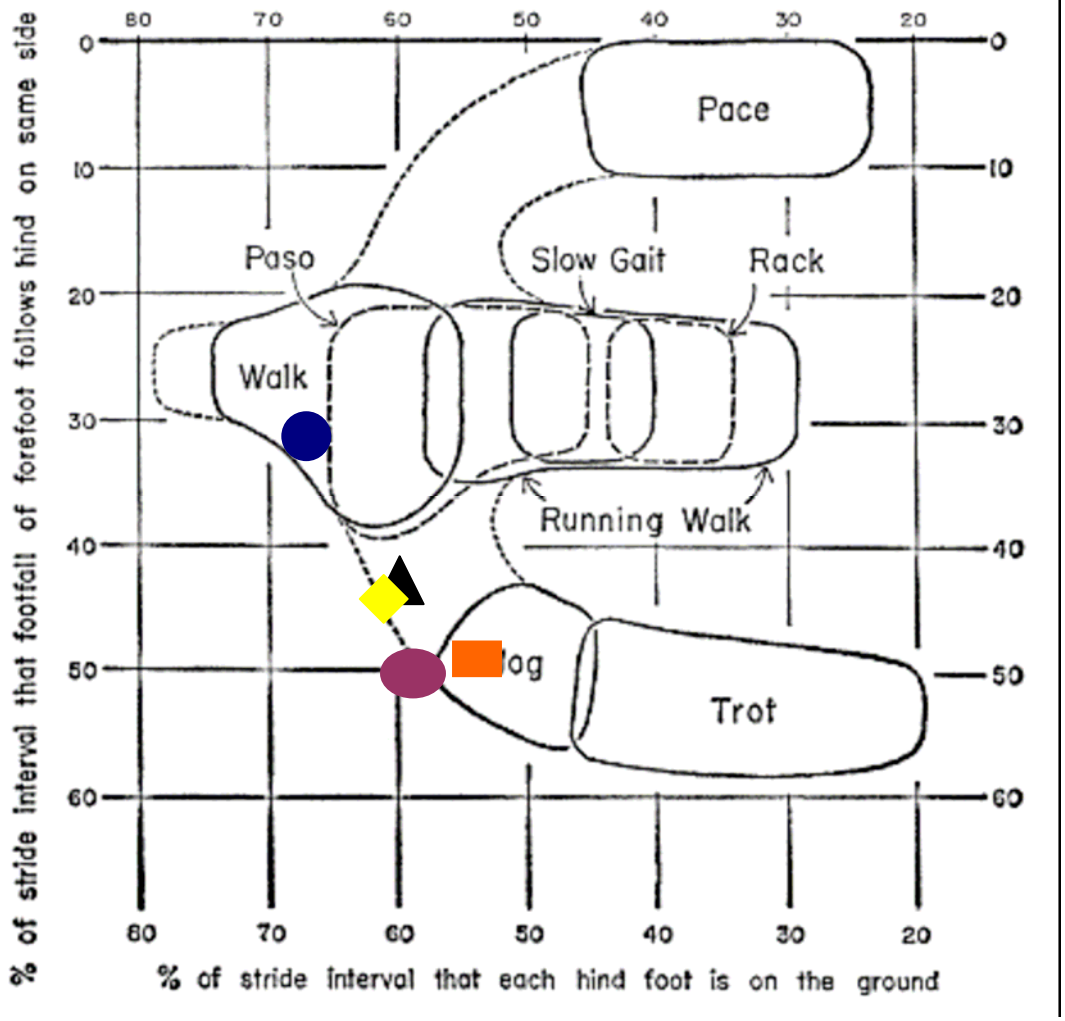

Figure 5.2: The relationship between symmetrical gaits of horses. Gaits that would fall within areas indicated by dotted lines are unusual and have no common name (Hildebrand 1965). The blue filled circle indicates the Quarter Horse while the orange filled square indicates the Arabian horse. The black filled triangle (partially hidden) indicates the stock breed western pleasure jog as determined by Nicodemus and Booker (2007). The yellow filled diamond indicates the position where the collected jog would fit into the continuum while the purple filled oval indicates the position where the extended jog would fit into the continuum.

Temporal and linear kinematics.

In the current study, both the collected and extended jogs were scientifically determined to be symmetrical four-beat stepping gaits with lateral footfall sequences and no period of suspension. The present findings related to the collected jog are in accordance with previous studies where the jog, synonymous with the current study's collected jog, was found to have four-beats, a lateral footfall sequence, and an irregular rhythm due to diagonal couplets (Nicodemus and Booker 2007; Nicodemus and Clayton 2001a); the extended jog as performed by the stock breed western pleasure horse has not been studied previously, so no direct comparison can be made. Stride length was longest, as expected, for the extended jog, however the collected jog exhibited a much longer stride length than did its counter part in the Nicodemus and Booker study (2007) (Table 5.1). Further, the collected jog exhibited a longer stride duration than did the extended jog, however both were longer than those measured in Nicodemus and Booker (2007); conversely, stride frequency and velocity was smaller for the collected jog than the extended jog, and both were smaller than the Nicodemus and Booker (2007) jog. These findings indicate that current stock breed western pleasure horses are exhibiting longer stride lengths and durations but slower stride frequencies and velocities than did previous research on stock breed western pleasure horses. However, the relationship between stride length,

stride duration, stride frequency, and velocity indicates that the horse's legs are covering more distance yet moving slower. The differences seen in the above mentioned temporal and linear variables have resulted in a slower moving stock breed western pleasure horse could be due to a combination of breeding and training than due to breed association rule changes implemented since the previous research was conducted. Horses that cover more ground per step yet move the legs more slowly are more desirable in the current stock breed western pleasure horse industry because the horse is more closely following breed association guidelines with regards to the collected and extended jog being ground-covering gaits (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008).

Diagonal advanced placements and lift-offs indicate that both the collected and extended gaits were performed with diagonal couplets instead of diagonal pairs indicating that while the diagonal limbs moved in concert, they did not move synchronously (Table 5.1). The greatest time between placement and lift-off of the diagonal pairs was seen at the collected jog and indicates "poorer" gait performance than was seen in the Nicodemus and Booker (2007) jog; however, the extended jog indicated greater synchronization of diagonal pairs than the collected jog. The substantial percentage of stride spent in diagonal bipedal limb support during the collected and extended jog gave both gaits a trot-like appearance and provides the basis for the classification by the

breed association for the jog to be considered a variation of the trot (Table 5.1). Further inspection of limb support phases indicates that the jog previously studied by Nicodemus and Booker (2007) consisted of a percentage of stride in quadrupedal, tripedal with two forelimbs, and tripedal with two hindlimbs similar to those of the collected and extended jog in the present study. Differences seen in limb support percentages between the present, Nicodemus and Booker (2007), and Nicodemus and Clayton (2001a) studies are most likely due to the speed at which the gaits were performed; however, it should be noted that while gait velocity was measured in the current study, it was not a controlled variable because western pleasure gait definitions set forth by stock breed associations do not indicate a standard with regards to speed.

Comparisons regarding vertical excursions of the head and croup do not indicate differences between the jog, collected jog, and extended jog (Table 5.1). Vertical excursions of the coffin suggest that current stock breed western pleasure horses do not pick their hooves up as high as past stock breed western pleasure horses (Table 5.1) (Nicodemus and Booker 2007).

Table 5.1: Means (± s.d.) for temporal and linear variables of the collected and extended jog for the present study and the jog from the Nicodemus and Clayton (2001a) as well as the Nicodemus and Booker study (2007). NP indicates temporal or linear variables that were not present in the Nicodemus and Clayton (2001a) study.

