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POSTURAL SWAY ANALYSIS

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POSTURAL SWAY ANALYSIS IN HORSES

By

David Elyezer Bialski

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Large Animal Clinical Sciences

2001

Professor Hilary Clayton

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ABSTRACT

POSTURAL SWAY ANALYSIS IN HORSES

By

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Postural sway analysis offers an objective method of assessing a horse's balance. The objectives of this study were to measure postural sway in normal horses and to assess the effects of detomidine (10 μg/kg and 20 μg/kg) on the horse's balance at 15 minute intervals for 120 minutes. Horses stood with four hooves on the force platform, while force data (1,000 Hz) were collected for 10 s periods, with five repetitions per condition. Summary statistics were used to quantify the center of pressure (COP) movements and the effects of the drug on the horse's balance. Mediolateral COP movements, COP area and mean COP radius returned to no sedation values (0.94 ± 0.21 cm, 0.72 ± 0.22 cm^2, 0.34 ± 0.05 cm, respectively) within 15 minutes after 10 μg/kg and within 30 minutes after 20 μg/kg of detomidine. Mean COP velocity returned to the no sedation value (0.91 ± 0.07cm/s) in both levels of sedation after 30 minutes. Craniocaudal COP movements returned to the no sedation value (1.15 ± 0.11 cm) after 60 minutes and 90 minutes for 10 μg/kg and 20 μg/kg, respectively. It is concluded that the horse should not be moved, have its limbs manipulated or collect postural sway data for 30 minutes after administration of detomidine.

DEDICATION

This work is dedicated to Israel†, Clara†, José†, Bella†, Tereza†, Alzira, Helio, Adrianne, Berenice†, Bernardo, Dayana, Claudio, Daniel, Juliana, James, Alessandra, Andrea, Victor, Igor and Clarinha, because without your help, love and comprehension I would never be the person I am today and I would never had accomplished this.

Thank you.

ACKNOWLEDGMENTS

- First of all I would like to thank God for being my mentor through life.

- I would like to thank my advisor Professor Hilary M. Clayton and also the members of my committee Dr. Harold Schott, Dr. Susan Ewart, Dr. Robert Bowker, and Dr. George Bohart for all the help and advice during my program.

- My sincerest appreciation is also expressed to Joel Lanovaz, who is the research coordinator at the Mary Anne McPhail Equine Performance Center, for his technical and intellectual assistance and also for his unconditional help through my research; and all the graduate students at the Mary Anne McPhail Equine Performance Center, particularly Wesley Singleton for assistance with my project and Molly Nicodemus for all the intellectual input.

- I would like to express my sincere gratitude to Sarah Fox, Acacia Wilson, Sergey Balinskiy and Cara O' Connor for all the help during the collection of data, also I would like to thank Cathy Berney and Susan W. Ebehart for facilitating my research .

This research was supported by the Mary Anne McPhail Endowment

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1. INTRODUCTION

Biomechanics applies mechanical principles to the study of living systems. With the use of biomechanics we can better understand how the different systems within the horse normally function and how the locomotor system reacts to development, change and human intervention (Lanovaz, 1997). Horses perform a wide repertoire of gaits including the walk, trot, pace, canter, gallop and other more specialized gaits. Training transforms ordinary gaits into elegant movements such as piaffe and pirouettes. Horses move differently when carrying a rider than when they are performing at liberty (van Weeren, 2000). They also have lighter ground reaction forces especially in the forelimbs (Clayton, et al., 1999), which may increase the risk of injury. Injuries of the locomotor system are by far the most common problem in equine athletes (Jeffcott et al., 1985). The necessity to understand the mechanics of injury prevention has been cited in the literature since the 17th century (reviewed by van Weeren, 2000).

The importance of "balance" of the horse is well recognized in relation to athletic performance (Schamhardt et al., 1992), although data defining balance in horses are scarce. Balance is the ability to maintain a state of equilibrium while at rest or in motion (Kirby et al., 1987). The body counteracts both internal and external forces that are disruptive to equilibrium by a dynamic system of sensory input, motor responses and cognitive processes that work together to maintain the body's center of gravity over its base of support. Balance is not only a reactive response to disruptive forces but can also be proactive and adaptive based on prior experience and intended movement (Horak et al., 1997).

Winter (1990) describes the center of gravity (COG) as an imaginary point where body weight is concentrated. The line of gravity is a vertical line through the COG. When a horse is standing in a balanced position the line of gravity contacts the ground within the base of support, which is circumscribed by the four hooves that are in contact with the ground. The nervous system maintains the COG above the base of support. Each hoof exerts a force against the ground and the ground exerts a force against each hoof that is called the ground reaction force (GRF). The GRF is equal in magnitude and opposite in direction to the force exerted by the hoof against the ground, and it represents the force of the ground on the body. A force platform is a device that measures the total GRF over its entire surface and locates its point of application. When a horse has more than one hoof in contact with a force platform, it cannot distinguish between the individual hooves, and the center of pressure (COP) is the centroid of the total force distributed on its surface (Figure 1.1). If the horse stands perfectly still with all four hooves on the force platform the GRF vector is superimposed on the line of gravity. Even during quiet standing, however, small adjustments of muscle tension are reflected by movements of the COP (Winter, 1990). These movements are described as postural sway. In normal standing there is always some postural sway and the amount of sway is an indicator of the stability of the COP (Winter, 1990).

Somatosensory, vestibular and visual pathways provide feedback for the maintenance of balance (Jeka et al., 1998). During a clinical neurological examination, several observations and manipulative tests of balance are performed. These assess head position and coordination of head movements: normal horses maintain the head in a typical vertical position and are able to perform certain acts, such as prehension of food. Some neurological diseases, such as vestibular disease, cause changes in head position and stability (Smith, 1992). Balance is evaluated during the neurological examination by determining the horse's response to manipulations that include elevating the horse's head or pulling the horse's tail to one side as the horse walks in a straight line. Responses are assessed subjectively and interpretation depends on the experience of the clinician (MacKay and Mayhew, 1991). Postural sway analysis offers an objective method of assessing a horse's balance.

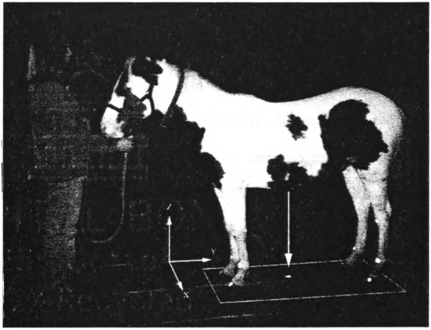

Figure 1.1- Horse standing still and square on a force platform which is outlined in white. The arrow pointing vertically downwards represents the line of gravity and the dot on the force platform represents the center of pressure (COP). The three mutually perpendicular arrows indicate the coordinate system of the force platform.

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The balance mechanism is such that the COP is allowed to drift a short distance before being corrected. More specifically, over short term an open-loop control scheme is utilized by the postural control system, in which the body drifts away from its equilibrium position. Over longer time intervals closed loop control mechanisms are called into play, in which the body drifts away then returns to its equilibrium (Collins and De Luca, 1993). These drifts and corrections are measured by postural sway analysis. The results of postural sway analysis are indicative of the horse's innate ability to balance.

Preliminary studies of postural sway (Clayton et al., 1999) encountered difficulties in making horses stand still and square on a force platform for long enough to collect useful data. This problem may be overcome using sedation. A sedative that is commonly used in horses is detomidine (Dormosedan, Pfizer, New York, NY). This study measures the effects of sedation with detomidine on postural sway analysis. The results will indicate whether detomidine is likely to have an adverse effect on the horse's ability to balance during procedures such as shoeing, clipping and traveling.

Sedatives are used on a daily basis in veterinary practice to provide chemical restraint during a diverse range of procedures. Their use has resulted in improved safety both for the horses and for the people who work with them. Previous studies have examined the physiological response of horses to specific drugs and have identified suitable drugs to facilitate various procedures in equine medicine. However, the effects of those drugs on the horse's balance have not been studied objectively.

Nonopioid analgesics include a large number of drugs used for their anti-inflammatory properties to combat pain. Most of those drugs can be categorized as nonsteroidal anti-inflammatory drugs (NSAID) or nonopioid analgesics such as

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detomidine and xylazine (Muir and Hubbell, 1991). These drugs belong to a much larger group of sedative analgesics called alpha$_2$ adrenoceptor agonists, which act directly on the central nervous system (Jöchle, 1984).

Detomidine was chosen for this study because it is frequently used by equine practitioners, has a long duration of action, and has obvious effects on the horse's balance (ataxia) shortly after administration. It is commonly used as a chemical restraint for procedures such as bronchoscopy or nasogastric intubation, and to provide pain relief for minor surgical procedures and colic. It usually induces decreased heart rate, profound lethargy, and reduced sensitivity to environmental stimuli. Paradoxically some horses have an extreme response to external stimuli after detomidine sedation even when they look deeply sedated (Muir and Hubbell, 1991). A short time after administration, horses show incoordination and a fixed base-wide stance. Occasionally, side effects include a partial atrioventricular block. The use of atropine may prevent the occurrence of arhythmias (Allen et al., 1993). The respiratory rate slows initially but after 5 minutes returns to normal. Salivation, penile prolapse and sweating may be seen as well. Duration of sedation following detomidine administration is dose dependent lasting from 30 minutes to 2 hours. This study will apply postural sway analysis to assess the effects of detomidine on the horse's balance.

1.1. Research Objectives

1. To measure postural sway in a group of sound horses.
2. To determine the effects of light sedation with detomidine (10 μg/kg IV) on balance of horses at selected intervals after administration.
3. To determine the effects of heavy sedation with detomidine (20 μg/kg IV) on balance of horses at selected intervals after administration.

2. LITERATURE REVIEW

The horse has had a very close relationship with man in the 7000 years since it was domesticated. Since the early days after its domestication, the horse has been used as a sport and competition animal and also as a pet, which creates a bond of affection between horse and man. Thus, horses have always had a unique relationship with people that has ensured the horse's survival even after mechanization (van Weeren, 2000).

Unlike almost all other species, the horse was domesticated for its locomotor capabilities rather than as a supplier of food or clothing materials. As a result of this important role in transportation, combined with its closeness to man, the horse was a focus of attention as veterinary science developed in the ancient societies and later as it became a prospering branch of science during the Greek and Roman civilizations. Subsequently, interest in equine veterinary medicine and equine locomotion has kept pace with public recognition of the importance of the horse (van Weeren, 2000).

After World War II horses became less important due to advances in mechanization. However, interest in the species reappeared at the end of the 1960's and in the early 1970's when equestrian sports developed a tremendous popularity that continues to increase today (van Weeren, 2000).

Advances in technology, especially in photographic techniques facilitated the study of equine locomotion. At the end of the 19th century, Marey and Muybridge took advantage of new technology to further acquire knowledge of equine locomotion. Later in the twentieth century, as the interest in horses for sports and recreation increased, the incredible development of computer technology facilitated complex computational tasks making this area of research much more accessible.

The study of locomotion is closely associated with biomechanics, the science of investigating the effects of internal and external forces upon living bodies. The science of biomechanics can be divided into biostatics and biodynamics. Biostatics is applied to study systems with no accelerated motion, in which the sum of the external forces acting on the system is zero: the forces are balanced. Biostatics is more related to study of tissues, tendons bone and cartilage. Biodynamics is the study of unbalanced systems of forces on the body, which result in movement. When the horse is moving freely in three dimensional space the position of any part of the body can be located using a cartesian coordinate system (x, y and z coordinates). The study of biodynamics includes kinematics and kinetics. Kinematics describes the geometry of movement with no regard for the forces producing motion. Kinetics is concerned with the forces that initiate and alter motion (Winter, 1990).

There are no easy methods to produce athletic success in horses, but descriptions of exercise physiology and sport biomechanics, provide some guidelines to trainers, veterinarians and owners (Dalin and Jeffcott, 1994).

2.1. BALANCE

During quiet standing, balance is maintained by small adjustments in muscular tension that are reflected by movements of the center of pressure (COP). These movements are referred to as postural sway and reflect the stability of balance in an animal. Balance is measured by tracking the movements of the COP on a force platform. Previous studies in human subjects have shown that postural sway changes with age (Sinclair et al., 1990; Panzer et al., 1995), loss of visual proprioception (Kollegger et al., 1992) and development of neurological diseases (Nakamura et al., 1997; Rand et al., 1998). In horses the effect of age has not been investigated, but it seems likely that postural stability may develop at a relatively young age due to the precocious development of locomotion capabilities in this species. In a previous study of normal horses COP velocity did not change due to loss of visual proprioception (Bialski et al., 2000), though the findings may be different in horses with neurological disease.

Panzer et al. (1995) studied the effect of aging on balance using the Romberg Test to assess subjectively the balance in a group of 24 normal people ranging in age from 21-77 years old. The results showed that in normal aging there was an increase in variability in the craniocaudal movements of the center of mass (COM) without a corresponding increase in variability of total COM displacement.

Smith et al. (1997) studied the cumulative neurological effects of JP-8 jet fuel vapor from an aircraft on postural sway stability. The results showed that exposure to JP-

8 caused a deficit in balance. Two groups were studied (low exposure and high exposure) and in both groups the amount of postural sway was higher after exposure.

Collins et al., (1995) studied the effects of spaceflight on open loop and closed-loop postural control mechanisms, and found that there may be in-flight adaptations to higher level descending postural control pathways. This change may also be a consequence of a compensatory postural control strategy which is adopted by the astronauts to compensate for post flight unsteadiness.

Maintenance of a stable posture is important for all animals. For humans, maintaining balance is more challenging due to the narrow bipedal base of support. Approximately two thirds of body mass is precariously balanced some distance from the ground (Winter, et al., 1990). The importance of "balance" of the horse is well recognized in relation to athletic performance (Schamhardt et al., 1992), though data defining balance are scant.

Stability is achieved using a combination of visual and vestibular input, combined with somatosensory information from all four limbs. A deficiency in any of these inputs can lead to instability. Light touching of a stable target close to the person's body decreases postural sway in people of all ages. However, finger contact with a target at a greater distance from the body led to an increase of postural sway (Reginella et al., 1999)

To better understand how the central nervous system (CNS) adapts to different environmental conditions, it is important to understand postural control and the role of sensory perception. It has been shown that translating the body with different frequencies requires changes in the coordination patterns of the head, trunk and legs to accommodate the different forces acting on the body. Translating the body at different frequencies also moves the sensory system outside the optimal operational ranges (Buchanan and Horak, 1999).

The influence of moving visual fields on postural sway stability depends, not only on the characteristics of the visual environment, but also on the characteristics of the support surface. Humans and cats with profound loss of vestibular function show normally coordinated postural responses in the limbs with perturbations at the surface, but responses in head kinematics and electromyographic (EMG) responses are exaggerated and more variable. The CNS increased COP amplitude to counter higher forces associated with increasing translation frequency. There was a clear adaptation with repeated exposure even when the frequencies were presented in random order. Control of the head and trunk is a critical strategy for balance at all translation frequencies because the trunk represents a large percentage of body mass and also serves as a platform for the vestibular and visual organs located in the head (Buchanan and Horak, 1999).

2.1.1. Somatosensory, vestibular and visual systems

The subsystems that make up the postural control system involve sensory input from the vestibular, visual and somatosensory system, and the CNS.

The somatosensory system, which consists of muscle, joint and cutaneous receptors, provides information about the state of the effector system in relation to the environment. It uses receptors in the joints, ligaments, muscles and skin to provide information about muscle length, tension, and contraction, and also about temperature, pain, pressure and joint position.

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The vestibular system gives information about the body orientation in the inertial frame of reference and accelerations of the body. It provides information about the position of the head with respect to gravity and inertial forces. The otoliths, which respond to slow head movements, detect two kinds of motion: linear acceleration and tilt angle of the head. The resulting information describes the head movement and orientation with respect to the gravity.

The visual system is also a proprioceptive system because it not only provides information about the environment but also about the orientation and movement of the body (Winter et al., 1990). Visual proprioception provides information about the verticality of the head with respect of the surrounding environment and adjusts head position when necessary. It also provides information for proactive postural control by allowing the individual to accommodate to the environment. Visual input is not necessary for standing, however, because an individual can stand upright with closed eyes (Winter et al., 1990).

On a stable surface the principal system used for balance is the somatosensory system, while the visual system is more important on less stable surfaces such as sand. When responses from the somatosensory and visual systems are present the vestibular system plays a minor role, but without somatosensory and visual input it plays critical role (Shumway-Cook and Wollacott, 1995).