	Jog (2001a)	**Jog (2007)**	**Collected Jog**	**Extended Jog**
Stride Length (m)	NP	1.01 (0.1)	1.28 (0.17)	1.42 (0.16)
Stride Duration (s)	0.95 (0.04)	0.92 (0.03)	1.91 (0.12)	1.75 (0.08)
Stride Frequency (stride/s)	NP	1.09 (0.04)	0.53 (0.03)	0.57 (0.03)
Velocity (m/s)	NP	1.10 (0.09)	0.67 (0.01)	0.87 (0.01)
Hind Stance (s)	0.65 (0.50)	0.56 (0.04)	1.16 (0.12)	1.02 (0.07)
Fore Stance (s)	0.69 (1.75)	0.62 (0.04)	1.30 (0.20)	1.13 (1.11)
Diagonal Advanced Placement (s)	0.33 (0.02)	0.07 (0.04)	0.13 (0.05)	0.06 (0.03)
Diagonal Advanced Lift-off (s)	NP	0.04 (0.03)	0.09 (0.05)	0.07 (0.05)
Limb Support Phases (%)				
Diagonal Bipedal	43.00 (0.00)	60.00 (8.00)	57.78 (10.48)	70.20 (7.37)
Quadrupedal	9.00 (0.00)	17.00 (8.00)	19.26 (4.35)	14.07 (5.47)
Tripedal with two Forelimbs	48.00 (0.00)	19.00 (8.00)	16.72 (12.71)	13.31 (12.68)
Tripedal with two Hindlimbs		4.00 (8.00)	6.24 (7.28)	2.41 (4.80)
Vertical Excursions (m)				
Head	NP	0.13 (0.03)	0.12 (0.05)	0.12 (0.05)
Croup	NP	0.09 (0.03)	0.08 (0.01)	0.10 (0.01)
Fore Coffin	NP	0.23 0.05)	0.09 (0.02)	0.10 (0.02)
Hind Coffin	NP	0.22 (0.06)	0.11 (0.01)	0.11 (0.01)

The differences seen in the limb support percentages from the previously studied jog to those of the collected jog of the current study may be evidence of the effort of the western pleasure industry to more closely follow the gait definition set forth by breed associations. When considering limb support, it may be concluded that the industry has failed to improve gait quality of the jog due to the continued inclusion of tripedal and quadrupedal support as well as diagonal couplets instead of diagonal pairs during the collected and extended

jog; however, when taking into account the changes seen in stride length, duration, frequency, and velocity, it appears that gait improvements indeed have been made. The increase in stride length from the collected to the extended jog found in the current study is in line with breed association rules that define the extended jog as a lengthening of stride that covers more ground than that of the collected jog (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008). Further, the changes in temporal and linear variables have resulted in forward moving yet slow-legged horses that are most desirable as show horses in the current stock breed western pleasure industry. Even considering the positive changes in gait performance previously mentioned, the collected and extended jog still do not completely meet the gait definitions set forth by breed associations. Breed association guidelines dictate that the jog (i.e. collected jog) should be a two-beat diagonal gait that exhibits diagonal pairs. As determined by the current study, stock breed western pleasure horses exhibit diagonal couplets, not diagonal pairs, and do not maintain a two-beat rhythm for either the collected or extended jog. Additionally, the collected and extended jogs were determined to be stepping gaits (without suspension) rather than leaping gaits (with suspension). Suspension is implied in current breed association definitions of the gaits based on the two-beat requirement (APHA 2009; ApHC 2009b; AQHA 2009; PHBA

2008). Thus, performance of the collected and extended jog does not conform to current breed association guidelines.

Angular kinematics.

Similarities can be noted between the joint motion patterns of the fore and hindlimbs of stock breed western pleasure horses performing the jog, collected jog, and extended jog. During swing phase, the shoulder gradually extended and the elbow, carpus, and forelimb fetlock gradually flexed (Figure 4.3 & 5.3). Peak flexion of the carpus preceded the elbow during swing phase while peak flexion of the forelimb fetlock was not as obvious at the jog as at the collected and extended jog. Gradual extension of the elbow and carpus and flexion of the shoulder continued throughout stance; peak extension of the forelimb fetlock occurred at mid stance. The hip gradually extended throughout stance to reach peak extension at late stance; the hock reached peak extension during stance and peak flexion at mid swing phase (Figure 4.4 & 5.4). During swing phase, the hip, stifle, and hock gradually flexed. Peak extension of the hindlimb fetlock occurred during early swing for all jogs; however, stock breed western pleasure horses performing the jog exhibited another peak of extension during swing phase that was not present during the collected or extended jog (Booker 2005; Nicodemus and Booker 2007). Similarities in joint motion graphs, other than the

fetlock joint, indicate that stock breed western pleasure horses have not adjusted joint motions in order to achieve the temporal or linear kinematic changes seen between the Nicodemus and Booker (2007) and present study; the horses are just moving slower. The secondary peak of fetlock extension found during swing phase in Nicodemus and Booker (2007) was not found in the current study and indicates that horses are no longer "snapping" the hindlimb fetlock to push off the ground harder thereby eliminating the dramatic fetlock extension seen in the previous study.

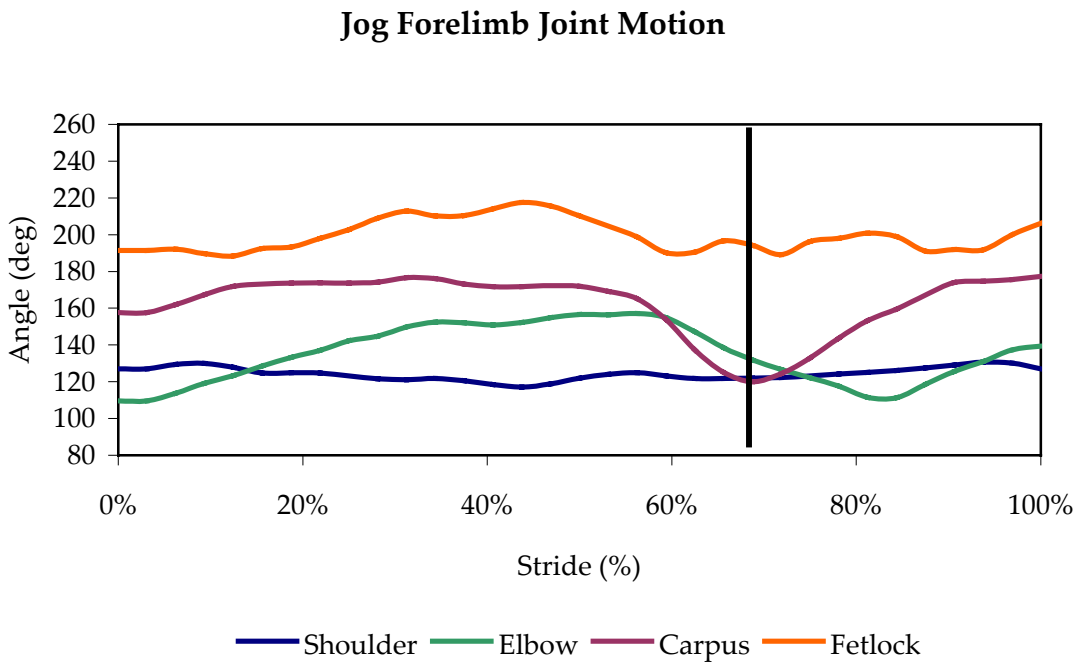

Figure 5.3: Forelimb motion graph of the shoulder, elbow, carpus, and fetlock joints (deg) as a percentage of stride (%) for one stride of the jog of the stock breed western pleasure horse (Booker 2005; Nicodemus and Booker 2007). The black vertical line indicates hoof off.