Humans use several strategies to maintain posture such as: the ankle strategy (moving the ankles to the side to achieve balance), hip strategy (swaying the hips to the side or front to back to achieve balance) and stepping strategy.

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Maintenance of balance depends on the visual, somatosensory, and vestibular systems, which provide input to inform the CNS about the location of the COM and the ability to use the appropriate strategy to maintain posture. Strategies used by horses to maintain balance include weight shift, body sway and limb stepping.

2.2. POSTURAL SWAY ANALYSIS

The early tests of postural sway involved subjective assessments and were not very sensitive. Romberg developed a test to subjectively assess postural sway in people (figure 2.1). The subject's stood with their feet together and arms folded. Breaking stance in less than a minute defined failure (Romberg, 1851). Mitchell and Lewis (1886) positioned subjects in front of a grid pattern and observed the amount of sway. Hinsdale (1887) attached a flat record sheet to a subject's head and recorded impressions made by a stationary stylus on the sheet. This procedure offered a graphic record of sway and was used later by many other investigators. Later in the same year, Hinsdale introduced a method of recording the sway in a kymograph through using a stylus attached by a pulley system to the subject's head. Moss (1931), used an unstable platform, which moved upon a central pivot as the subject shifted weight to measure sway. Hellebrandt (1938) used the same platform to quantify forward and lateral sway. Thomas and Whitney (1959) used a suspended platform in which horizontal motion was elastically restrained to measure foot center of pressure location and the horizontal ground reaction forces. Many investigators tracked head movements photographically (e.g. Goldberg, 1943; Borman and Jalavisto, 1953). More recently force platforms have been accepted as the standard method for

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collecting postural sway data (Kilburn et al., 1994). A force platform measures the vertical ground reaction force (GRF) and provides a means of computing the COP by measuring force at three or more points on the platform or by measuring the torque around its horizontal axes (Goldie et al., 1989).

In the Romberg test, the standing patient performs tasks of increasing difficulty, while the tester observes the response to positional stress, displacement or loss of visual input. This test is usually performed before any kind of balance tests, but today is also used as a way to measure postural sway with the patient standing on a force platform.

Figure 2.1- Foot placements used during the Romberg test.
1-Feet comfortably apart
2-Feet together
3-Feet semi-tandem (heel-to-instep)
4-Feet tandem (heels –to-toe)

During the test the patient performs tasks that include raising the arms, crossing the arms in front of the chest and behind the back. The same tasks are performed sighted and blindfolded. There are many variables to be observed during this test, such as: mediolateral range of COP motion, craniocaudal range of COP motion, mean velocity of the COP, mean radius of the COP and area and many others.

2.2.1. Previous studies in humans

Postural sway has been studied extensively in humans since the seventeenth century. Postural sway analysis is now used as part of the examination in sports and orthopedic clinics all over the world. The Romberg test, which was described earlier, is a subjective test to assess postural sway. This is in contrast to the objective assessment of a person's balance using a force platform.

Postural stability is the ability of the balance system to return the body close to its equilibrium point when exposed to a perturbation. For humans to remain upright it is crucial to know the position of the different body segments relative to the environment. During normal standing the mediolateral (ML) sway is mainly controlled by using a load-unload strategy. Control of craniocaudal (CC) movement is by a strategy called the ankle strategy (Horak and Nashner, 1986) that uses the flexor and extensor muscles of the ankle to change the forces between the foot and the ground. Information about standing balance in humans has provided insights into basic mechanisms of neurological integration into biomechanics in health and disease. People affected by neurological diseases employ a variety of different foot positions to adjust the standing balance, postural sway and mean position of the COP.

Karlsson (2000) studied the accuracy of using of the force plate to analyse postural sway and to assess the vertical force that acts during standing. He found that cardiac activity affects the vertical force component. The beating of the heart perturbs human standing resulting in vertical body oscillations.

Mochizuki et al. (1999) analyzed the effect of different bases of support in the analysis of postural sway and concluded that craniocaudal and mediolateral sway can be independent in case of instability.

Yardley et al. (1999) determined that postural sway increases when a person performs a verbal test of mental arithmetic (backward counting). He also verified that this increase in postural sway is due to demand for attentional resources, perturbation of posture by articulation, or a combination of both factors.

The orientation of the body or specific body segments with respect to the vertical axis is controlled both in quadrupeds and in humans. The head, trunk and leg axes are oriented relative to the vertical axis during stance and locomotion in both species. In quadrupeds the trunk axis orientation is parallel to the ground, and the position of the COG with respect to the base of support would not be under direct central control, but is controlled indirectly by the control of body geometry. The COP during static position represents the position of the center of mass (Massion et al, 1998).

Le Clair and Riach (1996) studied postural stability during quiet standing to determine the variability of the COP and influence of time. They proved that time affects the measurements of postural sway.

The use of a force platform to assess postural sway analysis (posturography) comes from the clinical assessment of balance using the Romberg test, which was performed with the patient standing still with the eyes closed and open and seeing how much sway happens in those two conditions. The basic assumption underlying postural sway analysis is that COP represents the vertical projection of the COG in the transverse plane, and the path of the COP about this point is called the sway path. Healthy young subjects and adults have similar sway but use different strategies to achieve balance (Panzer et al., 1995).

During normal standing, proprioceptive input from the legs provides the most sensitive means of perceiving postural sway. Perception of sway comes from signals related to position, velocity or acceleration and each sensory system provides different information about these parameters (Fitzpatrick et al., 1994).

Kilburn et. al. (1994) compared postural sway measured simultaneously with a force platform and a device that registers head (and trunk) movements in a group of people who worked in a metal casting plant and assessed the effects of trichloroethylene (TCE) and polychlorinated biphenalys (PCBs) and they found that both tests were suitable to show that years of exposure to those chemicals cause impaired balance in people.

Jeka and Lackner (1994) proved that contact with external surfaces could modify proprioceptive inputs to the perception of body orientation. The effect of age, sex, height, weight, shoe area and grip strength on both measurements were examined. People stood on a force platform with their feet in specified positions and they were instructed to look at a point in front of them. Movements of the COP were recorded a 100 Hz. They found that the time delays between body sway and fingertip contact forces were much larger with light touch contact. Their findings suggest that the fingertip is providing information that allows anticipatory innervation of musculature to reduce body sway.

Experiments in microgravity suggest that there is an internal representation of the body schema, which is not primarily based on sensory information. It deals with body kinetics and kinematics, body mass, inertia and the orientation of the body with respect to the vertical (Gurfinkel, 1994).

Even in young healthy subjects, who are trying to stand still, movements of the COP normally occur and can be followed in a global coordinate system. A plot of the time varying coordinates of the COP in a horizontal plane is known as a stabilogram. The majority of investigators tried to analyze the response of the human body to various external perturbations (Collins and De Luca, 1992).

Macpherson et al. (1988) studied the effects of initial stance configuration on automatic postural responses in humans. The subjects were tested in both bipedal and quadrupedal stance postures. The most significant finding was an asymmetry in the use of the upper limbs and the lower limbs during postural corrections in quadrupedal stance. Humans subjects in quadrupedal stance posture used the lower limbs as levers, protracting or retracting the hips in order to propel the trunk back to its original position with respect to the hands and feet. Postural responses of the subjects during qudrupedal stance were remarkably similar to those of cats subjected to similar perturbations of the supporting surface. Also, the same predominance in lower limb correction is characteristic for both species.

Kirby et al. (1987) collected data with the subjects barefoot, in a quiet room looking at a point in the distance. Data were collected under different conditions with the right or left foot in front, with the toes pointing in or out at different angles. The influence of foot angle and mediolateral and craniocaudal movements were measured for all conditions. Changes in foot angle resulted in little variation in standing balance except with the extremes of toeing-in, when the movements of the COP were predominantly to the right

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the right. Disturbances of body balance are common in many diseases, but whether sex and normal aging have an influence on spontaneous postural sway is still controversial. The risk of falling is increased not only by cognitive impairment, sedative use and lower extremity disability, but also by abnormalities of balance and gait.

2.2.2. Previous studies in quadrupeds

It is not a simple task, from a physiological point of view, for a terrestrial animal to maintain posture and orientation through changing terrains. Maintenance of posture requires not only that the body be supported against gravity, but also that the body's COG remain within the limits of support in the horizontal plane. Quadrupeds have an intrinsically stable musculoskeletal framework. Movements of any body segment must be properly counterbalanced to preserve equilibrium. Stance maintenance is a dynamic task in which the sensorimotor systems must interact with the external environment, to maintain stability and proper alignment of the limbs and trunk, and head-neck system. (Fung and Macpherson, 1995).

Interpaw distance has a significant effect on the forces exerted by the cat during both quiet stance and perturbation of the support surface, which may have an impact on trunk stability. It was postulated that with long stance distances, the force constraint strategy was mechanically useful in preventing bending movements of the spine, whereas with short stance distances, trunk stability was provided by tonic activation of the epaxial trunk muscles (Fung and Macpherson, 1995).

Roberts (1973) performed a behavioral observations in animals, and proposed that the vestibular and neck reflexes may interact to produce appropriate tonic muscle activities in the limbs to maintain trunk stability during stance on uneven or inclined surfaces. These involved either constraining the orientation of the trunk and inclining the limbs or maintaining a constant vertical alignment of the limbs and changing the curvature of the spine.

Cats seem to have a very simple strategy to maintain balance in the face of destabilizing movements of the supporting surface in the horizontal plane. For the hind limbs a simple choice is made to generate an average horizontal force in one of the craniocaudal and mediolateral directions. Forelimb participation in the correction of balance in the horizontal plane was not obligatory (Macpherson, 1988).

The effect of prior experience concerning the direction of postural perturbation on the balance response of cats to translations of their support surface was studied. It was determined that the use of the force constraint strategy and the amplitude of the response were independent of prior experience with direction of translation, as was the amplitude of the response (Macpherson, 1994).

2.2.3. Postural sway analysis in horses

During a clinical neurological examination in horses, several observations and manipulative tests of balance are performed. These include head position and coordination of head movements: normal animals maintain the head in a typical vertical position and are able to perform certain acts, such as prehension of food. Some neurological diseases, such as vestibular disease, cause changes in head position and stability (Smith, 1992). Balance is evaluated during the neurological examination by assessing the horse's response to manipulations including walking with the head elevated or pulling the horse's tail to one side as the horse walks in a straight line. Responses are assessed subjectively and interpretation depends on the experience of the clinician (MacKay and Mayhew, 1991).

Postural sway analysis is an objective test of a horse's balance. If performed in a standard manner, and if normal ranges are determined for postural sway measurements in horses of different ages and breeds, then it may be possible to quantify disturbances in balance due to various neurological diseases and different conditions such as use of sedatives. Furthermore, postural sway may be useful for differentiating neurological problems from mild lameness and for assessing recovery or response to treatment of neurological diseases.

Previous studies of postural sway in horses were performed with either the forelimbs or the hind limbs on the force platform. Since the amount of postural sway measured is confined within the base of support, the detection of craniocaudal sway is limited (Clayton et al., 1999). Humans normally show a greater range of postural sway in the craniocaudal direction than in the mediolateral direction (Jeka et al., 1997). In horses mediolateral range of motion is influenced by sideways movements of the head and neck, and a trend toward higher values for mediolateral range in the equine forelimbs than the hind limbs may reflect the in proximity to the head and neck. When the horses were blindfolded there was a trend toward smaller mediolateral range of COP motion and lower mean COP velocity for the forelimbs, possibly indicating that the loss of visual proprioception may increase stability in horses (Bialski et al., 2000). This is contrary to results in humans (Jeka et al., 1997) and worthy of further study. Head movements can be regarded as internal perturbations to postural sway, which tend to alter the position of the COP and require a balance response. In humans, the balance response that produces postural sway is called an ankle strategy (Jeka et al., 1998) .The mechanics of the equine response have not been investigated.

Balance is also important during locomotion. According to the Fédèration Equestre Internationale (FEI) rules for dressage, the objectives of collection include development of the horse's balance and equilibrium, which has been displaced by the additional weight of the rider (Anon., 1991). Postural stability increases when the horse has more limbs in the ground at one time because the base of support has a larger area.

In general the average number of limbs supporting the horse during the stride is inversely related to speed. At slower speeds the horse needs to compensate for the loss of dynamic stability by increasing the number of limbs in contact with the ground (Clayton, 1989).

2.3. EFFECTS OF THE USE OF DRUGS ON POSTURAL SWAY

The use of sedatives might be a solution to facilitate the collection of postural sway data over longer periods of time in horses. As a prerequisite, the influence of sedatives on the horse's balance must be assessed. In human subjects, many investigators tried to assess postural control in patients with labyrinthine disease who were highly medicated at the time of data collection. The results indicated that the use of sedatives decreased the craniocaudal range of motion in 80% of patients (Paulus et al. 1987).

England et al. (1992) tested the effects of different doses of the sedatives used more frequently by veterinarians for chemical restraint in horses. Detomidine was used at two dosage rates and within 5 minutes after administration horses showed signs of ataxia. The head was lowered for 90 minutes at a dose of 10 μg/kg and for longer when a higher dose of 20 μg/kg was administrated.

Sedation with detomidine was least pronounced and most short-lived at a dose rate of 10 μg/kg and increased significantly in depth and duration at higher doses, when the effects could last for more than 4 hours (Hamm et al., 1995)

A study of the effect of detomidine as a pre-anesthetic in a large group of horses concluded that it is an excellent sedative and analgesic. Side effects such as ataxia, staggering, sweating and diuresis were not regarded as harmful to the animals (Szeligowski et al., 1986).

A comparison study between romifidine and detomidine determined that detomidine had a longer period of ataxia and instability than romifidine (Jochle et al., 1984).

Previous studies using repeated administration of detomidine used an interval at least 72 hours between successive administrations (Muir and Hubbell, 1991 ; Hamm et al., 1995).

3. METHOD OF INVESTIGATION

3.1. SUBJECTS

Six horses were selected for inclusion in the study, on the basis of being similar in morphology (Quarter Horse cross) and age (15-21 months old) and having been assessed clinically to be sound and free from neurological disease. The horses were weighed and their height was measured to the highest point of the withers. Shoulder width was measured as the distance between the greater tubercles on the left and right humeri and hip width was measured as the distance between the left and right coxal tuberosities (Table 3.1).The log sheet used to gather descriptive information for each individual horse prior to data collection is shown in appendix A.

Table 3.1- Morphological characteristics of horses

Horse (#)	Weight (kg)	Height (cm)	Shoulder width (cm)	Hip width (cm)
210	350	150	21	51
211	339	146	22	47
212	313	141	20	50
213	359	135	21	48
214	333	142	20	45
215	328	144	23	47
mean	334	141	21	47
SD	16	5	1	2

3.2. DATA COLLECTION PROTOCOL

3.2.1 Force Data

Force data were measured using a force platform (LG6/4/8000, AMTI, Watertown, Massachusetts) measuring 60 x 120 cm^2. Data from the force platform were collected using a laptop computer (Toshiba Satellite 2535 CDS, New York, NY) and a 12-bit A/D data processor card (DAQ CARD™-700, National Instruments, Austin, TX). The horses stood with the four hooves on the force platform and the limbs were oriented as vertically as feasible when viewed in a frontal plane. A handler stood directly in front of the horse. The lead rope was loose during data collection, without restricting movements of the head and neck. A helper stood to the side or behind the horse to help the handler (Figure 3.1). Each recording lasted 10 s with a sampling frequency of 1,000 Hz. Five recordings were made for each horse under each condition.

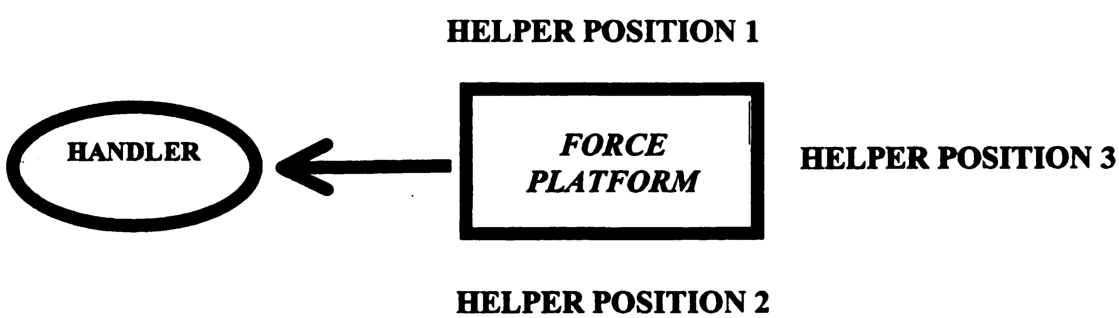

Figure 3.1. Position of handler and helper relative to the horse and force platform during data collection. The horse's head faces toward the handler and the helper stood to one side or behind the horse during data collection.

3.2.2 Kinematic data

Reflective skin markers were placed on the mid dorsal aspect of the hoof, fetlock and carpus in the forelimbs and hoof, fetlock and tarsus in the hind limbs to measure limb angles and hoof locations on the force platform. A marker was placed on the head between the left and right supraorbital foramina, to measure head height while recording COP data. On the corners of the force platform four markers were placed, to find the 0,0 location on the force platform (Figure 3.2). To determine the accuracy of the video data, a triangle calibration with 3 markers placed at known locations was recorded on the force platform (Figure 3.3).

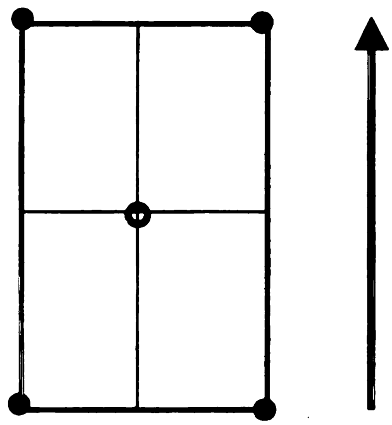

Figure 3.2. Coordinate system viewed from above, the horse's head is facing upwards in the same direction of the big arrow. The open circle represents the 0, 0 location on the force platform. The filled circles represents the markers placed on the corners of the force platform.

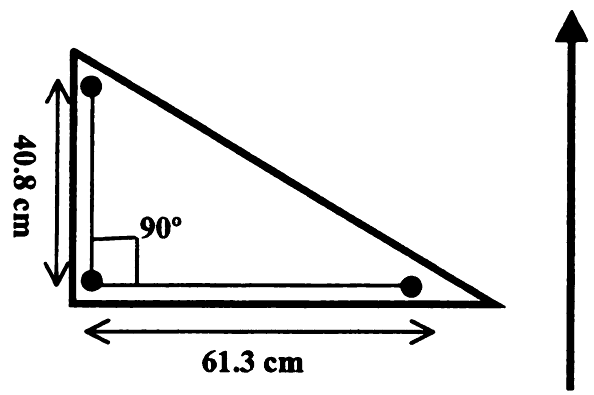

Figure 3.3. Coordinate system viewed from the side. The filled circles represent the markers, which were placed in the triangle. The triangle was placed on the middle of the force platform in an upright position as indicated by the arrow.

During collection of COP data, video recordings were made using two camcorders (Figure 3.4, 3.5). The camcorders recorded at a sampling frequency of 60 Hz and were synchronized with each other and with the force data using a numerical counter. The counter was triggered by the laptop computer, so that it started simultaneously with the force platform data acquisition. The counter was visible to both camcorders, which allowed temporal synchronization of the video frames with the force recordings. The video data were used to measure and correct orientation of the body axes, determined from the placements of the hooves, relative to the axes of the force platform, and to account for different limb conformations. The x direction corresponds with the transverse axis of the force platform and the y direction corresponds with the longitudinal axis of the force platform.

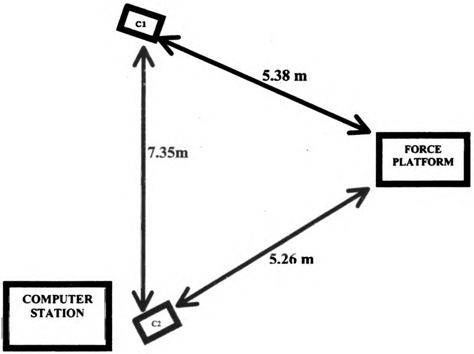

Figure 3.4. Scheme of the data collection. Force data were recorded on a computer located at the computer station. The 2 camcorders were located at C1, C2.

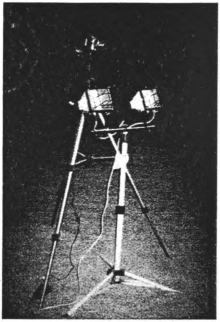

Figure 3.5. Camera and illumination set up for the data collection.

3.3. DRUG ADMINISTRATION

For each horse data were collected under three different conditions, no sedation, light sedation and heavy sedation. The order in which the three conditions were recorded was randomly assigned following a cross over design and an interval of 72 hours elapsed between data collections in an individual horse. The data collection schedule is shown in Table 3.2. For the light sedation condition the horses received 10 μg/kg detomidine (Dormosedan-Pfizer, New York, NY), which is the dose used clinically for light sedation. For heavy sedation the horses received 20 μg/kg of detomidine (Figure 3.6), which is a typical pre anesthetic dose. The precise quantity of detomidine or, for the no sedation condition an equivalent volume of saline solution, was administered intravenously (IV) in the jugular vein (Appendix B). Data collections were made at intervals of 0, 15, 30, 45, 60, 75, 90, 105 and 120 minutes after administration of detomidine or saline solution using a data collection form (Appendix C). During data collection all the reactions of the horse were recorded in a logbook (Appendix D).

Figure 3.6. Saline solution (left) and detomidine (right) administered to the horses.

Table 3.2- Data collection schedule

Day	Time	Horse #	Condition
1	morning	210	no sedation
1	afternoon	211	light sedation
2	morning	212	heavy sedation
2	afternoon	213	no sedation
3	morning	214	light sedation
3	afternoon	215	heavy sedation
4	morning	210	light sedation
4	afternoon	211	heavy sedation
5	morning	212	no sedation
5	afternoon	213	heavy sedation
6	morning	214	no sedation
6	afternoon	215	light sedation
7	morning	210	heavy sedation
7	afternoon	211	no sedation
8	morning	212	light sedation
8	afternoon	213	light sedation
9	morning	214	heavy sedation
9	afternoon	215	no sedation

3.4. DATA ANALYSIS

3.4.1- Force data analysis

The force data for each trial were displayed graphically as a stabilogram, plotting longitudinal (craniocaudal) position of the COP on the vertical axis against transverse (mediolateral) position of the COP on the horizontal axis (Figure 3.7). Each data point on the graph represents a point in time during the 10 s period of data collection, during which data were recorded at a sampling rate of 1,000 Hz. The centroid of all the points comprising the stabilogram was located at the point 0,0 on the graph. We determined the 0,0 location of the stabilogram on the force platform, using a calibration frame system, then the area and center of the horse's base of support were determined using Heron's Theorem, which is based on calculation of the areas of two triangles for which the length of the sides are known (see section 3.4.2).

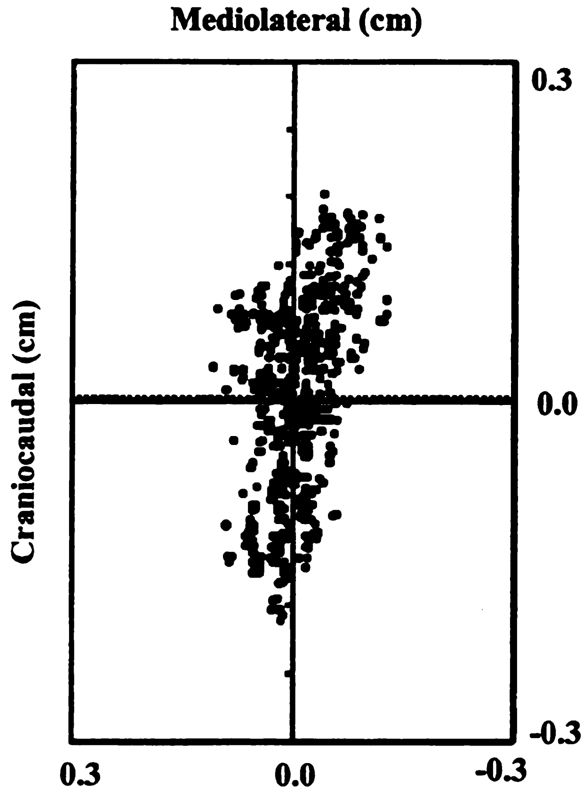

Figure 3.7. Stabilogram showing COP movements in craniocaudal and mediolateral directions. Each data point on the graph represents the position of the COP at a point in time during the 10 s period. The 0,0 location , which is the centroid of all the points, is located in the intersection of the mediolateral and craniocaudal axes of the stabilogram.

Seven variables were calculated to quantify the movements of the COP:

- mediolateral range of COP motion - the range of motion along the horizontal axis of the stabilogram, which corresponds with the x axis of the coordinate system (Figure 3.8). Using a custom software program, the x location for each data point was determined and the mediolateral range of motion for the entire trial was calculated from the minimum and maximum x values.
- craniocaudal range of COP motion - the range of motion along the vertical axis of the stabilogram, which corresponds with the y axis of the coordinate system (Figure 3.8). Using a custom software program, the y location for each data point

was determined and the craniocaudal range of motion for the entire trial was calculated from the minimum and maximum y values.

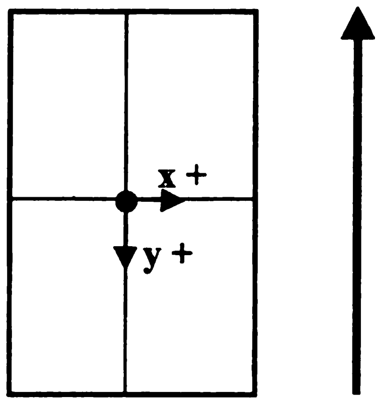

Figure 3.8. Coordinate system viewed from above, the horse's head is facing upwards in the same direction of the big arrow. The filled circle represents the 0, 0 location on the force platform. The arrows represents the positive directions of the coordinate system used to calculate the mediolateral and craniocaudal range of COP motion.

- COP area - area encompassed by the stabilogram. Using a special feature in Matlab (Matlab 5.3, The Mathworks, Natick, MA) called the Delaunay triangulation (Figure 3.9), the area of the stabilogram was divided into unique triangles in which each data point was connected to two other data points in such a way that there was no overlap between the triangles. The sum of the areas of all the triangles gave the area encompassed by the stabilogram.

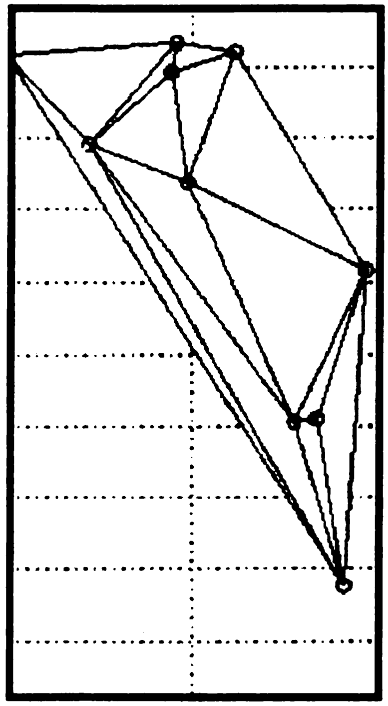

Figure 3.9. Graphic representation of the Delaunay triangulation. Each data point is connected to two other data points to form a triangle with no overlap between adjacent triangles.

- mean COP radius - the average distance between the centroid of all points on the stabilogram and each individual data point. Using the custom software the centroid of all the points comprising the stabilogram was determined as the 0,0 location. The distance from the 0,0 location to each data point on the stabilogram was measured and the mean value was calculated.

- COP velocity - average velocity of the COP between each two successive data points. The distance between each two successive data points was calculated from the x and y coordinates using Pythagoras theorem. The velocity was calculated from the distance and time.

3.4.2 Kinematic data analysis

The kinematic data were used to check that the limb placements and body orientation were standardized between trials and between horses. The videotapes were analyzed using an Ariel Performance Analysis System (APAS, Ariel Dynamics Inc., Trabuco Canyon, CA). Each video field was grabbed and stored digitally, then the markers on the horse, corner files and triangle files were manually digitized. The raw data were transformed using a direct linear transformation technique and smoothed with a fourth order Butterworth digital filter, with a cut-off frequency of 6 Hz.

The locations of the hooves were determined using custom software (Matlab 5.3, The Mathworks, Natick, MA). The 0,0 location for the horse and for the force platform were located, corrected and matched if necessary using the corner files, for both mediolateral and craniocaudal directions.

The longitudinal axis of the force platform bisects it lengthways and the transverse axis of the force platform bisects it crossways. All horses faced in the same direction when standing on the force platform. The craniocaudal (y) axis of the horse was defined as running from the mid point between the two fore hooves to the mid point between the two hind hooves.The y axis of the horse was approximately aligned with the longitudinal axis of the force platform and it was positive in the caudal direction of the horse. The mediolateral (x) axis of the horse was defined as running from the midpoint between the left fore and hind hooves on one side to the midpoint between the right fore and hind hooves on the other side The mediolateral axis of the horse was approximately aligned with the transverse axis of the force platform, and it was positive to the right of the horse's body. The locations of the four hooves on the force platform were determined from the 3-D video coordinates of the hoof markers. The accuracy of the video data was determined using the triangle calibration. (Figure 3.12).

The following kinematic variables were measured:

- Hind limb distance - the distance between the hind limbs during data collection
- Forelimb distance - the distance between the forelimbs during data collection
- Right side distance - the distance between the right fore and right hind limbs of the horse during data collection
- Left side distance - the distance between the left fore and left hind limbs of the horse during data collection
- Right and left limb frontal plane angles – a line connecting the carpal/tarsal and fetlock markers forms the angle of cannon segment (Figure 3.10). The angle of this segment is measured relative to a vertical line drawn through the carpus/tarsus. A positive sign is assigned when the distal part of the segment rotates counter clockwise as seen from the front.

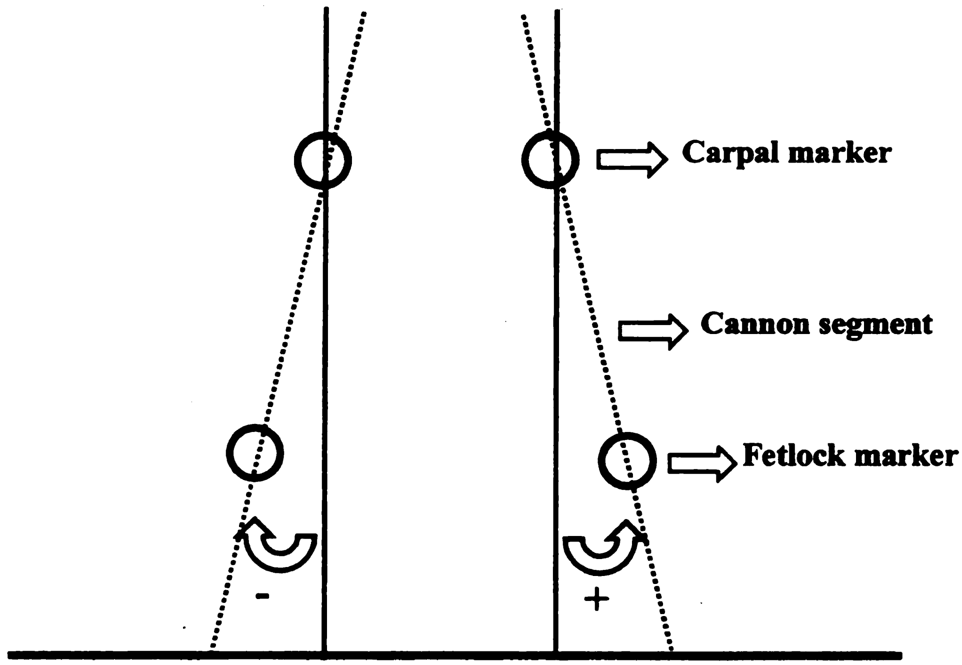

Figure 3.10. Calculation of frontal plane limb angles. The circles represent the markers placed on the horse limbs. The dashed lines connect the carpus and fetlock in the forelimbs and tarsus and fetlock in the hind limbs, forming the angle of cannon segment. The solid lines are drawn through the carpus / tarsus and the angle of cannon segment is measured relative to this vertical line. Counter clockwise rotation of the distal part of the cannon segment is positive.

- Height of the head- average height of the head marker above the left and right carpal markers during data collection (Figure 3.11).