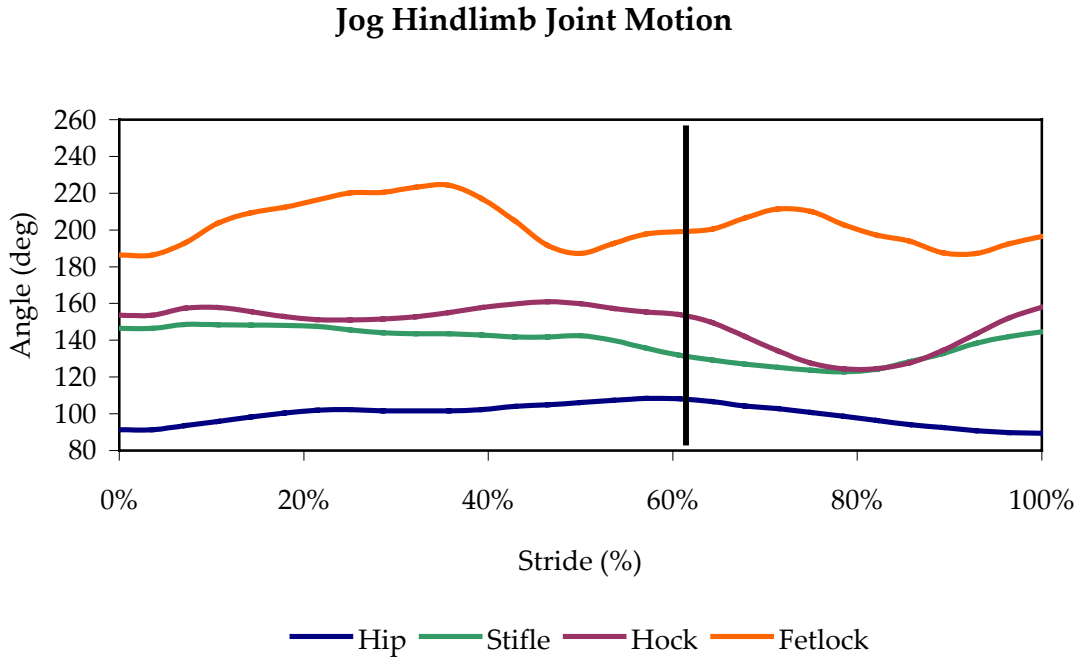

Figure 5.4: Hindlimb motion graph of the hip, stifle, hock, and fetlock joints (deg) as a percentage of stride (%) for one stride of the jog of the stock breed western pleasure horse (Booker 2005; Nicodemus and Booker 2007). The black vertical line indicates hoof off.

Breed association guidelines.

The AQHA's Official Handbook of Rules and Regulations (2009) indicates that the jog should be "a smooth, ground-covering two-beat diagonal gait. The horse works from one pair of diagonals to the other pair. The jog should be square, balanced and with straight, forward movement of the feet" (p.140-141). As well, "[w]hen asked to extend the jog, it moves out with the same smooth way of going" (p. 140). AQHA (2009) further indicates that western pleasure horses "should carry his head and neck in a relaxed, natural position, with his

poll level with or slightly above the level of the withers" (p. 215). Other major stock breed associations follow the guidelines set forth by AQHA with only minor changes in wording (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008).

Based on the above guidelines for gait performance and the scientifically determined temporal, linear, and angular kinematic variables presented in previous paragraphs, the extended jog does more closely follow some of the guidelines set forth by major stock breed associations for western pleasure competition than does the collected jog. The extended jog indicated greater synchronization of diagonal pairs than the collected jog thereby more closely following the two-beat requirement of the jog as set forth by breed associations. Greater synchronization of the diagonal pairs is most likely due to the increased stride length and velocity found in the extended jog when compared to the collected jog. However, had the extended jog completely conformed to the two-beat requirement for the jog, the smoothness of the gait would have been lost; the lack of suspension and inclusion of diagonal couplets means there is no "bounce" in the stride and allows for a smooth, comfortable ride. Correct performance of a two-beat gait includes suspension, which creates "bounce" and therefore roughness during the ride. Losing the smoothness of the stride would be contradictory to all stock horse breed association guidelines. Horses performing the collected and extended jog carried a level topline that does

correspond to guidelines for gait performance. Therefore, it would be prudent of major stock breed associations to take into consideration the way in which the jog is currently being performed and either adapt current western pleasure gait definitions to more closely match what is being performed or to fully enforce the gait definitions as written. The area in which horses are in direct violation of breed association guidelines is in regards to a two-beat gait for the jog, so to make educated decisions concerning the adaptation of gait definitions, breed associations must choose between a two-beat gait, which will not be smooth, and the current performance of the jog as a four-beat jog, which is smooth.

With respect to horses moving from the collected to extended jog, horses performing the extended jog had an increased stride length and velocity when compared to the collected jog. This increase in stride length and velocity indicates that horses did "move out" and follow recommendations related to gait performance. Further, the insignificance seen for forelimb as well as hock and hindlimb fetlock angular kinematics indicate that horses moved out from the collected jog "with the same smooth way of going" as the extended jog due to the fact that horses did not adjust joint motions to achieve temporal or linear kinematic changes; the horses just moved faster and covered more ground. For these reasons, horses did more closely follow breed guidelines with regards to performance of the extended jog when compared to the collected jog.

Collected and Extended Lope

Temporal and linear kinematics.

In the current study, the left lead collected lope as well as the right and left lead extended lope were performed with a lateral footfall sequence while the right lead collected lope was performed with a diagonal footfall sequence. All four gaits were performed as asymmetrical four-beat stepping gaits, having no period of suspension, and no periods of quadrupedal support. Diagonal limb pairs moved closely together in time, creating a diagonal couplet, and rarely was hoof placement or lift-off made at precisely the same moment. Disuniting the diagonal pair created a gait with a four-beat rhythm. Comparisons between the current study and the Nicodemus and Clayton (2001a) and Nicodemus and Booker (2007) indicate changes in performance over time (Table 5.2). Stride length and duration have increased while stride frequency and velocity have decreased; even the right and left lead extended lope was not performed at a velocity found in Nicodemus and Booker (2007) (Table 5.2). These findings indicate that current stock breed western pleasure horses are exhibiting longer stride lengths and durations but slower stride frequencies and velocities than did previous research on stock breed western pleasure horses. The relationship between stride length, stride duration, stride frequency, and velocity indicates that the horse's legs are covering more distance yet moving slower. The

differences seen in the above mentioned temporal and linear variables have resulted in a slower moving stock breed western pleasure horse most likely due to a combination of breeding and training associated with breed association rule changes implemented since the previous research was conducted. Horses that cover more ground per step yet move the legs more slowly are more desirable in the current stock breed western pleasure horse industry because the horse is more closely following breed association guidelines with regards to the collected and extended lope being ground-covering gaits (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008)

In accordance with Nicodemus and Booker (2007), horses in the present study performed the right and left lead collected and extended lope without periods of quadrupedal support unlike those horses in the Nicodemus and Clayton (2001a) (Table 5.2). The percentage of tripedal limb support found for horses in the present study was between that of the horses in the Nicodemus and Booker (2007) and Nicodemus and Clayton (2001a). The current horses spent a lesser percentage of stride in diagonal bipedal limb support and a greater percentage of stride in unipedal forelimb support than did previously studied stock breed western pleasure horses. Differences seen in limb support percentages between the present, Nicodemus and Booker (2007), and Nicodemus

and Clayton (2001a) are most likely due to the speed at which the gaits were performed.

Comparisons concerning vertical excursions of the head indicate only slight differences between the lope, collected, and extended lope while the croup of horses in the present study appear to have much greater vertical excursions than did the horses in previous work (Table 5.2). Vertical excursions of the coffin suggest that current stock breed western pleasure horses do not pick their hooves up as high as past stock breed western pleasure horses (Table 5.2) (Nicodemus and Booker 2007).