Figure 3.11. Measurements of height of the head. The distance is measured from a reflective marker on the horse's forehead (between left and right supraorbital processes) to the markers on the left and right carpi.

- Transverse orientation angle - the angle between the transverse axis of the force platform and the mediolateral axis of the horse. A positive angle is assigned if the rotation of the horse relative to the force platform, viewed from above, occurs in a counterclockwise direction (Figure 3.12).
- Longitudinal orientation angle - the angle between the longitudinal axis of the force platform and the craniocaudal axis of the horse. A positive angle is assigned if the rotation of the horse relative to force platform, viewed from above, occurs in a counterclockwise direction (Figure 3.12).

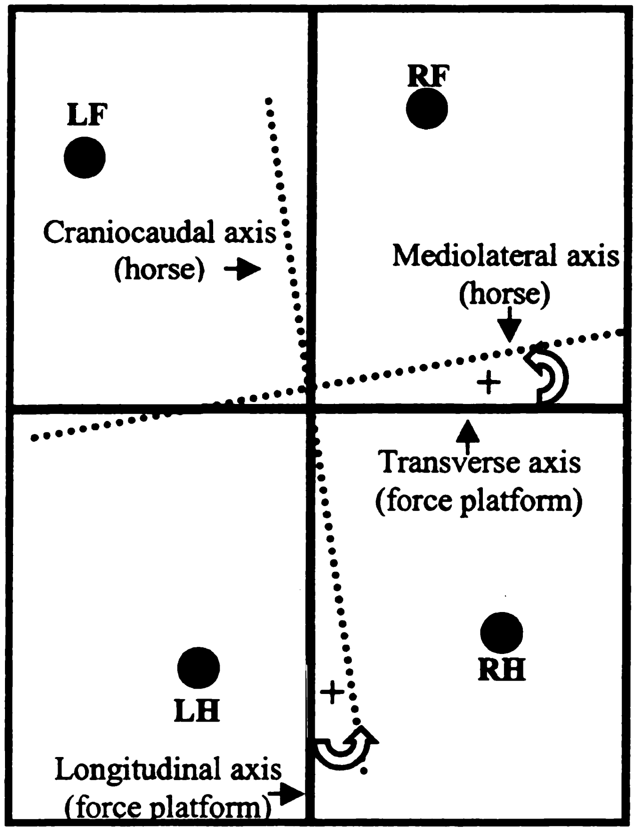

Figure 3.12. Alignment of the horse relative to force platform as seem from above. The longitudinal and transverse force platform axes are shown in solid lines. The filled circles represent the location of the four hooves on the force platform (LF=left forelimb, RF=right forelimb, RH=right hind limb and LH=left hind limb). The dashed lines are the craniocaudal and mediolateral axes of the horse's body. The angles measured are the longitudinal and transverse orientation angles. In this case the angles are positive (counter clockwise rotation as seen from above).

- Area of the base of support - the area circumscribed by the four hoof placements (Figure 3.13).
- Center of the base of support - the geometric center of the base of support was located at the point where lines connecting diagonal limb pairs intersected (Figure 3.13).

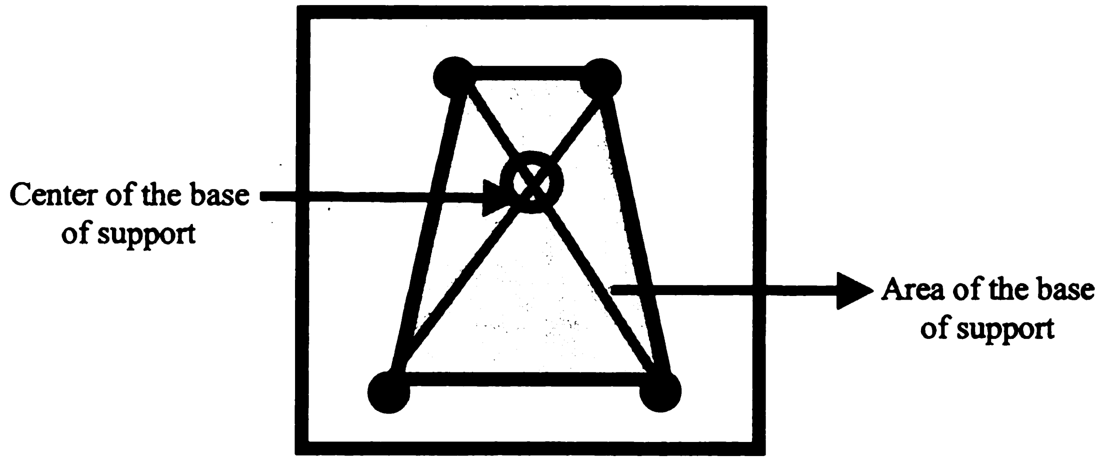

Figure 3.13. The filled circles represent the hooves. The shaded area is the area of the base of support. The open circle is the center of the base of support and it is located at the point where the lines connecting the diagonal pairs of limbs intersect.

The area of the base of support is calculated as the sum of the areas of two triangles represented by triangle 1 and triangle 2 (Figure 3.14). The lengths of the sides of the triangles were measured from the video coordinates of the hoof markers and the areas of the triangles were calculated using Heron's Theorem.

$$Area = \sqrt{perimeter(perimeter - side1)(perimeter - side2)(perimeter - side3)}$$

For triangle 1: $Area = \sqrt{s(s-c)(s-d)(s-e)}$,

where c, d, e are the lengths of the sides of the triangle and s is the perimeter of the triangle, $s = c + d + e$

For triangle 2: $Area = \sqrt{s(s-a)(s-b)(s-c)}$,

where a, b, c are the lengths of the sides of the triangle and s is the perimeter of the triangle, $s = a + b + c$

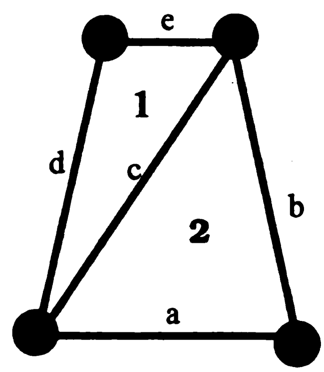

Figure 3.14. Diagramatic representation of Heron's Theorem. The areas of triangles 1 and 2 were calculated and the sum of both areas is the area of the base of support. The filled dots are the hooves.

- Mean longitudinal and transverse displacement of base of support from COP: distance between location of the COP derived from force data and the geometric center of the base of support derived from kinematic data measured in the x and y directions.
- Total data collection time: total time taken to collect 5 data trials of 10 s duration under each condition.

3.5. STATISTICAL ANALYSIS

The data were analyzed using SAS software (SAS institute Inc., Cary, NC). This study had a cross over design and was a randomized and balanced study. For each variable, the mean value ± SD were calculated on a horse by horse basis, under the three conditions (no sedation, light sedation and heavy sedation) within the nine different time intervals ranging from 0-120 minutes. The mean values for the individuals were used to determine the group mean ± SD.

Before analyzing the data, the assumption of normality and homogenous variances through factors were checked using PROC UNIVARIATE and residual plots.

PROC MIXED PROCEDURE was used with repeated statement based on the covariance structure (compound symmetry). The three sedation conditions were the factors and the nine time intervals were the levels. The time * treatment interaction was assessed separately for the nine levels within the three factors. The model included order as a fixed factor, time, treatment, and treatment versus time interaction as a random factor, horse. Differences between the levels of the factors were determined by LS MEANS with post hoc TUKEY-KRAMER adjustments in PROC MIXED procedure for all statistical tests the level of significance chosen was $p<0.05$ alpha.

4. RESULTS

For each variable, the mean value ± SD were calculated on a horse by horse basis, under the three conditions (no sedation, light sedation and heavy sedation) within the nine different time intervals ranging from 0-120 minutes. The three sedation conditions were the factors and the nine time intervals were the levels and the time * treatment interaction was assessed separately for the nine levels within the three factors.

4.1.POSTURAL SWAY VARIABLES

Examples of stabilograms for horse 213 at times 0, 15, 30 and 120 minutes after detomidine or placebo administration are shown in figure 4.1. The postural sway variables were measured from the stabilograms to determine how long it took for the horse's balance variables to return to the same value as in the no sedation condition following the administration of the two doses of detomidine (10 μg/kg for the light sedation and 20 μg/kg for the heavy sedation). The results for each variable are shown in tables and graphs. Confidence intervals (99% CI) for the no sedation condition were used as a further indicator of whether the values were within the normal range.

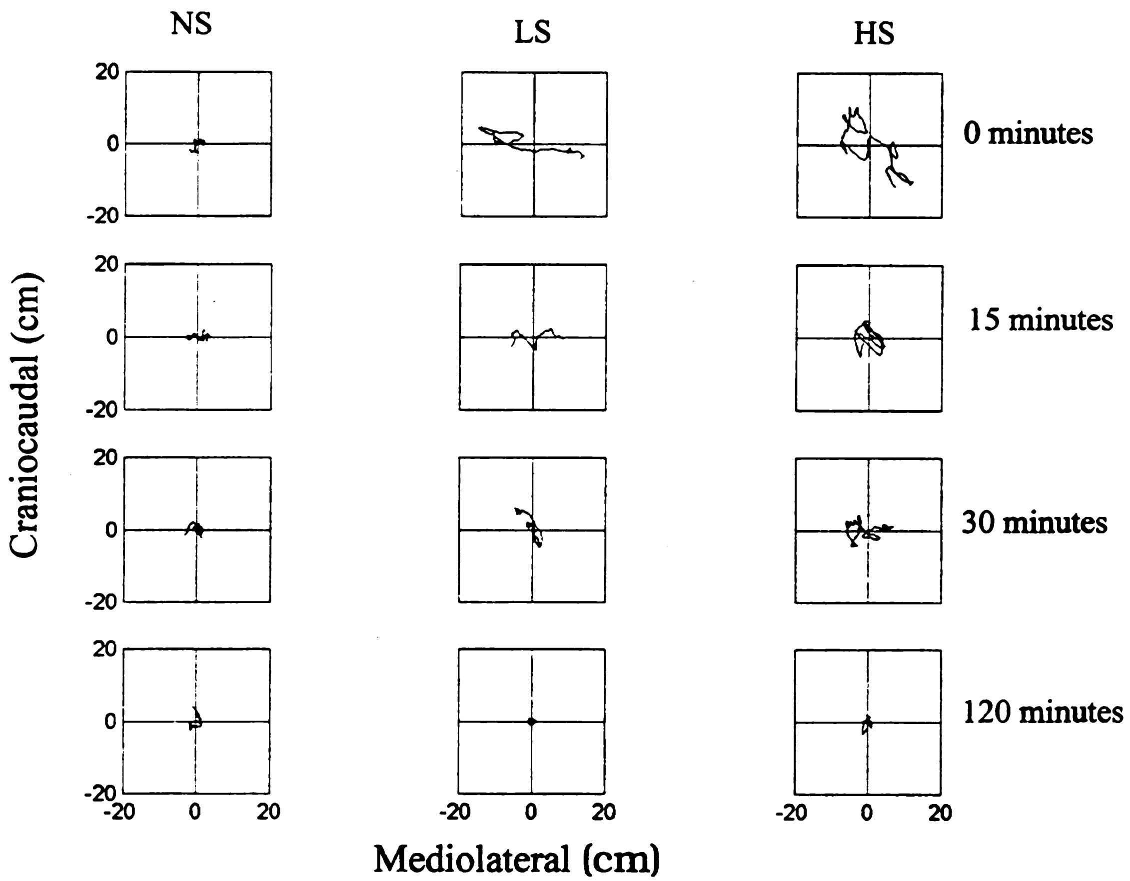

Figure 4.1. Sample of stabilograms of a single horse, for no sedation (placebo), light sedation (10 μg/kg detomidine) and heavy sedation (20 μg/kg detomidine) conditions at times 0, 15, 30 and 120 respectively.

4.1.1. Mediolateral range of COP motion

For the overall model, the mediolateral (ML) range of COP motion was smaller under the no sedation condition than in the light and heavy sedation conditions. Differences between the time intervals for the overall model are shown in table 4.1. The time* treatment interaction showed time significant differences between no sedation and light sedation and no sedation and heavy sedation at time 0 (Figure 4.2).

Table 4.1. Mediolateral range of COP motion (cm) for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo) light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine).

Time (min)	No sedation	Light sedation	Heavy sedation
0^{1}	0.78 ± 0.08^{a}	2.84 ± 0.31^{b}	2.90 ± 0.38^{b}
15^{2}	1.05 ± 0.39	1.19 ± 0.14	1.88 ± 0.38
30^{3}	0.89 ± 0.10	0.70 ± 0.06	0.90 ± 0.10
45^{3}	0.82 ± 0.08	0.64 ± 0.06	0.72 ± 0.09
60^{4}	0.74 ± 0.09	0.57 ± 0.07	0.53 ± 0.04
75^{3}	0.72 ± 0.09	0.89 ± 0.11	0.66 ± 0.08
90^{3}	0.98 ± 0.10	0.86 ± 0.11	0.74 ± 0.10
105^{2}	1.21 ± 0.21	0.94 ± 0.13	0.80 ± 0.09
120^{2}	1.32 ± 0.25	0.98 ± 0.11	0.93 ± 0.11

*Reading across the treatment rows, values with different superscripts letters are significantly different within each time period ($p<0.05$).
*Reading down the time column, time periods with different superscripted numbers are significantly different for the overall model ($p<0.05$).

In figure 4.2, the mediolateral range of COP motion at time 0 for the light sedation condition along with times 0 and 15 for heavy sedation, are outside of the 99% confidence interval for the no sedation condition.

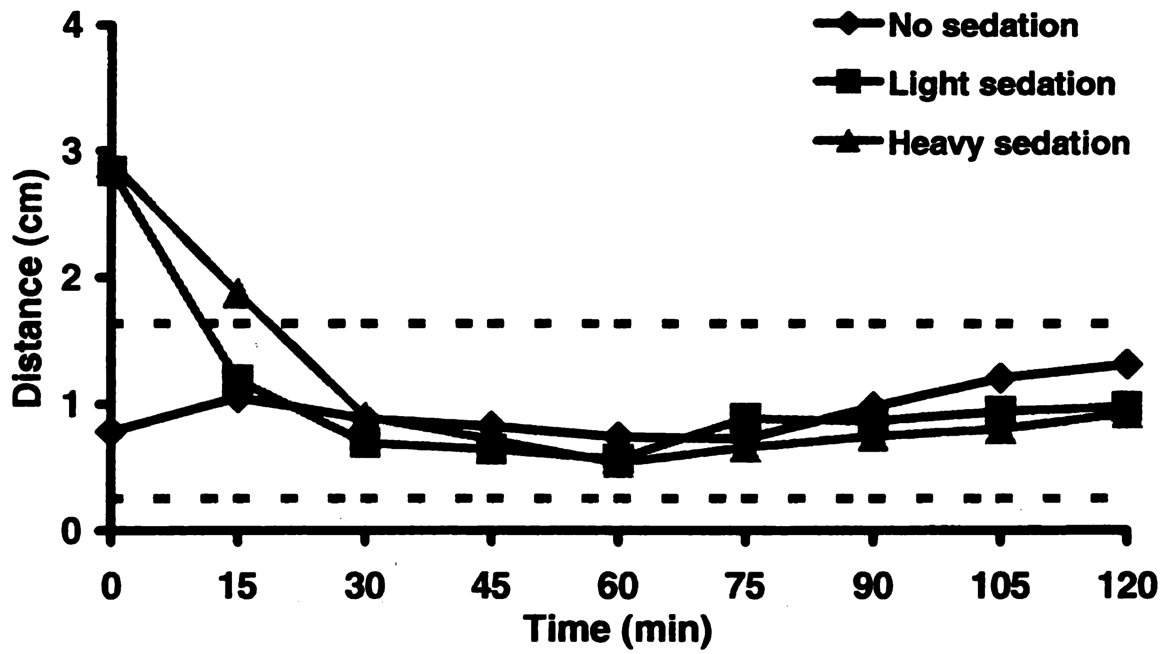

Figure 4.2. Mediolateral range of COP motion. The 99% CI for the no sedation condition is delineated by the dashed lines.

4.1.2. Craniocaudal range of COP motion

For the overall model, the craniocaudal range of COP motion was smaller for the no sedation than the light and heavy sedation conditions. In addition, there were significant differences between time intervals for the overall model (Table 4.2, Figure 4.3).