Table 5.2: Means (± s.d.) for temporal and linear variables of the collected and extended lope for the present study and the lope from the Nicodemus and Clayton (2001a) as well as the Nicodemus and Booker study (2007). NP indicates temporal or linear variables that were not present in the Nicodemus and Clayton (2001a) study. Collected and extended lope variables linear variables are as calculated from right hind down placements. Tripedal with two forelimbs and tripedal with two hindlimbs support phases as well as diagonal bipedal limb support phases have been combined for the sake of comparison.

	Lope (2001a)	**Left Lead Lope (2007)**	**Collected Lope**		**Extended Lope**	
			Right	**Left**	**Right**	**Left**
Stride Length (m)	NP	1.24 (0.09)	1.57 (0.18)	1.50 (0.17)	1.68 (0.15)	1.70 (0.21)
Stride Duration (s)	0.72 (0.03)	0.72 (0.04)	1.35 (0.07)	1.39 (0.08)	1.32 (0.08)	1.33 (0.08)
Stride Frequency (stride/s)	NP	1.40 (0.08)	0.74 (0.04)	0.72 (0.04)	0.76 (0.05)	0.76 (0.05)
Velocity (m/s)	NP	1.74 (0.13)	1.16 (0.15)	1.09 (0.13)	1.28 (0.12)	1.28 (0.19)
Limb Support Phases (%)						
Tripedal	49.00 (0.00)	36.00 (7.00)	44.68 (5.30)	41.55 (7.54)	40.11 (6.43)	43.02 (6.58)
Diagonal Bipedal	39.00 (0.00)	44.00 (6.00)	34.09 (8.28)	36.41 (9.38)	33.56 (8.73)	32.00 (9.71)
Unipedal Fore	4.00 (0.00)	7.00 (2.00)	9.20 (2.16)	10.00 (3.78)	14.37 (2.45)	13.80 (4.56)
Quadrupedal	2.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Vertical Excursions (m)						
Head	NP	0.44 (0.14)	0.41 (0.09)	0.42 (0.11)	0.40 (0.05)	0.38 (0.09)
Croup	NP	0.18 (0.04)	0.40 (0.08)	0.51 (0.13)	0.32 (0.20)	0.45 (0.06)
Leading Fore Coffin	NP	0.25 (0.06)	0.15 (0.02)	0.12 (0.02)	0.15 (0.03)	0.13 (0.02)
Trailing Fore Coffin	NP	0.30 (0.08)	0.15 (0.03)	0.17 (0.02)	0.15 (0.02)	0.18 (0.03)
Leading Hind Coffin	NP	0.25 (0.08)	0.13 (0.02)	0.16 (0.04)	0.13 (0.03)	0.18 (0.04)
Trailing Hind Coffin	NP	0.30 (0.06)	0.15 (0.05)	0.14 (0.02)	0.15 (0.04)	0.13 (0.02)

Diagonal advanced placements and lift-offs indicate that the collected and extended lopes were performed with diagonal couplets instead of diagonal pairs indicating that while the diagonal limbs moved in concert, they did not move synchronously (Table 5.3). When evaluating the trailing fore to leading hindlimb advanced placements, the greatest time between placement of the diagonal pairs was seen at the right lead extended lope and indicates "poorer" gait performance when compared to the right and left lead collected lope or left lead extended lope; however, the left lead extended lope indicated the greatest synchronization of diagonal pair placement when compared to other lopes. These differences in diagonal pair synchronization are most likely due to the "handedness" or preference of the horses to perform one lead better than another (Deuel and Park 1990). In order to control for the "handedness" of the rider, the same rider rode all horses. Advanced placement in the stock breed western pleasure horse was longest between the leading fore and trailing hind which is in line with previous Nicodemus and Clayton (2001a) work but contrary to Nicodemus and Booker (2007). This time period between placement of the leading fore and trailing hindlimb is usually reserved for suspension in other breeds of horses, but the stock breed western pleasure horse has adapted the lope as a stepping gait rather than a leaping gait (Clayton 1994a).

Table 5.3: Means (± s.d.) for diagonal advanced placement and diagonal advanced lift-off (s) of the collected and extended lope for the present study and the lope from the Nicodemus and Clayton (2001a) as well as the Nicodemus and Booker study (2007). NP indicates temporal or linear variables that were not present.

	Lope (2001a)	**Left Lead Lope (2007)**	**Collected Lope**		**Extended Lope**	
			Right	**Left**	**Right**	**Left**
Advanced Placement (s)						
Leading Fore to Leading Hind	0.21 (0.02)	0.27 (0.06)	0.49 (0.04)	0.58 (0.17)	0.48 (0.05)	0.47 (0.05)
Leading Fore to Trailing Hind	0.02 (0.00)	0.21 (0.04)	0.82 (0.15)	0.80 (0.14)	0.71 (0.19)	0.85 (0.12)
Trailing Fore to Leading Hind	0.22 (0.03)	0.04 (0.03)	0.19 (0.39)	0.16 (0.19)	0.38 (0.51)	0.12 (0.20)
Trailing Fore to Trailing Hind	0.42 (0.03)	0.22 (0.06)	0.40 (0.05)	0.47 (0.14)	0.35 (0.07)	0.43 (0.26)
Advanced Lift-off (s)						
Leading Fore to Leading Hind	NP	0.23 (0.04)	0.49 (0.06)	0.47 (0.03)	0.46 (0.05)	0.48 (0.08)
Leading Fore to Trailing Hind	NP	0.17 (0.04)	0.85 (0.18)	0.76 (0.23)	0.58 (0.15)	0.87 (0.10)
Trailing Fore to Leading Hind	NP	0.04 (0.02)	0.09 (0.12)	0.17 (0.21)	0.04 (0.03)	0.03 (0.01)
Trailing Fore to Trailing Hind	NP	0.29 (0.05)	0.85 (0.18)	0.76 (0.23)	0.58 (0.15)	0.45 (0.06)

Angular kinematics.

Similarities can be noted between the joint motion patterns of the leading fore and hindlimbs of stock breed western pleasure horses performing the lope, collected lope, and extended lope. During stance phase, the elbow and carpus gradually extended and the fetlock reached peak extension (Figure 4.15, 5.5, & 5.6). The shoulder gradually flexed throughout stance (Figure 5.5). The elbow, carpus, and fetlock gradually flexed throughout swing phase (Figure 5.5 & 5.6). Peak flexion of the carpus occurred prior to peak flexion of the elbow and peak extension of the shoulder occurred in early swing; peak flexion of the forelimb fetlock was not as obvious at the lope as at the collected and extended lope.

Leading Forelimb Shoulder and Elbow Joint Motion During the Lope

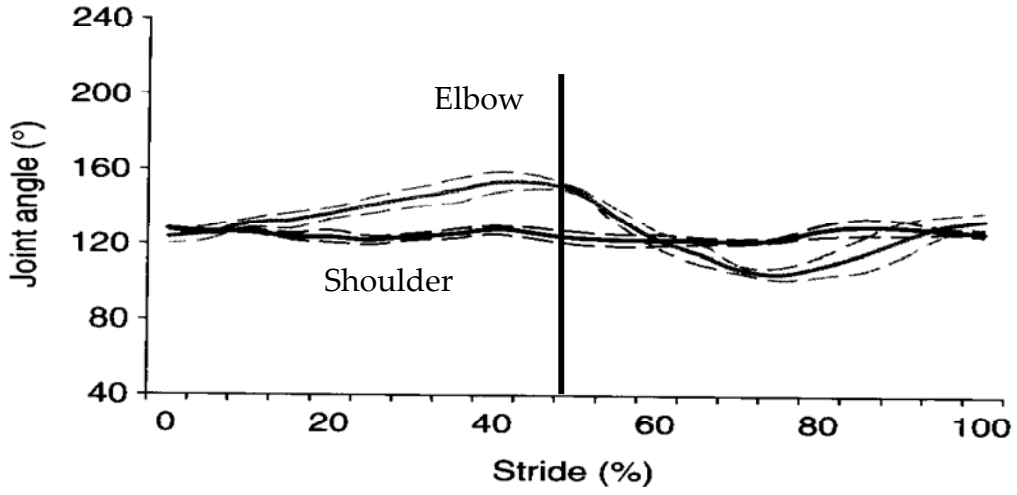

Figure 5.5: Mean (solid lines) ± SD (dashed lines) joint motion for the shoulder and elbow joints of the leading forelimb during the lope of the stock breed western pleasure horse (Nicodemus and Booker 2007). The black vertical line indicates hoof off.