Table 4.2. Craniocaudal range of COP motion (cm) for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo), light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine).

Time(min)	No sedation	Light sedation	Heavy sedation
00[1]	1.02 ± 0.07[a]	2.70 ± 0.26[b]	2.59 ± 0.48[b]
15[2]	1.19 ± 0.13[a]	1.62 ± 0.12[a]	2.10 ± 0.20[b]
30[2]	1.02 ± 0.57	1.42 ± 0.12	1.62 ± 0.12
45[3]	1.14 ± 0.09	1.24 ± 0.09	1.05 ± 0.07
60[3]	1.09 ± 0.09	1.24 ± 0.10	1.30 ± 0.11
75[3]	1.30 ± 0.12	1.16 ± 0.07	1.06 ± 0.08
90[3]	1.10 ± 0.07	1.22 ± 0.06	1.20 ± 0.07
105[2]	1.24 ± 0.10	1.41 ± 0.11	1.21 ± 0.10
120[2]	1.30 ± 0.14	1.50 ± 0.13	1.43 ± 0.08

*Reading across the treatment rows, values with different superscripts letters are significantly different for each time period ($p<0.05$)
*Reading down the time column, time periods with different superscripted numbers are significantly different for the overall model ($p<0.05$).

The craniocaudal range of COP motion at time 0 was significantly different between no sedation and light sedation and between no sedation and heavy sedation conditions. At time 15 minutes there was no significant difference between no sedation and light sedation but both were different from the heavy sedation condition (Table 4.2). Time 0 and 15 minutes for light sedation condition and times 0, 15 and 30 minutes for the heavy sedation condition are outside of the 99% confidence interval for the no sedation condition (Figure 4.3).

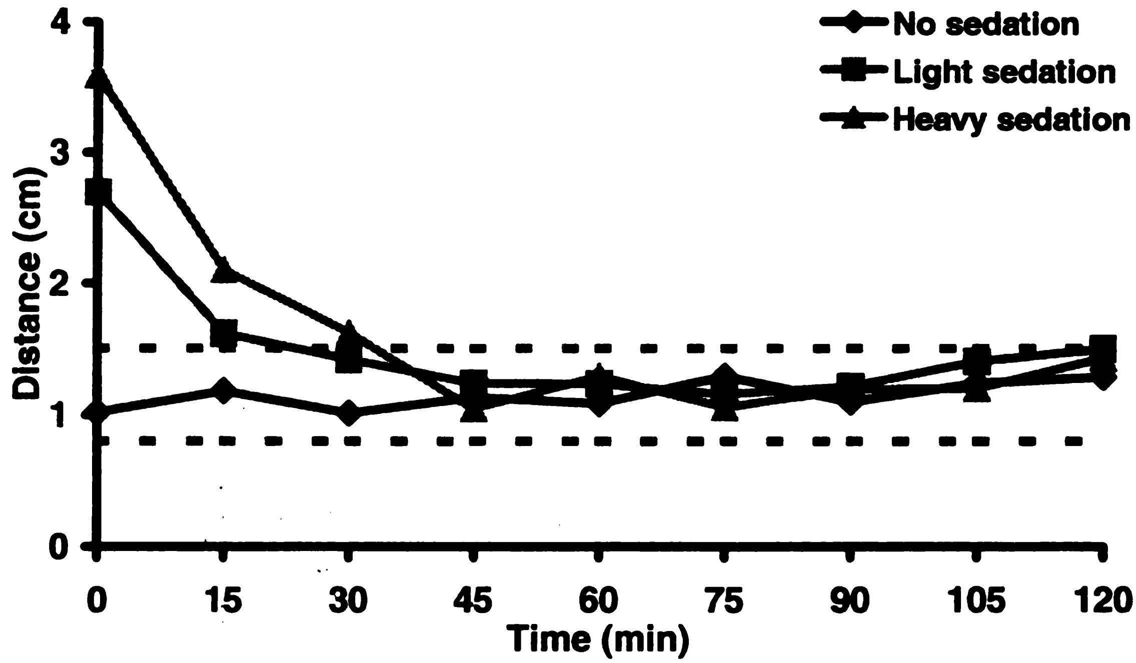

Figure 4.3. Craniocaudal range of COP motion. The 99% CI for the no sedation condition is delineated by the dashed lines.

4.1.3. Mean COP radius

For the overall model the mean COP radius was smaller under the no sedation condition than in the light or heavy sedation conditions. After injection of detomidine or saline solution there were significance differences between time intervals for the overall model (Table 4.3).

Table 4.3. Mean COP radius (cm) for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo), light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine).

Time (min)	No sedation	Light sedation	Heavy sedation
0^{1}	0.28 ± 0.03^{a}	0.98 ± 0.10^{b}	1.16 ± 0.14^{b}
15^{2}	0.37 ± 0.04	0.48 ± 0.04	0.68 ± 0.10
30^{3}	0.31 ± 0.02	0.37 ± 0.03	0.43 ± 0.03
45^{3}	0.31 ± 0.03	0.32 ± 0.02	0.30 ± 0.02
60^{3}	0.29 ± 0.03	0.30 ± 0.02	0.32 ± 0.02
75^{3}	0.34 ± 0.04	0.36 ± 0.02	0.30 ± 0.03
90^{3}	0.33 ± 0.03	0.36 ± 0.03	0.34 ± 0.02
105^{2}	0.41 ± 0.04	0.40 ± 0.03	0.38 ± 0.03
120^{2}	0.39 ± 0.04	0.43 ± 0.04	0.43 ± 0.03

*Reading across the treatment rows, values with different superscripts letters are significantly different for each time period ($p<0.05$).
*Reading down the time column, time periods with different superscripted numbers are significantly different for the overall model ($p<0.05$).

The mean COP radius at time 0 was significantly different between no sedation and light sedation condition and no sedation and heavy sedation condition (Table 4.3). The mean COP radius for the light and heavy sedation condition at time 0 and 15 minutes were outside of the 99% confidence interval for the no sedation condition (Figure 4.4).

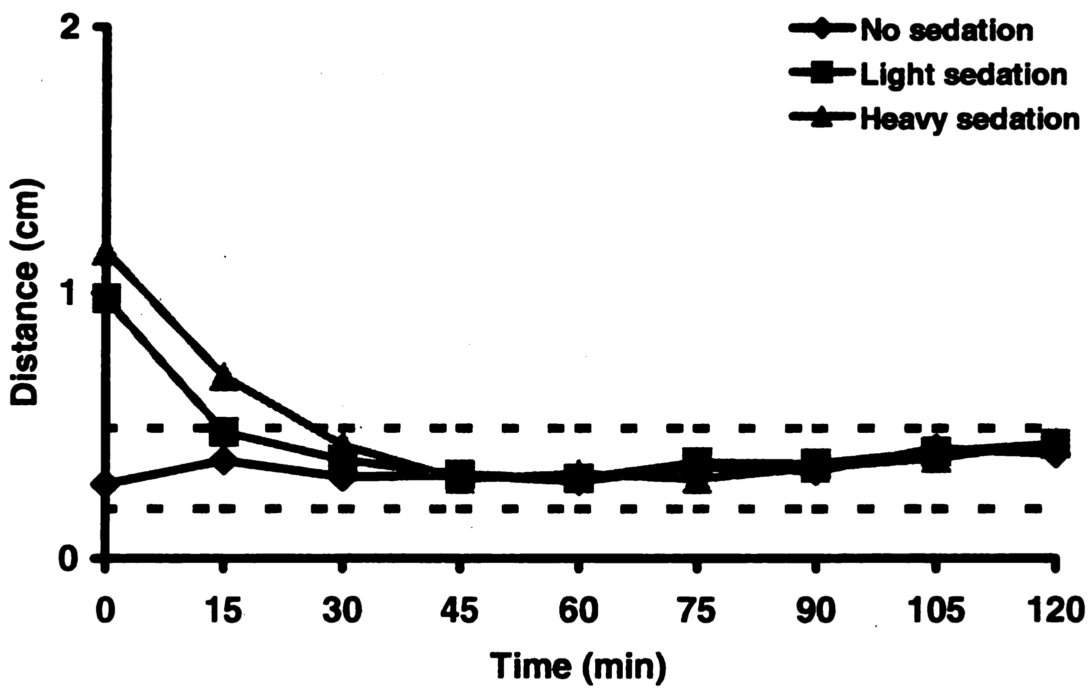

Figure 4.4. Mean COP radius. The 99% CI for the no sedation condition is delineated by the dashed lines.

4.1.4. Area of the COP

For the overall model, the area of the COP was smaller for the no sedation condition than for the light or heavy sedation. In addition, there were significant differences between time intervals for the overall model (Table 4.4).

Table 4.4. Area of the COP (cm^2) for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo), light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine).

Time (min)	No sedation	Light sedation	Heavy sedation
00^1	0.55 ± 0.12^a	5.20 ± 0.84^b	8.70 ± 1.94^b
15^2	0.91 ± 0.29	1.35 ± 0.21	3.34 ± 0.94
30^3	0.55 ± 0.06	0.62 ± 0.07	0.93 ± 0.13
45^3	0.62 ± 0.10	0.48 ± 0.06	0.52 ± 0.11
60^4	0.53 ± 0.10	0.45 ± 0.07	0.44 ± 0.06
75^3	0.56 ± 0.09	0.63 ± 0.07	0.47 ± 0.09
90^3	0.70 ± 0.12	0.68 ± 0.11	0.55 ± 0.10
105^3	0.97 ± 0.18	0.90 ± 0.17	0.60 ± 0.08
120^5	1.12 ± 0.31	1.11 ± 0.21	0.85 ± 0.14

*Reading across the treatment rows, values with different superscripts letters are significantly different for each time period ($p<0.05$).
*Reading down the time column, time periods with different superscripted numbers are significantly different for the overall model ($p<0.05$).

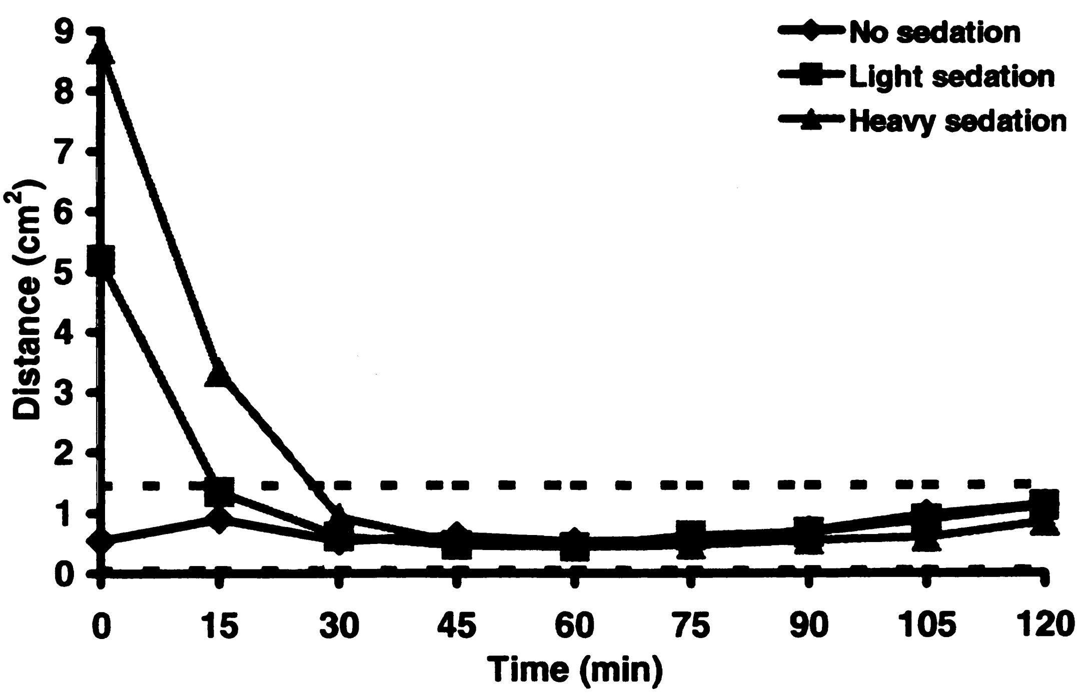

Figure 4.5. Area of the COP. The 99% confidence interval is delineated by the dashed lines.

The area of the COP at time 0 was significantly different between no sedation and light sedation condition and no sedation and heavy sedation condition (Table 4.3). At time 0 and 15 minutes the values for light and heavy sedation conditions were outside of the 99% confidence interval for the no sedation condition (Figure 4.4).

4.1.5. Mean COP velocity:

For the overall model the mean COP velocity was slower for the no sedation condition than the light and heavy sedation conditions, it was also slower under light sedation than heavy sedation. The differences within the time intervals are shown in table 4.5.

Table 4.5. Mean COP velocity (cm/s) for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo), light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine).

Time (min)	**No sedation**	**Light Sedation**	**Heavy Sedation**
00^{1}	**0.89 ± 0.04^{a}**	**1.74 ± 0.12^{b}**	**1.90 ± 0.22^{b}**
15^{2}	**0.99 ±0.06**	**0.92 ± 0.04**	**1.39 ± 0.18**
30^{3}	**0.87 ± 0.03**	**0.78 ± 0.03**	**0.94 ± 0.07**
45^{3}	**0.87 ± 0.04**	**0.70 ± 0.02**	**0.74 ± 0.04**
60^{4}	**0.83 ± 0.04**	**0.69 ± 0.02**	**0.70 ± 0.03**
75^{4}	**0.84 ± 0.04**	**0.70 ± 0.03**	**0.66 ± 0.02**
90^{3}	**0.90 ± 0.04**	**0.72 ± 0.03**	**0.67 ± 0.02**
105^{3}	**1.00 ± 0.06**	**0.89 ± 0.06**	**0.69 ± 0.02**
120^{2}	**1.03 ± 0.06**	**1.12 ± 0.11**	**0.78 ± 0.04**

*Reading across the treatment rows, values with different superscripts letters are significantly different for each time period ($p<0.05$).
*Reading down the time column, time periods with different superscripted numbers are significantly different for the overall model ($p<0.05$).

Mean COP velocity at time 0 was significantly different between no sedation and light and heavy sedation conditions and both sedated conditions are above of the 99% confidence interval for the no sedation condition. In addition mean COP velocity for the heavy sedation was outside of the 99 % CI for the no sedation condition at time 15 minutes. The mean COP velocity showed a trend from time 45 to time 90 for the light sedation and from time 45 to time 105 after heavy sedation (Figure 4.6).

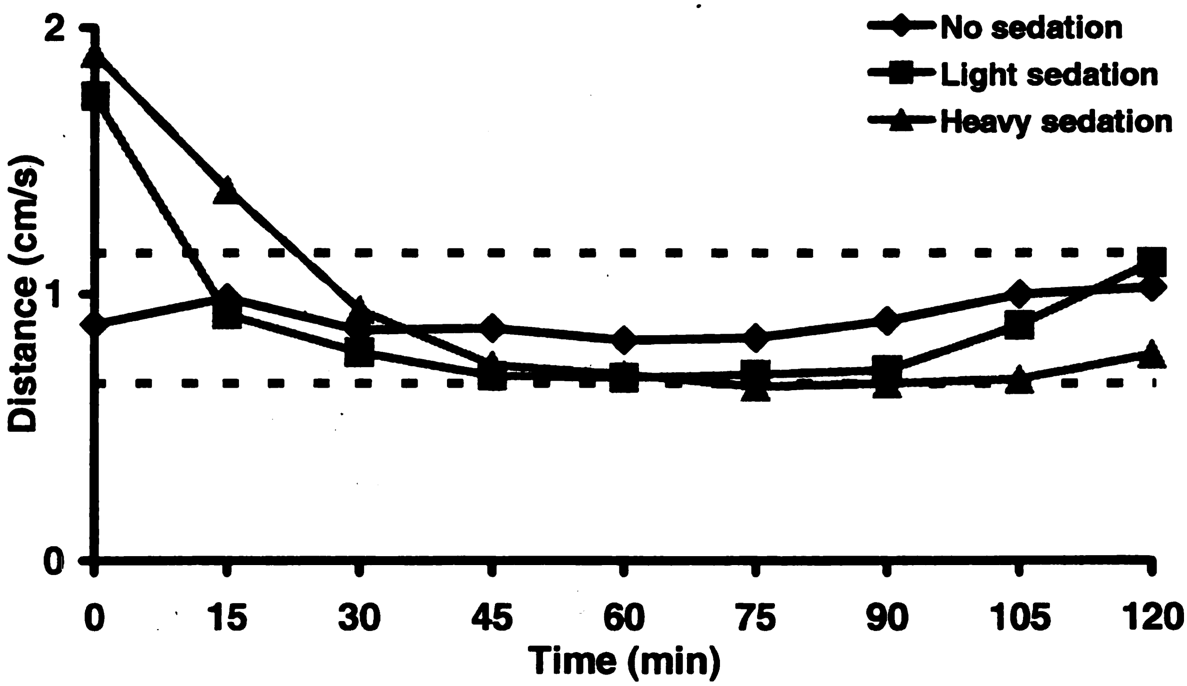

Figure 4.6. Mean COP velocity. The 99% CI for the no sedation condition is delineated by the dashed lines.