Leading Forelimb Carpus and Fetlock Joint Motion During the Lope

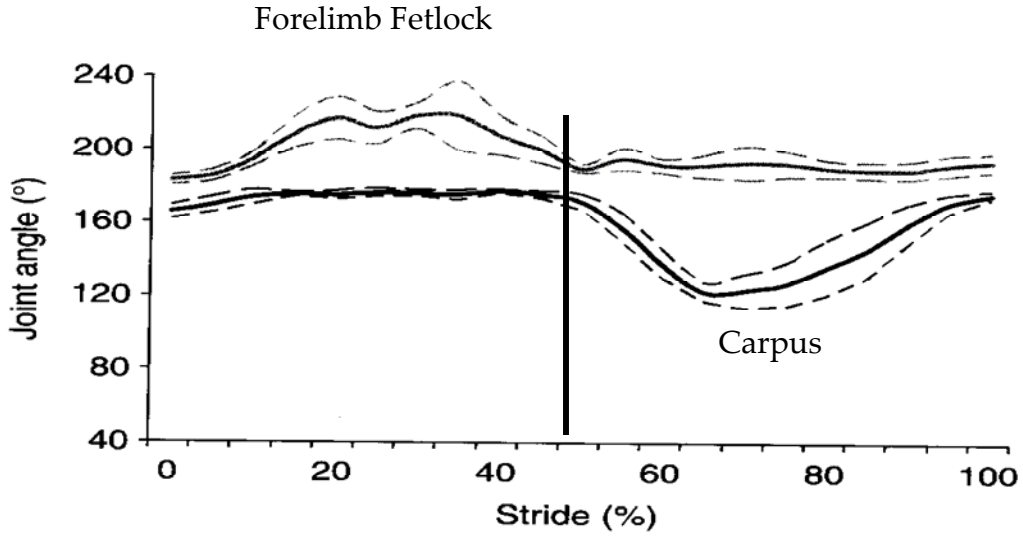

Figure 5.6: Mean (solid lines) ± SD (dashed lines) joint motion for the carpus and forelimb fetlock joints of the leading forelimb during the lope of the stock breed western pleasure horse (Nicodemus and Booker 2007). The black vertical line indicates hoof off.

The hip, stifle, and hock gradually flexed and then extended throughout stance (Figure 4.17, 5.7, & 5.8). During swing phase, the hip, stifle, and hock gradually flexed (Figure 5.7). Peak flexion of the hindlimb fetlock was not as obvious at the lope as at the collected and extended lope (Figure 5.8) (Booker 2005; Nicodemus and Booker 2007). Similarities in joint motion graphs indicate that stock breed western pleasure horses have not adjusted joint motions to achieve the temporal or linear kinematic changes seen between the Nicodemus and Booker (2007) and the present study; the horses are just moving slower. It should be noted that trailing fore and hindlimbs of the loping stock breed

western pleasure horse have not been previously examined, so further comparisons of angular kinematics cannot be made.

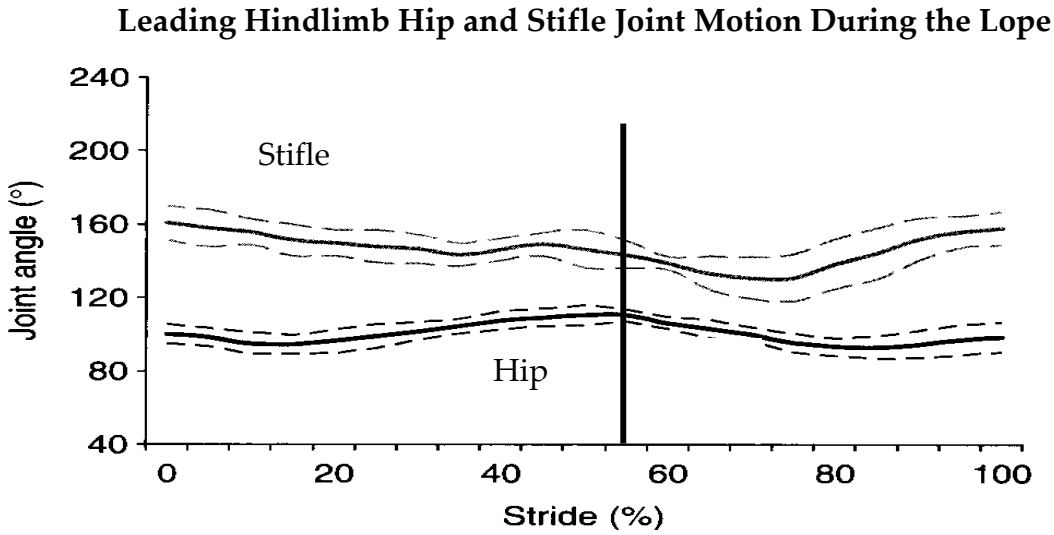

Figure 5.7: Mean (solid lines) ± SD (dashed lines) joint motion for the hip and stifle joints of the leading hindlimb during the lope of the stock breed western pleasure horse (Nicodemus and Booker 2007). The black vertical line indicates hoof off.

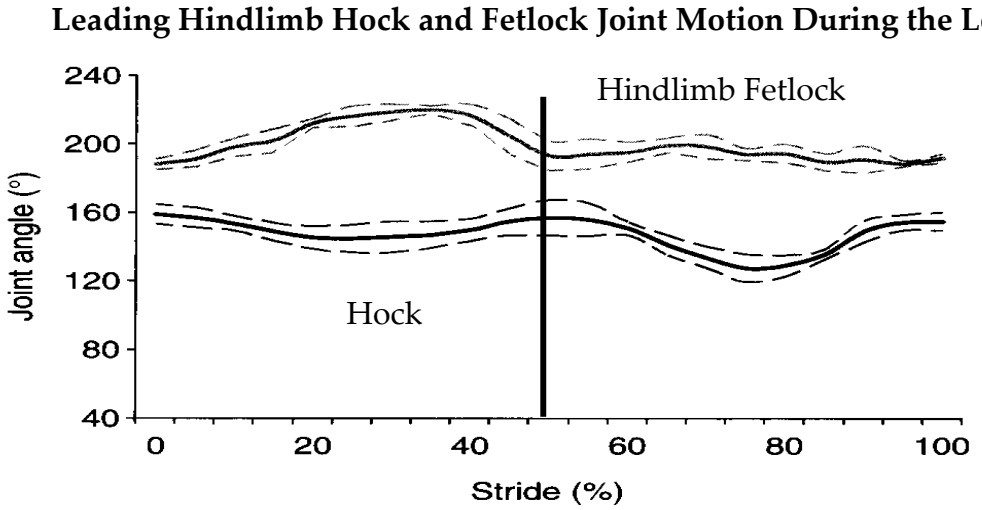

Figure 5.8: Mean (solid lines) ± SD (dashed lines) joint motion for the hock and hindlimb fetlock joints of the leading hindlimb during the lope of the stock breed western pleasure horse (Nicodemus and Booker 2007). The black vertical line indicates hoof off.

Breed association guidelines.

The AQHA's Official Handbook of Rules and Regulations (2009) indicates that the lope should be

> …an easy, rhythmical three-beat gait. Horses moving to the left should lope on the left lead. Horses moving to the right should lope on the right lead. Horses traveling at a four-beat gait are not considered to be performing at a proper lope. The horse should lope with a natural stride and appear relaxed and smooth. It should be ridden at a speed that is a natural way of going. (141)

As well, "[e]xcessive slowness in any gait, loss of forward momentum (resulting in an animated and/or artificial gait at the lope)" is considered a fault that should be penalized according to severity (p. 216). Other major stock breed associations follow the guidelines set forth by AQHA with only minor changes in wording (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008).

Based on the above guidelines for gait performance and the scientifically determined temporal, linear, and angular kinematic variables presented in previous paragraphs, it is still unclear as to whether the extended lope more closely follows the guidelines set forth by major stock breed associations for western pleasure competition than does the collected lope. Only the left lead extended lope indicated greater synchronization of the diagonal pair and more closely followed the three-beat requirement of the lope as set forth by breed associations. While greater synchronization of the diagonal pair during the left lead extended lope is most likely due to the increased stride length and velocity found in the extended lope when compared to the left lead collected lope, the same was not true for the right lead extended lope when compared to the collected lope. However, had the extended lopes completely conformed to the three-beat requirement for the lope, the smoothness of the gait would have been lost; the lack of suspension and inclusion of diagonal couplets means there is no "bounce" in the stride and allows for a smooth, comfortable ride. Correct

performance of a three-beat gait includes suspension, which creates "bounce" and therefore roughness during the ride. Losing the smoothness of the stride would be contradictory to stock horse breed association guidelines. Horses performing the collected and extended lopes did not indicate proper head carriage or a level topline and did not conform to guidelines for gait performance. Therefore, it would be prudent of major stock breed association's to take into consideration the way in which the lope is currently being performed and either adapt current western pleasure gait definitions to more closely match what is being performed or to fully enforce the gait definitions as written. The two areas in which horses are in direct violation of breed association guidelines are in regards to a three-beat gait and level topline during the lope, so to make educated decisions concerning the adaptation of gait definitions, breed associations must choose between a three-beat gait, which will not be smooth, and the current performance of the four-beat lope, which is smoother. In addition, breed association guidelines should attempt to address the topline variability.

Although dropped by the AQHA (2009), the forward motion clause which states that "[l]ope with forward motion will become the only gait recognized as a lope" is still present in the APHA (2009), PHBA (2008), and ApHC (2009b) rulebooks. With respect to horses moving from the collected to extended lope,

horses performing the extended lope had an increased stride length and velocity when compared to the collected lope. This increase in stride length and velocity indicates that horses did "move out" when asked to extend the lope; however, based on the increase in stride length from the earlier lope studies to the current study, it is fair to suggest that horses were already moving with forward motion at the collected lope and did not need to further extend the stride to comply with breed association guidelines (Nicodemus and Booker 2007). While horses may have already been moving with "forward motion" the slight adjustments in vertical excursions of the head and croup indicate that the extended lope was "easier" and less balance compromising to perform because horses were able to maintain a more level topline. It is interesting to note, however, that the insignificance seen for angular kinematics for the right lead collected to extended lope and the forelimb as well as hindlimb fetlock angular kinematics for the left lead collected to extended lope indicates that horses "moved out" from the collected lope to the extended lope due to the fact that horses did not adjust joint motions in order to achieve temporal or linear kinematic changes; the horses just moved faster and covered more ground.

Injuries

Following current breeding trends for stock breed western pleasure horses, horses in the current study were taller and had less muscle mass over the shoulders and hindquarters with steeper shoulder and pastern angles than typical stock horses (Black 1999). All horses were shod at steep hoof angles with aluminum shoes, which increased hoof angle and decreased breakover time for carpus flexion to allow for the "flat kneed" appearance of the stock breed western pleasure horse. It should also be noted that none of the horses used in the current study had been subjected to intra-articular joint injections of the stifle, hock, fetlock, or coffin for osteoarthritis within the last year, which eliminates joint injections with any substance as a variable in the current study. No scientific literature exists directly linking western pleasure to osteoarthritis, but it is accepted in the equine industry that elite performance horses that have been showing at the national level since the age of two do not often maintain a show career after the age of five. This lack of senior aged performance horses has been anecdotally linked to osteoarthritis induced by the intense training these horses receive early in their show career and the ultra slow gait they are expected to achieve. For the current study, the oldest horse was 8 years while the youngest horse was 3 years, and one reason these horses had not been subjected to joint injections may be due to a late start, for whatever reason, in western pleasure

training thereby potentially reducing the injury to the joint and the need for injection of anti-inflammatory agents. Another contributing factor that lessened the need for joint injections in these relatively young horses might be the changes in breed association guidelines for gait performance of stock breed western pleasure horses. By encouraging horses to have a natural stride of reasonable length and rewarding those horses with forward motion, stock breed associations might anecdotally be reducing injury to stock breed western pleasure horses (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008). Rule changes inducted in 2005 may be showing effectiveness in the current horses' collected jog and lope based on the current study's subjects, so it is reasonable to assume that the extended jog and lope would continue this trend and conform to a more natural way of going for stock breed western pleasure horses thereby reducing risk of joint injury and trauma than does the collected jog and lope.

Furthering this argument that the extended jog and lope are more natural to the horse's way of going are the shifts in limb support percentages seen when moving from the collected jog and lope to the extended jog and lope. Previous research has indicated that having more limbs on the ground increases stability because limb support is related to speed (Clayton 1989; Hodson *et al.* 1999; Nicodemus and Clayton 2001a). In effect, the slower the horse is moving the more limbs are on the ground at one time as the horse must compensate for the

lack of dynamic stability (Hodson *et al.* 1999). Other equine gaits that have been found to lack forward motion include longer periods of tripedal and quadrupedal limb support that are not found at faster versions of the same gait (Burns and Clayton 1997; Clayton 1997; Hodson *et al.* 1999; Leach 1986). In parallel, the current stock breed western pleasure study indicated a greater percentage of stride spent in diagonal bipedal limb support and a lesser percentage of stride spent in quadrupedal and tripedal limb supports when horses moved from the collected to the extended jog (Table 5.1). While opposite effects were found in the percentage of stride horses spent in tripedal limb support when moving from the right collected to extended lope than from the left collected to extended lope, both leads indicated a decrease in diagonal bipedal and in increase in unipedal forelimb support (Table 5.2). As well, the increase in stride length found in horses moving to the extended from the collected versions of the jog and lope allows the horse to have a greater base of support and greater forward motion. Thus, it can be suggested that both the collected jog and lope lack forward motion thereby challenging the horse's balance to a higher degree than does the extended jog and lope.

Another indication that the collected jog and lope do increase the challenge to a horse's balance is vertical excursion of the head and croup. Vertical excursion of the head and croup did not change when horses moved

from the collected to extended jog, but this finding is not surprising due to the symmetry and balanced nature of the jog (Table 5.1). However, an asymmetrical gait such as the lope that is performed at such slow velocities is an ideal gait in which to visually and quantitatively assess balance based on topline excursion. Vertical excursions of both the head and croup decreased when horses moved from the right and left lead collected to extended lope (Table 5.2). The ability of horses to hold a steadier topline during the extended lope indicates that the increased forward motion, based on an increase in stride length, combined with the shift in limb support phases decreases the balance challenge and increases dynamic stability when compared to the collected lope.