4.1.6. Data collection time

When the horses were sedated, it was much easier to keep them standing still and quiet on the force platform (Figure 4.7 and Table 4.6). There were significance differences between time intervals for the overall model (Table 4.7). Total time taken to collect data was considerably shorter when the horses were sedated at all times except 120 minutes. The differences were not significant different however due to large standard deviations.

Table 4.6. Total time for data collection (s) for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo), light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine).

Time	No sedation	Light sedation	Heavy sedation
00^1	556 ± 648	325 ± 125	390 ± 118
15^1	276 ± 305	143 ± 99	182 ± 83
30^1	361± 140	134 ± 67	127 ± 98
45^2	358 ± 230	137 ± 35	104 ± 52
60^2	352 ± 183	164 ± 87	120 ± 39
75^2	415 ± 206	185 ± 116	202 ± 167
90^2	348 ± 147	252 ± 138	200 ± 82
105^3	384 ± 248	287 ± 202	167 ± 106
120^3	192 ± 120	322 ± 320	337 ± 248

*Reading across the treatment rows, values with different superscripts letters are significantly different for each time period ($p<0.05$).
*Reading down the time column, time periods with different superscripted numbers are significantly different for the overall model ($p<0.05$).

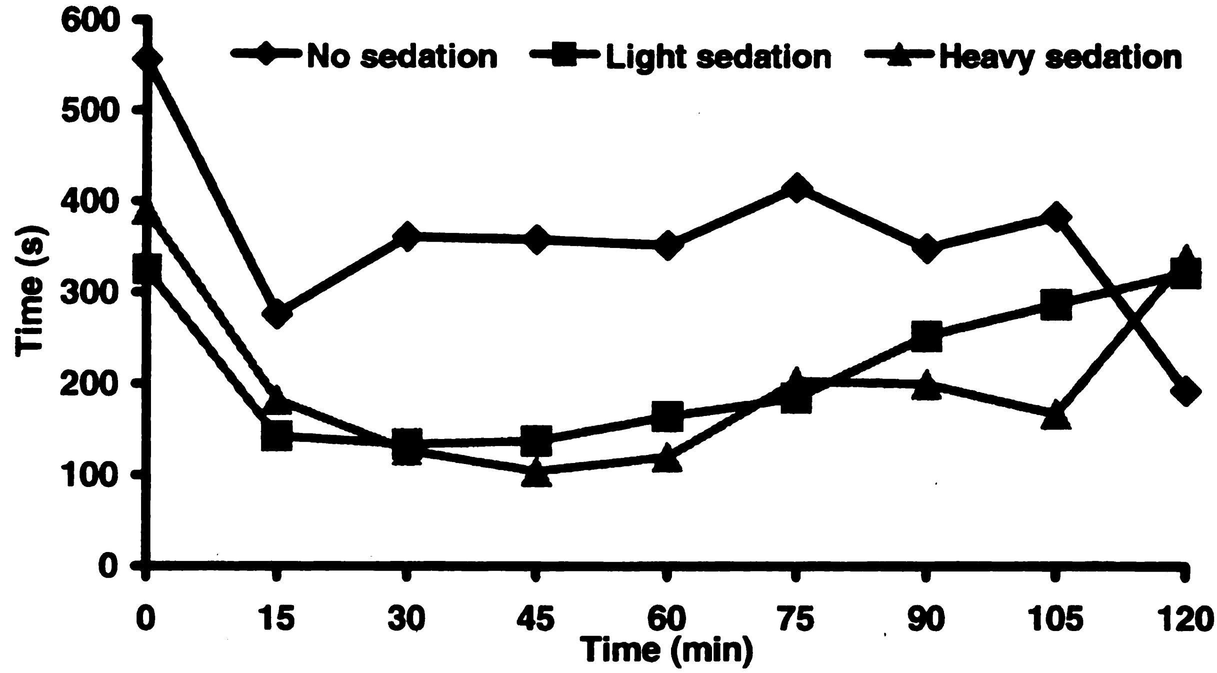

Figure 4.7. Total time to collect data.

Under the no sedation condition the time taken to collect data was highest at time 0 and then decreased which reflects habituation by the horses. During the period from 15 to 60 minutes after sedation, data collection time was short for both conditions.

4.2.KINEMATIC VARIABLES

The kinematic variables were used to check if the horses were standing in the same position within and between treatments. The kinematic variables measured were: height of the head, limb angles, right side distance, left side distance, forelimb distance, hind limb distance, longitudinal angle, transverse angle, craniocaudal difference, mediolateral difference and area of the base of support.

The overall distances and angle for the triangle calibration were calculated on each day of data collection. The average distances and angle for the 9 days were

calculated and it showed that the average length error was 1 cm in 61.3 cm for side 1 and 0.57 cm in 40.8 cm for side 2, and 0.6 degrees in the 90 degrees angle in between the two sides, showing that the video data were accurate and coherent.

4.2.1. Height of the head

The height of the head was measured for comparison with the results of previous physiological studies, in which ataxia and lowering of the head were reported after administration of detomidine, and also to assess the effects of the height of the head on the horse's balance

For the overall model, the head was significantly higher in the no sedation than in the light and heavy sedation conditions and there were significant differences between time intervals. Differences between conditions persisted until time 90 minutes after detomidine administration (Table 4.7).

Table 4.7. Height of the head (cm) for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo), light sedation (10 µg/kg detomidine) or heavy sedation (20 µg/kg detomidine).

Time(min)	No sedation	Light Sedation	Heavy Sedation
00^{1}	129.1 ± 2.5^{a}	84.6 ± 3.8^{b}	86.07 ± 2.9^{b}
15^{1}	129.4 ± 1.7^{a}	79.9 ± 3.2^{b}	80.03 ± 2.5^{b}
30^{2}	134.0 ± 1.7^{a}	91.5 ± 4.3^{b}	81.29 ± 2.9^{b}
45^{3}	129.3 ± 1.9^{a}	96.3 ± 4.0^{b}	92.89 ± 3.2^{b}
60^{4}	130.9 ± 2.5^{a}	104.3 ± 3.8^{b}	96.38 ± 3.5^{b}
75^{5}	136.5 ± 2.6^{a}	117.1 ± 3.0^{a}	110.12 ± 3.1^{b}
90^{6}	136.6 ± 1.9^{a}	126.0 ± 2.8^{a}	110.49 ± 3.0^{b}
105^{6}	133.1 ± 2.5	130.2 ± 2.3	119.80 ± 2.7
120^{2}	137.2 ± 2.4	133.4 ± 2.2	123.21 ± 3.2

*Reading across the treatment rows, values with different superscripts letters are significantly different for each time period ($p<0.05$).
*Reading down the time column, time periods with different superscripted numbers are significantly different for the overall model ($p<0.05$).

Immediately after administration of detomidine the head was lowered by 40-50 cm. After light sedation, the head height increased gradually from 30 minutes, returning to the no sedation height by 75 minutes. After heavy sedation, the horses did not begin raising their heads until 45 minutes after sedation, returning to normal at time 105 minutes. The head was below the lower limit of the 99 % CI for the no sedation condition through out the period of the study for the heavy sedation and until 90 minutes after administration of detomidine for the light sedation condition (Figure 4.8).

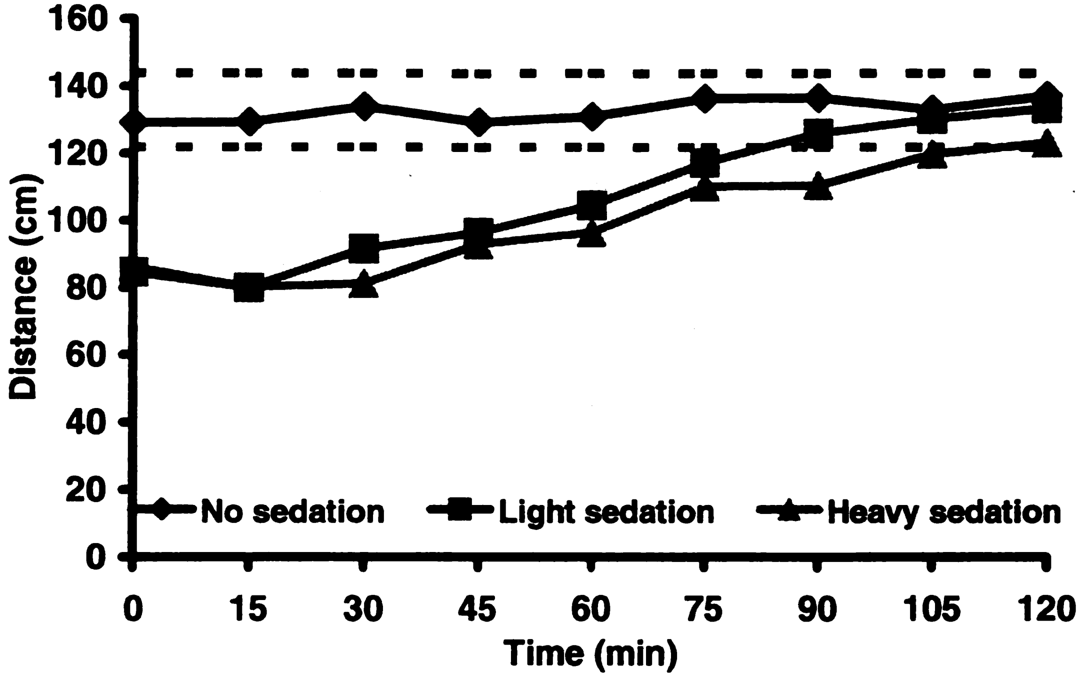

Figure 4.8. Height of the head. The 99% CI for the no sedation condition is delineated by the dashed lines.

4.2.2. Spatial kinematic variables

The distances between the forelimbs and hind limbs and area of the base of support did not change in response to light or heavy sedation. The area of the base of support showed a small but insignificant change after 45 minutes. Generally between the time 45 and time 60 minutes the horses were moved off of the force platform to urinate. When the horses returned to the force platform, they were encouraged to stand in the same position as they were before being moved. However, they tended to use a smaller base of support after being moved. There were no significant differences between times in the limb angles, limb distances, longitudinal or transverse angles and mediolateral or craniocaudal range of COP motion relative to center of the base of support (Table 4.8).

The fact that the linear variables were not significantly different after sedation in this group of normal horses showed that the horses were standing with their limbs in the same position during the different data collections. Therefore, stance did not affect the postural sway measurements. The fact that the area of the base of support and the angular variables did not differ significantly between treatments showed that this study did not introduce systematic errors by having horses standing in a particular way during data collection. The order in which the sedation conditions were evaluated had no influence on the postural sway measurements.

Table 4.8. Mean ± SD for 6 horses within 3 levels of sedation at 9 periods of time, ranging from 0 to 120 minutes after no sedation (placebo), light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine).

	No sedation	Light sedation	Heavy sedation
Mediolateral difference (cm)	**1.00 ± 0.10**	**0.58 ± 0.07**	**1.30 ± 0.11**
Craniocaudal difference (cm)	**-4.39 ± 0.28**	**-5.03 ± 0.17**	**-4.80 ± 0.06**
Area of the base of support (cm^2)	**2281.4 ± 17.0**	**2204.5 ± 12.4**	**2391.6 ± 13.4**
Longitudinal angle (degrees)	**-0.54 ± 0.11**	**0.53 ± 0.13**	**0.25 ± 0.08**
Transverse angle (degrees)	**-0.95 ± 0.20**	**-0.03 ± 0.13**	**-0.90 ± 0.25**
Right fore angle (degrees)	**-1.03 ± 0.09**	**-1.26 ± 0.06**	**-1.73 ± 0.12**
Left fore angle (degrees)	**3.23 ± 0.16**	**2.97 ± 0.10**	**3.16 ± 0.11**
Right hind angle (degrees)	**-1.02 ± 0.09**	**-1.22 ± 0.18**	**-1.12 ± 0.16**
Left hind angle (degrees)	**0.86 ± 0.09**	**1.50 ± 0.10**	**1.70 ± 0.19**
Forelimb distance (cm)	**24.4 ± 0.2**	**24.6 ± 0.2**	**26.7 ± 0.1**
Hind limb distance (cm)	**27.7 ±0.2**	**27.7 ± 0.2**	**27.9 ± 0.2**
Right side distance (cm)	**88.2 ± 0.3**	**85.4 ± 0.4**	**88.7 ± 2.5**
Left side distance (cm)	**88.1 ±0.3**	**85.2 ± 0.3**	**88.0 ± 0.2**

***No significant difference between conditions.**

4.3.OBSERVATIONS

A degree of penile prolapse was first noted 5 to 30 minutes after of the injection of detomidine in both rates. Sweating was noted in all horses, which varied from a damp coat to profuse sweating. Urination was noted with equal frequency in all the horses usually occurring 45-60 minutes after drug administration. Trembling, locking and unlocking joints, shifting weight and obvious swaying were consistently noted in all horses during the first 10 to 15 minutes after the administration of the drug in both levels of sedation.

The grade of sedation assessed for each horse at each time for each condition are shown in appendix E.

5-DISCUSSION

Balance is considered to be important in athletic horses in which a high level of motor coordination is required. Some horses are naturally better balanced than others, though the trainer assesses this subjectively. Horses, just like in humans are stronger on one side the other, which is called by trainers the "stiff" and the "hollow" sides. The left side is usually the "stiff" side, due to the fact that in the beginning of the training, the majority of young horses prefer to travel crooked with their left hind limb tracking toward the midline of the body. Later in training and also while performing movements that require strength and balance, such as piaffe; they prefer to use the left hind limb for support.

Certain diseases are associated with loss of coordination and balance and veterinarians use a number of tests to assess a horse's balance clinically. These include proprioception tests, complementary and observation tests, the interpretation of which relies on the experience of the clinician. Disturbances of balance accompany many neurological diseases in horses, such as equine protozoal myeloencephalitis, equine degenerative myeloencephalopathy, vestibular disease and cervical vertebral malformation-malarticulation, commonly known as "wobblers" (MacKay and Mayhew, 1991). Advanced neurological diseases with profound loss of balance are easy to detect, but the subtle signs are more difficult to assess.

During a neurological examination several tests of balance are performed that involve the head and cranial nerves, palpation and observation of movement of the neck, forelimbs, back, hind limbs and anus (MacKay and Mayhew 1991). Questions are asked about the horse's behavior and recent changes in behavior or mental status (patient's state of awareness or consciousness is verified). Examination of the head includes palpation of the foramina, detection of edema or swelling, evaluation of head posture and coordination. Normal animals maintain the head in a certain posture and are able to perform certain acts, such as prehension of food. Some neurological diseases (e.g. EPM) can cause changes in this posture and incapacity to perform normal functions, other diseases (e.g. bilateral vestibular disease) can cause continuous movements of the head or incapacity to keep the head in a normal position. Each of the twelve pairs of cranial nerves has its own function, and these functions are tested from the most rostral nerves proceeding caudally. Abnormalities discovered during examination of the function of the cranial nerves are most helpful in diagnosing brainstem lesions. Gait and posture are evaluated for the presence of weakness, ataxia, hypometria or hypermetria. All of these tests are assessed subjectively.

Postural sway analysis is an objective test of a horse's balance that may prove useful in detection of disturbances in balance due to neurological diseases, in differentiating neurological problems from mild lameness, and in assessing balance changes in horses after the administration of a specific drug.