For example, consider a person hopping forward on one foot while moving in slow motion. Not only is there an obvious challenge to balance that has been intensified by decreasing forward motion, the risk for injury is easy to visualize as the human wobbles to maintain balance. In effect, this very same scenario is occurring when horses are asked to move forward at slow velocities, so as does the human when the compromise in balance is too great, the horse puts additional limbs on the ground to increase balance and shows greater vertical excursions over the topline. The additional limb support phases and "wobbling" of the topline indicate a loss in dynamic stability and may be translated to the risk of injury to the horse. While no scientific research exists to

directly link lack of balance to injury in stock breed western pleasure horses, it is reasonable to conclude that the increased demands associated with threatened balance could lead to injuries.

Summary

In summary, results indicate that horses exhibited more desirable head carriage and a level topline during the collected and extended jog that was not found during the collected and extended lope. As well, stride length was not altered independently of stride duration due to the changes seen in stride length, stride duration, stride frequency, and velocity when the collected jog and lope are compared to the extended jog and lope. Stock breed western pleasure horses perform the collected and extended jog as symmetrical four-beat stepping gaits with no period of suspension and diagonal couplets instead of diagonal pairs. The extended jog was performed with a greater stride length, stride frequency, and velocity than the collected jog but shorter stride duration. Lack of suspension as well as periods of quadrupedal and tripedal limb support during the jog indicated that stock breed western pleasure horses had limited forward motion that leads to a loss of dynamic stability. Ultimately, the extended jog indicated greater synchronization of diagonal pairs than the collected jog thereby

more closely following the two-beat requirement of the jog as set forth by breed associations.

The left lead collected lope as well as the right and left lead extended lope were performed with a lateral footfall sequence while the right lead collected lope was performed with a diagonal footfall sequence. All four loping gaits were performed as asymmetrical four-beat stepping gaits with leads that had no period of suspension and no periods of quadrupedal support. However, based on the inconsistencies in diagonal synchronization at the extended lope it is unclear as to whether the extended lope more closely follows the guidelines set forth by major stock breed associations for western pleasure competition than does the collected lope with regards to the three-beat requirement of the lope. An increase in stride length and velocity when moving from the collected to extended lope indicates that horses did "move out" when asked to extend the lope, but based on the increase in stride length from the earlier lope studies to the current study, it is fair to suggest that horses were already moving with forward motion at the collected lope and did not need to further extend the stride in order to comply with breed association guidelines with regards to forward motion. However, the changes seen in vertical excursions of the lope when horses performed the extended lope when compared to the collected lope indicate that, theoretically, more forward motion may be the answer when considering topline

stability. The combination of diagonal synchronization inconsistencies, forward motion, and topline variability leaves the question as to whether the extended lope more closely follows guidelines set forth by major stock breed registries for western pleasure competition than does the collected lope mostly unanswered and provides the foundation for additional research associated with stock breed western pleasure horses.

Therefore, it would be prudent of major stock breed association's to take into consideration the way in which the jog and lope are currently being performed and either adapt current western pleasure gait definitions to more closely match what is being performed or to fully enforce the gait definitions as written. Stock breed western pleasure horses are in direct violation of breed association guidelines in regards to the two-beat nature of the jog and three-beat nature of the lope, so in order to make educated decisions concerning the adaptation of gait definitions breed associations should choose between the smoothness of the gait and the correctness of beats as well as address topline carriage during the lope. Recommendations concerning changes to lope guidelines are made cautiously as data showed inconsistencies between the collected and extended lope that resulted in the inability to draw complete conclusions regarding performance.

It can be suggested that the rule changes of 2005 have made an impact on the injury rate of stock breed western pleasure horses when examining the current pool of subjects. By encouraging horses to have natural stride of reasonable length and rewarding those horses with forward motion, stock breed associations might anecdotally be reducing injury to stock breed western pleasure horses (APHA 2009; ApHC 2009b; AQHA 2009; PHBA 2008). So, continued gait definition transformations should theoretically improve gait quality and continue to reduce injury rates resulting in healthier, happier stock breed western pleasure horses and owners. Based on the previous statement, I propose that stock breed association change gait definitions to more fully and completely identify the jog and lope of western pleasure horses as four-beat stepping gaits without visible separation of the diagonal pairs. This definition change would 1) keep the smoothness of the gaits, 2) disregard the implied suggestion of suspension required during the jog and lope, 3) continue with the gait quality improvements already in place thereby reducing injury, and 4) more appropriately categorize the jog and lope of stock breed western pleasure horses.

Chapter VI

Conclusion

The purpose of this study was to collect temporal, linear, and angular kinematics of the stock breed western pleasure horse in order to compare the variables of the collected and extended jog and the collected and extended lope to determine consistency with current rulebooks of major stock breed associations. Additionally, this study sought to determine if the extended jog and lope conform to a more natural way of going for stock breed western pleasure horses, which may reduce the risk of joint injury and trauma than does the collected jog and lope. The current chapter presents the conclusion on the topics of a) collected and extended jog, b) collected and extended lope, c) injuries, and d) future research.

Collected and Extended Jog

The collected and extended jog of stock breed western pleasure horses in the current study was performed as a four-beat stepping gait in contrast to the leaping gait status implied by breed association guidelines. Horses exhibited

symmetry and a lateral footfall sequence with no period of suspension during both the collected and extended jog. Additionally, the jog was performed with diagonal couplets that moved closely together in time instead of diagonal pairs as dictated by stock breed association guidelines. The extended jog did exhibit greater diagonal synchronization of the diagonal pairs than did the collected jog, but failed to reach coincidence. Periods of tripedal and quadrupedal support found in the collected and extended jog indicates that the jog was performed with limited forward motion that lead to a loss of dynamic stability, albeit less in the extended jog. Vertical excursions of the horses during the collected and extended jog indicated that horses maintained a level topline throughout the gaits. When examining angular kinematics, current stock breed western pleasure horses exhibited similar joint motions for the shoulder, elbow, carpus, hip, stifle, and hock joints to the previously studied stock breed western pleasure horses. The hindlimb fetlock joint indicated an extension peak during the swing phase in earlier stock breed western pleasure research that was not present in the current study; further, both the fore and hindlimb fetlock joint motions were not as obvious in earlier stock breed western pleasure joint motion as in the current study (Nicodemus and Booker 2007).

The current study indicated results that determined that, contrary to our hypothesis, stock breed western pleasure horses do not alter stride length

independently of stride duration during the jog. The inverse relationship found among stride length, stride frequency, and velocity to stride duration indicated that horses did not alter stride length independently of stride duration when comparing the collected to extended jog. Congruent with our hypothesis, the extended jog more closely followed the two-beat requirement of the jog set forth by stock breed western pleasure guidelines for gait performance. As well, horses followed breed guidelines with regards to performance of the extended jog when compared to the collected jog based on increases in stride length and velocity. Horses' head carriage and topline did not, however, more closely follow the guidelines set forth by major stock breed associations for western pleasure competition during the extended jog as horses maintained a level topline during both the extended and collected jog. Based on the results determined by this study, it is proposed that stock breed associations, including AQHA, APHA, ApHC, and PHBA, change the gait definition of the jog to more closely and completely identify the gait as performed by stock breed western pleasure horses. By defining the jog as a four-beat stepping gait without visible separation of the diagonal pairs, horses will maintain the smoothness desired during the jog yet rid the definition of the implied suspension related to a two-beat leaping gait.