Due to morphological differences between species it is difficult to compare postural sway variables recorded in horses with those recorded in people. In humans the trunk acts as a platform that supports the vestibular and visual receptors. The postural reflexes attempt to maintain the orientation of the head in relation to the environment (Buchanan and Horak, 1999). Humans are bipeds with about 2/3 of their mass located 2/3 of body height from the ground (Winter et al., 1990). In horses the visual and vestibular organs in the head are located at a considerable distance in front of the trunk, rather than immediately above it. The entire head and neck, which account for 14% of the total body weight are used to maintain and change a horse's balance: movements to the side shift the COM to that side, stretching forward shifts the COM towards the forelimbs, retraction shifts the COM towards the hind limbs and lowering results in a slight lowering of the COM. Lowering the head and neck does not change the COP location in a horizontal plane unless it is accompanied by a forward shift in the COM of the head and neck.

Horses are quadrupeds, but the ability to measure postural sway with all four hooves on the force platform simultaneously depends on having a large force platform. Previous studies of postural sway have focused on people and cats, both of which have a much smaller base of support and therefore require a much smaller force platform than horses. In these species a considerable body of literature is available. Horses do not appear to have been studied previously, except for the pilot studies in our laboratory. This is probably due to the need for a large force platform to accommodate the large base of support of a horse, which is not available in other laboratories.

The force platform used in this study measured 60 x 120 cm^2, which proved adequate for collecting data with all four hooves placed on the force platform comfortably for this group of horses that ranged in height from 135 cm to 150 cm and ranged in weight from 313 kg to 350 kg. In these relatively small horses, the average limb separations on the right side (87.44 cm) and left side (87.13 cm), and the distances between the forelimbs (25.20 cm) and hind limbs (27.76 cm) were easily accommodated by the dimensions of the force platform. In larger horses it might be possible to measure postural sway separately for forelimbs and hind limbs, but the accuracy and reliability of these data have not been evaluated and compared with those from horses standing with all four hooves on the force platform.

Mean COP velocity and craniocaudal range of COP motion showed less variability than the other postural sway variables, indicating that these might be the variables of choice to assess postural sway in a clinical setting. However, craniocaudal range of COP motion took longer to return to non-sedated levels making it less suitable for assessing horse's balance after detomidine administration.

Barbelini and Macpherson (1998) studied the kinematic and kinetic responses to different head positions in cats: neutral position, head up, head down, head left, head right. Large changes in head orientation were associated with changes in forelimb kinematics and static joint torques, especially at the shoulder and elbow joints. Hind limb kinematics did not change, and head position had no consistent effect on static ground reaction forces or COP, indicating that the stance and balance were maintained with different head positions. The dynamic postural response to translation of the surface showed movement of the COM in the direction opposite to that of translation. When the postural response was evoked, the COM trajectory slowed and reversed its direction. Neither the distance or the direction of trajectory (spatial) nor the response time (temporal) were affected by head position. The main change was observed in joint torques at the forelimbs evoked by perturbation. Electromyography showed changes in the amplitude of the evoked response of muscles in the proximal forelimb and cranial trunk, but not in their temporal or spatial response. Information regarding the location of the head in space is provided by vestibular proprioceptors and information about the position of the head and neck relative to the trunk is provided by neck proprioceptors. Vestibular and neck proprioceoptors interact closely to provide an important reference signal for postural equilibrium (Barbelini and Macpherson, 1998).

Standing cats do not show changes in COP response to change in head and neck position, which reflects the fact that cats compensate easily by adjusting the forces exerted by the limbs. In horses even after sedation with detomidine the lowering of the head and neck did not appear to be responsible for changes in postural sway variables, since these variables returned to the resting values before the head was raised to its normal level.

People can use light contact of their fingers with a stationary object to improve their balance, but horses and other quadrupeds do not have this option since they already have the four hooves in contact with the ground. Horses are not thought to use tactile receptors on the side of the head for balance due to the fact that this area does not have a particularly good supply of proprioceptive receptors (De Lahunta, 1983). Therefore, it seems unlikely that gentle restraint applied to the side of the halter would change postural sway patterns to any great extent. Even so, there is a possibility that horses may derive support from a person holding the halter, especially when sedated, therefore the horse's head movements were not restrained during this study.

There are major differences in the area and shape of the base of support between horses and humans, which partially explain the different strategies used to maintain balance in the two species. In people the craniocaudal base of support is determined by the length of the feet and the mediolateral dimension is determined by the separation of the feet. In standard tests of postural sway in people, several foot placements are used:

the feet are placed together, one foot in front of the other, toe in, toe out or 15 to 45 cm apart depending of the size of the force platform. In horses we do not have the option of using different stance positions. Instead the goal is to standardize the standing position according to each horse's conformation by having the horses stand straight and square on the force platform, to facilitate comparison between different evaluations. The kinematic variables were used to check consistency of limb placements and the fact that there were no significant differences between conditions confirms that this was achieved. In human subjects it has been shown that the foot position significantly affects the mean position of the center of pressure and postural sway (Kirby et. al., 1987). The area of the base of support depends on the type of positioning adopted, but the base of support is wider mediolaterally than craniocaudally, which gives greater stability from side to side than from front to back. This is in contrast to the situation in quadrupeds in which the craniocaudal dimension (between the forelimbs and hind limbs) exceeds the mediolateral dimension (between the left and right limbs). This gives the animal greater stability from head to tail than from side to side. In this study the mean length of the base of support was 75 cm craniocaudally and 23 cm mediolaterally suggesting much greater stability in the head to tail direction. It might have been expected that the horses would use a wider base of support to keep their balance when sedated, but this was not the case: the dimension and area of the base of support were not significantly different after sedation.

If the amount of sway is expressed as the percentage of the length of the base of support then horses have relatively less sway craniocaudally than mediolaterally. This is contrast to the situation in humans who have relatively more sway mediolaterally than craniocaudally. These findings support the suggestion that stability is directly related to the size of the base of support rather than to the absolute amount of sway (Goldie et al., 1989).

Trunk orientation is maintained above the base of support using proprioceptive receptors in the trunk. These receptors are located in the muscles of the vertebral column as well as the joint receptors (De Lahunta, 1983). They detect the forces acting on the trunk including compressive and gravitational forces. This information is used to maintain the spatial orientation of the trunk and to keep appropriate intralimb geometry of the four limbs. The most important considerations are to maintain the trunk height and orientation relative to the support surface (Macpherson et al., 1995). For example, cats have an optimal stance distance, and an optimal postural orientation that are related to energetics and morphometrics, such as length of the torso and limb segments. During galloping, cats maintain a constant trunk orientation by changing the limb orientation (Macpherson et al., 1995).

The distance between the limbs has a great effect on the mechanics of quiet stance and on the dynamic reaction to translation of the support surface (Macpherson et al., 1994). Remarkable differences were observed when cats were positioned with their limbs separated by long and short distances. At long distances each limb exerted a force outward along the diagonals during quiet stance. At short distances, the force vectors during quiet stance had a more convergent orientation in the craniocaudal direction.

One of the prerequisites in our protocol for the collection of equine postural sway data was that the horses must be standing still and square on the force platform to avoid changes in balance associated with different postures. During the data collection the posture and placement of the horse on the force platform was always carefully observed and corrected with the hoof placement and limb angles being aligned visually. This method of placement appeared to be adequate based on the kinematic variables that were recorded to check the consistency of the horse's stance between different recordings. There were no significant differences between the data recording sessions in craniocaudal distance between the fore and hind limbs, the mediolateral distance between the right or left limbs, the angles of the four limbs or in the longitudinal or transverse angle in relation to the force platform. This consistency in limb kinematics removes a potential source of error in the postural sway data. These findings suggest that in future studies, if horses are placed carefully on the force platform; it should not be necessary to measure limb kinematics. Since this is a time-consuming part of the procedure, its omission will greatly facilitate the use of postural sway in horses in a clinical setting.

This study showed the feasibility of measuring postural sway in normal horses under non sedated and sedated conditions. In this first study of the effects of sedation on postural sway, we chose to use the sedative detomidine. This is a potent, non-narcotic tranquilizer/analgesic that is used frequently in horses. Chemically detomidine is an imidazole hydrochloride. $Alpha_2$ receptors exist pre-synaptically and post-synaptically in both the central nervous system and in the peripheral nervous system. Stimulation of the central pre-synaptic $alpha_2$ adrenergic receptors inhibits the release of noradrenalin, leading to a decrease in cortical neuron activity, which results in sedation (Jöchle, 1984). The physiological effect of detomidine on horses has been studied quite extensively (Jöchle, 1984; England, et.al., 1992, Short et al., 1986; Hamm et al., 1995 and Jöchle and Hamm, 1986). It has been shown to be a safe pre-anesthetic medication for horses (Short et al., 1986), but an interval of at least 30 minutes should elapse after administration, before proceeding with induction of anesthesia, to allow stabilization of the cardiovascular parameters and reduce the risk of injuries during intubation.

In a study comparing various sedatives for horses, detomidine was used at doses of 10, 20, 40 and 80 μg/kg (England et. al., 1992). Detomidine administration was associated with a considerable degree of ataxia the duration of which was dose dependent. Ataxia lasted for approximately 15 minutes at the lowest dosage rate increasing to one hour at the highest dosage rate. The response to stimuli was slower within 5 to 10 minutes of detomidine administration at all doses. The heart rate decreased rapidly and was significantly depressed within 1 minute after administration and did not start to increase until 90 minutes later. Horses that received 10 μg/kg of detomidine, recovered rapidly and by 90 minutes were considered normal, whereas at the highest doses it took 160 minutes for horses to return to the normal parameters (England et. al., 1992).

Similarly, Hamm et al. (1995) studied the effects of detomidine at several dosages at time intervals of 15 minutes until 165 minutes after the administration of the drug. Horses receiving detomidine at a dose of 10 μg/kg showed less ataxia than those receiving 20 μg/kg, with instability being short lived and lasting 30 to 45 minutes. The physiological effects of sedation with detomidine at doses ranging from 20 to 80 μg/kg persisted for 4 hours (Jöchle and Hamm, 1986).

To facilitate comparison between the effects of detomidine on the horse's balance with previous physiological studies, the same post-administration sampling frequency was used in this study as those described above (England et al., 1992, Hamm, et al., 1995). Postural sway can be used to quantify ataxia after the administration of medication and the results confirm that ataxia persists for longer periods under heavy sedation.

The results of this study showed that instability was relatively short lived after detomidine administration. For the light sedation condition the COP variables were within the 99 % CI for the no sedation condition values by 15 minutes after administration of detomidine. For the heavy sedation condition the COP variables returned to within the 99 % CI of the no sedation condition by 30 minutes after administration of detomidine, with exception of the craniocaudal range of COP motion, which returned to the same rate as the no sedation after 45 minutes for both light and heavy sedation. The time required for the postural sway variables to return to the non-sedated values correlates quite well with the subjective assessment of the duration of ataxia (Jöchle, 1984; England, et.al., 1992, Short et al., 1986; Hamm et al., 1995 and Jöchle and Hamm, 1986). This study assessed balance during stance but did not assess the effects of sedation on the horse's balance during locomotion. Normal gait involves spinal reflexes that may respond differently to sedation than the postural reflexes used during stance. Therefore it cannot be assumed that normal locomotor patterns are restored at the same time as normal balance patterns.

Some of the postural sway variables had large standard deviations, which made it difficult to detect significant differences between conditions in the ANOVA tests. The use of confidence intervals assisted in indicating when the variables were within the range recorded for the non-sedated condition. If postural sway analysis is used clinically to detect abnormal sway patterns in horses with neurological disease, then a range of "normal" values must be established for comparison. The confidence interval is a suitable range for this purpose.

Several studies have shown that detomidine is an excellent drug to be used routinely in clinics and hospitals under controlled doses and appropriate handling for sedation in horses (Jöchle, 1984; England, et.al., 1992, Short et al., 1986; Hamm et al., 1995 and Jöchle and Hamm, 1986). Sedatives and tranquilizers are sometimes used to facilitate minor procedures that are stressful to some horses, such as: trailering, clipping and shoeing horses. The results presented have suggested that detomidine is not the best choice of sedative for clipping due to the constant sweating. It is important to allow sufficient time for stabilization before proceeding with activities that require the horse to maintain its balance, such as trailering and shoeing. However, it should not be assumed that these manipulations are risk-free for the handler. Horses sedated with detomidine have been reported to show sudden and unpredictable movements, such as kicking, in response to handling (Jöchle, 1984).

The original motivation for performing this study was to seek a method of facilitating data collection for postural sway analysis in horses by reducing the time taken to collect data in horses that were reluctant to stand still on the force platform for long enough to collect representative data. In humans, data are normally collected for 30 seconds. A long period of data collection is necessary for statistical analysis using fractional Brownian motion. The general driving principle of this method of statistical mechanics is that although the outcome of an individual random event is unpredictable, it is still possible to obtain definite expressions of the probabilities of various aspects of stochastic process or mechanism (Collins and De Luca, 1993). People can be instructed to stand in a required position for a given length of time, making it easy to collect postural sway data for prolonged periods.

Pilot studies in horses indicated that it was not realistic to expect horses to stand motionless for 30 s and 10 s was more feasible. Therefore, equine studies of postural sway have used five repetitions, each for 10 s recording interval. It usually required several minutes in a quiet environment to collect data and the first data collection, which is the one used in a clinical evaluation, usually requires more time than subsequent data collections due to the novelty of the situation for the horses. This effect is clearly obvious in the time required for data collection in the no sedation condition: the first recording required the longest time. The presence of distractions (flies, other horses, etc) cause further increases in the time required to collect data. With the aid of sedation it might be possible to collect data for an extended (30 s) period of time even in horses that are normally reluctant to stand still. This would allow the use of the more sophisticated statistical methods designed by Collins and De Luca (1993). However, the effects of sedation on postural sway variables in normal horses and in horses with neurological diseases needs to be quantified before using sedation to facilitate data collection. This study has shown that sedation with 10 μg/kg of detomidine reduces the time required for data collection by about two thirds, with representative postural sway values being recorded by 30 minutes after administration in normal horses except for the craniocaudal range of COP motion.

Thus, for horses that are reluctant to stand still on the force platform during data collection, it may be useful to administer detomidine (10 μg/kg) and then wait 30-45 minutes before collecting data. In the long term, this may save time, effort and frustration in the process of data collection. However, this study used normal horses that were assessed to be free of neurological diseases. If sedation is to be used to facilitate postural sway analysis as a diagnostic tool in horses with neurological diseases, it will be necessary to evaluate the effects of sedation on postural sway in horses with neurological diseases.

6- CONCLUSIONS

- The postural sway variables for normal horses have been quantified. COP velocity and craniocaudal range of COP motion have relatively low variability, which suggests they may be suitable for detecting abnormal sway patterns in horses with neurological diseases.
- If horses are positioned on the force platform carefully in a standardized position, it is not necessary to measure kinematic variables.
- Lowering of the head when the horses were sedated did not change the location of the COP in relation to the location of the center of the base of support.
- Detomidine affects postural sway measurements with mediolateral range of COP motion, mean COP radius, COP area and mean COP velocity returning to the non sedated values within 15 minutes after administration of 10 μg/kg of detomidine and within 30 minutes after administration of 20 μg/kg of detomidine. Craniocaudal range of COP motion takes longer to return to the non sedated values: 45 minutes after administration of 10 μg/kg of detomidine and 60 minutes after administration of 10 μg/kg of detomidine.
- This study confirmed that detomidine can be used to facilitate collection of postural sway data, but data collection should not be commenced until 30 to 45 minutes following administration at which time most of the postural sway variables have stabilized.

6.1. Future applications

- If postural sway analysis is performed in a standard manner, and normal ranges are determined for postural sway measurements in horses of different ages and breeds, then it may be possible to quantify disturbances in balance due to various neurological diseases. Furthermore, postural sway may be useful for differentiating neurological problems from mild lameness and assessing recovery from neurological diseases or response to treatment of such diseases
- Detomidine can be used safely to sedate horses for trailering or shoeing but it is not recommended for clipping because sweating was noted in all the horses ranging from a damp coat to a profuse sweating. An interval of 30 minutes should elapse before performing procedures that require good balance
- In the future, it would be useful to combine postural sway analysis with electromyography to determine which muscles are firing to maintain the horse's balance.