Collected and Extended Lope

Horses performed all variations of the lope as asymmetrical four-beat stepping gaits with leads; the left lead collected and extended lope and the right lead extended lope exhibited a lateral footfall sequence while the right lead collected lope was performed with a diagonal footfall sequence. Diagonal couplets, instead of diagonal pairs, were found during the trailing forelimb and leading hindlimb of the right and left collected and extended lope indicating that the diagonally paired limbs moved closely together in time but not simultaneously. However, this greater synchronization of the diagonal pair was not found in the right lead extended lope and may be related to "handedness," (which was not examined) of the horses. Tripedal limb support, which has been shown to indicate a loss in dynamic stability in other breeds of horses, showed mixed results when moving from the right and left lead collected to extended lope, so without the inclusion of quadrupedal limb support, it is difficult to determine how dynamic stability during the lope is affected when evaluating limb support phases only. However, vertical excursions of the head and croup indicate that horses did not exhibit a level topline during the right or left lead collected and extended lope, which is a marker of dynamic stability and suggests that these gaits have a great balance demand. When examining angular kinematics of leading limbs to previously studied loping stock breed western

pleasure horses similar joint motions for the shoulder, elbow, carpus, hip, stifle, and hock are demonstrated. However, fore and hindlimb fetlock joint motion was not as clear in Nicodemus and Booker (2007) as in the current study

The current study determined that, contrary to the hypothesis, stock breed western pleasure horses do not alter stride length independently of stride duration during the lope. The inverse relationship found among stride length, stride frequency, and velocity to stride duration indicated that horses did not alter stride length independently of stride duration when comparing the collected to extended lope. Inconclusively, based on the discrepancies in diagonal synchronization at the extended lope it is unclear as to whether the extended lope more closely follows the guidelines set forth by major stock breed associations for western pleasure competition than does the collected lope with regards to the three-beat requirement of the lope. Horses' head carriage and topline did not, however, more closely follow the guidelines set forth by major stock breed associations for western pleasure competition during the extended jog as horses did not maintained a level topline during either the extended or collected lope. Based on the results determined by this study, it is proposed that stock breed associations, including AQHA, APHA, ApHC, and PHBA, change the gait definition of the lope to more closely and completely identify the gait as performed by stock breed western pleasure horses as well as address topline

carriage. By defining the lope as a four-beat stepping gait without visible separation of the diagonal pairs, horses will maintain the smoothness desired during the lope yet rid the definition of the implied suspension related to a three-beat leaping gait. In an effort to address topline carriage stock breed associations should, theoretically, continue to push for more forward motion during the lope, which should increase the horse's balance and result in a more level topline during the lope. As of yet, this described gait with greater forward motion is not available for study the previous statement is hypothetical and in complete speculation.

Injuries

Anecdotally, the changes in stock breed western pleasure guidelines from 2005 to the present have reduced the injury and joint trauma rate of current western pleasure horses by encouraging horses to have a natural stride of reasonable length and rewarding those horses with forward motion. The ability of horses to hold a steady topline indicates that the increased forward motion, based on an increase in stride length, combined with the shift in limb support phases decreases the balance challenge and increases dynamic stability. Decreasing the challenge to the horses' balance thereby increasing dynamic stability allows the horse to move more naturally and reduces joint injury and

trauma. Thus, continuing the gait definition transformation with regards to the lope to encourage even greater forward motion than was seen in the present study should theoretically maintain the reduction in joint injury and trauma to the stock breed western pleasure horse.

Future Research

Research concerning the stock breed western pleasure horse is still limited in comparison to other breeds; therefore, continuing research using the stock breed western pleasure horse should examine the right and left side of the jogging horse for asymmetry, continue defining the extended jog, compare the right and left lead lope, further evaluate the collected and extended lope, and hold velocity constant to determine its effect on stride length and duration.

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Appendix A

Form A.1

OWNER/AGENT CONSENT FORM

for a Research Study Entitled
"Comparison of stride kinematics of the collected and extended walk, jog, and lope of the stock breed western pleasure horse"

DEPARTMENT OF KINESIOLOGY
COLLEGE OF EDUCATION
AUBURN UNIVERSITY

1. **Project Director:**

Wendi H. Weimar, PhD — Principal Investigator
Associate Professor, Sport Biomechanics Laboratory Director

Joanna E. Shroyer — Lead Graduate Student

Department of Kinesiology
2050 Memorial Coliseum
Auburn, AL 36849
334.844.1468

2. **Purpose of the Research:** The purpose of this research is to determine the temporal, linear, and angular kinematics of the stock breed western pleasure horse's walk, jog, and lope.

3. **Procedures for the Research:** Animals considered for this study must be stock breed western pleasure horses whom are in current western pleasure training or competition. Upon agreeing to participate you will

sign the client consent form and mount and warm up your horse in preparation for data collection. After warming up, anatomical landmarks of the horse will be marked with 47 retroreflective markers. Then you will rider your horse through the capture volume at the collected and extended walk, jog, and lope. A minimum of three trials per gait will be required then your responsibilities as a participant in this study will be completed. Appointments may be made by contacting the lead graduate student, Joanna E. Shroyer at 334.844.1468.

4. **Potential Risks or Discomforts:** There are minimal risks of injury to the horse associated with participation in this study, but no more than when the horse is ridden normally.
5. **Potential Benefits:** Direct benefits to the patient include knowing how their stock breed western pleasure horse performs the collected and extended walk, jog, and lope with relation to stride length and duration, velocity, footfall sequence, and joint angles.
6. **Financial Considerations for Participation in the Study:** There will be no compensation for your participation in this study. There are no financial obligations by the owner to Auburn University for participation in this study.
7. **Additional Expenses Expected for Participation in the Study:** You, as the owner, are financially responsible for costs associated with the treatment of complications or accidental injury associated with this study.

8. **Client Consent:** I understand that I am free to withdraw my consent and discontinue participation in this research project at any time without this decision affecting my animal's medical care.

   I also understand that Auburn University will protect the confidentiality of my records to the extent provided by Law. All videotapes recorded during data collection will be destroyed after data extraction.

9. **Signatures:** I have fully explained to _____ the nature and purpose of the above-described procedure and the benefits and risks that are involved in its performance. I have answered and will answer all questions to the best of my ability. I may be contacted at the following telephone number: _____.

_____ _____

Signature of Principal or Co-Principal Investigator Obtaining Consent

Date

I have been fully informed of the above-described procedure with its possible benefits and risks and I have received a copy of this description. I certify that I am the legal owner (or agent of the owner) of, and am responsible for, this animal. I permit my animal's participation in this study.

_____ _____

Signature of Agent/Owner

Date

_____

Street Address of Agent/Owner

_____

City, Zip

Form A.2

EQUINE INFORMATION FORM

Subject Number: _____

for a Research Study Entitled
"Comparison of stride kinematics of the collected and extended walk, jog, and lope of the stock breed western pleasure horse"

DEPARTMENT OF KINESIOLOGY
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Project Directors:

Wendi H. Weimar, PhD
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Associate Professor, Sport Biomechanics Laboratory Director

Joanna E. Shroyer
Lead Graduate Student

Department of Kinesiology
2050 Memorial Coliseum
Auburn, AL 36849
334.844.1468

Equine Name: _____

Year Foaled: _____ **Sex: M G S Height:** _____ **Weight:** _____

Breed Registry: AQHA PHBA APHA Color: _____

Years of WP Competition: _____ **Years of WP Training:** _____

Awards/Points/Championships: _____

_____

_____

What type of bit does your horse show in? _____

Shoeing:

Is your horse shod? Front (Y / N) Back (Y / N)

Type of Shoe Front _____ Back _____

Where is your horse in his/her shoeing cycle? _____

Does your horse have any other shoeing concerns we should know about? If so, what are they? _____

_____

General Health:

Has your horse seen the veterinarian in the last week? If yes, why? _____

_____

When were your horse's last joint injections? _____

Joints Injected: Hock (R / L) Stifle (R / L)
Coffin (F / H) (R / L)
Fetlock (F / H) (R / L) Other: _____

Does your horse have any ongoing health concerns? If so, please state health concern. _____

_____

Is there anything else we should know about the health of your horse? If so, please explain. _____

_____

_____

Do you know of any reason why your horse may not be able to successfully complete the required tasks? _____

_____

This horse has been designated as "healthy" for the purpose of this research project by Robert Gillette, DVM.