7. GLOSSARY

#	Number
APAS	Ariel Performance Analysis System
C1	Camera 1
C2	Camera 2
CC	Craniocaudal range of motion
CI	Confidence interval
cm	centimeters
CNS	Central nervous system
COG	Center of gravity
COM	Center of mass
COP	Center of pressure
EMG	Electromyography
FEI	Fédération Equestre Internationale
GRF	Ground reaction forces
HEAD MOV.	Head movements
IV	Intravenous
kg	kilogram
LEAFORW	Leaning forwards
LEANBACK	Leaning backwards
ML	Mediolateral range of motion
NSAID	Nonesteroidal anti-inflammatory drugs

PCBs	Polychlorinated biphenalys
SD	Standard deviation
SHAK	Shaking
SHIFT	Shifting weight
TCE	Trichloroethylene
TREM	Tremors
UNLO	Unlocking joints

8. APPENDIX A

A.1. Information log sheet, which that was completed for each horse prior to data collection

Date: ______________________________

Personnel: ____

Owner's name: ____

Animal name: ____

Description: ____

Age: ________________________________

Weight: _____________________________

Height: _____________________________

Breed: ______________________________

Utility: ______________________________

Horse MEPC ID: ____________________

VTH ID: ____________________________

Shoulder width: ____________________

Hip width: __________________________

Comments or requests:

____

____

____

____

____

9. APPENDIX B

B.1. Volume of detomidine or saline solution injected intravenous into each individual horse for the no sedation (placebo), light sedation (10 μg/kg detomidine) or heavy sedation (20 μg/kg detomidine) conditions.

Horse	placebo	10 μg/kg	20 μg/kg
210	0.35 ml	0.35 ml	0.70 ml
211	0.68 ml	0.34 ml	0.68 ml
212	0.62 ml	0.31 ml	0.62 ml
213	0.72 ml	0.36 ml	0.72 ml
214	0.33 ml	0.33 ml	0.66 ml
215	0.66 ml	0.33 ml	0.66 ml

10. APPENDIX C

C.1. Log used to record trials and different behaviors or reactions during data collection.

DATE: __________ NAME: _____________ HORSE MEPC ID: ______

____SEDATED____NON SEDATED____PRE-ANESTHETIC____TOTAL TIME

TIME 0 15 30 45 60 75 90 105 120

DOSE 10μg/kg 20μg/kg

BASELINE_____

Heart rate _________(25-50)

File ID	Good Trial	Head Mov.	Information	Reactions
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	
			Tre/Shak/Shift/Unlo/ Leaforw/Leanback	

11. APPENDIX D

D.1. Parameters used to assess the level of sedation during the data collection.

ATAXIA	0 no change
	1 a little sway
	2 swaying and leaning
	3 swaying and leaning or unlocking for a better position

HEIGHT OF THE HEAD	0 head in the same position
	1 muzzle going down
	2 muzzle below the level of the carpus
	3 muzzle below the level of the fetlock

STIMULI	0 no response to stimuli
	1slow response to stimuli
	2 medium response to stimuli
	3 rapid response to stimuli

D.2. Classification of the grade of sedation based on the parameters from table D.1.

Grade	Classification	Parameters
1	Heavily sedated	Ataxia 2-3 Height of the head 2-3 Stimuli 0-1
2	Deeply sedated	Ataxia 2 Height of the head 1-2 Stimuli 1
3	Moderate sedated	Ataxia 1-2 Height of the head 1-2 Stimuli 1-2
4	Lightly sedated	Ataxia 0-1 Height of the head 0-1 Stimuli 2
5	Unsedated	Ataxia 0 Height of the head 0 Stimuli 3

12. APPENDIX E

E.1. Grade of sedation at the 9 time intervals under the three conditions for horse 210.

Horse 210	No sedation (placebo)	Light sedation (10 µg/kg detomidine)	Heavy sedation (20 µg/kg detomidine)
0	5	5	5
15	5	3	2
30	5	1	1
45	5	2	1
60	5	2	1
75	5	3	1
90	5	4	4
105	5	4	4
120	5	5	4

E.2. Grade of sedation at the 9 time intervals under the three conditions for horse 211.

Horse 211	No sedation (placebo)	Light sedation (10 µg/kg detomidine)	Heavy sedation (20 µg/kg detomidine)
0	5	5	5
15	5	3	2
30	5	3	1
45	5	1	1
60	5	1	1
75	5	2	1
90	5	3	3
105	5	4	4
120	5	5	4

E.3. Grade of sedation at the 9 time intervals under the three conditions for horse 212.

Horse 212	No sedation (placebo)	Light sedation (10 µg/kg detomidine)	Heavy sedation (20 µg/kg detomidine)
0	5	5	5
15	5	3	3
30	5	2	2
45	5	2	2
60	5	2	1
75	5	3	2
90	5	4	4
105	5	4	4
120	5	5	5

E.4. Grade of sedation at the 9 time intervals under the three conditions for horse 213.

Horse 213	No sedation (placebo)	Light sedation (10 µg/kg detomidine)	Heavy sedation (20 µg/kg detomidine)
0	5	5	5
15	5	3	2
30	5	2	1
45	5	1	1
60	5	2	1
75	5	2	1
90	5	3	4
105	5	4	4
120	5	5	4

E.5. Grade of sedation at the 9 time intervals under the three conditions for horse 214.

Horse 214	No sedation (placebo)	Light sedation (10 μg/kg detomidine)	Heavy sedation (20 μg/kg detomidine)
0	5	5	5
15	5	3	2
30	5	1	1
45	5	2	1
60	5	2	2
75	5	3	2
90	5	3	4
105	5	4	4
120	5	5	4

E.6. Grade of sedation at the 9 time intervals under the three conditions for horse 215.

Horse 215	No sedation (placebo)	Light sedation (10 μg/kg detomidine)	Heavy sedation (20 μg/kg detomidine)
0	5	5	5
15	5	3	2
30	5	2	2
45	5	2	1
60	5	2	1
75	5	3	1
90	5	4	4
105	5	4	4
120	5	5	4

13. REFERENCES

Allen, D.G., Pringle, J.K., Smith, D. and Conlon, P. (1993) Handbook of veterinary drugs. **Part II,** 280-281.

Anon. (1991) Rules for dressage events, 19th edn. Switzerland: Federation Equestre Internationale.

Barbelini, C.L. and Macpherson, J.M. (1998) Effect of head on postural orientation and equilibrium. *Exp. Brain. Res.* **122,** 175-184.

Bialski, D.E., Clayton, H.M., and Lanovaz, J.L. (2000) Postural sway analysis in horses. Abstracts, Fourth International Workshop on Animal Locomotion, Vienna, Austria.

Buchanan, J.J and Horak, F.B. (1999) Emergence of postural patterns as a function of vision and translation frequency. The American Physiological Society transcripts.

Clayton, H.M. (1989) Locomotion. In: Jones W.E. Equine Sports Medicine, (Ed) Lea and Febiger, Philadelphia, 149-187.

Clayton, H.M., Lanovaz, J.L., Littlefield, L. and Schott, H.C.(1999) Postural Sway Analysis in Horses. *J. Vet. Int. Med.* **13,** 441.

Collins, J.J and De Luca, C.J. (1993) Open –loop and closed-loop control of posture: A random walk analysis of center of pressure trajectories. *Exp. Brain. Res.* **95,** 308-318.

Collins, J.J., De Luca, C.J., Pavlik, A.E., Roy, S.H. and Emeley, M.S. (1995) The effects of spaceflight on open-loop and closed-loop postural control mechanisms: human neurovestibular studies on SLS-2. *Exp. Brain. Res.* **107,**145-150.

Dalin, G. and Jeffcott, L.B. (1994) In : Hodgson, D.R. and Rose, R.I. The Athletic Horse.W.B. Saunders company, Philadelphia. 27-48.

De Lahunta, A. (1983) Veterinary neuroanatomy and clinical neurology. (Ed) W.B. Saunders company, Philadelphia. 345-348.

England, G.C.W., Clarke, K.W. and Goosens, L. (1992) A comparison of sedative effects of three α_2-adrenoceptor agonists (romifidine, detomidine and xylazine) in the horse. *J. Vet. Pharmacol. Therap.* **15**, 194-201.

Fitzpatrick, R. and McCloskey, D.I. (1994) Proprioceptive, visual and vestibular thresholds for perception of sway during standing in humans. *J. Physiol.* **478,** 173-186.

Fung, J. and Macpherson, J.M (1995) Determinants of postural orientation in quadrupedal stance. *J. Neurosci.* **15(2),** 1121-1131.

Goldie, P., Bach, T. and Evans, O.M (1989) Force platform measures for evaluating postural control : reliabilty and validity. *Arch. Phys. Med. Rehabil.* **70,** 510-517.

Gurfinkel, V.S. (1994) The mechanisms of postural regulation in man. *Phys. Gen. Biol.* **7**, 59-89.

Hamm, D., Turchi, P. and Jöchle, W. (1995) Sedative and analgesic effects of detomidine and romifidine in horses. *Vet. Rec.* **136**, 324-327.

Hellebrandt, F.A (1938) Standing as a geotropic reflex: mechanism of a synchronous rotation of motor units. *Am. J. Phys.* **121**, 471-474.

Hindsdale, G. (1887) Station of man, considered physiologically and clinically. *Am. J. Med. Sci.* **93**, 478-485.

Horak, F.B. and Nashner, L.M. (1986) Central programming of postural movements: adaptation to altered support -surface configurations. *J. Neurophysiol.* **55**, 1369-1381.

Horak, F.B., Henry, S.M. and Schumway-Cook, A. (1997) Postural perturbations: New insights for treatment of balance disorders. *Physical Ther.* **77**, 517-533.

Jeffcott, L.B., Dalin, G., Ekman, S. and Olson, S.E. (1985) Sacroiliac lesions as a cause of chronic poor performance in competitive horses. *Equine Vet. J.* **17**(2), 111-118.

Jeka, J.J. and Lackner, J.R. (1994) Fingertip contact influences human postural control. *Exp. Brain. Res.* **100,** 495-502.

Jeka, J., Oie, K., Schoner, G., Dijkstra, T., and Henson, E. (1998) Position and velocity coupling of postural sway to somatosensory drive. *J. Neurophysiol.* **79,** 1661-1674.

Jöchle, W. (1984) Dormosedan: a new sedative and analgesic drug for horses with dose-dependent duration of effects: an introduction. *Proc. Am. Assoc. Equine Pract.* **30,** 221-224.

Jöchle, W. and Hamm, D. (1986) Sedation and analgesia with Dormosedan (detomidine hydrochloride) in horses: dose responses studies on efficacy and its duration. *Acta vet. Scand.* **82,** 69-84.

Karlsson, A. and Frykberg, G. (2000) Correlation's between force plate measures for assessment of balance. *Clin. Biomech.* **15,** 365-369.

Kilburn, K.H., Warshaw, R.H. and Hanscom, B. (1994) Balance measured by head (and trunk) tracking and a force platform in chemically (PCB and TCE) exposed referent subjects. *Occup. Envir. Med.* **51,** 381-385.

Kirby, R.L., Price, N.A. and MacLeod, D.A. (1987) The influence of foot position on standing balance. *J. Biomech.* **20,** 423-427.

Kollegger, H., Baumgartner, C., Wober, C., Oder, W. and Deecke, L. (1992) Spontaneous body sway as a function of sex, age, and vision: posturographic study in 30 healthy adults. *Eur. Neurol.* **32,** 253-259.

Lanovaz, J.L. (1997). In vitro impact attenuation characteristics of equine digits. MSc Thesis University of Saskatchewan.

Le Clair, K., Riach, C. (1996) Postural stability measures: what to measure and for how long. *Clin. Biomech.* **11,** 176-178.

MacKay, R.J. and Mayhew, I.G. (1991) Equine Medicine and Surgery. 4th edition, **1**, 723-845.

Macpherson, J.M. (1988) Strategies that simplify the control of quadrupedal stance. I. Forces at the ground. *J. Neurophysiol.* **60**, 204-217.

Macpherson, J.M. (1994) Changes in a postural strategy with inter-paw distance. *J. Neurophysiol.* **71**,931-940.

Macpherson,J.M. (1994) The force contraint strategy for stance is independent of prior experience. *Exp. Brain. Res.* **101**, 397-405.

Massion, J., Amblard, B., Assaiante, C., Mouchnino, L., and Vernazza, S. (1998) Body orientation and control of coordinated movements in microgravity. *Brain Res. Rev.* **28**, 83-91.

Mitchell, S.W. and Lewis, M.J. (1886) Tendon jerk and muscle jerk in disease and specially posterior sclerosis. *Am. J. Med. Sci.* **92**, 363-372.

Mochizuki, L., Duarte, M., Zatsiorsky, V.M, Amadio, A.C. and Latash, M.L. (1999) Effects of different bases of support on postural sway. *Proc. 23rd Ann. Mtg. Am. Soc. Biomech.*

Moss, F.A. (1931) Development of the wobblemeter for measuring bodily steadiness as an indication of riding comfort. *J. Soc. Autom. Engin.* **28**,580.

Muir, W.W. and Hubbell, J.A.E. (1991) Equine anesthesia: monitoring and emergency therapy. Ed. Mosby, New York. **11**, 257-280.

Muybridge, E. (1899) Animals in motion. In : L.S. Brown (ed.). New York: Dover Publications.

Nakamura, T., Meguro, K., Yamazaki, H., Okuzumi, H., Tanaka, A., Horikawa, A., Yamaguchi, K., Katsuyama, N., Nakano, M., Arai, H., and Sasaki, H. (1997) Postural and gait disturbance correlated with decreased frontal cerebral blood flow in Alzheimer disease. *Alzheimer Dis. Assoc. Disord.* **11**, 132-139.

Panzer, V.P., Bandinelli, S. and Hallett, M. (1995) Biomechanical assessment of quiet standing and changes associated with aging. *Arch. Phys. Med. Rehabil.* **76**, 151-157.

Paulus, W., Straube, A. and Brandt, T.H. (1987) Visual postural performance after loss of somasensory and vestibular function. *J. Neurol. Neurosurg. Psych.* **51**, 1542-1545.

Rand, M.K., Wunderlich, D.A., Martin, P.E., Stelmach, G.E. and Bloedel, J.R. (1998) Adaptive changes in responses to repeated locomotor perturbations in cerebellar patients. *Exp. Brain. Res.* **122**, 31-43.

Reginella, R. ,L., Redfern, M.S. and Furman, J.M. (1999) Postural sway with earth fixed and body-referenced finger contact in young and older adults. *J. Vest. Res.* **.9**, 103-109.

Roberts, T.D.M. (1973) Reflex Balance. *Nature* **244**, 156-158.

Romberg, M.H. (1851) Lehrbuch der nevenkrankheiten des menschem. 2 aufl., Berlin, Germany.

Schamhardt, H.C., Van-den-Bogert, A.J. and Hartman,W. (1992) Measurement techniques in animal locomotion analysis. *Acta Anat. Basel* **146**, 123-129.

Short, C.E., Mathews, N., Harvey, R. and Tyner, C.L. (1986) Cardiovascular and pulmonary function studies of a new sedative/analgesic (detomidine/domosedan) for use alone in horses or as a preanesthetic. *Acta vet. Scand.* **82**, 139-155.

Shumway-Cook, A and Wollacott, M. (1995) Motor Control: Theory and practical applications. Williams and Wilkins (Ed), Baltimore.

Sinclair, A.J. and Nayak, U.S. (1990) Age-related changes in postural sway. *Compar. Ther.* **16**, 44-48.

Smith, J.M. (1992) In: Robinson, N.E. (Ed) Current Therapy in Equine Medicine. 3rd edition. W.B Saunders, London. 575-577.

Smith, L., Bhattacharya, A., Lemasters, G., Succop, P., Puhala II, E., Medvedovic, M. and Joyce, J. (1997) Effect of chronic low-level exposure to jet fuel on postural balance of US air force personnel. *J.O.E.M.* **39**, 623-631.

Szeligowski, A., Janicki, M. and Krzeski, M. (1986) Detomidine (Dormosedan) in sedation, premedication and general anaesthesia of horses. *Acta vet. Scand.* **82**,181-185.

Thomas, D.P. and Whitney, R.J. (1959) Postural movements during normal standing in man. *J. Anat.* **93**, 524-539.

Van Weeren,P.R. (2000) History of equine locomotion. In: Equine Locomotion; Back, W. & Clayton, H.M. (Ed) W.B Saunders, London. 1-20.

Yardley, L., Gardner. M., Leadbetter, A. and Lavie, N. (1999) Effect of articulatory and mental tasks on postural control. *Neurorepor.* **10**, 215-219.

Winter, D.A. (1990) Biomechanics and motor control of human movement. 2nd edition. (Ed) A Wiley-Interscience Publication, New York. 89-96.

Winter, D.A., Aftab, E.P and Frank, J.S. (1990) Assesment of balance in humans. *Med. Proc. Tech.*, **16**, 31-51.